INCH POUND

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# MILITARY STANDARDIZATION HANDBOOK

# MANUFACTURE AND INSPECTION OF ADHESIVE BONDED, ALUMINUM HONEYCOMB SANDWICH ASSEMBLIES FOR AIRCRAFT

This military handbook is approved for use by all Departments and Agencies of the Department of Defense.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to SA-ALC/TILDD, Kelly AFB, TX 78241-5000, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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# 1.0 GENERAL INFORMATION

1.1 Introduction. Adhesive bonded, aluminum honeycomb sandwich assemblies used in aircraft were developed in the late 1940s. This product provided designers with a lightweight, strong, fatigue resistant and aerodynamically smooth construction material. The honeycomb core was made of 3003 aluminum alloy and was of corrugated construction. The adhesive used for bonding the skins to the core and the closure members was a polyvinyl or phenolic material which contained highly volatile solvents, and when cured under heat and pressure, liberated water vapor as a by-product of the chemical reaction. Consequently, with the development of all these gases inside the part during the curing process, the aluminum honeycomb core had to be perforated to provide an escape path. Curing was performed under a vacuum to facilitate removal of the volatile substances.

Soon to follow was the development of the process for making aluminum honeycomb core by the expansion method. This process used less node bond adhesive because it was applied to the foil in thin, narrow strips. This resulted in a stronger core because thicker aluminum foil could be used to obtain the same density as had previously been available with the corrugation process.

Early applications of aluminum sandwich assemblies in aircraft were mostly trailing edges of control surfaces such as flaps, ailerons, rudders, and horizontal stabilizers.

In the late 1950s, structural adhesives made from modified epoxy resins became available. These adhesives produced significantly fewer volatiles when cured, which permitted the use of a nonperforated core. More heat resistant adhesives were developed along with stronger and more heat resistant cores. The core construction alloys became 5052, 5056, and 2024.

From the initial use of this type of construction on the exterior of aircraft, the problem of preventing the entrance of water into bond lines and into the honeycomb core has been present. Trapped water in the core contributes to corrosion of bonded metal-to-metal elements in the aluminum core, and to degradation of the adhesive system. Significant improvements in the materials and processes for sandwich construction have been made in recent years that have helped reduce these problems. These include:

- Use of nonperforated aluminum core.
- Elimination of clad aluminum in bond lines as a result of industry testing that proved that the cladding would corrode (sacrifice itself) in the presence of a corrosive medium such as salt water. The corrosion of the cladding led to the failure of the bond line.
- Development of corrosion resistant coatings for aluminum core including phosphoric acid anodizing of the foil and priming with a corrosion inhibiting adhesive.
- Development of corrosion inhibiting adhesive primers.
- Development of more durable adhesive systems having greater resistance to water.
- Development of the wedge-crack test by the industry which led to improved durability of bonded assemblies through better control of surface preparation procedures.
- Improvements in surface preparation methods for bonding aluminum from chemical conversion coatings to sulfuric acid/sodium dichromate etch to modified sulfuric acid/sodium dichromate etch, and nonsealed chromic acid anodizing to phosphoric acid anodizing.
- Development of more durable exterior sealants.

- Design improvements to lessen potential water entry paths such as chemically milled doublers, fewer holes into the core area for fasteners, better fit of closure members.
- Improvements in nondestructive testing in radiography, ultrasonics, and leak testing.

Today's applications of aluminum honeycomb assemblies in secondary structures have progressed from trailing edges of control surfaces to the entire assembly, including cargo doors, engine noise suppressors, etc. With the use of advanced composite skins such as boron/epoxy and carbon/epoxy, primary aluminum honeycomb structural applications have also been developed such as for horizontal and stabilator torque boxes.

**1.2 Purpose.** This handbook presents information on the manufacture and inspection of adhesive bonded, aluminum honeycomb sandwich assemblies for aircraft. It was developed specifically to be used as a Reference Guide that provides information useful in meeting specification requirements for individual parts.

1.3 Scope. This handbook focuses primarily on the requirements for fabrication and inspection for acceptance of adhesive bonded, aluminum faced, nonperforated aluminum honeycomb core sandwich assemblies intended for use as aircraft spare parts. An extensive collection of terms and definitions has been provided in an attempt to standardize pertinent terminology. Corrugated core assemblies are not addressed in detail. Repair of used honeycomb structures is not covered.

A list of references and an index are included at the end of the Handbook. The reference list includes only those sources not covered in the Applicable Documents chapter. Company specifications or procedures that were used as sources of information are cited in the reference list. Some of these references have a limited distribution; acquisition of these documents may require approval of the author company.

Engineers making use of the material contained herein are invited to submit comments and suggestions as to the expansion and improvement of the document. Such comments should be submitted to SA-ALC/TILDD, Kelly AFB, Texas 78241-6416.

**1.4 Use of Handbook and Limitations.** This handbook should be used as a supplement to the applicable Air Force current procurement specifications that address the fabrication of aluminum honeycomb sandwich assemblies. In the case of a conflict between the requirements specified in this document and the applicable procurement specification, the latter will take precedence.

The information presented in this handbook is intended as an aid in fabricating aluminum honeycomb sandwich assemblies for aircraft spare parts. In specific cases where procedures or facilities are believed to be superior to those called out in this handbook, acceptance of those procedures or facilities must be obtained from the appropriate procurement or certification agency. The applicability and interpretation of specific provisions of this handbook must also be defined by the appropriate procurement, regulatory, or certifying agency.

In general, English units are used in this handbook. Where temperatures are specified, they are presented in degrees Fahrenheit only.

Reference information cited in this handbook may not comply in every respect with the guidelines or other criteria specified in this document.

**NOTE**

The use of trade names and proprietary product names does not constitute an endorsement of those products by the Government.

**1.5 Approval Procedures.** This handbook was reviewed and approved by the Air Force Materiel Command Honeycomb Spare Parts Working Group. Input from industry was solicited and incorporated where applicable and approved by the Working Group. Subsequent revisions and updates to this document will be reviewed and approved by this group. Requests for inclusion of new material in this handbook should be submitted to the Working Group for review through Kelly Air Force Base, as identified in Section 1.3.

# 2.0 APPLICABLE DOCUMENTS

2.1 Government Documents.

2.1.1 Specifications and Standards. The following specifications and standards are directly applicable to this handbook. Unless otherwise specified, the issues of these documents represent those listed in the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, as cited in the applicable procurement specification.

2.1.1.1 Specifications.

*FEDERAL*

| | | |
|---|---|---|
| O-A-51 | — | Acetone, Technical |
| O-T-236 | — | Perchloroethylene (Tetrachloroethylene) |
| O-T-620 | — | Methyl Ethyl Ketone for Use in Organic Coatings (MEK) |
| MMM-A-132 | — | Adhesives, Heat Resistant, Airframe Structural, Metal-To-Metal |
| TT-I-735 | — | Isopropyl Alcohol (IPA) |
| TT-N-95 | — | Aliphatic Naptha |

*MILITARY*

| | | |
|---|---|---|
| MIL-I-6870 | — | Inspection Program Requirements, Nondestructive: For Aircraft and Missile Materials and Parts |
| MIL-C-7438 | — | Core Material, Aluminum, for Sandwich Construction |
| MIL-A-8625 | — | Anodic Coatings for Aluminum and Aluminum Alloys |
| MIL-S-8802 | — | Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High-Adhesion |
| MIL-A-9067 | — | Adhesive Bonding, Process and Inspection Requirements for |
| MIL-Q-9858 | — | Quality Program Requirements |
| MIL-I-45208 | — | Inspection System Requirements |
| MIL-C-81769 | — | Chemical Milling of Metals, Specification for |
| MIL-A-83376 | — | Adhesive Bonded Metal Faced Sandwich Structures, Acceptance Criteria |
| MIL-A-83377 | — | Adhesive Bonding (Structural) for Aerospace and Other Systems, Requirements for |
| MIL-C-83873 | — | Cleaning Compound, Precoating Surface, Aircraft and Aerospace Ground Equipment |
| MIL-C-87937 | — | Cleaning Compound, Aerospace Equipment |
| TO 42C-1-20 | — | Technical Manual, Air Force Maintenance Operations, Chemical Cleaning |

2.1.1.2 Standards.

*FEDERAL*

| | | |
|---|---|---|
| FED-STD-209 | — | Airborne Particulate Cleanliness Classes in Clean Rooms & Clean Zones |

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| | | |
|---|---|---|
| MIL-STD-10 | — | Surface Roughness, Waviness and Lay (Use ASME B46.1) |

| | | |
|---|---|---|
| MIL-STD-105 | — | Sampling Procedures and Tables for Inspection by Attributes |
| MIL-STD-410 | — | Nondestructive Testing Personnel Qualification and Certification |
| MIL-STD-453 | — | Inspection, Radiographic |
| MIL-STD-1530 | — | Aircraft Structural Integrity Program, Airplane Requirements |

2.1.1.3 Handbook.

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| | | |
|---|---|---|
| MIL-HDBK-5 | — | Metallic Materials and Elements for Aerospace Vehicle Structures |
| MIL-HDBK-17 | — | Polymer Matrix Composites, Vol I Guidelines |
| MIL-HDBK-106 | — | Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes (Superseded by MIL-STD-1235) |
| MIL-HDBK-337 | — | Adhesive Bonded Aerospace Structure Repair |

Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Naval Publications and Forms Center, (ATTN: NPODS), 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

2.2 Non-Government Publications. The following documents form a part of this handbook to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the document cited in the solicitation.

*SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)*

| | | |
|---|---|---|
| ARP 1524 | — | Surface Preparation and Priming of Aluminum Alloy Parts for High Durability Structural Adhesive Bonding Phosphoric Acid Anodizing |

(Application for copies of SAE publications should be addressed to the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096).

*AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)*

| | | |
|---|---|---|
| ASTM C 273 | — | Shear Properties in Flatwise Plane of Flat Sandwich Constructions or Sandwich Cores |
| ASTM C 297 | — | Tensile Strength of Flat Sandwich Constructions in Flatwise Plane |
| ASTM C 364 | — | Edgewise Compressive Strength of Flat Sandwich Construction |
| ASTM C 365 | — | Flatwise Compressive Strength of Sandwich Cores |
| ASTM C 393 | — | Flexural Properties of Flat Sandwich Construction |
| ASTM C 394 | — | Shear Fatigue of Sandwich Core Materials |
| ASTM D 740 | — | Specification for Methyl Ethyl Ketone |
| ASTM D 1002 | — | Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal) |
| ASTM D 1781 | — | Climbing Drum Peel Test for Adhesives |
| ASTM E 94 | — | Standard Guide for Radiographic Testing |
| ASTM E 747-90 | — | Controlling Quality of Radiographic Examination Using Wire Penetrameters |

(Applications for copies of ASTM publications should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103).

*AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING (ASNT)*

SNT-TC-1 — Recommended Practices (equivalent to MIL-STD-410E)

Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.

2.3 Order of Precedence. In the event of a conflict between the text of this document and the reference cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulation unless a specific exemption has been obtained.

# 3.0 DEFINITIONS OF TERMS AND ACRONYMS

The following definitions are provided for terms used within this handbook. This glossary of terms is not totally comprehensive but it does represent commonly used terms. Where specific usage is intended, this is noted explicitly in the definition.

For ease of identification the terms and acronyms are listed alphabetically.

**Accuracy**–The degree of conformity of a measured or calculated value to some recognized standard or specified value. Accuracy involves the systematic error of an operation.

**Adherend**–An object bonded or to be bonded to another object by an adhesive.

**Adhesion**–The property denoting the ability of a material to resist delamination or separation into two or more layers.

**Adhesive**–A substance capable of holding two matarials together by adhesion. In this handbook, the term is used specifically to designate structural adhesives, i.e., those which produce attachments capable of transmitting significant structural loads.

**Adhesive Failure**–Delamination due to separation between the adhesive and the adherend interface.

**Adhesive Flash**–Accumulation of adhesive at the edge of the bond line caused by flow of adhesive during cure cycle. This is also called squeeze-out.

**Autoclave**–A closed vessel for producing an environment of fluid pressure, with or without elevated temperatures. The enclosed object will undergo a chemical reaction, such as curing, or other operation, such as consolidation.

**Autoclave Molding**–A process similar to the pressure bag technique. The lay-up is covered by a pressure bag, and the entire assembly is placed in an autoclave capable of providing heat and pressure for curing the part. The pressure bag is normally vented to the outside (atmosphere).

**Auxiliary Structure**–See Nonstructural Applications.

**Bag Molding**–A method of molding or laminating characterized by the application of fluid pressure to a flexible material which transmits the pressure to the material being molded or bonded. Fluid pressure usually is applied by means of air, steam, water, or vacuum.

**BAJ**–Bond Assembly Jig. See bond fixture.

**Bending Loads**–Loads acting on a body that tend to cause it to assume a curved or angular shape. These loads are generally applied to (or reacted by) a body at more than one location and in more than one direction.

**Black Light**–Ultraviolet light.

**Bleeder or Bleeder Material**–Material used in lay-up operation to absorb adhesive flash (squeeze-out) during cure.

**Blind Type Insert**–An insert installed into the sandwich panel that penetrates one or both face sheets. The core and internal threads or protrusions are accessible for panel attachment from only one side of the panel.

**Blown Core**–A term used to describe the structural deterioration of the core as a result of local over-pressurization (usually due to bag leaks or water/solvents brought to high temperatures) resulting in either misformed cell walls or misformed cells with node separation. A blown core is illustrated in Figure 3(a).

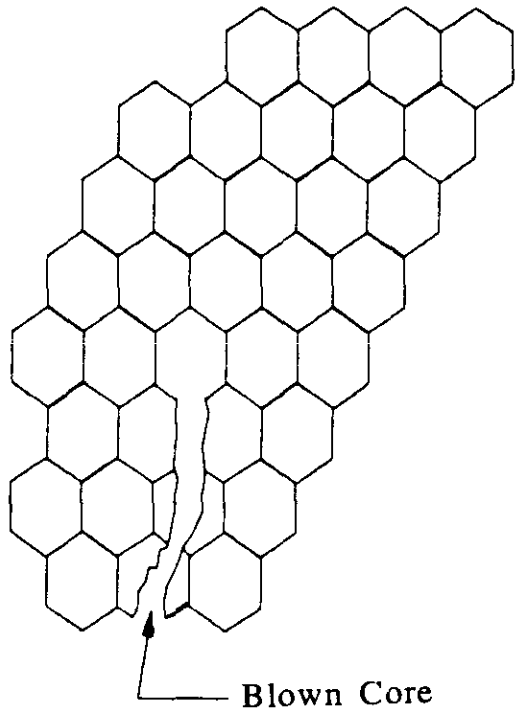



*FIGURE 3(a) Blown core.*

**Bond**–The adhesion of one surface to another by welding, brazing, or adhesive. For this handbook, bonding refers to the use of adhesives. See Joint.

**Bond Fixture**–Tooling used for assembly of details for subsequent adhesive bonding. Same as BAJ.

**Bond Line**–A layer of adhesive that is located between two pieces of metal or between a metal face and honeycomb core.

**Bond Line Temperature**–Actual temperature measured in the bond line or in the adhesive flash (squeeze-out) immediately adjacent to the bond line.

**Bond Line Temperature Rise Rate**–Rate of change of bond line temperature with time.

**Bonded Insert**–Inserts installed into sandwich panels which utilize an adhesive bond film between the insert, the face sheet(s), and/or the core material. Bonded inserts may be either chemically or thermally activated, for retention of the insert.

**Breather or Breather Material**–Material used in bagging operation to provide escape path for air and volatiles released during the cure cycle.

**Bridging**–Spanning a gap between tooling details and assembly details with a vacuum bag which results in an area of no or low pressure.

**Buckled Core**–Columnar failure of core cell wall(s). See Figure 3(b).

**Caul Plate**–Thin sheet of smooth material (generally aluminum) placed on skin of assembly during lay-up to minimize mark-off and improve overall appearance.

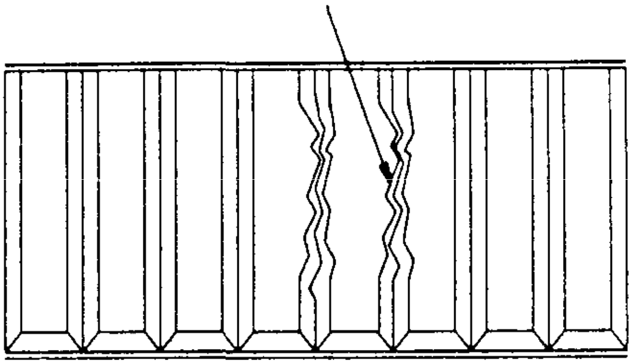



*FIGURE 3(b) Buckled core.*

**Cavity Press**–Device used to bond assemblies under application of heat and pressure without use of vacuum bag.

**Cell**–The defined shape of the solid portion of the core of honeycomb structure which completely surrounds a specific air space.

**Cell Alignment Defects**–Undesired characteristics of honeycomb core.

**Cell Size**–The distance between ribbons of corrugated core or expanded core. See Figure 3(c).

**Certification**–The act of certifying (approving) personnel or equipment to perform specific bonding operations.

**Certified**–Designation for personnel or equipment approved to perform specific operations during fabrication of bonded assemblies.

**CIAP**–Corrosion inhibiting adhesive primer.

**Clearance Hole Type Inserts**–Permanently installed nonthreaded inserts designed to transmit axial and/or shear loads from a fastener into a structure of sandwich construction.

**Coated Reservoir**–Container for adhesive primer to be applied to honeycomb core for rigidizing purposes.

**Cohesive Failure**–Delamination due to failure within the adhesive.

**Composite Part**–A complex part in which two or more distinct, structurally complementary details are combined to produce some structural or functional properties not present in any individual component.

**Compressed Core**–Buckling of core. Compressed core can sometimes be considered a controlled deformation to better conform the core material to the assembly configuration. See Figure 3(d).

**NOTE:**

Crushing of core can degrade its corrosion preventative coatings. It is normally advisable to machine core to desired contour.

**Condensed Core**–Collapse or deformation of core material in the W or transverse direction. See Figure 3(e).

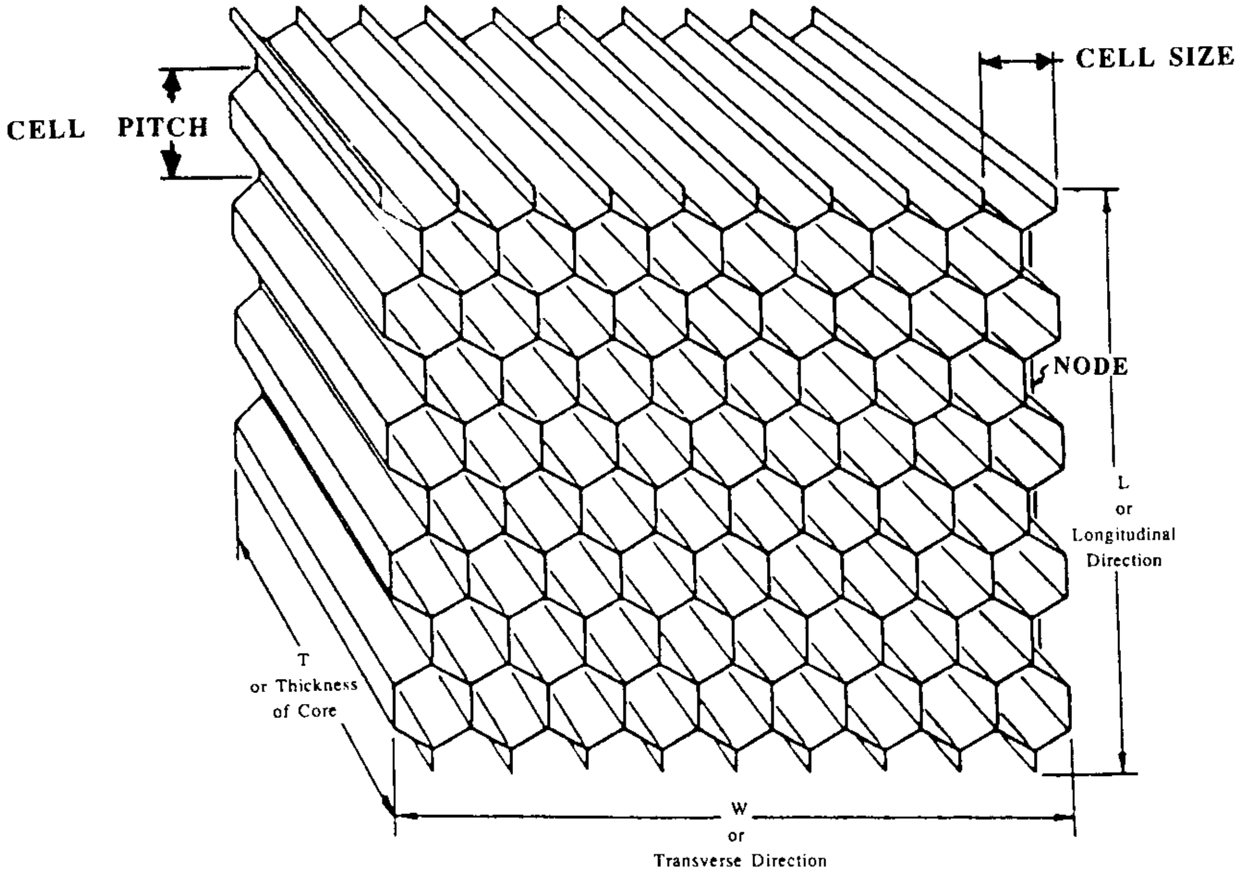



*FIGURE 3(c) Honeycomb core designations.*

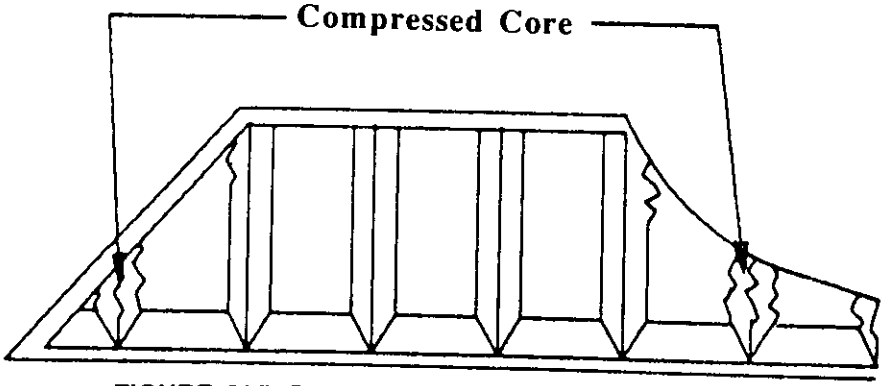



*FIGURE 3(d) Compressed core for contoured part.*

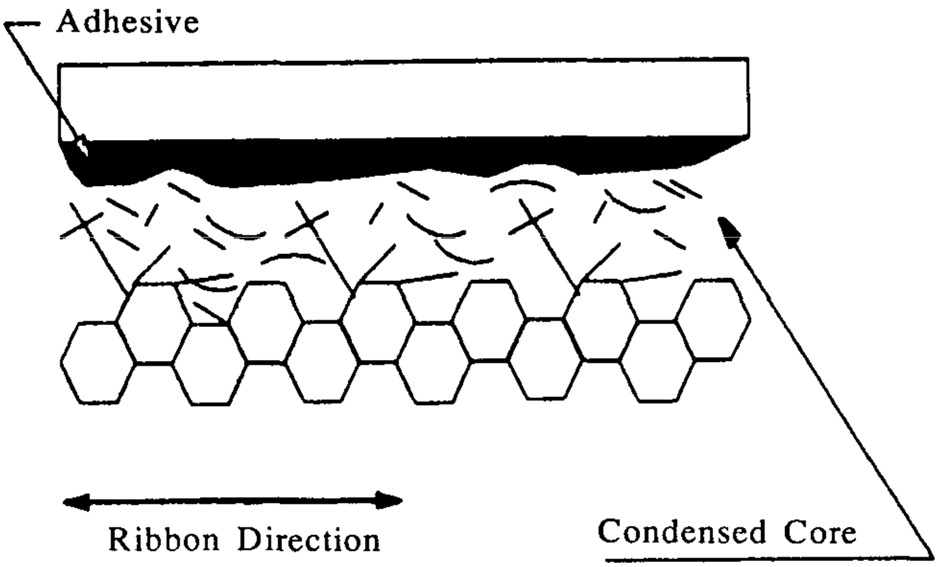



***FIGURE 3(e) Condensed core.***

**NOTE:**

Condensed core does not always occur at edge members.

**Consolidation**–The process of compacting detail layers through elimination of trapped air. See Debulk.

**Consumables or Consumable Materials**–Materials that are used in the fabrication of bonded assemblies, but do not become part of the finished product.

**Contaminants**–Any form of release agents, lubricants, natural skin oils, perspiration, protective creams, dirt, dust, chips, powder, condensate, or other material found to impair or otherwise prevent the formation of, or reduce the strength of an adhesive bond.

**Controlled Contamination Area**–Area for lay-up of adhesive bonded assemblies where temperature, humidity, pressure, and contamination are controlled. Also referred to as lay-up room, fit-up room.

**Core**–The central member of a sandwich construction, to which the faces of the sandwich assembly are bonded. It is made of a lightweight natural, synthetic, or fabricated material. It separates the facings and supports them against permanent deformation under stress.

**Core Deformation**–A permanent distortion of core shape in any orthotropic core direction. Compare Crushed Core, Condensed Core, and Compressed Core.

**Core Material**–See Core.

**Core Splice**–See Splice.

**Core Splice Gap**–That space between core segment edges and other core segments that is filled with core splice adhesive.

**Core Splice Void or Disbond**–Any unbonded area situated in the plane of a bond between two core segments.

**Corrosion**–A breakdown of the metal surface due to an electrochemical reaction. Almost all metals are subject to corrosion. Corrosion may be present in parts exposed to water and moisture, in parts without protective coatings, and in parts where dissimilar metals come into electrical contact.

**Couplant**–An acoustic couplant is a film of oil, grease, or water applied to a surface to provide a path for the passage of ultrasonic energy between the sound transmitter and the part surface for NonDestructive Inspection (NDI).

**Crack**–A break or split in the part, but without complete separation. Cracks may be found in parts which have been ground, heat-treated, fatigued, or stress-corroded.

**CRT (Cathode Ray Tube)**–Provides visual display of ultrasonic inspection information.

**Crushed Core**–Collapse or deformation of core material in the L direction. Note that crushed core does not always occur at edge members. See Figure 3(f).

**Crushed Core Honeycomb**–Sandwich panel edge closure without the use of additional members, laminates, or solid sheets. The core or cell structure is compressed between the face sheets until the core approaches a solid mass with minimal cell structure left intact in the crushed core area.

**C-scan**–Printout of ultrasonic test results during NDI of part.

**Cup Cutter**–Device used to machine honeycomb core to compound curvatures. Cutting head resembles a cup; hence the name.

**Cure**–To permanently change the properties of a chemical system (i.e., adhesive) by applying heat and pressure. This is a nonreversible process.

**Cure Cycle**–The process of curing an assembly by a controlled increase in temperature and pressure followed by one or more dwell time periods, then a controlled decrease of temperature and pressure. Uncontrolled cure processes lead to incomplete adhesive cures, part shifting in bond tools, and blown or deformed core.

**Debond**–See Disbond.

**Debulk**–A process to remove the air and compress the assembly details prior to curing by the application of vacuum under a vacuum bag or by using autoclave pressure.

**Defect**–A discontinuity, or fault, that is detrimental to the serviceability of the part or material in which it is contained.

**Deformation**–The change in shape of a specimen caused by the application of a load or force.

**Degradation**–An undesirable change in material properties.

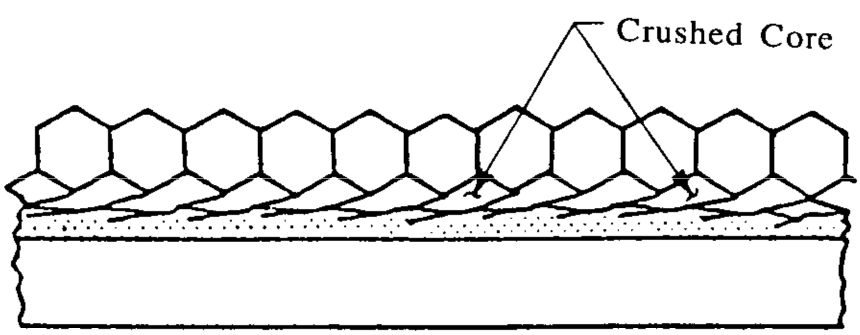



*FIGURE 3(f) Crushed core.*

**Delamination**–The separation of layers in an assembly because of failure of the adhesive, either as a cohesive failure or as an adhesive failure.

**Density**–The mass per unit volume.

**Deviation**–Variation from a specified dimension or requirement, usually defining the upper and lower limits.

**Disbond or Metal-to-Metal Voids**–Lack of a bond in a joint area between two separate details resulting from improper fit of details, failure of the adhesive bond, or contamination of one or more of the bonded surfaces.

**Discontinuity**–An interruption in the normal physical structure of a part. It may be in the form of a crack, forging lap, seam, porosity, disbond, etc.

**Distorted Core**–Distorted core may occur during the manufacture of honeycomb core or part assembly. Distortion is either in the L (longitudinal) or W (transverse) direction of the core.

**"Dog-Ears"**–Pleats in vacuum bag to take up the excess material. Created during bagging operation.

**Double Foil**–A double foil is a core manufacturing defect that occurs only during the manufacture of the HOBE (Honeycomb Before Expansion). Double foil is detected only after core is expanded. See Figure 3(g).

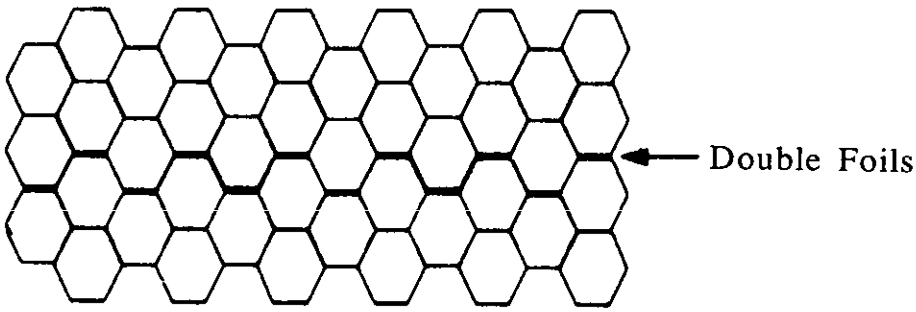



*FIGURE 3(g) Double foil.*

**Drape**–Ability of adhesives or other materials to conform to an irregular shape.

**Dwell Time**–A period of a process in which process parameters are held constant, e.g., time, temperature, pressure.

**Edge Member**–The configuration of the edge of a sandwich construction where face sheets are formed to close upon each other or where solid members are added to the panel edge.

**Edgewise**–Describes the application of forces parallel to and in the plane of a sheet or sandwich.

**Extensometer**–A device for measuring linear strain.

**External Parts**–Those parts which form a portion of the exterior of the skin (envelope) and parts installed within the cavities of bays, such as wheel wells, which are classed as external for the purpose of establishing finishing requirements.

**Externally Threaded Insert**–Inserts having a threaded element protruding from the face skin, permanently installed, and designed to transmit axial and/or shear loads into and/or through sandwich structure.

**Face Sheets**–The high density material on both sides of the core material of the sandwich construction.

**Face-To-Core Voids**–Voids are areas in which adhesive is not present or the distance between the face and the core was greater than the adhesive thickness causing inadequate adhesive contact. See Disbond.

**Facing**–One of two outer layers which have been bonded to the core of a sandwich. Same as face sheets and skins.

**Fairing Compound**–Plastic material, generally epoxy, used to fill in surface irregularities on honeycomb assemblies.

**Faying**–Fitting together closely.

**FEP**–A type of film used as a parting agent (nonadhesive) or as a release layer.

**Filler**–A substance added to an adhesive to improve or alter its working properties, permanence, viscosity, strength, or other qualities.

**Film Adhesive**–Adhesive, usually available as one-part systems, supplied in thin sheets. Adhesive films are either supported by scrim cloth or backing, or unsupported by reinforcement.

**Finish System**–Constitutes a combination of a surface treatment or plating and organic finishes for protection of a surface.

**Finishes**–A general term which includes surface treatments, plating, organic finishes (primers and topcoats), corrosion preventive compounds, or any other coating material designed to protect a surface.

**Fit-Up Room**–See Controlled Contamination Area.

**Fixed Threaded Element Insert**–An insert having a separate or integral threaded element, external or internal, which, once installed, does not allow or provide radial or axial movement of the threaded element.

**Flatwise**–Describes the application of forces in a direction normal to the plane of a sandwich structure. Flatwise compression and flatwise tension designate forces applied to compress the sandwich core and to pull the facings from the core, respectively. Flatwise flexure designates bending to produce curvature in the plane of a sheet of a sandwich.

**Floating Element Insert**–An insert having a separate, internally threaded component which, after the insert is permanently installed, will move a predetermined amount radially and/or axially.

**Foam Adhesive**–Adhesive, usually available as one-part systems, supplied in thin sheets. This type of adhesive expands to several times its original thickness upon application of cure temperature and pressure. This adhesive is used to bond core to edge members, inserts, channels, etc., where a film adhesive is not suitable for adequate bonding.

**Forming Core**–The process of changing the flat piece of honeycomb into simple or compound contours.

**Gap**–A space left between parts that exceeds design limits.

**Hand Lay-Up**–A process in which components are applied either to a mold or working surface, and the successive plies are built up and worked by hand.

**Hardness**–Resistance to deformation; usually measured by indention. Types of standard tests include Brinell, Rockwell, Knoop, and Vickers.

**Heat Survey**–Applies to bond fixtures. Process by which thermal characteristics of bond fixtures are determined.

**HOBE**–Honeycomb core manufacturer's designation for a block of honeycomb core before expansion.

**Honeycomb**–A term used to identify a type of sandwich construction consisting of a lightweight core of a cellular-type physical configuration (metallic or non-metallic) to which relatively thin, dense, high-strength or high-stiffness face sheets are adhered.

**Humidity, Relative**–The ratio of the pressure of water vapor present to the pressure of saturated water vapor at the same temperature.

**Ice Chucking**–Method of holding core in place during machining operations. Water is frozen after core is positioned in a small depth of water. After machining is completed, ice is thawed and core removed from fixture.

**Impression Prefit**–Process by which the fit of assembly details is determined by placing a simulated adhesive material in bond lines and conducting a simulated cure cycle.

**Inclusion**–A physical and mechanical discontinuity occurring within a material or part, usually consisting of impurities embedded in the material in the forming stage. Inclusions can be deep in the part or near the surface.

**Inert Atmosphere**–See Inert Gas.

**Inert Gas**–Noncombustible gas, e.g., nitrogen, used to pressurize autoclaves.

**Insert**–Any fastener element which is permanently installed into a sandwich construction which is in intimate contact with the core material and/or potting compound. See also Blind Type, Clearance Hole Type, Floating Element, Internally Threaded, and Stud.

**Interface**–The boundary between the individual, physically distinguishable constituents of a part.

**Interior and Exterior Surfaces**–Refers to aircraft skin surfaces only.

**Internal Parts**–All parts within the envelope formed by the aircraft skins, and not subject to direct contact of atmospheric moisture during operation.

**Internally Threaded Insert**–Permanently installed internally threaded inserts, designed to transmit axial and/or shear loads from a fastener into a structure of sandwich construction.

**Isotropic**–Having uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing. Compare to orthotropic.

***Joint***–*The location at which two adherends are bonded together.*

**L Direction**–See Orthotropic Core Directions.

**Lay-Up Room**–See Controlled Contamination Area.

**Machined Fittings**–Parts machined from castings, forgings, bars, extrusions, and heavy plate requiring milling operations for part manufacture.

**Mark-Off**–Dent or crease in an assembly component caused by the presence of a foreign object on the tool or part surface during the curing operation.

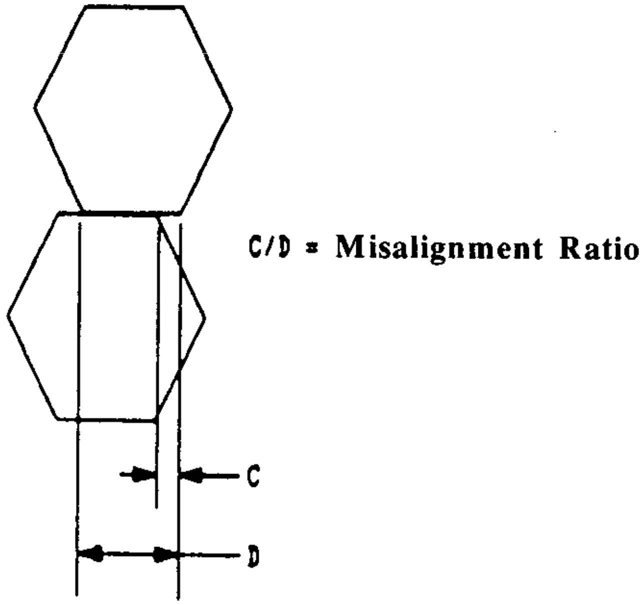



*FIGURE 3(h) Mismatched nodes.*

**Mechanical Prefit**–Process by which fit of assembly details is determined by assembling in a fixture and measuring gaps between details by various methods.

**Mechanical Properties**–The properties of a material that are associated with elastic and inelastic reaction when force is applied, or the properties involving the relationship between stress and strain.

**Metal-Bond Assembly**–Adhesively bonded assembly, with or without core, made of metal (generally aluminum).

**Metal-to-Metal Voids or Disbonds**–Any unbonded areas occurring between two solid, nonporous members that are joined by an adhesive bond line.

**Mismatched Nodes**–A defect caused by misalignment of the ribbon foil during corrugated core manufacture. See Figure 3(h).

**Mold Release**–See Parting Agent.

**Multiple-Stage Bonding**–Process of creating a final assembly by first bonding several components into one or more subassemblies. These are in turn bonded together with other subassemblies or detail parts to form the completed assembly.

**NC Milling**–Process of machining core with numerically controlled equipment.

**NDT Level I**–An NDT Level I individual should be qualified to properly perform specific calibrations, specific tests, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDT Level I shall receive the necessary instruction or supervision from a certified NDT Level II or III individual.

**NDT Level II**–An NDT Level II individual should be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The NDT Level II should be thoroughly familiar with the scope and limitations of the methods for which the individual is qualified and should exercise assigned responsibility for on-the-job training and guidance of trainees and NDT Level I personnel. The NDT Level II should be able to prepare written instructions, and to organize and report the results of nondestructive tests.

**NDT Level III**–An NDT Level III individual should be capable of establishing techniques and procedures; interpreting codes, standards, specifications, and procedures; and designating the particular test methods, techniques, and procedures to be used. The NDT Level III should be responsible for the NDT operation for which qualified and to which assigned, and should be capable of interpreting and evaluating results in terms of existing codes, standards, and specifications. The NDT Level III should have sufficient practical background in applicable materials, fabrication, and product technology to establish techniques and to assist in establishing acceptance criteria where none are otherwise available. The NDT Level III should have general familiarity with other appropriate NDT methods, and should be qualified to train and examine NDT Level I and II personnel for certification.

**Nested Cells**–A nested cell [Figure 3 (i)] is a core manufacturing defect which occurs only during the corrugated core manufacturing process. Nested cells are due to nodes being misaligned by one-half pitch and the node consequently being bonded to the preceding ribbon.

**Node**–That part of the ribbon surface which is bonded to another ribbon during manufacture of core. See Figure 3(c).

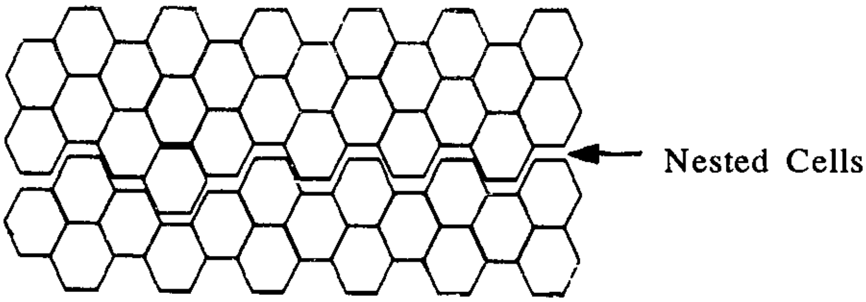



***FIGURE 3(i) Nested cells.***

**Node Delamination**–Nodes that come apart after being bonded together by node adhesive.

**Node Separation**–Node delamination or unbonded nodes. See Figure 3(j).

**Nondestructive Evaluation (NDE)**–Broadly considered synonymous with NDI.

**Nondestructive Inspection (NDI)**–A process or procedure for determining the quality or characteristics of a material, part, or assembly without permanently altering the subject or its properties.

**Nondestructive Testing (NDT)**–Broadly considered synonymous with NDI.

**Nonstructural Application**–That structure which is not essential to the aircraft's basic structure or does not contribute directly to the aircraft's performance or mission accomplishment. Its failure would not significantly affect the structural integrity, performance, or mission accomplishment of the aircraft. Examples are: walkway panels, navigator's tables, flight station doors, partition panels. This definition also applies to auxiliary structure.

**Orthotropic**–Describes material, either facings or cores, having different strength and elastic properties in different directions.

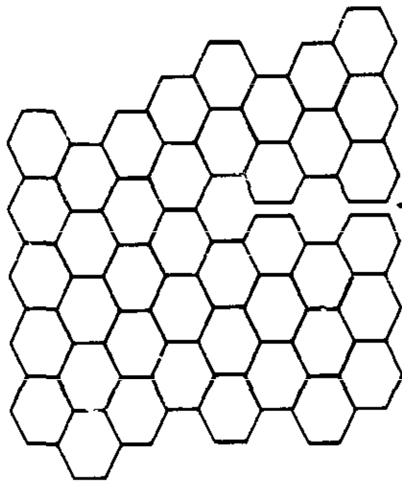



*FIGURE 3(j) Node separation.*

**Orthotropic Core Directions**–The identification of the different axes for strength determinations of core [see Figure 3(c)]. They are designated as "T," "L," and "W," as follows:

| Core | "T" direction | "L" direction | "W" direction |
|---|---|---|---|
| Honeycomb | Thickness of core | Longitudinal; Parallel to core ribbons | Transverse; Perpendicular to core ribbons |

**Orthotropic Facing Directions**–Usually described in terms appropriate to the facing composition, such as warp and fill direction in cloth, for example.

**Out-Time**–The time a material (i.e., adhesive) is outside its ideal storage environment.

**Overlay**-A nonwoven fibrous mat (glass or other fiber) used as the top layer in a mat lay-up to give a smooth finish or to minimize the fibrous pattern on the surface.

**Parting Agent**–Material applied to tooling surfaces to prevent adhesion of adhesives during bond cycles.

**pH**–A measure of acidity or alkalinity of a solution, with neutrality represented by a value of 7, with increasing acidity corresponding to progressively smaller values and increasing alkalinity corresponding to progressively higher values.

**Pitch**–The distance between nodes in the L or longitudinal direction. See Figure 3(c).

**Platen Press**–Device used to cure assemblies under heat and pressure. Only applicable to flat surface parts.

**Plating**–A thin metal coating applied to a metal surface electrolytically, chemically, or by vacuum deposition to increase corrosion or abrasion resistance.

**Porosity**–A condition of trapped pockets of air, gas, or vacuum within a solid material, usually expressed as a percentage of the total nonsolid volume to the total volume (solid plus nonsolid) of a unit quantity of material.

**Portable Instrument**–A portable instrument refers to NDT inspection equipment having portability. Portability refers to equipment that can be used in a shop, laboratory, warehouse, or in the field, thus permitting in-place inspection and requiring only moderate power from a power line or small generator.

**Post-Cure**–Additional elevated temperature cure, usually without pressure, to improve final properties or complete the cure or both.

**Pot-Life**–The length of time an adhesive system can be used or worked before the curing process starts. Also called the working life.

**Potting**–Insert which is installed into the sandwich panel by utilizing an agent, usually an epoxy-type adhesive compound, inserted in fluid form into a void created by removal of the core material surrounding the insert, and chemically or thermally activating the material until it solidifies. The solidified potting compound retains the insert. Also, the filling of an area of core or space with the material as described above, without the presence of a separate insert.

**Potting Compound**–One or two part pastes (nonmetallic material) that may be trowelled or cast to fill holes, depressions, core cells, and other honeycomb core cavities.

**Pour Coat**–An adhesive primer applied to the honeycomb core to stiffen the core and to protect it from corrosion.

**Prefit**–Positioning the details of an assembly together to determine how well they fit prior to actual bonding operation. Prefit may be mechanical or impression method.

**Prepreg**–Ready to mold or cure material in sheet form which may be fiber cloth, or mat, impregnated with resin and stored for use. The resin is partially cured to a B-stage and supplied to the fabricator for lay-up and cure.

**Pressure**–The force or load per unit area.

**Pressure Bag Technique**–Procedure for forcing details together for adhesive bonding utilizing a membrane such as nylon or rubber and a compressed gas such as air or nitrogen.

**Pressure Multiplier**–Tooling technique to locally apply greater pressure than the rest of the part, during curing operation.

**Primary Structure**–That structure which is essential to the basic airframe primary structure and failure of which would cause a major effect on the aircraft's structural integrity or performance. Examples are spoilers, underfloor bulkheads, aileron trailing edge, and nacelle/pylon structural panels.

**Primer**–A paint coating normally applied over a surface treatment or directly to a surface to increase corrosion resistance and improve the adhesion of subsequent topcoats.

**Pulse Echo**–The pulse echo method (in ultrasonic testing) is a method of inspection in which the presence and position of a reflector are indicated by the echo amplitude and time.

**PVC**–Abbreviation for polyvinyl chloride, a thermoplastic material used to line processing tanks.

**Qualification**–Process of accepting materials for use in bonded assemblies by conducting various receiving inspection tests.

**Qualified**–Terminology used to describe personnel who have demonstrated by various methods their ability to perform various adhesive bonding operations. Also used to describe materials that have been determined to be acceptable for use in bonding operations via various recovering inspection testing.

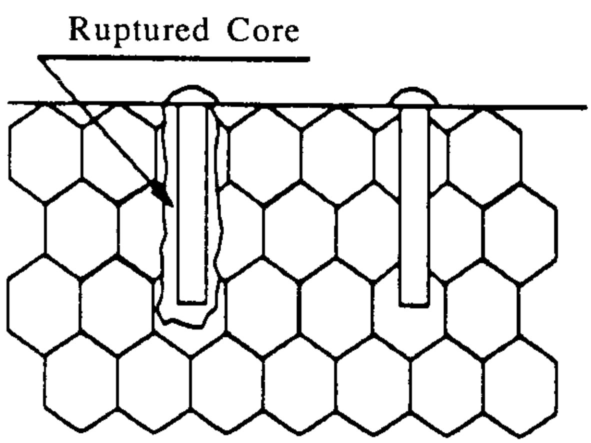



*FIGURE 3(k) Ruptured core.*

**Release Fabric or Material**–Material treated with substance such as teflon or cured silicones that is used during lay-up operations to prevent adhesion of squeeze-out adhesive during subsequent curing operation.

**Requalification**–Process of retesting previous qualified material to determine acceptability for continued usage.

**Requalified**–Designation for material that has successfully passed additional testing after expiration of original qualification period.

**Rigidifying**–Process of supporting local areas of core to prevent deformation during subsequent crushing of other core areas. Support is provided by application of pour coat adhesive to areas not to be crushed, and curing of the adhesive prior to crushing operation. Support material remains on the core.

**Rigidizing**–Process of supporting core during machining with materials such as polyethylene glycol, ice, double-sided tape, and temporary adhesives. Support materials are removed after machining is completed.

**Room Temperature**–Usually, 72 ± 5°F.

**Ruptured Core**–Core destroyed by the insertion of a fastener, or by drilling or other means, causing damage to core after part manufacture. See Figure 3(k).

**Sacrificial Adhesive**–Designation for film adhesive cured on primed surfaces to be subsequently bonded. The cured adhesive is "sacrificed" by partial removal of the cured adhesive by abrasion or scraping methods. After removal of the sanding dust or scraped particles, the resulting surface is acceptable for subsequent bonding operations.

**Sandwich**–A laminar construction, consisting of thin facings bonded to a relatively thick lightweight core, resulting in a rigid and lightweight panel. In this standard, bonded means "joined by welding, brazing or adhesive."

**Sandwich Construction**–A structural panel concept consisting in its simplest form of two relatively thin, parallel sheets of structural material bonded to, and separated by a relatively thick, light-weight core.

**Scrim**–A reinforcing fabric woven into a mesh construction, used as a backing to adhesive films to facilitate handling.

**Sealant**–Material applied externally to a bonded assembly to prevent moisture entry through openings in the part. Modified polysulfides are used for most applications. Silicones are used for high temperature applications.

**Sealing Compound**–See sealants.

**Secondary Bonding**–The joining together by adhesive bonding two or more already cured or bonded parts or details.

**Secondary Structure**–That structure which is essential to the aircraft's performance or mission accomplishment and whose failure would cause degradation of the aircraft's performance or mission capabilities. Examples are: main landing gear wheel well pods, wing fillets, fuselage tail cone fairing, wing edges surface panels.

**Shelf Life**–The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specification requirements and/or remain suitable for its intended function.

**Shifted Core**–Shifted core is caused by forcing core into its final assembly configuration prior to bonding. The cell walls of shifted core are no longer considered capable of bearing compressive loads. See Figure 3(l).

**Skins**–See face sheets.

**Solute**–The dissolved material.

**Specimen**–A piece or portion of a sample or other material taken to be tested. Specimens normally are prepared to conform with the applicable test method.

**Splice**– A splice is a fabrication step during assembly of an article when separate pieces of core are adhesively joined after core manufacture. Splices can be in the W or L direction, or at an angle out of the W or L direction. See Figure 3(m).

**Split Cell Walls**–A split cell wall is any tear in a core cell wall.

**Stabilizing**–Process of supporting local areas of core by application of pour coat adhesive prior to subsequent crushing of these core areas. Adhesive is dried but not cured prior to crushing.

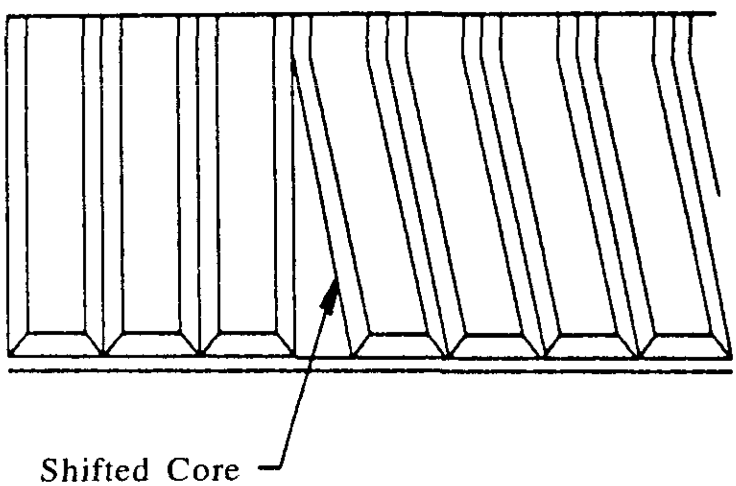



*FIGURE 3(l) Shifted core.*

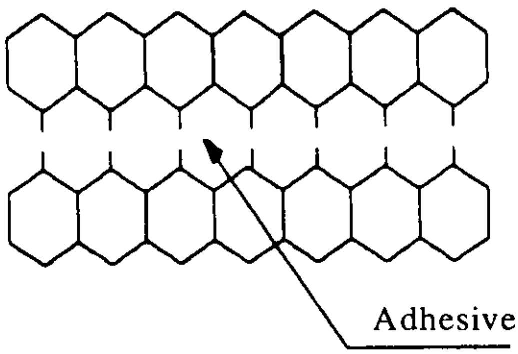



*FIGURE 3(m) Core splice.*

Support material remains with core. Adhesive is subsequently cured after crushing during final cure or subassembly operations.

**Static Pressure Port**–Tooling opening into the vacuum bag or bond fixture to which is attached a gauge (through the autoclave plumbing and wall) that indicates the pressure built up under the vacuum bag during the cure cycle.

**Stiffening**–Process of supporting local core areas via application and curing of pour coat adhesive, to prevent collapse of core during handling and assembly operations. Support material remains on the core.

**Strength, Compressive**–The maximum compressive stress which can be sustained. Compressive strength is calculated from the maximum load and the original cross section.

**Strength, Tensile**–The breaking load or force per unit cross-sectional area of the unstrained specimen.

**Stress**–The intensity of the internal forces or components of force at a point in a body that act on a given plane through the point. Stress is expressed as force per unit area and is calculated on the basis of the original cross-sectional area for tension, compression and shear testing.

**Stress, Bearing**–The applied load divided by the bearing area.

**Stress, Compressive**–The normal stress caused by forces directed toward the plane on which they act.

**Stress Crack**–An external or internal crack caused by tensile stresses less than the short time mechanical strength of the material.

**Stress-Strain Curve (Diagram)**–A graphical representation showing the relationship between the change in dimension of the specimen in the direction of the externally applied stress and the magnitude of the applied stress. Values of stress usually are plotted as ordinates (vertically) and strain values as abscissa (horizontally).

**Stud Insert**–Similar to externally threaded inserts except that the protruding element is not threaded.

**Subassembly**–Two or more detail parts of an assembly bonded together prior to the final bonding operation.

**Surface Treatment**–A treatment which alters the surface of a material by other than mechanical means, for purposes of improving corrosion resistance or to provide a bond for subsequent organic coatings. This definition includes chemical treatment, anodic treatment, and passivation, but excludes alkaline cleaning, degreasing except for core, solvent washes, pickling, or mechanical blasting treatment except for reinforced plastic laminates.

**Syntactic Material**–Low density substance obtained by adding light weight materials such as hollow glass or plastic spheres to the material which is generally epoxy.

**T Direction**–See Orthotropic Core Directions.

**Tack**–Stickiness of an adhesive before cure.

**Test Coupon**–Designation for bonded pieces of metal, core, or reinforced plastic representing the final assembly. Test panels (for coupons) should normally follow the assembly of components through prefit, surface preparation, and bonding operations. Also known as test specimens.

**Test Panel**–Designation of bonded assembly from which several test coupons (test specimens) will be taken.

**Test Specimen**–See Test Coupon.

**Thermocouple**–Two chemically different wires joined together at one point (junction) which produce a slight electrical current when heated. The electrical current is measured via a potentiometer and converted into a temperature reading.

**Tolerance**–The total amount by which a quantity is allowed to vary.

**Topcoat**–A paint coating normally applied over a primer to obtain increased corrosion resistance and to serve as a decorative finish.

**Toughness**–A measure of a material's ability to absorb work, or the actual work per unit volume, or unit mass of material that is required to rupture it. Toughness is proportional to the area under the load-elongation curve from the origin to the breaking point.

**Unbond**–An area within a bonded interface between two adherends in which the intended bonding action failed to take place. Also used to denote specific areas deliberately prevented from bonding in order to simulate a defective bond, such as in the generation of quality standards specimens. See Disbond.

**Unbonded Nodes**–Nodes that are separated due to lack of adhesive contact.

**Vacuum Bag Molding**–A process in which the lay-up is cured under pressure generated by drawing a vacuum in the space between the lay-up and a flexible sheet placed over it and sealed at the edges.

**Vacuum Port**–Tooling opening into the vacuum bag or bond fixture through which a vacuum may be drawn on the part to be cured.

**Valve Stem Cutter**–Cutter for machining core so named because it resembles an automobile valve. Valve stem cutters can be used to cut straight line elements, flat surfaces, and compound curvature parts.

**Vapor Hone**–Operation of preparing surfaces of reinforced plastic parts for bonding by propelling specific abrasive grit materials suspended in air or water at the surface to remove surface gloss (glaze).

**Vented-to-Atmosphere**–Process of allowing atmospheric pressure to enter the vacuum bag through valves during the curing operation.

**Verification Film (Verifilm)**–Film adhesive with FEP on both sides. Verifilm is used to measure bonding uniformity between honeycomb and face sheets.

**Void**–A void is the area in which air bubble entrapment in the adhesive or lack of adequate adhesive causes incomplete bonding.

**W Direction**–See Orthotropic Core Directions.

**Working Life**–See Pot-Life.

# 4.0 GENERAL REQUIREMENTS

**4.1 Introduction.** This chapter covers important aspects of honeycomb sandwich construction. These include sandwich construction, face skins, core, adhesives, and auxiliary manufacturing materials. The discussions are limited to aluminum core and aluminum and fiberglass facing constructions. The purpose of this chapter is to provide a manufacturing engineer with the basic knowledge of honeycomb sandwich constructions necessary to carry out successful assembly of honeycomb structures for aerospace applications.

**4.1.1 Sandwich Construction**. A structural honeycomb sandwich consists of three elements, as shown in Figure 4.1.1(a), (1) a pair of thin, strong facings; (2) a thick, lightweight core to separate the facings and carry loads from one facing to the other; and (3) an attachment which is capable of transmitting shear and axial loads to and from the core. The facings of a sandwich panel act similarly to the flanges of an I-beam by taking the bending loads–one facing in compression and the other in tension. The honeycomb core, like the web of the I-beam, resists the shear loads and increases the bending stiffness of the structure by spreading the facings apart; unlike the I-beam's web, it gives continuous support to the flanges or facings.

Structural sandwich constructions were one of the first forms of composite structures to have attained broad acceptance and usage. Virtually all commercial airliners and helicopters and nearly all military air and space vehicles make extensive usage of sandwich construction. The effectiveness of sandwich construction is shown in Figure 4.1.1(b).

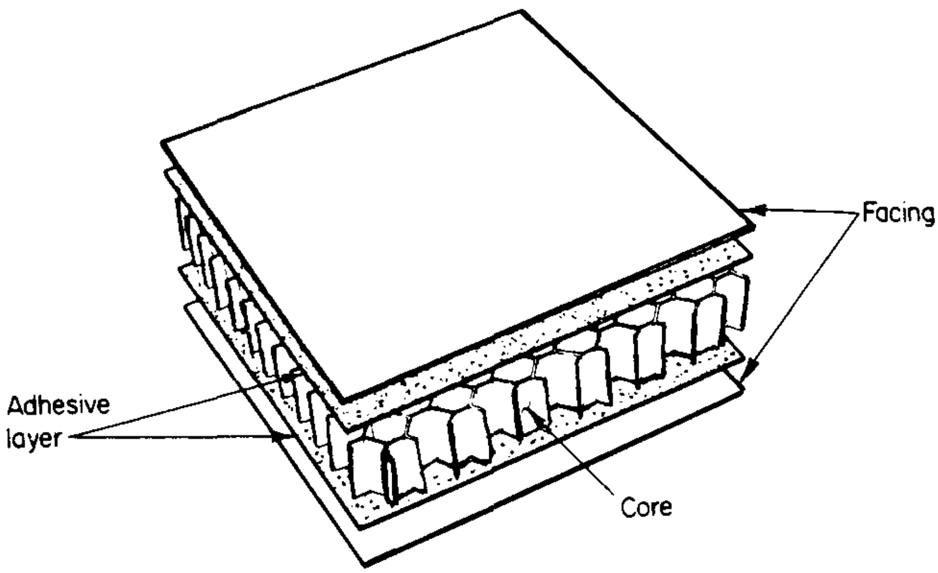
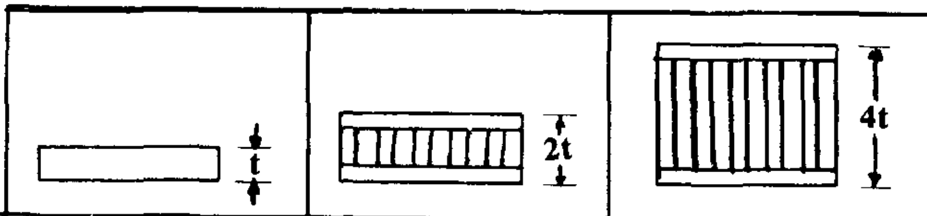



*FIGURE 4.1.1(a) The elements of a honeycomb sandwich structure are as follows: (1) two rigid, thin, high strength facings; (2) one thick, low density core; and (3) an adhesive attachment which forces the core and facings to act as a continuous structure.*

*Industry and government specifications and standards are listed in Chapter 2.

**Company specifications and general sources of information are included in the list of references at the end of this Handbook.




| | | | |
|---|---|---|---|
| Relative Stiffness (D) | 100 | 700 | 3700 |
| Relative Strength | 100 | 350 | 925 |
| Relative Weight | 100 | 103 | 106 |

*(Courtesy Hexcel Corp.)*

***FIGURE 4.1.1(b) An example of how honeycomb stiffens a structure without materially increasing its weight.***

**4.1.2 Materials Selection and Fabrication.** When choosing facing, as well as core, adhesive, or other materials for an application, it is wise to examine the less obvious properties of the material, such as toughness or brittleness, mode of fracture, durability and weatherability, compatibility with rivets and bolts, and other such attributes which may directly affect the usability or success of the end product, even though they are not directly involved in stress analysis or weight savings.

An understanding of these requirements has resulted in a switch from aluminum to fiberglass skins, and from fiberglass to aramid cores for most aircraft cabin interior panels. This understanding is also the reason for the use of hybrid skin composed of graphite fabric with a surface layer of aramid fabric on much of the sandwich structure of several airliners.

The key requirements for the selection of sandwich materials are strength, stiffness, and weight. In addition to these, consideration of the other secondary items described above will allow the design engineer, as well as the manufacturing engineer, to assemble an effective structural part.

In assembling structural sandwich parts, two procedures are commonly followed. One involves a two-step operation, in which the facings are laid up and cured independently before bonding to the core material. The other is a one-step or "co-curing" method, in which the facings are laid up and applied to the core in the "B" staged condition. In this case, the sandwich assembly is cured and bonded in one autoclave operation.

As new manufacturing methods and techniques have been investigated, it has been found that quality sandwich panels can often be fabricated by co-curing. This procedure achieves the same structural integrity as the two-step operation, but at a considerable savings in labor and tooling costs.

In special cases involving complex core machining and forming, it may be desirable in either of the above methods to bond only one face sheet at a time. One example of a special case is to machine one side of the core and bond the facing to core in a formed mold, and then to machine the other side of the core in the restrained position and co-cure the second face sheet.

Panels are manufactured by the vacuum/autoclave process, lay-up, and bagging techniques. In the *co-curing method, facings may be laminated from adhesive type prepregs made from a modified* resin system used for adhesive bonding, in which resin content and flow of the prepreg material are such that a uniform filleted bond between facings and core is obtained. Strength properties of the laminate, however, are somewhat lower when the modified adhesive resin systems are used. It is suggested that a higher strength epoxy resin prepreg be used with an adhesive film applied between the core and laminated facing, as is done in the two-step precured face sheet-to-core bonding. To prevent damage to the core and facing in the co-cured method, the total molding pressure is normally not in excess of 50 psi. Cure and post-cure temperatures are also limited to avoid degradation of the core. Fiberglass facings between the core and graphite skins are recommended to prevent corrosion of aluminum honeycomb core.

For nonmetal facings such as fiberglass and graphite reinforced plastic laminates, the bonding surface should be cleaned with acetone at room temperature. After adhesively bonding the facing to the core, mild pressure (not exceeding a few atmospheres) should be cautiously applied. Scrim cloth may be used for bond line control.

All materials used in bonded assemblies and repairs should conform to applicable Government or other acceptable specifications. Care must be taken to ensure that materials requiring refrigeration are maintained at proper temperature levels during transit and until placed in receiving storage. During storage, proper temperature and humidity controls must be provided.

Upon receipt, materials must be checked to determine whether they meet minimum specification requirements. This can be accomplished by performing in-house tests or by requiring the supplier to furnish certified qualifying test results. A guide to the types of tests that should be conducted in-house is given in Chapter 5. All material shall be clearly marked to indicate its storage or expiration date. Out-dated material should be requalified or discarded in accordance with applicable specifications.

Instructions regarding material handling and storage must be carefully followed. Refrigerated polymeric materials, e.g., adhesives, potting compounds, sealants, etc., must be allowed to stabilize at room temperature before opening. The material should be hermetically sealed before being returned to storage and the out-time recorded. Special precautions should be taken in handling flammable materials.

Cleaned and primed metal details, to be stored rather than immediately used in a bonded assembly, should be wrapped in oil-free kraft paper, black polyethylene film, or similar materials as a protection from deterioration caused by ultraviolet exposure.

**4.2 Face Skins.**

**4.2.1 Function and General Description.** The primary function of the face sheets is to provide the required bending and in-plane shear-stiffness and to carry the axial, bending, and in-plane shear loading. In aerospace applications, most commonly chosen facings include resin impregnated fiberglass cloth (usually "prepreg"), graphite prepreg (either unidirectional tape or woven fabric), or aluminum, titanium, or stainless steel sheet. Even the most economical of these products represents a substantial cost, and customary practice is to choose among them very carefully on a value engineering, or lowest lifetime cost, basis.

The facings of a sandwich part serve many purposes, depending upon the application, but in all cases they carry the major applied loads. The stiffness, stability, configuration, and, to a large *extent, the strength of the part are determined by the characteristics of the facings as stabilized by* the core. To perform these functions, the facings must be adequately bonded to a core of acceptable quality. Facings sometimes have additional functions, such as providing a profile of proper aerodynamic smoothness, a rough nonskid surface, or a tough wear resistant floor covering. To better fulfill these special functions, one facing of a sandwich is sometimes made thicker, or of slightly different construction than the other.

**4.2.2 Aluminum Face Skin.** The stronger aluminum alloys, such as 7075-T6, 2024-T3, or 2014-T6 are commonly used as facings for structural, as well as for nonstructural, sandwich applications. MIL-HDBK-5 is a source of design properties for typical aluminum face skin materials.

**4.2.3 Fiberglass Face Skin.** Resin-impregnated glass-fabric facings possess acceptable properties for structural sandwiches when properly fabricated. Because of their excellent dielectric characteristics when fabricated with the proper resin, this type of facing is used almost universally for sandwich construction radomes. A variety of weaves are available commercially, which makes it practical, by orienting the fiber directions in the facing, to achieve a wide range of directional strength properties.

In many airframe applications, facings are exposed to moisture, either in the form of high humidity or free water. Even though the amount of moisture absorbed by glass-reinforced plastic is generally quite small (on the order of 0.5-1.5 percent), the strength properties are decreased. The amount of decrease depends upon the type of finish applied to the glass fabric. Current specification requirements permit only small losses of strength after exposure to moisture, that are consistent with results of tests on fabrics made with more recent and effective finishes. MIL-HDBK-17 is a source of design properties for typical fiberglass face skin materials.

**4.3 Sandwich Cores (Aluminum).**

**4.3.1 Function and General Description.** A sandwich construction is an innovative structural concept. The honeycomb core provides stiffness and at the same time reduces the weight of the structure. The primary function of the core in sandwich structures is to stabilize the facings and to carry out most of the shear loads through the thickness. In order to perform this job efficiently, the core must be as rigid and as light as possible, and must deliver uniform and predictable properties in the environment (e.g., high humidity) in which the finished part is to perform.

To meet the performance requirements of the sandwich structure, the core must exceed minimum specification requirements for mechanical properties and physical characteristics and must conform to weight limitations. Aluminum cores with various densities and core configurations are available to meet specific requirements. All aluminum core intended for use in military aircraft must be certified to MIL-C-7438.

**4.3.2 Types of Core.** The various types of core commonly available for sandwich construction can be described as follows:

4.3.2.1 Hexagonal. The standard hexagonal honeycomb core, shown in Figure 4.3.2.1, is the basic and most common cellular honeycomb configuration, and is currently available in all the metal and nonmetal combinations described in this chapter. Hexagonal core is available in both expanded and corrugated forms.

4.3.2.2 Corrugated or Over-Expanded. The corrugated or over-expanded (OX) core configuration, as shown in Figure 4.3.2.2(a), is a hexagonal honeycomb which has been over-expanded in the "W" direction, providing a rectangular cell configuration which facilitates curving or forming in the "L" direction. The OX process tends to increase "W" shear properties and slightly reduce "L" shear properties, compared to hexagonal honeycomb core.

A variation of the traditional OX configuration, as shown in Figure 4.3.2.2(b), provides for exceptional formability into compound curvatures with reduced anticlastic curvature and without buckling the cell walls. Curvatures of very tight radii are easily formed. When formed into tight radii, this type of core provides higher shear strengths than comparable hexagonal core of equivalent density. Corrugated core can be manufactured in most of the materials from which hexagonal honeycomb is made.

4.3.2.3 Waffle-Type. Cores of sheet material fabricated into a configuration resembling a waffle have been produced, as shown in Figure 4.3.2.3. Metal sheets embossed or dimpled into a waffle configuration with square or triangular lands on either side have been manufactured. The waffle-type core does not lend itself well to sandwich constructions that require tapered core thickness. This type of core is relatively uncommon.

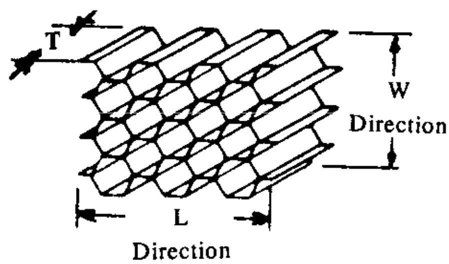



***FIGURE 4.3.2.1 Hexagonal core.***

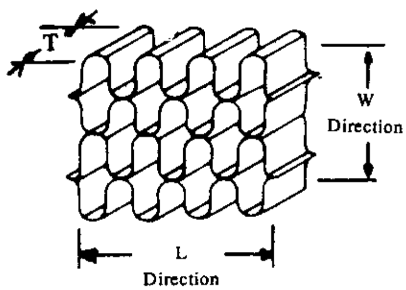



***FIGURE 4.3.2.2(a) Traditional corrugated core configuration.***

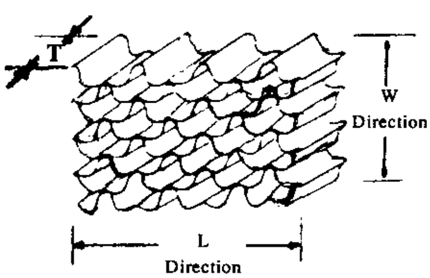



***FIGURE 4.3.2.2(b) Variant of traditional corrugated core configuration.***

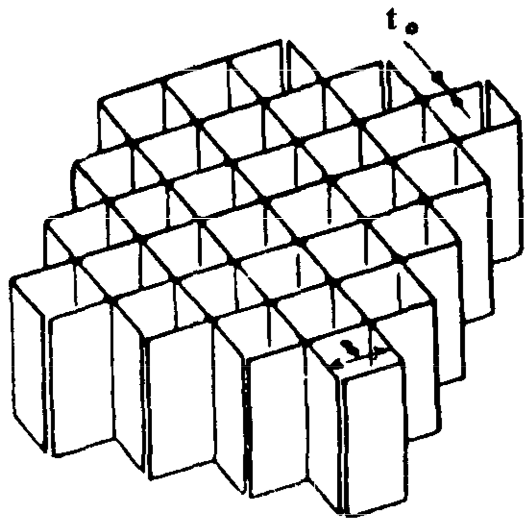



*FIGURE 4.3.2.3 Waffle-type core.*

## 4.4 Adhesives.

**4.4.1 Function and General Description.** Adhesives are used primarily to assemble the core and the skin into an integral structural part. Adhesives are also used for rigidizing, stiffening and stabilizing of core and to reinforce core walls after crushing. For honeycomb sandwich skin repairs, precured foam-in-place materials and co-cured replacement plies can be used. The repair patches can be put in place with adhesive to rigidize, stiffen and stabilize the damaged area.

Two general types of adhesives are used, namely, adhesive films and foam adhesives. Adhesive films are generally supported, i.e., they have a carrier such as nylon or woven glass or polyester substrate. The foam adhesives are unsupported and are mainly epoxy type with fillers dispersed in them for processability. There are also blowing agents which release gases such as nitrogen and carbon dioxide during curing to provide the foaming characteristics.

Adhesives for sandwich composite structures differ somewhat from those commonly used for joining composite laminates in aerospace applications. These differences have lessened for the newer modified epoxy materials. However, because of different requirements during fabrication, some factors still must be taken into consideration.

Various types of pastes and liquids are used in the bonding operation. Most of these paste materials are epoxies, modified epoxies or epoxy polyamides. Cleaning liquids include methyl ethyl ketone (MEK) and isopropyl alcohol. Water (often in the form of steam) is also used for general cleaning purposes.

4.4.1.1 Products Given Off During Curing. Some adhesive types, such as phenolic, give off a vapor as a product of the curing reaction. The presence of these secondary materials can lead to several problems, such as:

- Internal pressure, resulting in little or no bond in some areas, or "blisters."
- Core splitting, as the gas forces its way to a lower pressure area.
- Core movement, sometimes several inches, resulting in an unusable cured part.

- Subsequent corrosion of core or skins by the chemical action of the vapor or its condensate.

4.4.1.2 Bonding Pressure. Adhesives such as the phenolics and some others require more than atmospheric pressure in order to prevent excessive porosity. Certain forms may be suitable for solid cores like balsa, but cannot be used at all in open cores such as honeycomb or large cell foams. Also, most core materials will not withstand compressive bonding loads exceeding a few atmospheres, and, consequently, cannot be used with an adhesive system requiring higher pressures.

4.4.1.3 Fillet Forming. In order to achieve a good attachment to an open cell core, such as honeycomb, the adhesive must have a good combination of surface wetting and controlled flow during the early stages of curing. Controlled flow prevents the adhesive from flowing down the cell wall and leaving a low strength top skin attachment and an overweight bottom skin attachment.

4.4.1.4 Adaptability. The requirements noted above must all be met while also meeting all the requirements of a skin-to-skin or skin-to-doubler attachment. In the case of contoured parts, the adhesive must also be a good "gap-filler" without appreciable strength penalty, since tolerance control of details is much more difficult to achieve on contoured panels, and a greater degree of latitude for misfit must usually be allowed.

4.4.1.5 Bond Line Control. This requirement exists because of occasional misfitting details. It involves the capability of the adhesive to resist being squeezed out from between faying surfaces when excessive pressure is applied during curing to a local area of the part. Many adhesives are formulated to achieve good core filleting and are subsequently given controlled flow by adding an open weave cloth or fibrous web, cast within a thicker film of adhesive. This "scrim cloth" then prevents the faying surfaces from squeezing out all the adhesive, which would result in an area of low bond strength.

4.4.1.6 Toughness. The word "toughness" has many meanings in the world of adhesives. Usually, it refers to the capability of the adhesive in preventing bond line cracks from growing under impact loads. In the area of sandwich core-to-facing bonds, it refers to the capability of the adhesive to resist loads which act to separate the facings from the core under either static or dynamic conditions. It has been found from experience that greater toughness in the bond line usually equates to greater durability, and, thus, to longer service life.

Many types of tests have been devised to measure toughness, but the most common one used for sandwich structures is the climbing drum peel test. This test has the virtue of being easily duplicated, as well as possessing an obvious relationship to the toughness whose value is sought. Values of peel strength will vary considerably, depending upon:

- Toughness of the adhesive.
- Amount of adhesive used.
- Density of the core.
- Cell size of the core.
- Direction of the peel (with, or across the ribbon direction).
- Adequacy of the surface preparation.
- Degradation of the adhered surface subsequent to bonding.

Because these variables can lead to widely differing peel strengths for the same adhesive, all of them must be properly understood and controlled if the peel test is to be used, and its value compared to other test results.

The peel test is used to control quality throughout the sandwich industry. If the adhesive weight and core material are in balance, values obtained will give indications of tooling or cure problems, and of adhered surface preparation problems. It is particularly useful for quality control when an environmental exposure involving both elevated temperature and high humidity is interposed between manufacture and test. The peel test can be adapted for nearly any skin material, except that it becomes impractical with very thick or very stiff skins.

It can be readily seen that a number of points of difference separate the sandwich adhesives from other structural adhesives. Fortunately for the sandwich user, many adhesives are available which meet both sets of requirements satisfactorily. The types available, along with some salient features, are as follows.

**4.4.2 Phenolic.** One of the principal types of adhesives developed specifically for bonding metals is based on phenolic resins modified with the elastomers neoprene or butadiene-acrylonitrile synthetic rubbers, or the polyvinyls.

4.4.2.1 Neoprene Elastomer-Phenolic. This type of adhesive exhibits limited flow during the bonding process. Consequently, it is applied as a smooth film. Uniformly high pressures are used to obtain contact over the entire bonding area. This adhesive was formulated to be cured in the range of 300-335°F, and adhesives cured within this range are commonly referred to as elevated-temperature-setting.

Neoprene phenol adhesives are generally classified as having moderate shear strength (2,500-3,500 pounds per square inch) in standard 1/2 inch aluminum lap-joint specimens at room temperatures. The strength of bonds made to aluminum with these adhesives has been found to deteriorate, in some instances, when exposed to salt water spray or high humidity conditions. Adhesives of this type generally are being replaced by acrylonitrile-modified phenolic adhesives or others with improved properties.

4.4.2.2 Nitrile Elastomer-Phenolic. In the search for adhesives having better resistance to elevated temperature, numerous formulations based on the combination of phenol resin with butadiene-acrylonitrile synthetic rubber have been developed. These adhesives are available as solvent solutions, as unsupported films, and as films on nylon or glass-fabric carriers. Some of these formulations have good strength and aging properties at temperatures to 350°F and short, intermittent exposure at temperatures as high as 500°F may be possible. However, for many of the butadiene-acrylonitrile phenolic adhesives, the maximum design temperature is 250-260°F. These adhesives usually have a shear strength from 2,800-4,600 pounds per square inch at room temperatures in the standard 1/2 inch aluminum lap-joint specimens.

4.4.3 Epoxy.

4.4.3.1 Epoxies Modified with Nylon or Other Polyamide Polymers. The epoxy adhesives were the first to have excellent filleting and controlled flow properties, along with both high strength and high toughness, although they are somewhat moisture sensitive. Some versions are provided as one side of a two-sided tape adhesive, in which the other side is a rubber or vinyl-phenolic. This combination provides both excellent peel resistance and durability at the skin side, and excellent peel resistance at the core side.

4.4.3.2 Nitrile Modified Epoxies. These make up a broad group of more recent materials which provide many of the flow and toughness properties shown by the nylon epoxies, along with the durability and weather resistance of the vinyl phenolics. They are the most common of the "toughened" thermosetting adhesives and are usually limited to about 300°F service temperature. Some of these materials routinely achieve shear strengths of 5000 psi, and most can be cured over a wide range of temperatures and pressures.

4.4.3.3 Phenolic-Epoxy. The adhesives of this family give off at least some water during curing and, therefore, are used only where their high strength, durability, or high temperature mechanical properties are essential. The out-gassing cure products usually require venting or perforating the core material. Their use as sandwich adhesives has declined in recent years because a number of non-out-gassing, high temperature adhesives have become available.

**4.4.4 Other Organic Systems.**

4.4.4.1 Urethanes. Urethane based adhesives are used in many commercial structures. Both moisture-cured and two-part systems are available. These materials are used for controlled flow and good surface wetting in applications such as filleting. They provide good flexibility in adhesively bonded joints. Urethanes have moderate strengths (not as high as epoxy based adhesives).

4.4.4.2 Other Polyamides, Thermoplastics, and Highly Specialized Adhesives. These adhesives are used in a number of applications ranging up to about 700°F service temperature, but do not represent a very large group of materials. They can be categorized by chemical type, or by the form in which they are available, as follows:

- **Light Liquids, Heavy Liquids, Pastes, Putties, or Syntactic Foams.** Only a few are used for core-to-face bonds, but many are used in sandwich construction to splice pieces of core to each other; to provide high strength edges, areas, or surfaces; to carry shear loads from fittings, inserts, or end ribs; and for similar uses. Most of the materials so used are epoxies, modified epoxies, or epoxy polyamides. Curing temperatures vary from as low as 40°F for some two-part systems up to 420°F for some materials intended for service at elevated temperatures.

- **Supported Films Having a Carrier of Light Glass Fiber, Cotton, Nylon, or Polyester Cloth, or Spunbonded Synthetic Fiber.** These types are provided either dry or with slight to moderate "tack" or stickiness, so that the parts of the assembly stay in place as they are being assembled.

- **Unsupported Films, Containing Only the Adhesive, With No Carrier.** The very low weight films are nearly always furnished without a carrier, as the weight of the carrier itself becomes quite appreciable in very light sandwich structures. They are often hard to handle and sometimes have bond line control problems.

- **Reticulating Films.** These films are intended for use at very low weights, with the adhesive being melted after placing on the core, so that it draws back to the cell edge and leaves material to form the largest possible fillet without wasting any on the inside facing surface in the middle of the cell.

- **Cell-Edge Adhesive.** This material is placed on the cell edge by the honeycomb manufacturer to provide the same results as those produced with reticulating films.

- **Self-Adhesive Skins.** These skins are structural fabrics of glass, graphite, quartz, or aluminum coated glass fibers pre-impregnated with a resin, which is then cured so that the fiber-filled resin becomes both the face structure and the attaching material.

**4.4.5 Adhesive Primers.** Adhesive primers are generally used to provide corrosion protection within the bond line. Furthermore, they protect the clean surface and provide longer time to assemble the honeycomb part. Another important function of the primer is to promote adhesion between the adhesive film and the metal.

Typical adhesive primers are one-component, low viscosity epoxy with strontium chromate. The high temperature cure system uses dicyandiamide as curing agent. The low temperature systems are amine cured. The adhesive primers are generally applied in thin films with thickness varying between 1/10,000 and 5/10,000 inch. For proper selection and use, consult the applicable version of the honeycomb procurement specification.

**4.5 Auxiliary Manufacturing Materials.**

**4.5.1 Cleaning Agents.** Cleaning Agents should be used during the assembly of honeycomb composite structure if oil contamination of the core is suspected during the cutting operation. For aerospace applications, acetone (O-A-51) is often used as a guideline for degreasing operations. Aqueous cleaners such as MIL-C-87937, Type I or MIL-C-83873 also work well for some applications.

Two solvents commonly used for cleaning aluminum honeycomb core are methyl ethyl ketone (MEK) and perchloroethylene (see ASTM D 740 and O-T-236). Typically, a suspect core is put in a vapor degreasing tank at 190-200$^{\circ}$F. The part is taken out after a specified time and is dried in an oven. It is then either wrapped in a polyethylene bag or wrapped in paper and shipped to the assembly area.

**4.5.2 Sealants/Aerodynamic Smoothers.** Sealants are used in aerospace applications for mating (faying) two similar or dissimilar surfaces and sealing integral fuel tanks in aircraft wings. Aerodynamic smoothers are fairing compounds that are used to fill gaps in butt joints and to repair scratched or dented areas on exterior surfaces of aircraft. These compounds are formulated to adhere to joint surfaces over a wide range of temperatures, joint movements, and environment stress conditions. Desirable properties for aerospace sealant applications are good adhesion, solvent and fuel resistance, flexibility, and low shrinkage.

Sealants are used to seal areas such as tooling holes and assembly corners not filled with adhesive. Sealant should not be used to cover up defective bond lines or debonded areas. Sealant will not absolutely ensure that moisture will remain out of the part. Only a good, tight, void-free bond line can prevent moisture entry into an assembly (see MIL-S-8802).

**4.5.3 Bagging Materials.** Several types of bagging materials are used during honeycomb part fabrication. Typical bagging films are Nylon 6 and Nylon 6/6 films. The last one is more heat resistant and can be used for 350$^{\circ}$F cure systems. These films are typically 2 mils thick. Another type of film that is also used extensively is silicone rubber film.

**4.5.4 Potting Compounds.** Potting compounds contain an inert filler added to a liquid resin to produce a paste consistency. Potting compound pastes are used to reinforce honeycomb core.

**4.6 General Requirements.** This section describes the general requirements for personnel, manufacturing and inspection facilities and equipment, record keeping, and safety considerations for the fabrication and inspection of adhesive bonded honeycomb assemblies.

**4.6.1 Personnel.**

**4.6.1.1 Skill Level.** Personnel should have the demonstrated skill level to adequately perform the assigned task(s).

**4.6.1.2 Classification/Certification.** Qualification of Bonding Personnel - Adhesive bonding operations should only be performed by qualified personnel. Bonding personnel are normally qualified by complying with all of the following:

- Passing the written test.
- Passing a practical proficiency test.
- Receiving on-the-job training.

Adhesive bonding operations are complex and they require significant attention to detail. As a result, prior working experience under the supervision of skilled personnel is vital before an individual is allowed to perform adhesive bonding operations independently. The training should be as part-specific as possible since the requirements and procedures may vary from one honeycomb assembly to another.

A list of qualified bonding personnel and their level of proficiency should be maintained, and issued, and made available for review by Government personnel.

Repair personnel must be fully qualified in the preparation of repair materials and in the repair of bonded honeycomb sandwich and metal laminate construction. Inspectors must be qualified and skilled in the use of the specified repair and inspection equipment. Qualification of inspection personnel should be in accordance with MIL-STD-410.

**4.6.1.3 Tool Qualification.** Prior to production, each bonding tool should be qualified in accordance with the applicable material and process specification to ensure that each tool is capable of producing acceptable assemblies when put into production use. The methods for tool qualification include verification film testing, destructive testing, and proof loading. Tool requalification is required if major modification is made or warranted by quality control test results.

**4.6.2 Manufacturing Facilities and Equipment.**

**4.6.2.1 Storage and Handling.** Proper storage and handling of raw materials, adhesives, core, potting compounds, sealants, consumable materials, detail parts, subassemblies, and finished assemblies contribute to the delivery of acceptable, bonded assemblies.

4.6.2.1.1 Raw Materials. Store sheet metal in original shipping containers interleaved with nonwaxed Kraft paper or cardboard under dry conditions to prevent surface damage and corrosion. Handle with crane, fork truck, cart, or manually, while taking care not to scratch, dent, or crease the sheet material.

Store castings, forgings, and bar and plate stock under dry conditions to prevent corrosion. Handle with care to prevent damage.

4.6.2.1.2 Adhesives, Potting Compounds, Sealants, and Paints. Store adhesive primers, film adhesives, foaming adhesives, paste adhesives, potting compounds, sealants, and paints per manufacturer's instructions in the original shipping containers to protect them from handling and storage damage. Use these adhesive storage facilities exclusively for this function.

Refrigerators and freezers should be equipped with temperature versus time recorders. Refrigerators should be maintained at $50^{o}$F or lower and freezers at $0^{o}$F or lower. The storage temperature and time should be in accordance with the applicable version of the procurement specification.

Materials should be protected from deformation, moisture, direct sunlight, fluorescent light, and other damage.

Each roll, package, or container should be marked with complete identification information including storage requirements, date of receipt or manufacture, as applicable, inspection qualification date, and the expiration date of this qualification. Material should be used on a first-in, first-out basis.

Unless otherwise specified, when materials are taken from storage for use, the unused portion should be carefully packaged to prevent moisture entry and returned to storage as soon as possible. Materials not in use should always be kept in sealed or tightly closed packages or containers to prevent contamination and moisture entry.

Materials exhibiting erratic handling characteristics during processing should be submitted to Quality Assurance for evaluation and disposition.

In order to prevent moisture absorption, allow material stored at $0^{o}$F or lower to warm to room temperature for 24 hours in its sealed bag or container before opening. Removal of a small quantity of adhesive at $0^{o}$F is permissible provided the removal is done at $0^{o}$F. The removed material should be placed in a polyethylene bag, the bag sealed at $0^{o}$F, and the contents allowed to reach room temperature before use. The roll from which the material is removed should be returned to its original bag and the bag sealed at $0^{o}$F. Store adhesive at room temperature in sealed, desiccated (with appropriate indicator to show need for desiccant replacement) metal container for a period not to exceed that permitted by the applicable version of the procurement specification. If the material is not used up at the end of this storage period, it may be discarded or reinspected and reused for the period of requalification allowed by the procurement specification.

Material stored at 35-$50^{o}$F should reach room temperature with no further condensation on the container before use. Material may be stored at room temperature if permitted, by the procurement specification for the maximum time permitted, requalified if permitted or returned to refrigerated storage after resealing the package or container to prevent moisture entry and preservation of the material.

4.6.2.1.3 Aluminum Honeycomb Core. Store aluminum honeycomb core in the original shipping container, if available, and in a dry place to prevent damage and contamination. If the original shipping container is no longer available, core should be carefully stacked and covered or wrapped in clean, nonwaxed Kraft paper. Many core users build cabinets (wooden or metal) to house core pieces. This protects core from damage or contamination from the shop environment while providing a convenient system for cataloging/tracking core pieces.

**NOTE**

Handle the core with extreme care to prevent damage.

Store machined aluminum honeycomb core in a suitable container (or cabinet) to prevent damage. If the core has been received in a "ready for bonding" condition or if the core has been cleaned for subsequent bonding operations, store it in a controlled contamination area or wrap it in clean, nonwaxed Kraft paper. Protect it from damage and handle the core with clean white gloves only.

1. All working surfaces which come in contact with the core must be kept clean by either covering it with clean, nonwaxed Kraft paper or wiping it with methyl-ethyl-ketone solvent and clean cheesecloth (or an equivalent material).

2. Wear clean, dry, white, lint-free gloves when handling core.

3. Do not use compounds containing talc, grease, waxes, uncured silicones, or other materials detrimental to bonding in any areas where clean handling operations are in progress.

4. Eating, drinking, and smoking are prohibited in the areas where core splicing is performed.

5. Air lines to machines and manufacturing areas must be equipped with filters capable of removing oil, moisture, etc., from the air. Such filters shall be drained and cleaned as necessary to prevent core contamination.

6. Cutting tools (saws blades, milling cutters, bread knives, router blades, etc.) must be free of any contaminating substance.

7. Completely cover core when not working on it with either clean, nonwaxed Kraft paper or a clean sheet of polyethylene.

4.6.2.1.4 Consumables. Store consumable materials (those that are used in the fabrication process but do not become part of the final product) in accordance with the material supplier's instructions.

Handle these materials with care to prevent damage or contamination. Take particular care during storage and handling of vacuum bag materials to prevent puncturing or stretching of the film.

4.6.2.1.5 Detail Parts and Skins. Store detail parts and skins to prevent damage and contamination. Interleaf or wrap them with nonwaxed Kraft paper.

Detail parts and skins that have been cleaned or cleaned and primed, and have adhesive applied should be handled only with clean white gloves.

**CAUTION**

DO NOT touch phosphoric acid anodized surfaces as they are easily contaminated and damaged. Store such parts in the controlled contamination area to prevent damage and contamination for no longer than the maximum period of time permitted by the procurement specification.

4.6.2.1.6 Subassemblies. Store and handle bonded subassemblies in the controlled contamination area to prevent damage and contamination.

4.6.2.1.7 Finished Assemblies. Store and handle finished parts under dry conditions in a manner that prevents damage to the assembly.

**CAUTION**

Pay particular attention to the bonded edges of an assembly to prevent any peeling action on the metal-to-metal bonded joints because these areas are particularly susceptible to damage.

**4.6.2.2 Lay-Up Room.** The following guidelines are important to follow to prevent contamination of surfaces to be bonded and to prevent degradation of bonding materials.

- The lay-up room (controlled contamination area) should be completely enclosed. The walls and the ceiling should be painted.
- The floor can be sealed or covered with nonflaking, easily cleaned material such as plastic, paint, vinyl tile, etc. There should be no silicones in the floor sealant or covering material.
- Filter all incoming air and periodically check, clean, or replace the filters to ensure proper operation.
- There should be a slight, positive air pressure differential such that unfiltered air does not enter the area through access doors or other openings.
- Keep doors closed when not in use.
- The area should be kept clean by periodic mopping, vacuuming, or other suitable means. Cleaning is required when visual inspection shows any accumulation of dust, dirt, or other contamination.
- Internal combustion engines should not be allowed in the area because the exhaust fumes are detrimental to the bonding operation.
- Smoking or eating should not be permitted in the area either.
- Contaminants detrimental to adhesion such as dirt, grease, or oil should not be allowed to accumulate on materials, tools, parts, or equipment taken into the area.
- Processes or operations which produce uncontrolled spray, dust, fumes, or particulate matter should not be permitted in the area.
- It is essential that the area's temperature and humidity be controlled per MIL-A-83377.

Structural fiberglass, graphite (carbon), and boron and aramid epoxy composites may be laid-up or assembled concurrently with metal bond assemblies, using the same controlled contamination area. Adhere to the following restrictions throughout the entire controlled contamination area.

1. All precautions and requirements for cleanliness and contamination control as stated above should be enforced.
2. Tools should be prepared prior to entering the controlled contamination area. Only nonsilicone containing parting agents may be applied to tooling details prior to entering the area.
3. Wherever possible, metal bonding operations should be segregated from composite lay-up operations.

4. White cotton gloves, wipers for cleaning, and all tapes should conform to the procurement specification requirements.

5. The following materials and procedures are prohibited in the controlled area:

   a. Uncured parting agents.

   b. Use of hand cream.

   c. Application of conductive coatings.

   d. Application of gel coats to molds.

   e. All grinding, sanding, or milling operations.

   f. Deposition of graphite (carbon) or boron dust or fibers on bond faying surfaces.

   g. Waxes, compounds containing silicone, or any material detrimental to adhesion.

An example of an environmentally controlled adhesive application area is shown in Figure 4.6.2.2. The activity in the area should be accomplished by individuals qualified or certified in the techniques of adhesive bonding. All work should be done by personnel wearing white gloves to avoid contamination.

4.6.2.2.1 Controlled Areas. The adhesive application area should be an enclosed space with special facilities to ensure that it is dust controlled. Filtered air should be constantly forced into the area to maintain the air pressure at a higher level than the surrounding area. This prevents contaminating substances from entering the dust-controlled area when the doors to the surrounding areas are opened.

Unless otherwise noted, temperature and humidity should be monitored to meet the requirements of MIL-A-83377. Any method and equipment may be used for monitoring that gives assurance of maintaining proper control.

4.6.2.2.2 Equipment.

- Tables or work benches used for cutting, core splicing, etc., should be covered with a minimum of 1/2-inch-thick polyurethane sheet to prevent the surfaces (and the part) from damage.
- All other work tables should be covered with a suitable material to prevent damage or contamination to any component being bonded.
- No steam-heated equipment or gas-operated vehicles should be allowed in the controlled area to prevent contamination of bonding materials and the surfaces of parts to be bonded.
- Depackaging of materials, filing, drilling, cutting, or grinding of metals should not be permitted in the controlled area to prevent contamination.
- All materials, parts, tools, equipment, and other items to be used in the controlled area should be free of extraneous dirt, grease, oil, talc, or wax to prevent contamination.
- All solvents used in this area should be contained in safety cans or other containers that meet safety and hazardous material handling requirements.
- Electrically operated equipment may be allowed in the controlled area for short periods of time only.

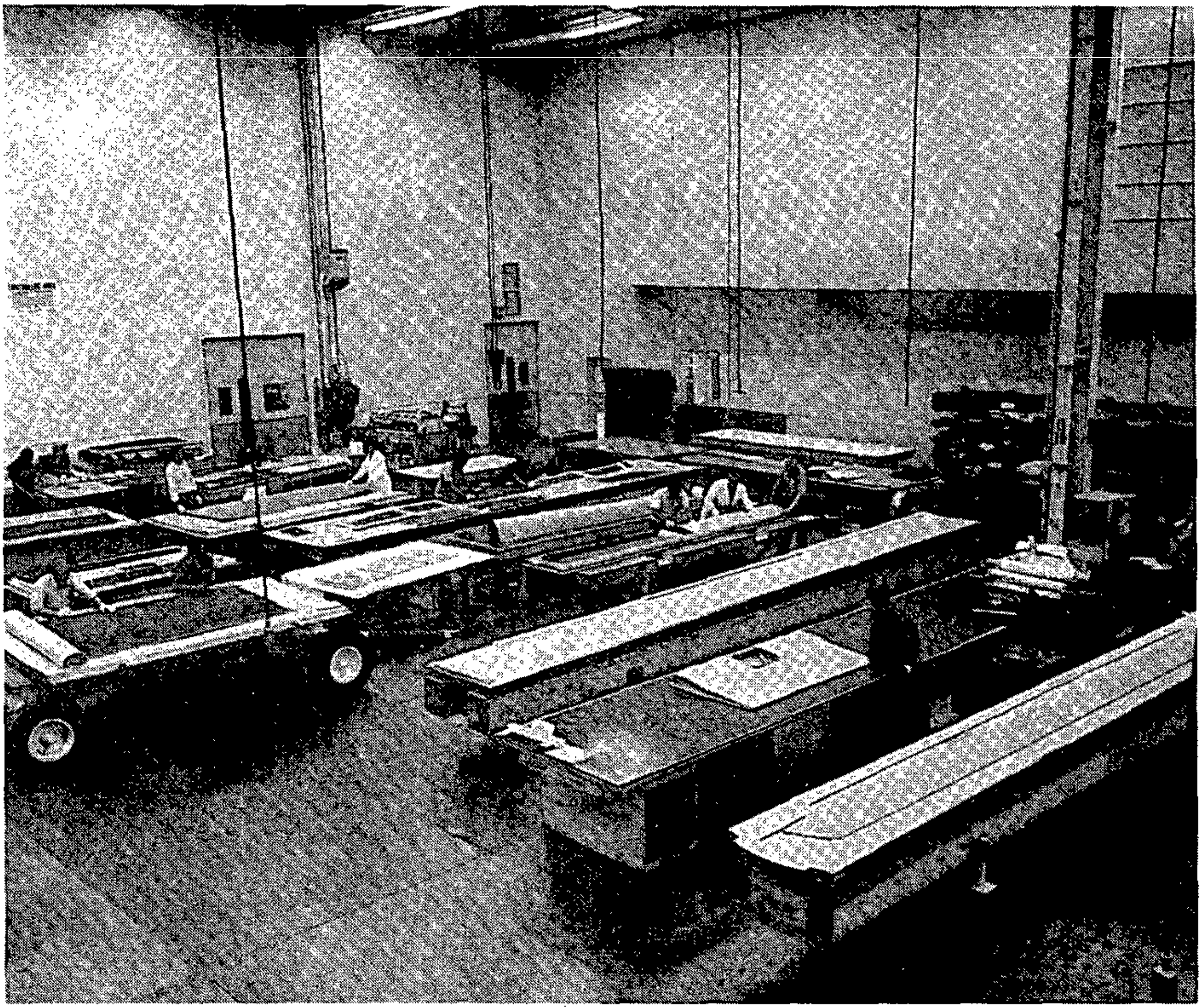


*FIGURE 4.6.2.2 Environmentally controlled adhesive lay-up area.*

4.6.2.2.3 Operating Conditions. In order to provide a controlled environment where contamination of bonding surfaces and materials can be prevented:

- Restrict all unnecessary traffic.
- Check cleanliness of parts before entering the area.
- Assure that protective clothing requirements for hats, coats, and white gloves are met.

Additional guidelines are provided in FED-STD-209.

4.6.2.2.4 Maintenance.

- Areas should be constructed to be easily maintained. Wide aisles and doorways will allow easy access of cleaning and maintenance personnel and equipment.
- Areas should be partitioned to help prevent drafts from carrying contaminants in from noncontrolled areas.

4.6.2.2.5 Personnel.

- Personnel, including supervisors and maintenance persons, who work in controlled environments should receive appropriate training in controlled area procedures.

**4.6.2.3 Surface Treatment Facilities and Related Equipment.**

4.6.2.3.1 Nonbondable Surfaces. Chemical milling facilities and equipment should be in compliance with MIL-C-81769.

Sulfuric acid and chromic acid anodizing facilities and equipment should be in compliance with MIL-A-8625. Phosphoric acid anodizing facilities and equipment used for nonbondable surfaces should be in compliance with ARP 1524.

4.6.2.3.2 Bondable Surfaces.

4.6.2.3.2.1 Aluminum (Except Core). Facilities and equipment for phosphoric acid anodizing of aluminum details (except core) and skins should be in compliance with SAE ARP 1524. Additional information and restrictions follow:

- It is essential that surface preparation facilities be in a completely enclosed area where internal combustion engines are not permitted. Air movement from any contamination area can be detrimental to metal bonding operations conducted in the same building. Therefore, contaminants should be kept out of the surface preparation facility area.
- To preclude solution cross-contamination during processing, the process flow should be arranged in such a manner that details proceed from a process solution directly into a rinse tank, with cross-over permitted only after rinsing.
- Processing tanks should be equipped with suitable timing and temperature control devices designed to maintain solution operating conditions within prescribed limits.
- Parts progressing through a surface preparation tank line are shown in Figure 4.6.2.3.2. Details such as the tank lining and solution temperature are listed for a typical system in Table 4.6.2.3.2.

Requirements that should be met concerning tank location and equipment are as follows:

1. Locate surface preparation and drying facilities remote from other activities and/or equipment that emit contaminants detrimental to adhesion. These include but are not limited to dust, grease, oil, exhaust vapor, and parting agents.
2. Filters and/or traps should be installed for removing airborne dust, moisture, and oil from all air lines used for solution agitation and drying of parts.
3. All tanks other than water rinse tanks to be operated at elevated temperatures should:

Table 4.6.2.3.2 Typical surface preparation tank system.

| Function | Special tank lining | Temp, °F | Agitation | Vent | Remarks |
|---|---|---|---|---|---|
| Vapor degrease | None | 188 | — | None | Deactivated cover (DCCR) |
| Alkaline cleaner | Mild Steel | 140 ± 5 | Air | Push air | |
| Rinse | Vinyl paint | 110 | Air | None | DCCR |
| Deoxidizer | Lead | 155 ± 5 | Air | Push air | Teflon heaters |
| 1st rinse | PVC | Amb | Air | None | DCCR |
| 2nd rinse | PVC | Amb | Air | None | DCCR |
| Phosphoric acid anodize | Stainless steel | Amb | Air | Ex | Phosphoric acid filter |
| Rinse | Vinyl paint | Amb | Air | None | DCR, timed water flow |
| Dryer | None | 140 max | — | None | |

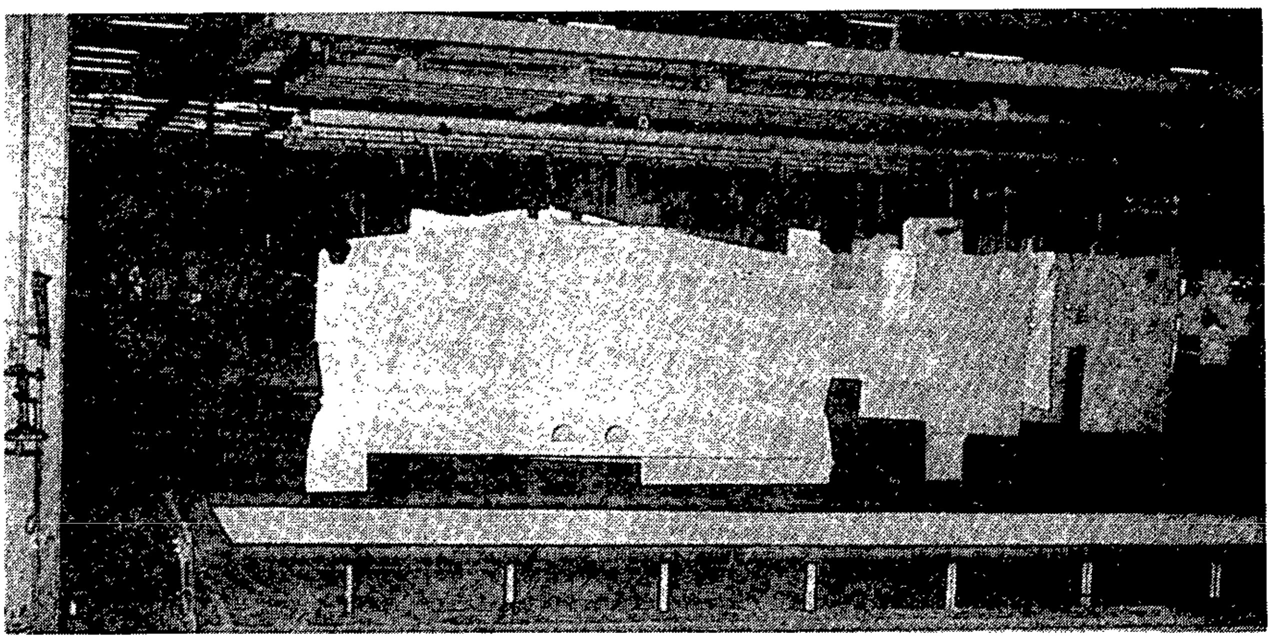


*FIGURE 4.6.2.3.2 Parts progressing through surface preparation tank line.*

Be equipped with automatic temperature indicating and regulating devices. Be air or mechanically agitated to minimize all temperature and concentration gradients. The maximum temperature gradient measured from the hottest to the coldest point in the tank should not exceed 10°F.

4. All instruments, gages, and regulators should be periodically calibrated or tested within the time limit specified by the applicable procurement specification.

5. Air cleaning devices (e.g., drainage traps, cleaning separators, and filter cartridges) should be inspected and serviced at frequencies necessary to assure meeting cleanliness requirements.

Air used for agitation of solutions should be filtered and oil free.

The final rinse of solution processed details should be accomplished by spraying with clean deionized water.

The operations essential to obtaining reliable and durable adhesive-bonded joints are metal preparation and adhesive primer application. An environmentally controlled, continuous process line can be used to accomplish these two operations. Automating such a facility can reduce process costs and improve reliability.

4.6.2.3.2.2 Stainless Steel. Facilities and equipment for preparing stainless steel for adhesive bonding should be in compliance with MIL-HDBK-337.

4.6.2.3.2.3 Titanium. Facilities and equipment for preparing titanium for adhesive bonding should be in compliance with MIL-HDBK-337.

4.6.2.3.2.4 Aluminum Honeycomb Core. Facilities and equipment for cleaning of aluminum honeycomb core in preparation for crushing, splicing, potting, stabilizing, or final bonding are as follows:

1. Suitable vapor degreaser equipped with condensate reservoir, and wand, environmentally compliant exhaust and reclamation, and equipped for use with perchloroethylene, O-T-236, or an equivalent solvent.

**NOTE**

Vapor degreasing tanks should be dedicated for bonding purposes only. They should not be used in other areas of the manufacturing facility.

2. Suitable baskets or racks for suspending core in the vapor phase of the degreaser.

3. Suitable hoist.

4. Vacuum source with clean brush to remove machining dust and chips from core that cannot be vapor degreased or solvent cleaned by hand.

5. Spray gun capable of being pressurized with dry, oil free nitrogen for spraying hexane to remove oil contamination from the machining operation.

6. Conventional spray gun for cleaning core by hand, using acetone or an equivalent solvent, under 75-100 psi pressure (compressed air).

**4.6.2.4 Adhesive Primer Application Facilities and Equipment.**

4.6.2.4.1 Adhesive Receiving Acceptance Tests. To assure that incoming adhesives will satisfy the process requirements when released to production, they need to:

1. Conform to the acceptance test procedures which include honeycomb peel, metal-to-metal peel, and lap shear.

2. Be properly identified/tagged.

3. Be stored and revalidated per the applicable procurement specifications.

4.6.2.4.2 Equipment Requirements. Required equipment includes a suitable paint mixer and a suitable spray gun(s) capable of applying material that has suspended solids, such as corrosion inhibiting agents and curing agents. The spray gun must have a continuous agitation cup or be connected to a mixing pot that has continuous agitation, including recirculation of primer in the hoses, to prevent settling of the solid materials.

**CAUTION**

Equipment used for the application of adhesive primers must be restricted exclusively for that function to prevent the possibility of contamination of the adhesive primer.

Solvent safety containers are essential and a compressor capable of supplying compressed air should meet the moisture and oil restrictions required by the procurement specification.

4.6.2.4.3 Primer Application Area. After preparing the metal surfaces, it is important that they are not touched, even with white gloves, until after the primer is applied to prevent contamination of bonding surfaces. Phosphoric acid anodized aluminum details are particularly vulnerable to contamination and coating damage before the primer has been applied. An overhead monorail system to which the parts can be suspended is one suggested method of providing a convenient means of transporting the parts for spray application of primer and for subsequent baking. Primer may be applied in a down-draft spray booth, such as that shown in Figure 4.6.2.4.3 or in an open-faced water wash booth.

The adhesive primer spray booth used for the applying adhesive primers to bond details should be supplied with filtered air moving at a velocity sufficient to prevent overspray accumulation on bond details.

The spray booth should be equipped with a suitable device to remove primer overspray from the air prior to exhaust into the atmosphere.

Periodic cleaning of the spray booth will prevent contamination of bonding details.

The primer application area should be under environmental controls. Temperature should be maintained between 65-80$^{\circ}$F and relative humidity should not exceed 60 percent.

**4.6.2.5 Drying/Curing Ovens.** Drying/curing ovens range in size from the small variety to larger walk-in types, as illustrated in Figure 4.6.2.5. The larger ovens are typically gas heated with an air circulation system. Ovens should be equipped with a vacuum supply, provided they are to be used for curing parts under vacuum, and multiple thermocouple connectors. These should also be coupled with automatic controlling and recording equipment.

Ovens may be used for curing when no pressure or vacuum pressure is used. They may also be used for post-curing when the initial cure is accomplished in an autoclave under higher pressure.

Ovens used for drying details prepared for adhesive bonding, drying adhesive primed details, and curing primers and/or adhesives should be exclusively restricted to these functions to prevent contamination of bonding surfaces.

*FIGURE 4.6.2.4.3 Primer application in down-draft spray booth.*

Ovens should maintain temperatures within the range specified for the particular operation being performed and be periodically cleaned to prevent accumulation of dust, dirt, and other contaminants determental to adhesive bonding. Periodic certification should occur on a schedule acceptable to the Government procuring activity.

#### 4.6.2.6 Core Manufacturing/Machining Equipment.

4.6.2.6.1 Core Manufacturing. Aluminum honeycomb core is manufactured by several suppliers, using either the corrugation process for high density materials or the expansion process for lower density materials. Expanded core is more widely used in aircraft assemblies. Manufacturers of core consider their operations proprietary. However, a simple description of the basic equipment and facilities appears below:

1. Foil cleaning.
2. Application of corrosion inhibiting coating.
3. Application of node bond adhesive.
4. Cutting foil into sheets.
5. Corrugation of foil, if applicable.
6. Holding corrugated foil in proper position during curing, if applicable.
7. Stacking sheets of foil into blocks for expansion process.
8. Curing (such as with a platen press).

4.6.2.6.2 Sawing. Unexpanded core block is sawed into smaller slices or wedges using a band saw. Constant thickness slices are sawed using a saw backstop set-up in relation to the saw blade. For unexpanded shapes, templates representing the desired configuration and optimum block utilization are taped to one end of the block using double-sided tape.

*FIGURE 4.6.2.5 Large walk-in curing oven.*

**NOTE**

An end refers to either side of the block parallel to the surface of the sheets.

Band saws of various sizes with preset blade angles are used to cut chamfers on expanded core, slices, or details. The size of the saw is dictated by the size of the cores being cut.

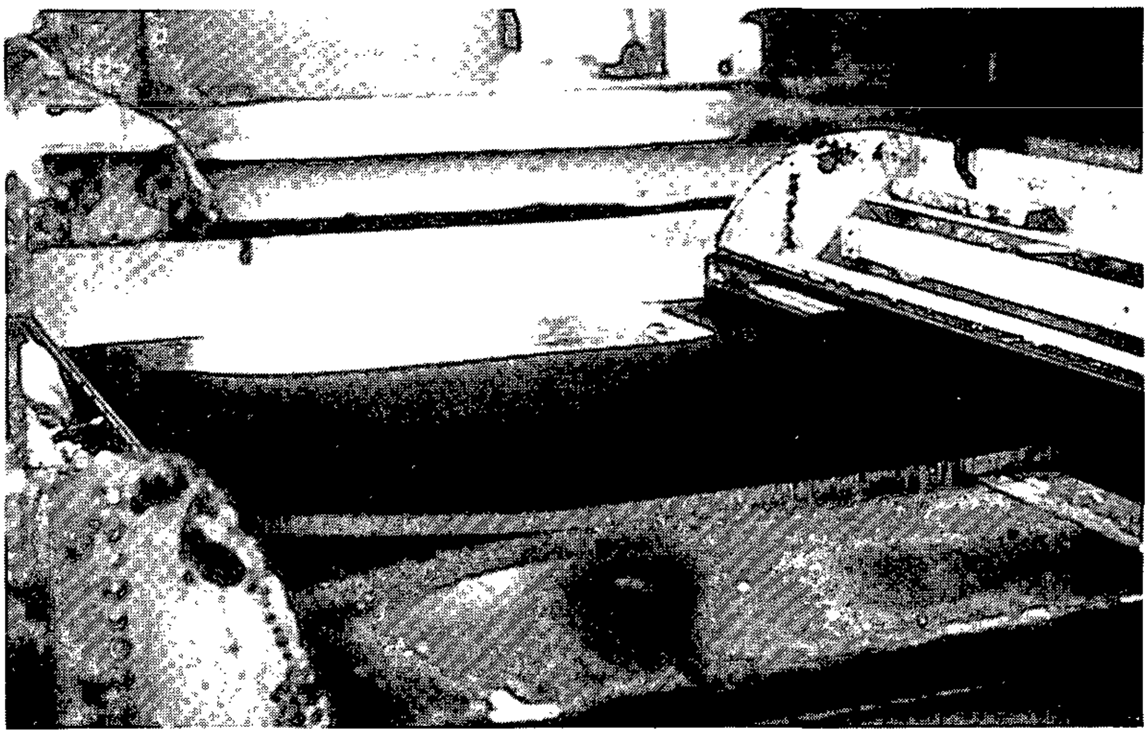
4.6.2.6.3 Expanding. The unexpanded core block is placed on the expander with sheets oriented vertically on the expander bed. One end of the block is secured to the expander via a fixture while the other end is being pulled away (perpendicular to the ribbon direction) creating expanded cells. The pulling force is intermittently relaxed to allow for springback. This is repeated until the specified cell count is attained.

Pins are used to (1) separate, or pick apart, the unexpanded cells that are stuck together and (2) align the distorted cell walls near the perimeter.

See Figure 4.6.2.6.3 which illustrates the core expansion process.

4.6.2.6.4 Rigidizing.

4.6.2.6.4.1 Using Polyethylene Glycol. Equipment required for rigidizing aluminum honeycomb core with polyethylene glycol prior to machining is as follows:



*[Photo courtesy of Hexcel]*

***FIGURE 4.6.2.6.3 Core expansion process.***

- Suitable device for melting polyethylene glycol.
- Metal pouring pot.
- Suitable fixture for holding core during rigidizing and machining operations.
- Suitable weights to hold core in place while glycol cools and hardens.

Facilities and equipment required to remove the polyethylene glycol after completion of machining operation are as follows:

- Heat table or oven for removal of gross amounts of glycol at approximately 200°F.
- Hot water tank (170 ± 10°F) and racks for supporting core to remove remaining glycol.
- Source of deionized water to rinse core with a sprayer or hose.
- Alternatively, a steam generator with capability of adding a cleaning aid to the steam.
- Blacklight inspection booth to ensure complete removal of polyethylene glycol.

4.6.2.6.4.2 Ice Chucking. Equipment required for ice chucking to rigidize core for machining is as follows:

- Suitable core-holding fixture capable of being cooled to freeze the water.
- Source of deionized water.
- Refrigeration unit capable of cooling the holding fixture to below 32°F to freeze the water.
- Suitable weights to hold the core in place while the water freezes.

4.6.2.6.5 Honeycomb Core Carving (Machining).

4.6.2.6.5.1 Equipment. There are various types of equipment for machining aluminum honeycomb core. The type you select for use depends upon the required shape of the finished core. These include:

- Machines for cutting straight line elements.
- Numerically controlled machines capable of cutting compound curvatures.
- Machines that are cam-followers or profile-followers.
- Specially constructed band saws.

Cutters are available in a variety of sizes and shapes. Several examples are:

1. "Valve stem" cutters.
2. Cup cutters.
3. Cutters designed to rough cut (end mill) and finish cut ("valve stem cutter") simultaneously.

Core carving equipment should be maintained and cleaned periodically to prevent contamination of the core with oil. The oil or fluid used in this equipment should contain a fluorescent dye capable of being detected by "black light" in the event the oil or fluid does contaminate the honeycomb core.

It is essential that the core carver be constructed to hold the core rigidly in place during the carving operation, such as with a vacuum chuck, ice chuck, etc. It should also be capable of carving honeycomb core to 0.005 inch in thickness.

4.6.2.6.5.2 *Facilities. If core is machined after cleaning and will not be recleaned by vapor* degreasing after machining, the core carving equipment should be located in an area that complies with the following requirements:

- The area is completely enclosed.
- Concrete floors are sealed with an appropriate latex, epoxy, or polyurethane sealer unless covered by vinyl or other composition material. These latter covering materials may be waxed (nonsilicone containing).
- The area is to be kept clean by periodic vacuuming, general cleaning and stripping, and resealing or rewaxing the floors. Sweeping of the major bulk of debris on the floor is permissible. However, the use of dust mops and sweeping compounds is prohibited.
- Personnel wear clean white gloves when handling cleaned or primed parts.
- The operation of fume producing equipment and fuel powered combustion engines is prohibited. Battery powered equipment is permitted.
- If the area is directly connected to the adhesive bonding lay-up area, the core carving has a lower air pressure than the lay-up area to prevent sanding and machining dust from entering the lay-up area.
- Eating, drinking, and smoking is prohibited.
- The use of any material dispensed from an aerosol container is prohibited.
- Lubrication of equipment is performed in a manner to prevent lubricants from being deposited on other surfaces of that equipment or on assemblies.
- Electrically powered equipment is preferred. Air powered equipment should be nonlubricated and supplied by filtered air. Any powered equipment should be run-up and wiped of excess lubricants before use, making sure that production parts and tanks are protected from contamination.
- Filters in the air supply system are the commercial disposable or recleaning type.
- An air pressurization system should maintain a slight, positive pressure such that dust and dirt do not blow into the area when the doors are closed.
- Use of release agents of any kind is prohibited in the area.
- Materials containing silicones as a release or adhesive agent are not allowed in this area.

4.6.2.6.6 Splicing. Honeycomb core may be spliced as a subassembly or spliced during the final assembly bonding operation. Equipment required for splicing as a subassembly consists of:

1. Suitable fixture for holding core details in a proper position during the curing operation for the splicing adhesive.
2. Suitable oven (circulating air).

4.6.2.6.7 Stabilizing (Stiffening, Rigidifying). Stabilizing, stiffening, rigidifying consist of coating specific areas of honeycomb core with the adhesive that is subsequently cured. Equipment for these operations consists of:

1. Suitable rack for holding the core while the adhesive is being poured in the areas required by the engineering drawing.
2. Drain pan for the adhesive.
3. Oven (circulating air).

4.6.2.6.8 Potting. Potting of areas specified on the applicable engineering drawing may be accomplished as a subassembly or during the lay-up of the final assembly. Equipment for potting consists of:

1. Core cutters such as a sharp knife or sharpened tube for cutting holes in core if required.
2. Suitable injection gun and/or spatulas for installation of the potting compound.
3. Rack for holding core during curing as a subassembly.
4. Oven (air circulating).

**4.6.2.7 Autoclaves.** The purpose of the autoclave is to provide a means of applying uniform high pressure and temperature to a part for curing. It has definite advantages over the use of other methods such as vacuum bags and heating blankets. The higher pressure provides a superior quality bond. Detail parts are better consolidated for intimate bond line contact.

Autoclaves should be operated by trained and certified operators whose task is to see that all safety procedures are followed throughout each cycle. Automatic recording and controlling equipment is available and should be used with each autoclave. The autoclave should be equipped with multiple thermocouple recording and/or controlling equipment so actual part temperatures can be monitored during curing.

Autoclaves are of various types and sizes. A large unit is shown in Figure 4.6.2.7. Heat is generated by electricity, steam, or hot oil with air circulation. Pressurization is achieved by positive air pressure or inert gas. Vacuum systems should be constructed so that they can be vented into the atmosphere or connected to a gage system on the control console. Venting vacuum outlet lines prevents a differential pressure from accumulating under the bag film. Although this practice is not recommended, in some cases combustible materials are used in the autoclave during curing. For example, wooden fairing bars may be used to keep the parts in position or to obtain proper pressure distribution. In these cases, the use of an inert gas in the autoclave is mandatory. The inert gas ($CO_2$ or $N_2$), when required, may be produced by an exothermic gas generator. The gases are compressed and stored in pressure vessels with adequate capability for the particular autoclave. Liquid nitrogen may also be used as a source for gaseous nitrogen. Inert gas usage is always recommended to prevent a fire, which can result in the loss of expensive tooling and assemblies. It can also prevent explosions in which the door can be blown off the autoclave.

Periodic certification of the autoclaves should occur on a schedule acceptable to the Government procuring activity.

Autoclaves should be equipped to provide a vacuum of up to 30 inches of mercury on the assembly being cured.

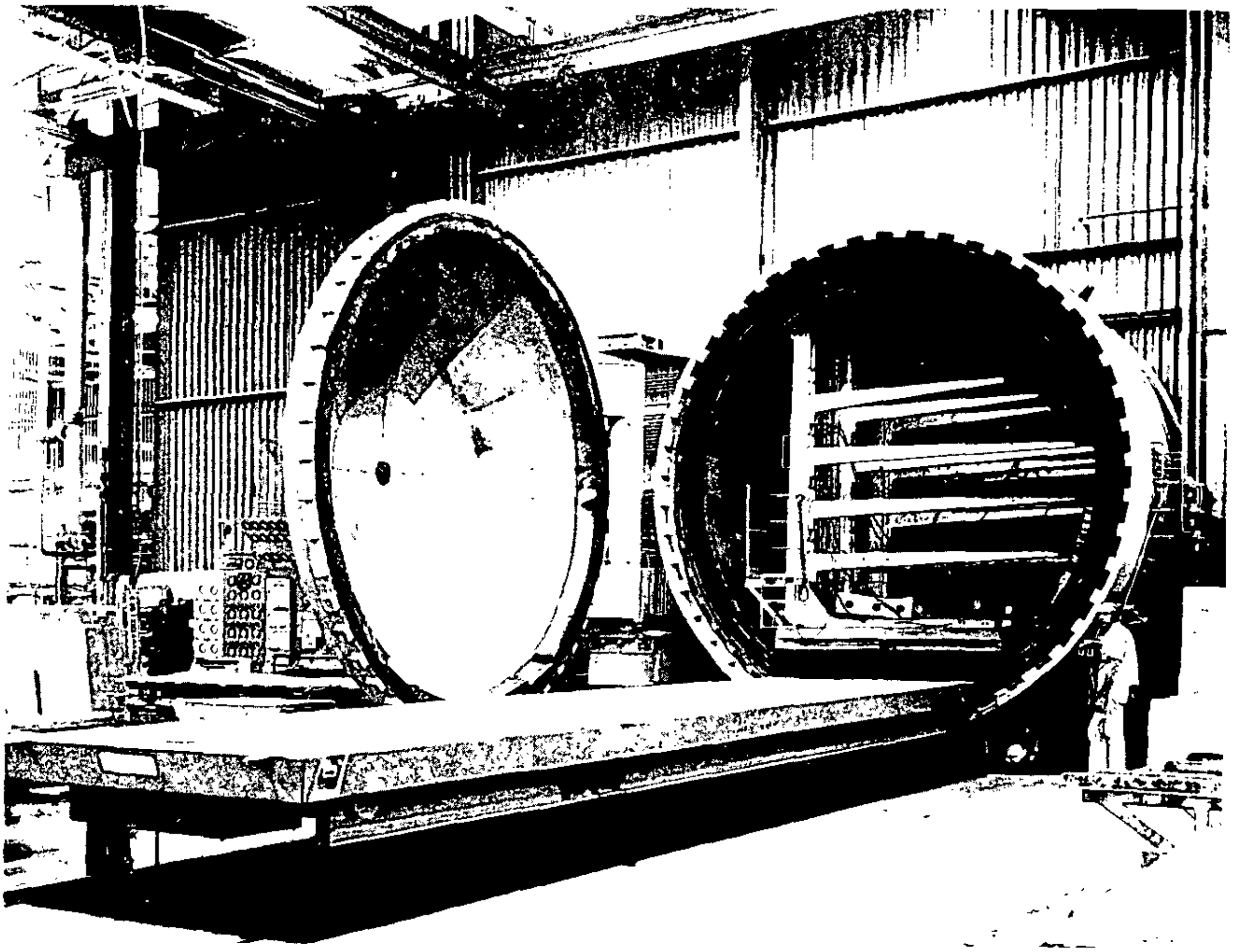


***FIGURE 4.6.2.7 Large autoclave for curing bonded assemblies.***

Curing pressure application by compressed air or inert atmosphere (preferred) should be ±5 psi and the specified cure temperature ±10$^{o}$F, with a heat up rate of 2-10$^{o}$F per minute on tools and assembly.

Temperature, pressure, and vacuum should be continuously recorded as a function of time.

Autoclaves may be controlled manually by cam or computer and they should be periodically cleaned to prevent accumulation of debris that could puncture a vacuum bag.

**4.6.2.8 Platen and Cavity Presses.** Platen and cavity presses primarily are hydraulic presses or, for certain applications, pneumatic presses, or either of these with a toggle lockup system.

They may be either down-acting or up-acting. The down-acting press more satisfactorily accommodates the many automatic feeding systems because the lower press or mold remains at a fixed height.

Platen and cavity presses typically range in capacity from a few tons pressure capability to over 5000 tons capacity. Working area in these presses varies from about 100 $in^2$ to over 10,000 $in^2$. Heating of the pressure platens is often achieved electrically, although steam or oil heating is also used. Cavity presses generally have contoured or shaped pressure plates that conform to the desired part shape, while platen presses have flat pressure plates.

Platen and cavity presses should be capable of applying uniform pressure and temperature to the assembly being bonded. Pressure should be controllable at ±5 psi and temperature ±10°F.

Record temperature and pressure versus time continuously during the bonding operation.

Platen and cavity presses should be periodically certified on a schedule acceptable to the Government procuring activity.

Cavity presses should meet the same requirements as specified for platen presses.

**4.6.2.9 Bonding Fixtures.**

4.6.2.9.1 Tooling Requirements. The design of adhesive bonding tools has evolved from the plaster master model to the more economical and accurate standard from which part and tool dimensions are now taken–the concept of Master Dimensions Information (MDI). Surfaces of the aircraft are described mathematically by the design engineer, and these data are fed into a computer that produces a tape that operates a numerically controlled milling machine. The mill will accurately reproduce the contour information generated by the design engineer.

4.6.2.9.2 Metal Tool Fabrication. The metal tool commonly referred to as a Bond Assembly Jig (BAJ) is used to position detail parts and/or subassemblies in the correct relationship to each other, within tolerance. It additionally provides or permits uniform pressure application to the assembly during the curing cycle. Typical BAJs for use in air- or platen-heated autoclaves are illustrated in Figures 4.6.2.9.2(a) through (d). General considerations regarding BAJ design are as follows:

1. **Material.**
   Aluminum, 6061, weldable, unpainted.

2. **Tolerance.**
   One-third of the production tolerance, unless otherwise specified.

3. **Finish.**
   125 microinch rms or better on surfaces contacting the part or assembly to be bonded.

4.6.2.9.3 General Requirements.

1. Bond fixtures should be constructed of materials capable of withstanding the cure pressure and temperature specified for the assembly.

2. Bond fixtures have to position and hold details properly during the bonding operation. Some details must be designed to "float" to allow for movement due to thermal expansion and/or contraction of details.

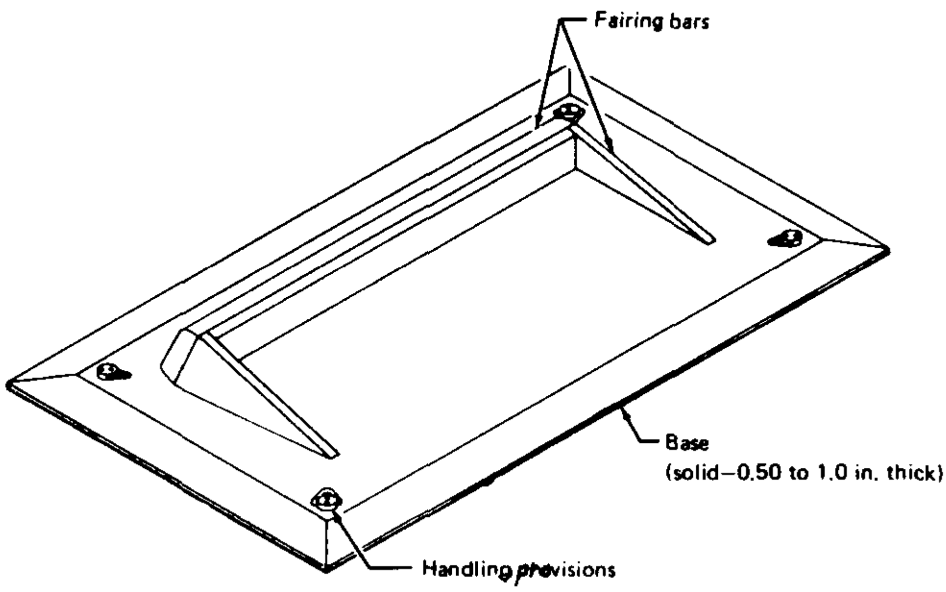
3. Bond fixtures designed for use in an autoclave or cavity press should permit application of fluid pressure on at least one side of the assembly.

4. Bond fixtures may be equipped with permanently located thermocouples.

5. A heat survey of each bond fixture is normally required prior to curing production assemblies on the tool to determine its thermal profile (hot and cold areas). The bond fixture should be loaded with unbonded details or a previously cured assembly during the heat survey. Results of the heat survey can be used to determine thermocouple locations. Sufficient thermocouples should be applied to accurately monitor the curing cycle.
6. The bond fixture, equipped with a sufficient number of vacuum ports and static pressure ports, should permit uniform application of vacuum and monitoring of the pressure build-up in the vacuum bag during the entire curing cycle.
7. Bond fixtures may be vacuum bagged on one side or completely enclosed in the vacuum bag.

4.6.2.9.4 General Design Criteria.

1. The BAJ must provide uniform heat transfer, bond line pressure, and configuration control.
2. The platen-heat autoclave transfers heat by conduction from the platen surface through the BAJ base to the curing assembly.
3. The air-heat autoclave transfers heat by convection to the BAJ and the curing assembly.




Note: This type of BAJ is used to accommodate assemblies that are flat or with slight contour. These BAJ's are machined from plate stock of sufficient thickness to ensure stability.

*FIGURE 4.6.2.9.2(a) Typical BAJ for platen-heated autoclave.*

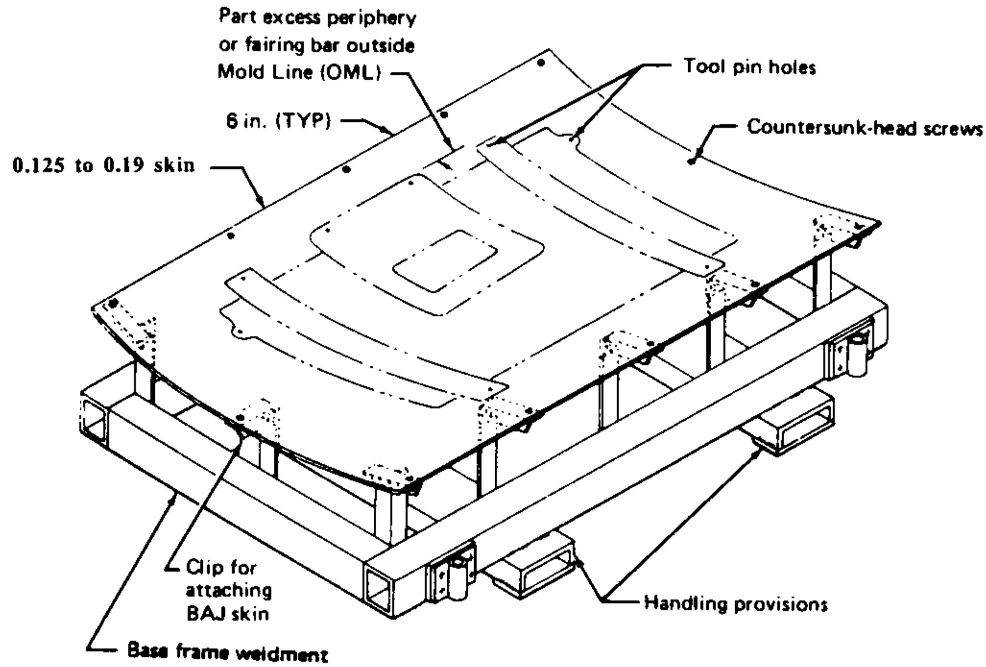



*FIGURE 4.6.2.9.2(b) Typical BAJ for air-heated autoclave using skin preformed to contour.*

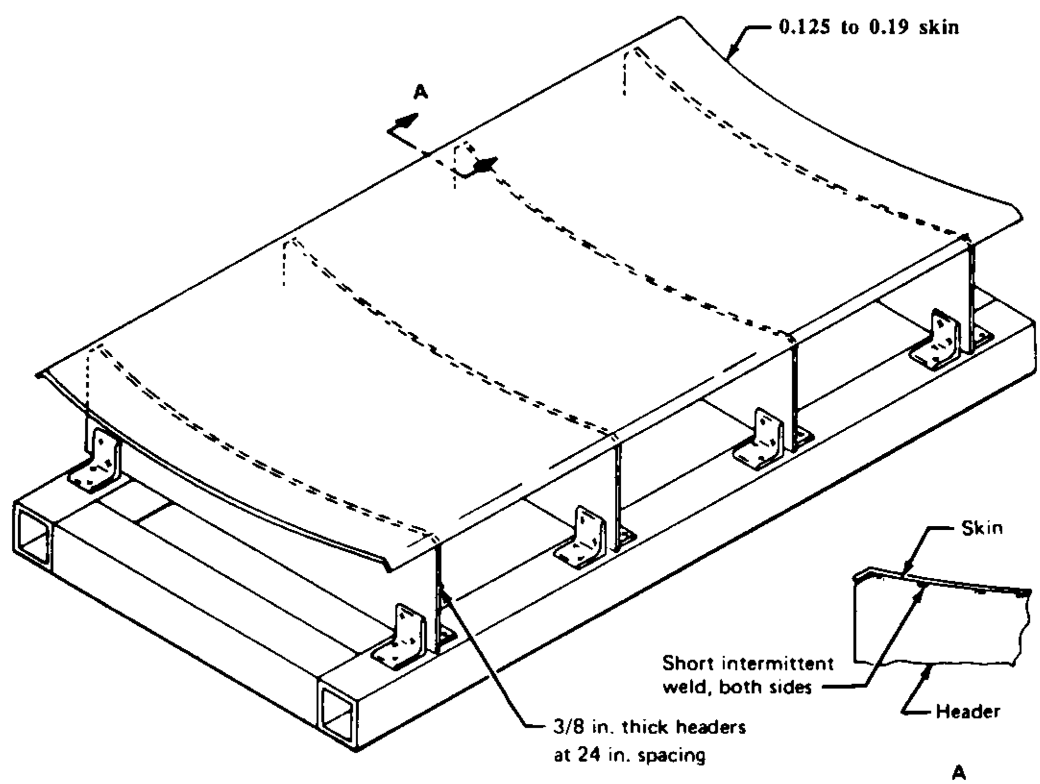



*FIGURE 4.6.2.9.2(c) BAJ for air-heated autoclave using skin preformed to contour.*

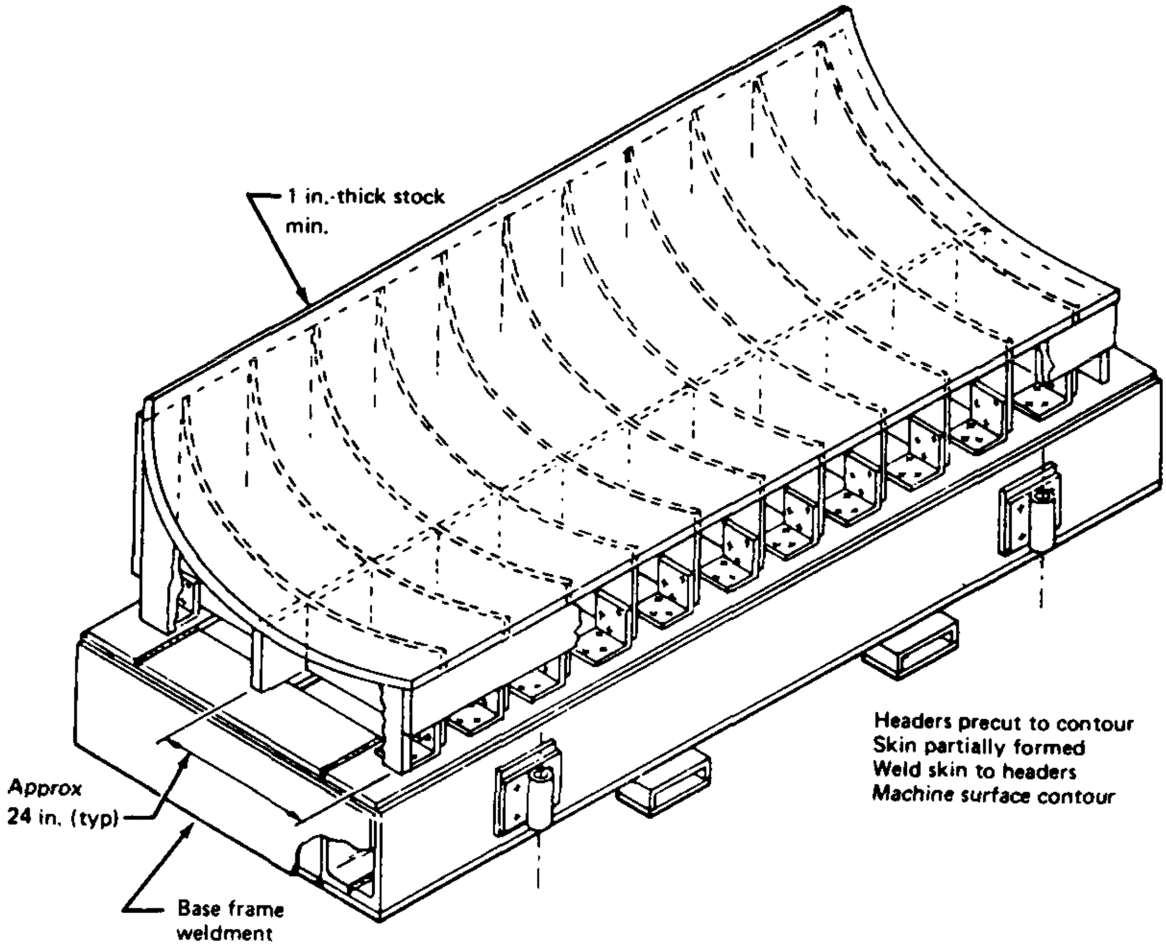



***FIGURE 4.6.2.9.2(d) BAJ for air-heated autoclave for compound or complex contour.***

4. Convection heated BAJs should be designed to provide maximum air movement through the tool support structure and to the surfaces that transfer the heat to the curing assembly.
5. The BAJ is designed to rest the assembly on the aerodynamic or appearance critical surface.
6. BAJs are constructed from materials that resist distortion as a result of the thermal cycling and have a thermal coefficient of expansion similar to that of the material being bonded.
7. Tool materials should be free of porosity and of a quality sufficient to ensure vacuum or pressure integrity during the entire bond cycle.
8. Working holes in aluminum tool details should have steel bushings.
9. Scribed lines, in the excess area around the assembly, may be called out on the BAJ tool drawing for locating edges of the part details.
10. Sight holes through tooling details that obscure the alignment view may be required.

4.6.2.9.5 Removable Tool Components. Removable tool components are positioned with locating pins. Vacuum blanket pressure applied to these components usually provides sufficient clamping. Removable components should also:

- Provide interchangeability between identical loose details and in hole patterns in details performing operations on the BAJ wherever practical.
- Minimize the use of screws and bolts that require removal or adjustment during BAJ use.
- Maintain the weight of individual components such that they do not exceed 25 pounds for ease of handling. Fairing bar lengths should be a function of weight and strength. Long lightweight bars should be divided into practical lengths for handling.

4.6.2.9.6 Fairing Bars. Fairing bars, removable from the BAJ, provide a smooth transition for the vacuum blanket from the bond assembly surface to the base of the BAJ. Typical fairing bar applications are illustrated in Figures 4.6.2.9.6(a) and (b).

The bar must be higher than the total height of the bond assembly to:

- Assure consistent pressure on the periphery of the bond assembly to reduce the chance of crushing the core.
- Contain the upper skin which, in most cases, is located by the fairing bar in order to reduce the chance for the skin to slip up on the fairing bar.

Fairing bars on severe contour BAJs may require fabricated construction. Consider fiberglass and resin laminate, molded urethane for up to 250°F service, and aluminum for service above 250°F.

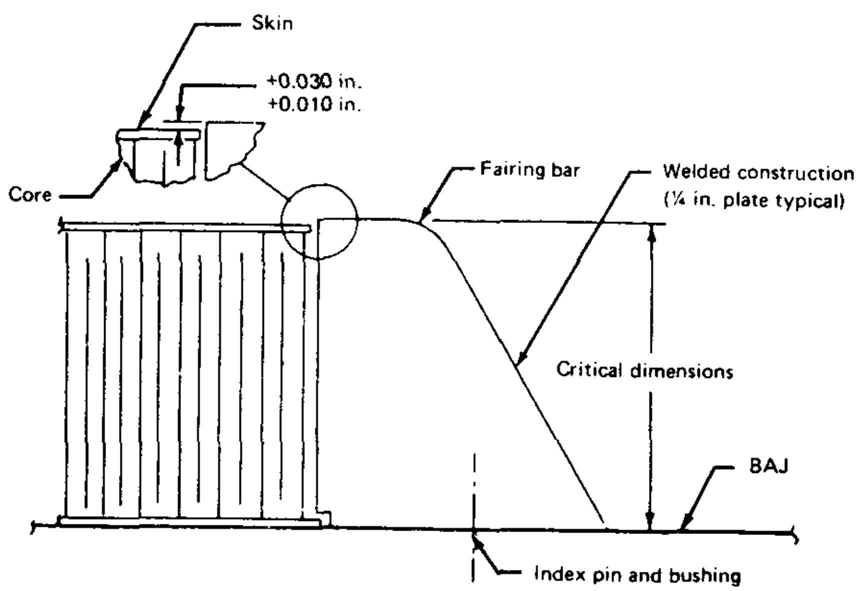



*FIGURE 4.6.2.9.6(a) Typical fairing bar application.*

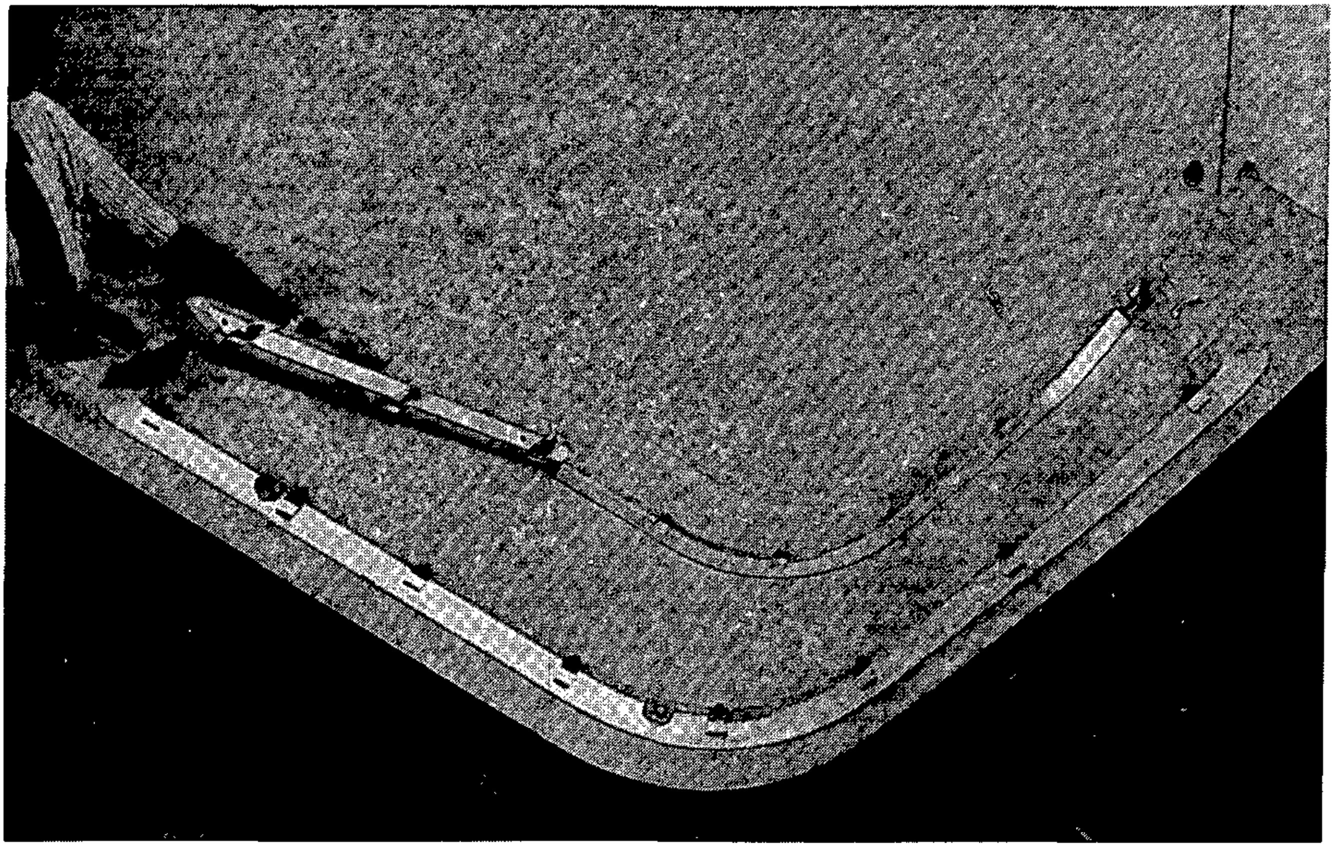


*FIGURE 4.6.2.9.6(b) Typical fairing bars shown on bonding tool.*

**NOTE**

Fairing bars and other tool details may be coated with a Teflon coating or wrapped in release film to prevent the adhesive from bonding to their surfaces.

4.6.2.9.7 Pressure Bars and Mandrels. Pressure bars and mandrels transmit pressure to the lower bond line, and may support an upper flange bond line or position the spar or edge member laterally. A typical mandrel application is shown in Figure 4.6.2.9.7.

Pressure bars and mandrels must be designed to transmit the desired unit pressure.

**CAUTION**

Avoid pressure multiplication!

Pressure bars must be free floating up and down.

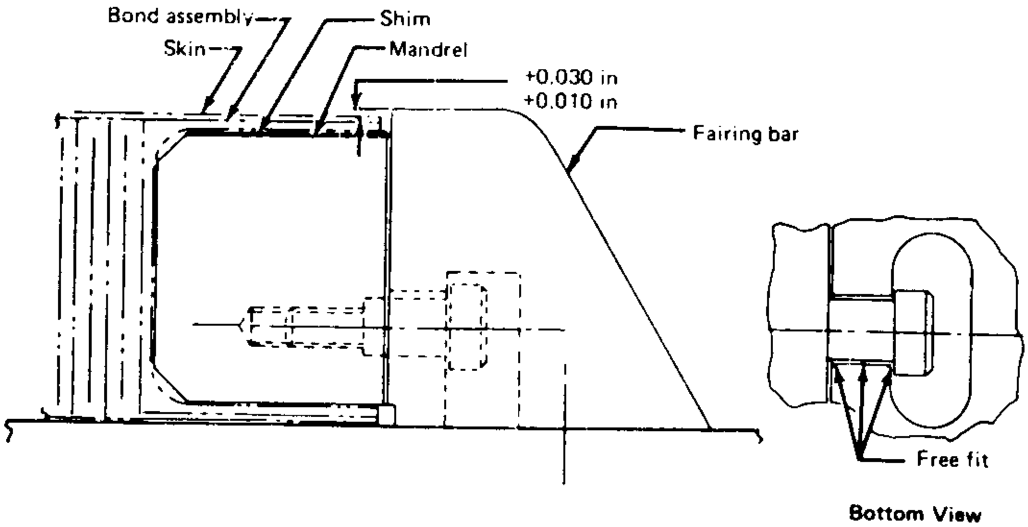



***FIGURE 4.6.2.9.7 Typical pressure mandrel application.***

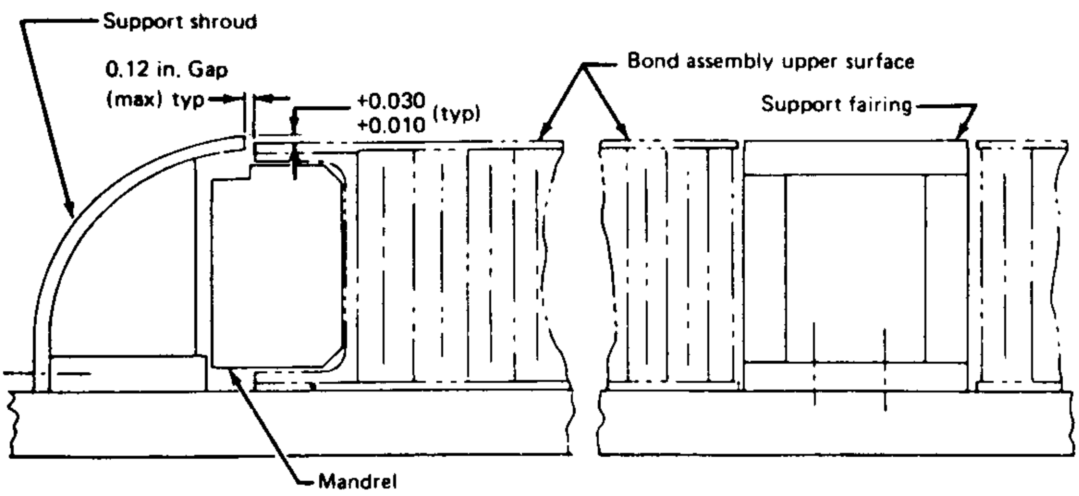



***FIGURE 4.6.2.9.8 Typical vacuum blanket support details.***

Heat-resisting silicone-type rubber is required for facing pressure bars and support pads where interface tolerance buildup presents a problem. In order to prevent contamination of bond lines, the silicone rubber should be baked at 400-425°F for 2 hours to remove any outgassing materials.

4.6.2.9.8 Vacuum Blanket Support Details. Fairing and shroud details must be provided to support the vacuum blanket. Their typical use is illustrated in Figure 4.6.2.9.8. Position these details next to mandrels, along with fairing bars, and in corners or openings in bond assemblies.

Consider the total pressures involved over the entire area when selecting material thickness and gusset requirements.

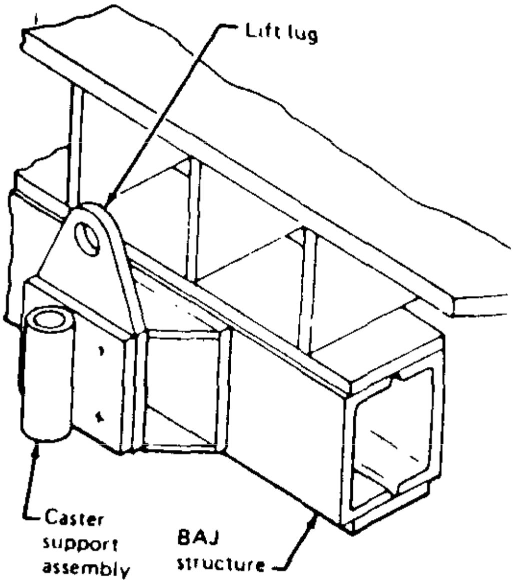



***FIGURE 4.6.2.9.9(a) Typical lift lug combined with caster support assembly.***

4.6.2.9.9 Handling Provisions. Hoist rings on BAJs should be located so they will not interfere with loading and unloading the bond assembly in the autoclave.

Generally, on the larger and heavier convection-heated BAJs, lift lugs should be attached to the sides of the BAJ base structure or made a part of the caster support assembly. In this way, any overhead lifting will not damage the top surface plate. See Figure 4.6.2.9.9(a). Holes should also be provided for fork lifts as is shown for the tool in Figure 4.6.2.9.9(b).

Convection-heated BAJs are commonly handled with fork lift equipment. When fork lift channels are included in the BAJ design, call out 8-inch channels with welded keeper-straps near each end. Position fork lift channels in such a way to clear finger racks used to support the BAJ in the autoclave or in storage.

Removable casters are commonly used for moving convection-heated BAJs in the shop. The BAJ design and construction should include the caster support assemblies. Typical caster and caster support assemblies are shown in Figure 4.6.2.9.9(c). Supports should be positioned so that the BAJ surface plate is approximately 30 inches from the floor.

4.6.2.10 Prefit Fixtures.

Prefit fixtures should be designed and constructed to properly position bonding details to assure that they will correctly fit together in subsequent bonding operations.

Prefit fixtures should be kept clean to prevent contamination of bonding details.

**4.6.2.11 Equipment for Material Acceptance, Process Control and Destructive Testing.** The governing procurement specification generally requires the fabrication and testing of various panels/specimens in order to determine the acceptability of materials and processes used in the fabrication of bonded assemblies. In addition, the governing specification generally requires

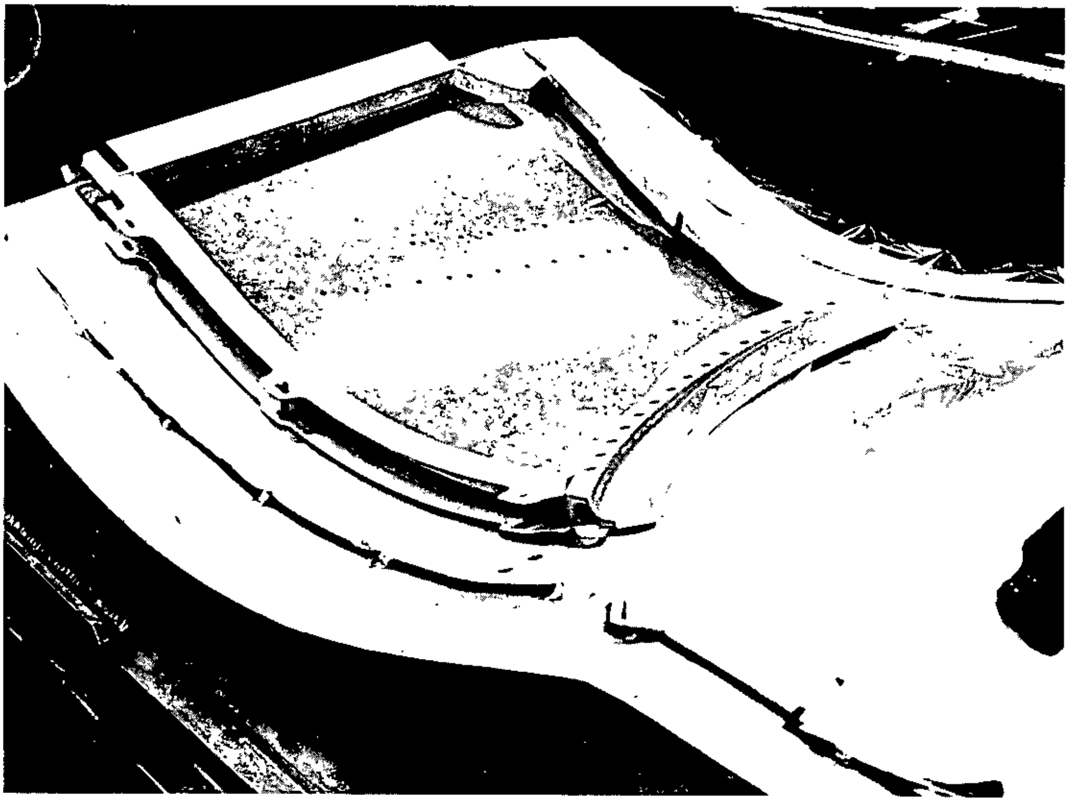


***FIGURE 4.6.2.9.9(b) Welded bonding tool showing fork lift hole-pinned details in place.***

destructive testing of production parts. Equipment required for the fabrication and testing of these panels/specimens includes the following items:

- Suitable tensile/compression testing machines with load versus head travel recorder.
- Suitable oven for heating test specimens during application of load with $\pm 10^{\circ}F$ temperature control.
- Suitable self-aligning jaws for holding lap shear specimens.
- Suitable loading fixtures for conducting climbing drum peel, beam shear, and flatwise tension and compression tests.
- Suitable bond fixtures for fabricating single lap shear, climbing drum peel, beam shear, flatwise tension, and wedge crack test panels.
- Band saw for sawing all specimens.
- Air circulating oven for determining foam expansion and density.
- Analytical balance.
- Milling machine for preparing of lap shear specimens taken from destruct parts.

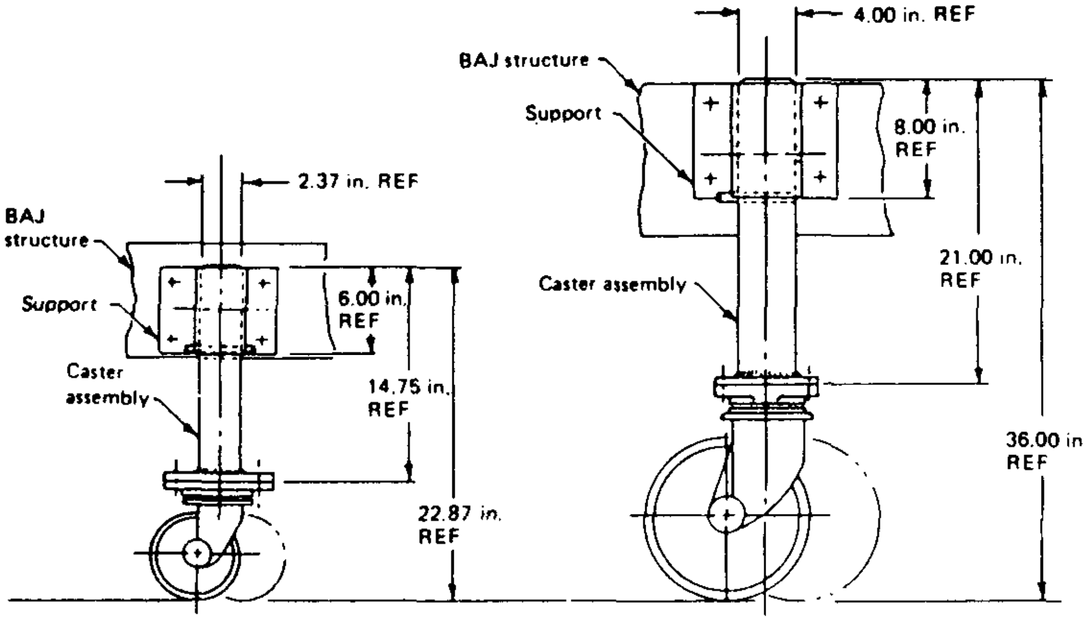



***FIGURE 4.6.2.9.9(c) Typical caster and caster support assemblies.***

The governing procurement specification also generally requires process control of solutions used in surface preparation of components of bonded assemblies and analyses of the compressed air used for adhesive primer application. In addition, "black light" inspection of the honeycomb core after removal of polyethylene glycol (used to rigidize the core during machining) and after machining (for the presence of oil) is often required. Equipment to perform these tests is as follows:

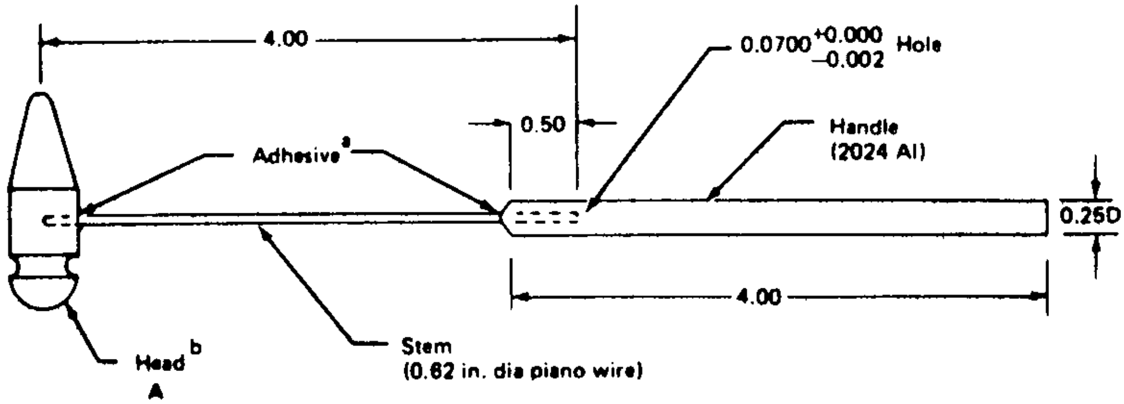
- Adequate chemical laboratory facilities and equipment to control the surface preparation solutions specified in Chapter 5.
- Equipment for determining the hydrocarbon and moisture content of compressed air used to spray adhesive primers (see applicable procurement specification).
- Instrument such as a Permascope to determine the thickness of dried adhesive primer and paints (see applicable procurement specification).
- Portable ultraviolet light source (black light).

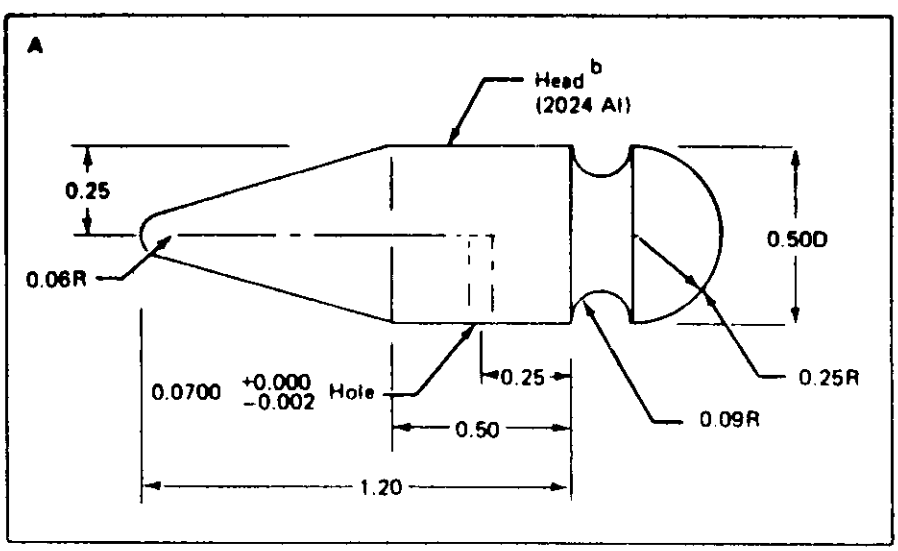
4.6.2.12 Nondestructive Inspection Equipment. Defect detection sensitivity of specific NDI techniques varies with changing conditions, such as part complexity, operator experience, etc. In some instances, special techniques and skills are needed to conduct a reliable inspection. Details of these procedures are provided in Chapter 5, sections 5.8.1 through 5.8.4.6.3.1. The equipment needed to perform the various types of inspections is summarized in the following sections.

4.6.2.12.1 Visual. Visual nondestructive inspection (NDI) is by far the oldest and most economical method. Consequently, visual inspection is performed routinely on part details and final assemblies. Equipment required typically includes magnifying glasses, a microscope, and a flashlight.

4.6.2.12.2 Tapping. Tapping inspection is a nondestructive method for detecting voids or delaminations in bonded areas. Required equipment consists of:

- Tapping hammer (Figure 4.6.2.12.2).




All dimensions in inches

[a] Liquid/paste adhesive may be used if desired. Hole in handle/head may be reduced to provide an interference fit and preclude the need for the adhesive.

[b] 125/ All machined surfaces, ref MIL-STD-10

*FIGURE 4.6.2.12.2 Inspection tap-hammer details.*

- Other suitable tapping devices that will not damage the part when properly used.

4.6.2.12.3 Ultrasonic. Ultrasonic inspection has proven very useful for detecting internal delaminations, voids, and inconsistencies in bonded structure. This method uses sound waves with a frequency above the audible range. The waves are induced into the part by a piezoelectric transducer transmitter. This ultrasonic energy travels through the part, and any marked change in acoustic properties of the material will affect the sound traveling to a receiving transducer.

The information to the transducer may be displayed by a meter or on an oscilloscope or chart.

**NOTE**

This use of induced sound waves is in contrast to the acoustic emission method in which the sound waves measured are those emitted by the part itself.

There are basically three types of ultrasonic inspection instruments used for bond testing:

- High frequency (1-5 mHz).
- Low frequency (15-50 kHz).
- Resonance.

The high frequency method requires a couplant such as oil, grease, or water between the interface of the transducer and the part. The units are quite commonly used at a fixed location and with recording equipment.

Low frequency equipment is more popular where portability is required. It does not require a couplant. It is, however, less accurate and typically does not provide a permanent record.

Resonant-type equipment, although generally portable, requires a couplant. It is considered more accurate than the low frequency equipment for inspecting laminated metal areas. Method selection should be as specified in the contractors's approved procedure.

4.6.2.12.3.1 High Frequency. High frequency ultrasonic inspection may be either conducted by the pulse echo method as shown in Figure 4.6.2.12.3.1(a) or by through-transmission shown in Figure 4.6.2.12.3.1(b). Several instruments are available. Examples include the Immerscope, Reflectoscope, Krautkramer, Magnaflux, etc.

The through-transmission method can conveniently be set up to automatically scan the part and produce a plan view record as shown in Figure 4.6.2.12.3.1(c). The record indicates the relative intensity of the signal through the part. The setup may be a go/no-go type recording or indicate levels of intensity. This latter may be accomplished with a multicolor recording head, as shown in Figure 4.6.2.12.3.1(d), or a computerized method may be used where the printout is a variable number or darkness, as shown in Figure 4.6.2.12.3.1(c).

Scanning rates are in the vicinity of 6 inches per second for black-and-white recording and 1 inch per second for multicolor recording. The latter is slower because of the response time of the multiple recording pens. An increased coverage rate may be obtained by the use of multihead transmitter/receiver units and computerized methods.

Defect detection sensitivity is quite dependent on the water jet diameter and the width of the scanning index. Typical jet diameters range from 3/16-1/4 inch. Traverse or scan widths are typically 0.030-0.040 inch for black and white recording and 0.070-0.080 inch for color recording. The scan width should be adjusted to 1/3-1/4 of the anticipated void size to maximize detection probability.

4.6.2.12.3.2 Low Frequency. Low frequency inspection units (15-50 kHz) have been developed especially for honeycomb bonded structures. Their main advantages are portability and the fact that they do not need a liquid or gelatin couplant between the part and transducer. Some degree of detection sensitivity is sacrificed over that of the high frequency through-transmission units.

**Harmonic Bond Tester**. The Harmonic Bond Tester [Figure 4.6.2.12.3.2(a)] is a portable low frequency instrument using a single transducer for inspection of metal laminates and metal-to-honeycomb bonded structures. The inspection is performed by using a coil which electromagnetically vibrates the metal face sheet of a laminate or honeycomb structure. It then measures the acoustical response of this vibrating face. The coil operates at approximately 15 kHz, and its electromagnetic field vibrates the face sheet at twice the coil frequency. The face sheet vibrations create sound waves that are air coupled to a microphone located above the electromagnetic coil in the probe. The amplitude of the acoustic response is indicated by a meter. The degree of the acoustic amplitude is directly related to the face sheet movement or disbond. Generally, the response from a part being inspected is compared to a previously prepared standard representing acceptable and rejectable areas.

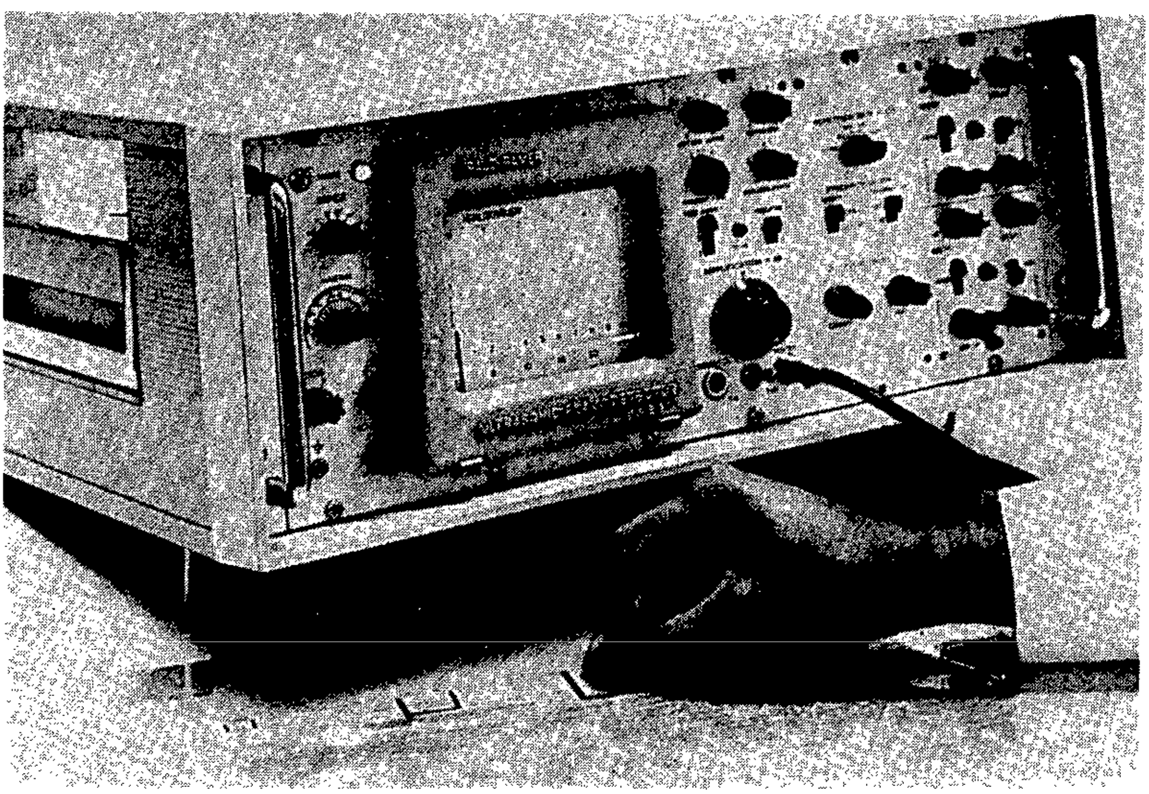


***FIGURE 4.6.2.12.3.1(a) Operation of pulse echo unit on multilaminate standard.***

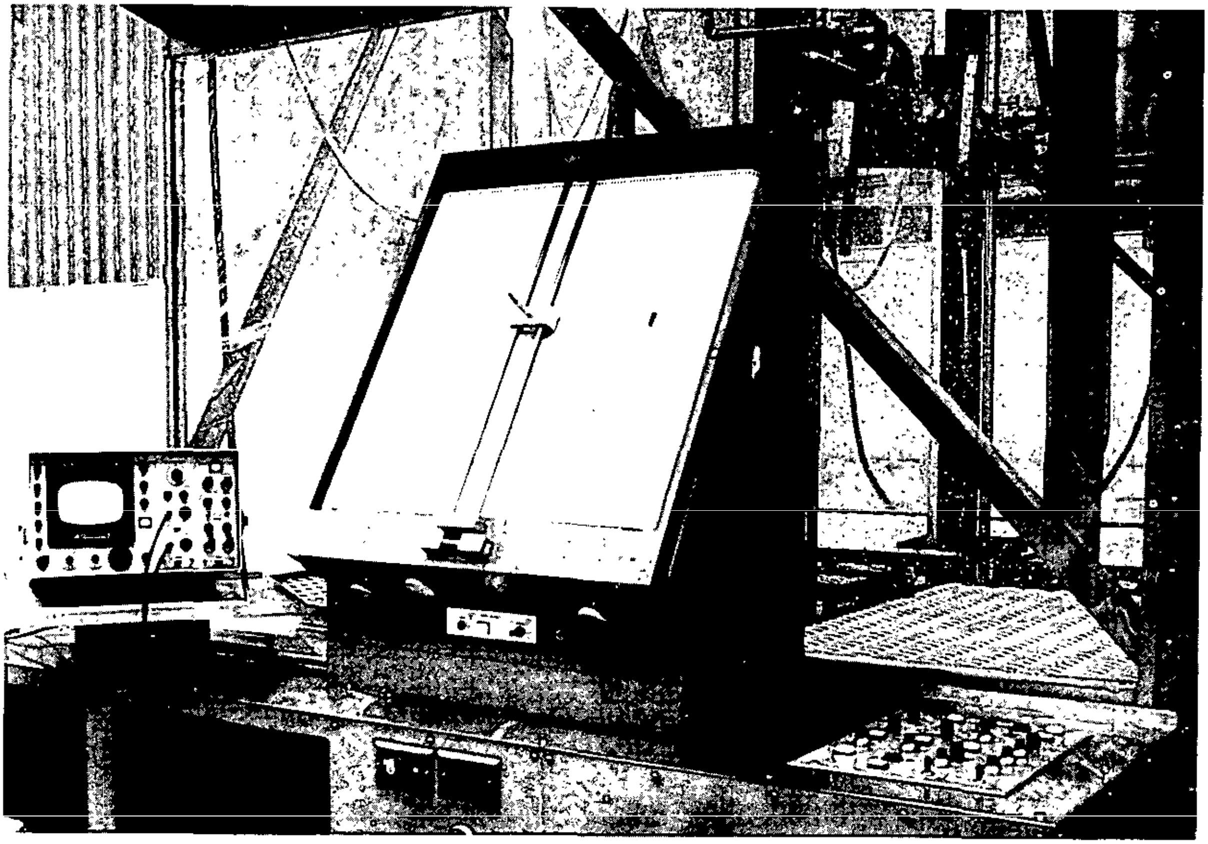


*FIGURE 4.6.2.12.3.1(b) Water coupled ultrasonic through-transmission unit.*

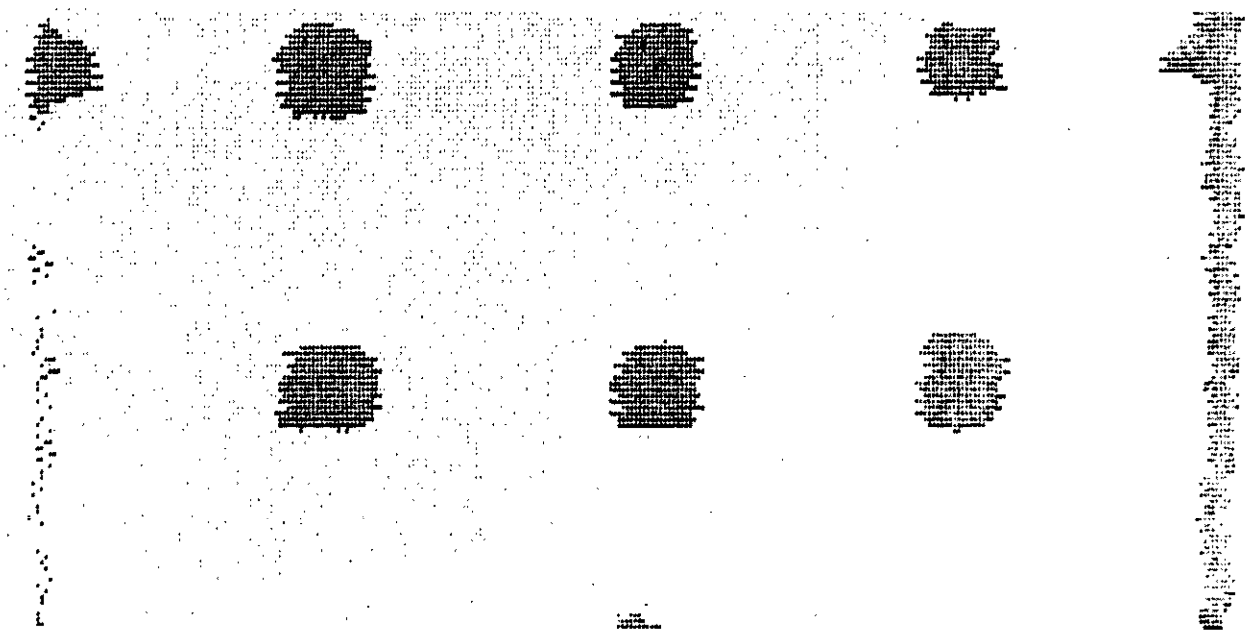


*FIGURE 4.6.2.12.3.1(c) Planform printout made by through-transmission unit showing voids in bonded demonstration panel.*

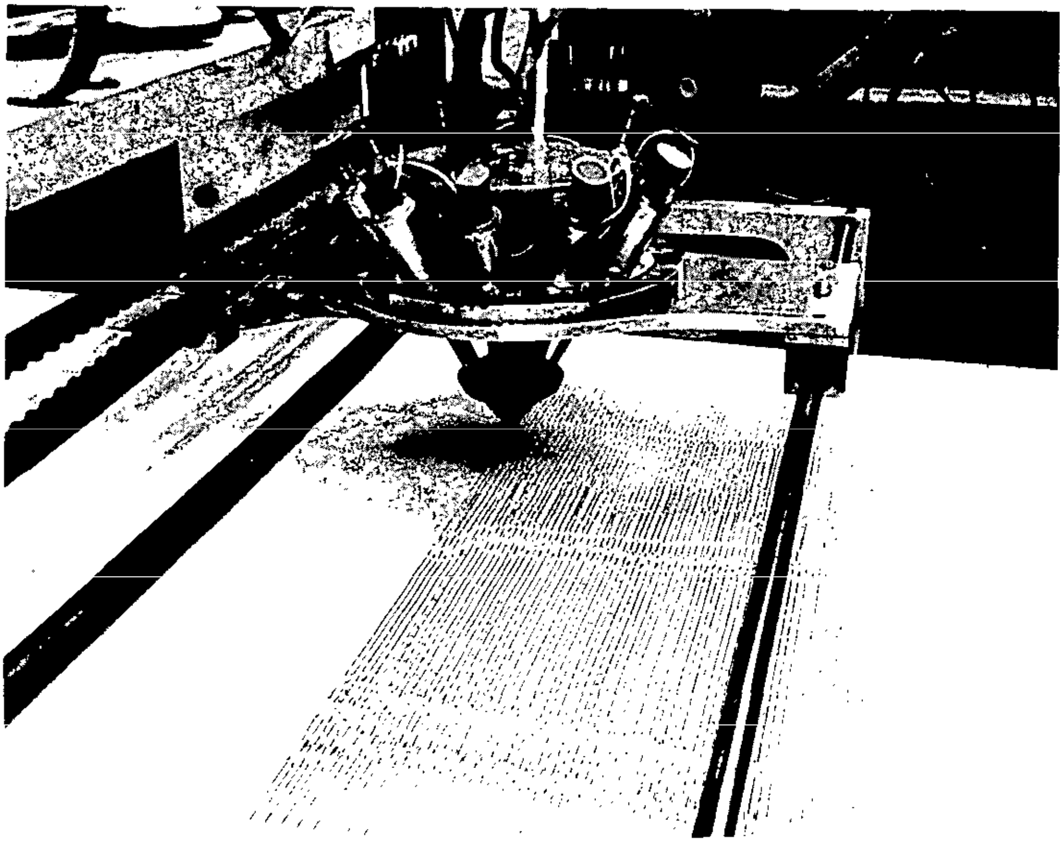


*FIGURE 4.6.2.12.3.1(d) Through-transmission unit printer using multicolor.*

**Sondicator.** The Sondicator [Figure 4.6.2.12.3.2(b)] is a pulsed transmit-receive ultrasonic portable instrument that is capable of operating in a very low acoustic frequency range, 25-50 kHz. The instrument operates within this range at a single frequency, which is selected by manual tuning for best instrument performance. The instrument is used primarily to detect delaminations of laminar-type voids in both nonmetal and metal structures. The inspection may be performed from one face of the structure [Figure 4.6.2.12.3.2(b)] or by through-transmission [Figure 4.6.2.12.3.2(c)].

The Sondicator transmits a short pulse of sound into a part and then receives the sound after it has traveled some distance through the part. During this travel, changes in the part's structure change the amplitude or phase (i.e., time shift) of the received sound. The Sondicator detects these changes in such a manner that the inspector can translate them into the corresponding changes in the structure. In manual application, the instrument has limited access to areas next to the vertical section of a tee and hat, as limited by the size of the probe (approximately 1-1/4 inches in diameter and 1-1/2 inches high).

Multiple bond lines and part edges will reduce the sensitivity of the instrument. The instrument probe generally contacts the part surface when inspecting from one side only. When used in this mode the condition of the surface, such as fiberglass roughness or perforated acoustic surfaces, may affect the reading and give false indications. Surface contact causes wear on the probe tips. These

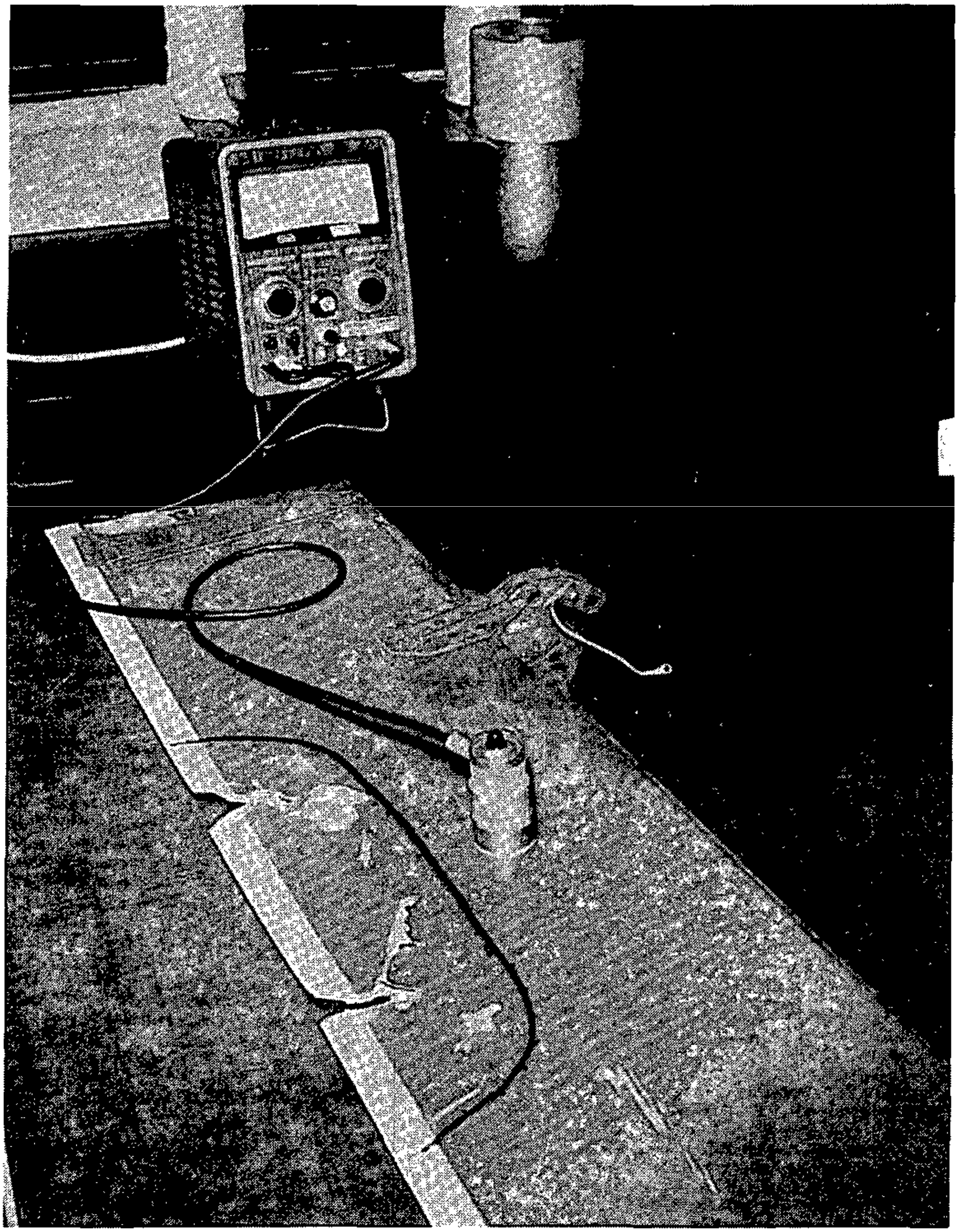


*FIGURE 4.6.2.12.3.2(a) Harmonic bond tester being used to inspect honeycomb component.*

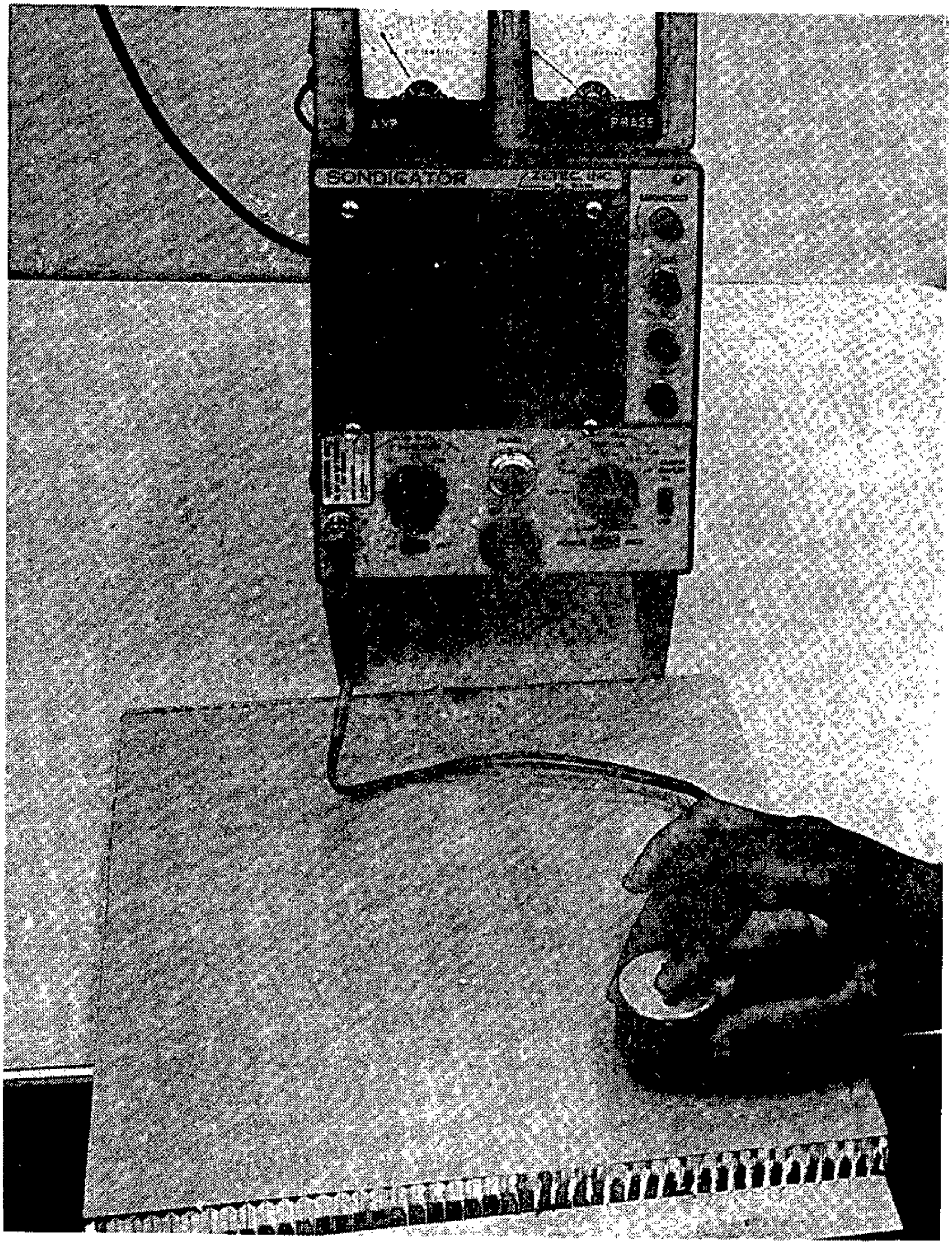



*FIGURE 4.6.2.12.3.2(b) The Sondicator being used to inspect honeycomb panel from one side.*

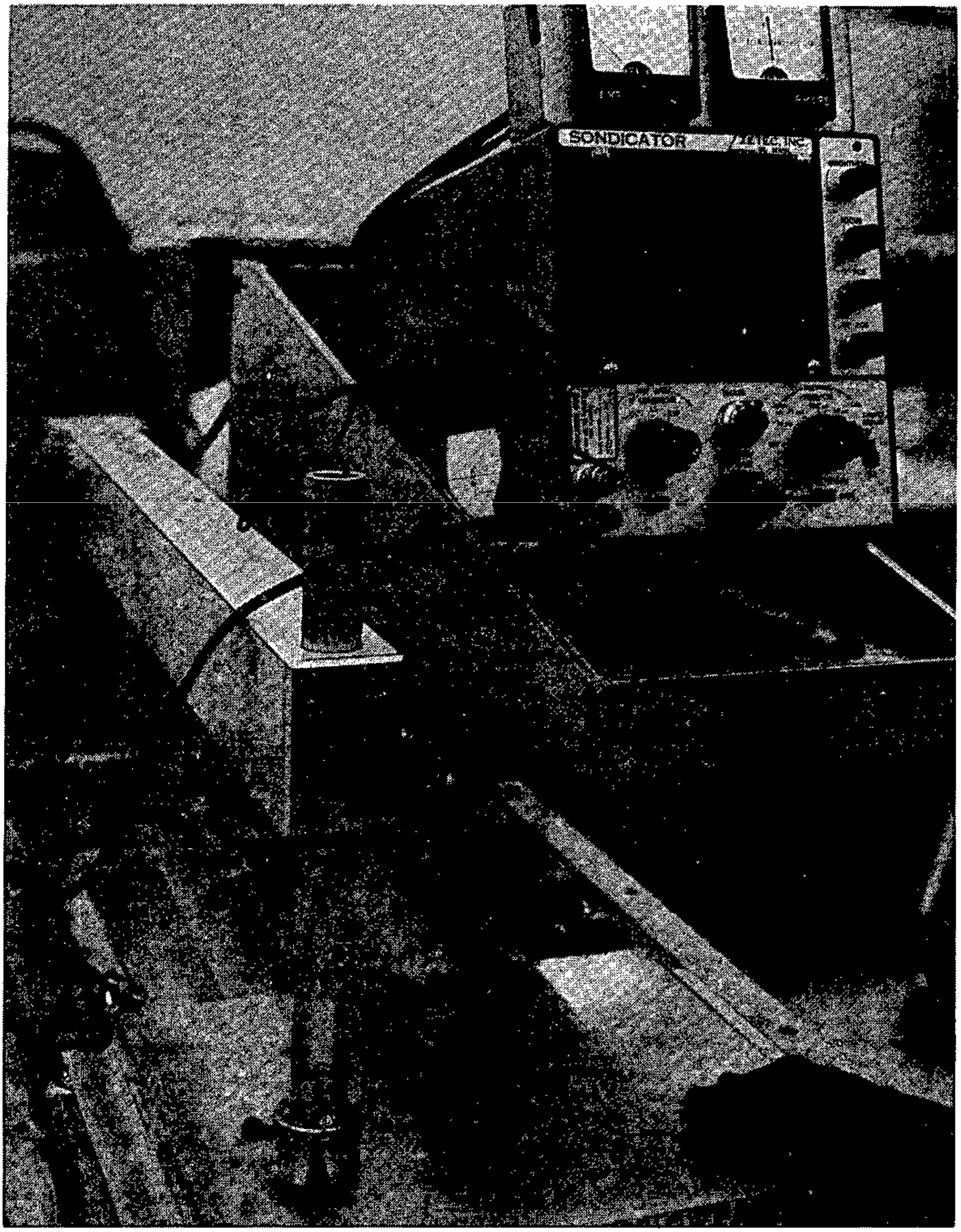



*FIGURE 4.6.2.12.3.2(c) Harmonic bond tester being used to inspect honeycomb panel by through-transmission.*

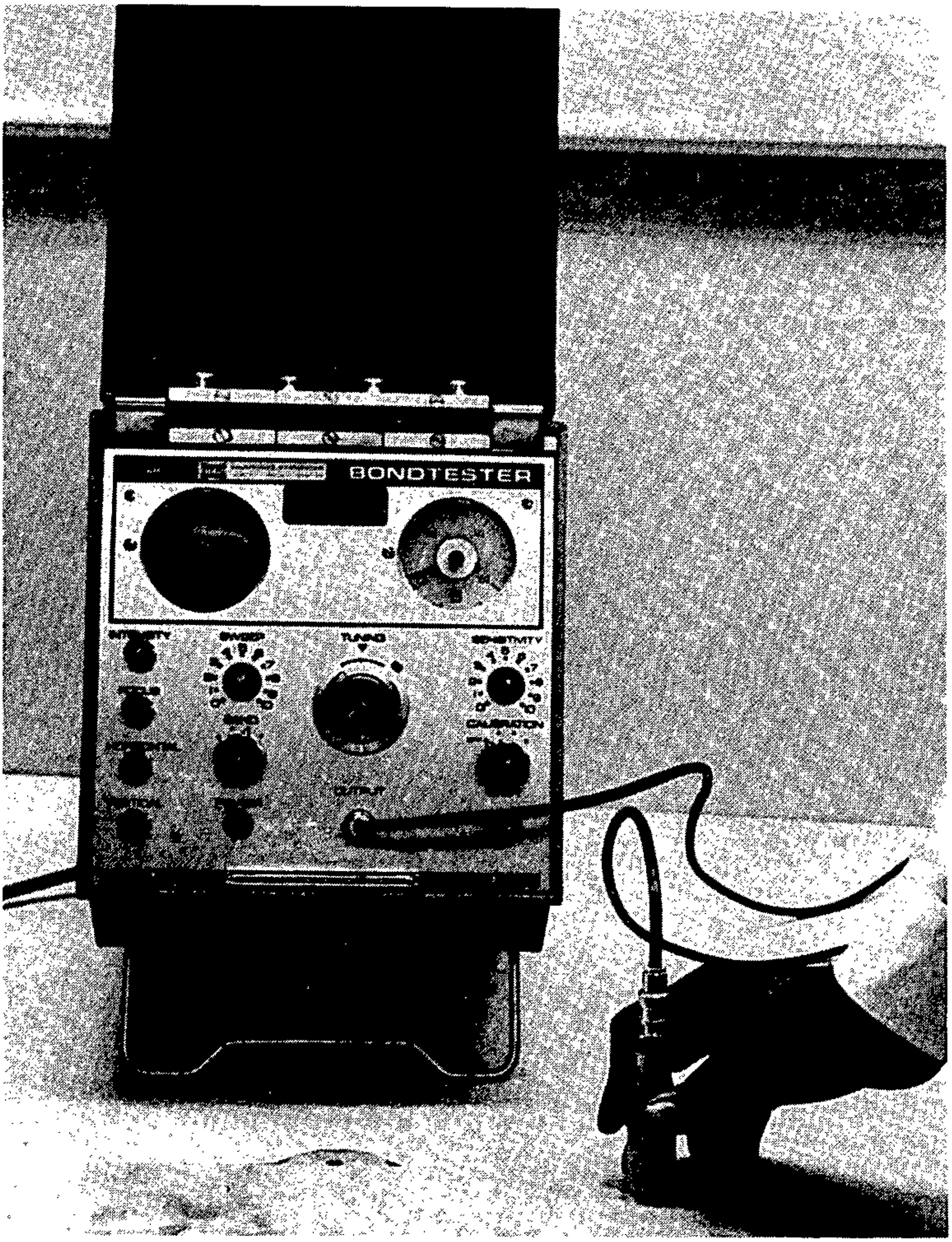



*FIGURE 4.6.2.12.3.3 Fokker bond tester being used to inspect metal laminate.*

should be examined frequently to assure they have not worn to a point where instrument sensitivity is affected. Sensitivity may be validated by inspection of a standard test panel.

**Flaw Detector**. The flaw detector works on the principle of sonic impedance in the range of 300 Hz to 8 kHz. The probe contains two piezoelectric crystals, one of which provides a continuous sonic beam.

The other crystal detects changes in the phase and amplitude of the response from the part. These changes are displayed on the instrument panel.

4.6.2.12.3.3 Resonance.

**Fokker Bond Tester**. The Fokker Bond Tester (Figure 4.6.2.12.3.3) is a portable instrument that operates by a resonant transducer method. The system is a combination of ultrasonic and physical vibrating techniques. The Fokker instrument consists of two basic elements. The bulk of the instrument, or its first element, is the power plant and the driving mechanism, as well as the readout scales. The second element is the transducer or probe, which is induced to vibrate at resonant frequency.

The instrument requires a couplant medium, such as a light oil or glycerine mixture. The necessity of removing the couplant after inspection is a disadvantage.

The Fokker Bond Tester is especially adaptable to inspecting bonded metal laminates. It is more sensitive for this application than the low frequency instruments described in Section 4.6.2.12.3.2. The instrument may discriminate between voids in multiple bond lines. However, the sensitivity decreases below the first bond line, especially in the case of heavy structures.

**Bondascope**. The Bondascope also works on the principle of ultrasonic resonance. The equipment consists of a hand-held ultrasonic probe attached to a variable frequency instrument. In use, the instrument is automatically tuned to a resonant frequency over a defect area in a standard. The part to be inspected is then scanned with the probe. The instrument displays the resonance amplitude and the impedance phase. Changes in these parameters indicate the presence and size of defects as well as the depth of the defect. Because these parameters are also affected by changes in the internal geometry, knowledge of part construction and suitable standards for each area to be inspected is required. A liquid or semiliquid couplant is required.

**Bond Tester.** The 210 Bond Tester is another device which operates on the principle of ultrasonic resonance. The probe is placed on the surface of the part to be inspected. The transducer emits a continuous ultrasonic beam, and the frequency is adjusted to produce coupled resonance. As the part is scanned, changes in impedance are measured and monitored for unacceptable indications.

4.6.2.12.3.4 Acoustics Holography. Acoustic or ultrasonic holography employs pulse echo ultrasonic techniques and focused transducers to "illuminate" the interior of a test part with sound. Scanning the part surface produces hologram of the amplitude and position information from reflections within the part. The resulting hologram is then inserted into an optical reconstructor for viewing the interior of the part.

4.6.2.12.3.5 Acoustic Emission. The acoustic emission method is based on the detection of sound or stress wave signals created by a material undergoing some physical or mechanical transformation. The equipment consists basically of an amplifier and a piezoelectric sensor with a resonant frequency in the low ultrasonic range (175 kHz). The emission level is recorded on a chart or meter. A visible light indicates when a predetermined emission threshold has been exceeded.

Simple heating methods using a hot-air gun or heat lamp are used to increase emissions from active corrosion sources and to create the stresses necessary to break moisture-degraded adhesive bonds.

4.6.2.12.4 Radiography. Radiography is a very useful NDI method in that it essentially allows a view into the interior of the part. Portable equipment is available, and in some instances inspection can be done without removing the part from the aircraft. In most cases, however, the part must be taken to the X-ray laboratory. This more readily allows access to both sides of the part and allows the part to be placed in a position where it can best be inspected for a particular defect.

Radiography provides the advantage of a permanent film record. On the other hand, it is relatively expensive, and special precautions must be taken because of the potential radiation hazard. When inspecting with a radiographic method, use trained personnel and follow verification standards. Conduct a daily check of the film-developing solutions. Do not bypass radiation safety requirements or attempt to reduce inspection time by increasing the kilovoltage.

This inspection method uses a source of X-rays or gamma rays to detect discontinuities or defects through differential densities in the material. A typical radiographic exposure setup is shown in Section 5.8.4.3.4. Variations in density over the part area are recorded by various degrees of the films. A standard (penetrameter) having various degrees of exposure of the films and degress of density, is used in the scene to indicate that proper exposure and resolution have been obtained.

Since the method records changes in total density through the thickness, it is not a preferred method for detecting defects such as delaminations that are in a plane normal to the direction of the radiation. It is the most effective method, however, for detecting the presence of water in honeycomb core cells. It is also very effective in identifying core that has been dislocated or damaged or voids in bond lines parallel to the ray direction.

4.6.2.12.5 Optical Holography. Optical holography is a method of recording the amplitude and phase of the optical wave fronts reflected from an object such that, when reconstructed, these wave fronts have the relative amplitude and phase of the original wave fronts. Three-dimensional properties are contained in the image of reconstructed wave fronts. In practice, a stress is applied to the part and a hologram made of the stressed area. Slight movement of the surface being viewed by holography during stressing may be detected and show a defect in the bonded part.

The main limitation of optical holography is the necessity to isolate the part and inspection system from extraneous movement.

**4.6.2.13 Environment Measuring and Recording Devices.** Temperature and humidity measuring and recording devices must be available for the controlled contamination area (lay-up room). See MIL-A-83377 for specific temperature and humidity requirements.

**4.6.2.14 Leak Test Equipment.** Each final assembly should be leak tested in accordance with the requirements of the procurement specification. Equipment required consists of:

- Suitable size metal tank with heating device capable of maintaining water at 170 ± $10^{\circ}$F. The tank should be equipped with a mechanism for holding, lowering, and raising parts into and out of the heated water. Since all honeycomb panels float, they must be securely held to prevent damage during leak testing.
- Clean, water absorbing cloths for removing water on surface of parts. Device capable of marking leaking area when part is submerged in the hot water.

Chapter 5 (Sections 5.7.2 and 5.8.4.3.6) contains detailed procedures for conducting the leak test.

**4.6.3 Supplier Requirements.**

**4.6.3.1 Approval of Materials and Processing Procedures.** The honeycomb manufacturer is normally required to obtain certification from raw material suppliers and other suppliers stating that the material supplied meets applicable specifications.

Approval of the processing procedures should be in accordance with the requirements of the applicable procurement specification.

**4.6.3.2 Departures From the Standard Procedure.** Any departure from the requirements and quality assurance provisions of the applicable procurement specification requires approval in writing by the procuring government agency (Contract Administrative Officer).

**4.6.4 Record Keeping.** A central inspection record system facilitates the retrieval and tracing of data on request. Traceability cross referenced to part number, and particularly to fracture/fatigue-critical designated parts, is required for accurate test data and service experience correlation.

**4.6.4.1 Traceability of Material.** Records for traceability of material should be maintained per MIL-STD-1530 (USAF). All acceptable materials should be stamped with a serial number, which is transferred to the record of parts fabricated from this material. After final installation of parts, the complete record is stored in a special storage area and is retrievable on demand.

**4.6.4.2 Identification of Assemblies.** Every assembly should be identified per the applicable engineering drawing, including a serial number. Identification plates, if required, should be installed by bonding or mechanically fastening, as specified on the applicable engineering drawing, and in accordance with the procedure contained in Section 5.7.5.

**4.6.4.3 Required Documentation.** All documentation specified in the applicable procurement specification is required. This includes data pertaining to materials acceptance, tool qualification, process control, and results of nondestructive and destructive testing.

**4.6.5 Safety Considerations.**

**4.6.5.1 Special Notes Concerning the Use of Solvents.** Solvents are important to use when fabricating bonded assemblies or accomplishing rework/repairs. However, they do present potential problems as a danger to health and the possible incidence of fire. Health and safety issues concerning solvents are addressed in subsequent paragraphs. Refer to TO 42 C-1-20 and other documents such as OSHA, Air Force, Army or Navy regulations and standards, and local government regulations and contractor's safety department regulations for further details.

Review OSHA and other regulations/laws for additional information on safety considerations.

4.6.5.1.1 Health Hazards. Health hazards related to the use of solvents include the following:

1. If absorbed through the skin, solvents may cause dermatitis. They can dissolve natural skin oils and result in drying and cracking of the skin, rendering it susceptible to infection. Solvents may cause irritation and allergic reaction to sensitive individuals.
2. If vapors are inhaled, solvents can cause mild symptoms of headache, fatigue, nausea, or visual and mental disturbances during prolonged and repeated exposure to moderate concentrations. Severe exposure may result in unconsciousness and even death.

Solvent vapors can also act as an anesthetic, or cause irritation of the eyes or respiratory system. They can result in blood, liver, and kidney damage if the solvents include specific agents harmful to these organs. Some solvents are noted as carcinogens.

3. Solvents are harmful if swallowed. Symptoms may be similar to those of vapor inhalation.

4.6.5.1.2 Personal Exposure. Personal contact with the liquid or inhalation of vapors should be minimized or eliminated by engineering techniques such as enclosing the process or equipment, isolating operations, and using local exhaust ventilation and protective clothing and equipment. Personnel should:

1. Assure that adequate ventilation is provided during the mixing and use of adhesives, solvents, and cleaning solutions. Avoid breathing fumes from these materials.
2. Always add acid to water. Never add water to acid. The solution should not come in contact with skin or clothing. In case of contact, skin or clothing should be washed off immediately with generous amounts of cold water. Always wear eye protection and rubber gloves when using these solutions.
3. Wear heat insulating gloves when handling hot equipment and repair materials. Respirators should be worn for operations creating excess dust, such as sanding metal or fiberglass.
4. Closely observe all applicable facility and Federal safety regulations.
5. Avoid solvent contact with the skin. Wear rubber or neoprene gloves when handling liquid solvents. Other equipment, such as impervious aprons, sleeves, coveralls, and boots, may be necessary in certain operations.
6. Avoid eye exposure to liquid solvent, vapor or overspray, by wearing chemical goggles or other approved eye protection.
7. Avoid using solvents as skin cleansing agents. If a solvent contacts the skin, wash the affected area immediately with soap and water and apply a nonsilicone skin conditioning cream, lotion, or ointment.
8. Avoid breathing solvent vapors. Use solvents only in well ventilated areas. Use respirators such as the chemical cartridge type, gas masks, or airline full-face respirators, where there is lack of engineering control and high vapor concentrations exist.
9. Avoid using solvents for unauthorized or unapproved purposes. Use only for purposes called out in appropriate specifications.

4.6.5.1.3 Fire Hazards. To eliminate or minimize the danger of fire and consequent destruction of life and property, flammable solvents should be used only in approved areas and with methods recommended by the local fire safety authority. Several recommended precautions include:

1. Eliminate all flames, smoking, sparks, and other sources of ignition from areas using solvents.
2. Use nonspark producing tools.
3. Eliminate or ground clothing or processes creating static electricity.
4. Assure that all electrical equipment (lights, motors, wiring, etc.) meets the electrical and fire codes for such locations.
5. Keep flammable solvents in closed safety containers and only in quantities to satisfy immediate use.

6. Provide adequate ventilation to prevent buildup of vapors.

7. Dispose of all rags, cloths, and wipers in special containers used only for this purpose.

**4.6.5.2 Nonsolvent Surface Preparation Materials or Solutions.** Acids and alkaline cleaner materials or solutions required for surface preparation of details to be bonded are hazardous. The following safety precautions should be practiced when handling these materials or using the solutions:

1. Avoid skin contact.
2. Wear safety goggles or a shield.
3. Wear protective clothing.
4. Wear rubber gloves.
5. Mix and use solvents in a well ventilated area.
6. Always pour acids into water; never pour water into acids because a violent reaction may occur and splatter acid onto personnel.
7. Avoid breathing fumes.

**4.6.5.3 Adhesives, Potting Compounds, Sealants.** Adhesives, potting compounds, and sealants are toxic and hazardous. The following safety precautions should be practiced when handling or mixing these materials:

1. Avoid skin contact.
2. Wear safety goggles when mixing adhesives, potting compounds, and sealants.
3. Handle film adhesives with clean white cotton gloves.
4. Avoid breathing fumes from material components or mixed materials because they may be irritating to the skin or even toxic.
5. Wash hands before eating or smoking to remove any irritating or toxic residue.

**4.6.5.4 Autoclaves, Platen Presses, Cavity Presses.** The following safety precautions are recommended when working with autoclaves, platen presses or cavity presses:

1. Wear insulated gloves when handling hot tooling, bond fixtures, assemblies or hot surfaces of the autoclave, or platen or cavity presses to avoid burns.
2. **Do not** place body parts between the platens of the press when the press is closing to avoid possible injury. Make certain the platen press is in a locked open position before working between the platens.
3. **Do not** leave extraneous, combustible materials inside the autoclave or cavity press to prevent fires.
4. **Do not** allow the autoclave door to be closed while operators are inside the chamber.
5. **Do not** exceed manufacturer's maximum temperature or pressure restrictions to prevent equipment damage and explosions.

**4.6.5.5 Disposal of Hazardous/Toxic Waste.** The disposal of chemical waste, in compliance with environmental regulation and in a manner that protects health and environment, is an extremely complex topic. Each waste stream that a commercial activity generates must be studied to determine the ways in which the waste may be classified as Hazardous Waste under the law. Waste streams must then be managed in a manner consistent with the regulations.

Spent acid baths, for example, may be legally hazardous waste simply by virtue of their pH causing them to be classified corrosive, or may be classified hazardous by virtue of containing any of a list of toxic metals above certain concentration levels. Organic solvents in most cases will be classified as hazardous waste in accordance with generic solvent-waste-stream listings in the regulations. In general, any changes made to the waste to reduce the hazards or render them nonregulated are also strictly regulated, and making such changes in the waste may require a treatment permit under the regulations.

The U.S. Environmental Protection Agency (EPA) provides a basic framework in regulations that were mandated by the Resource Conservation and Recovery Act (RCRA) in the mid-1970s. These are found in Title 40 of the Code of Federal Regulations, with regulations for waste generators beginning at about Part 260. Further modifications to the regulations have been mandated by Congress and promulgated by U.S. EPA, especially in the form of amendments passed in 1984 and land disposal restrictions beginning in 1986. The latter restrictions, known also as the "Land Ban" rules, were programmed to force development of waste treatment technologies and capacities, over a period of years running into the 1990s or beyond.

In addition to the U.S. EPA RCRA rules, many states have their own sets of rules. State regulations may cover many additional classes of chemicals, and may contain additional rules. Further, disposal of waste down a drain may be regulated by rules of several local agencies and by national or state permit systems and regulations that are separate from the hazardous waste rules.

In essence, any commercial activity must have a waste management function assigned within the organization, charged with learning what regulatory requirements apply and with finding ways to comply with the regulations. Both civil and criminal penalties for violations may be severe, and may be applied to individuals as well as to the business entity.

# 5.0 DETAILED REQUIREMENTS

**5.1 Introduction.** This section contains (1) descriptions of the processes employed to manufacture adhesive bonded assemblies and (2) the preferred procedures to accomplish those processes. The intent of this section is to supplement part-specific material and process specifications by providing the reader with stepwise instructions to conduct the identified procedures and operations. Nonconformance with the recommended methods should be discussed with the Air Force Contracting Officer.

For further detailed information on definitions, equipment and facilities, and testing and inspection procedures used for the production of bonded assemblies, please refer to Chapters 3, 4, and 5, respectively.

**5.1.1 Process Flow Chart.** The manufacturing processes presented in this section are shown in a flow chart (Figure 5.1.1). The progression of this section's contents parallels the processing sequence indicated in the flow chart.

**5.2 Fabrication Operations.** This subsection describes the processes with which the aluminum honeycomb core and aluminum skins and detail parts are fabricated into their final sizes for prefit. The aluminum honeycomb core is referred to simply as the core throughout Chapter 5.

**5.2.1 Aluminum Honeycomb Core.** Standard hexagonal aluminum core of varying thicknesses, cell sizes, and densities is fabricated from aluminum foil. The most commonly used aluminum alloys are 3003, 5052, 5056, and 2024. The primary core manufacturing processes are:

1. Foil cleaning and corrosion coating.
2. Foil printing [as shown in Figure 5.2.1(a)].
3. Foil cutting.
4. Foil stacking.
5. Block or press curing [as shown in Figure 5.2.1(b)].
6. Block sawing.
7. Core slice expanding.
8. Unexpanded block or expanded core sizing.

The overall core manufacturing process is complex, requiring large equipment and substantial space for operations such as sheet lay-up [see Figure 5.2.1(c)]. Extensive storage facilities are also required [see Figure 5.2.1(d)].

The primary core processing operations are reviewed in the following sections.

5.2.1.1 Sawing. Sawing is used to:

- Cut smaller segments of slices and wedges from cured unexpanded blocks.
- Rough trim the bond surface of expanded core where there is to be subsequent contour machining.
- Cut chamfer edges on cores.

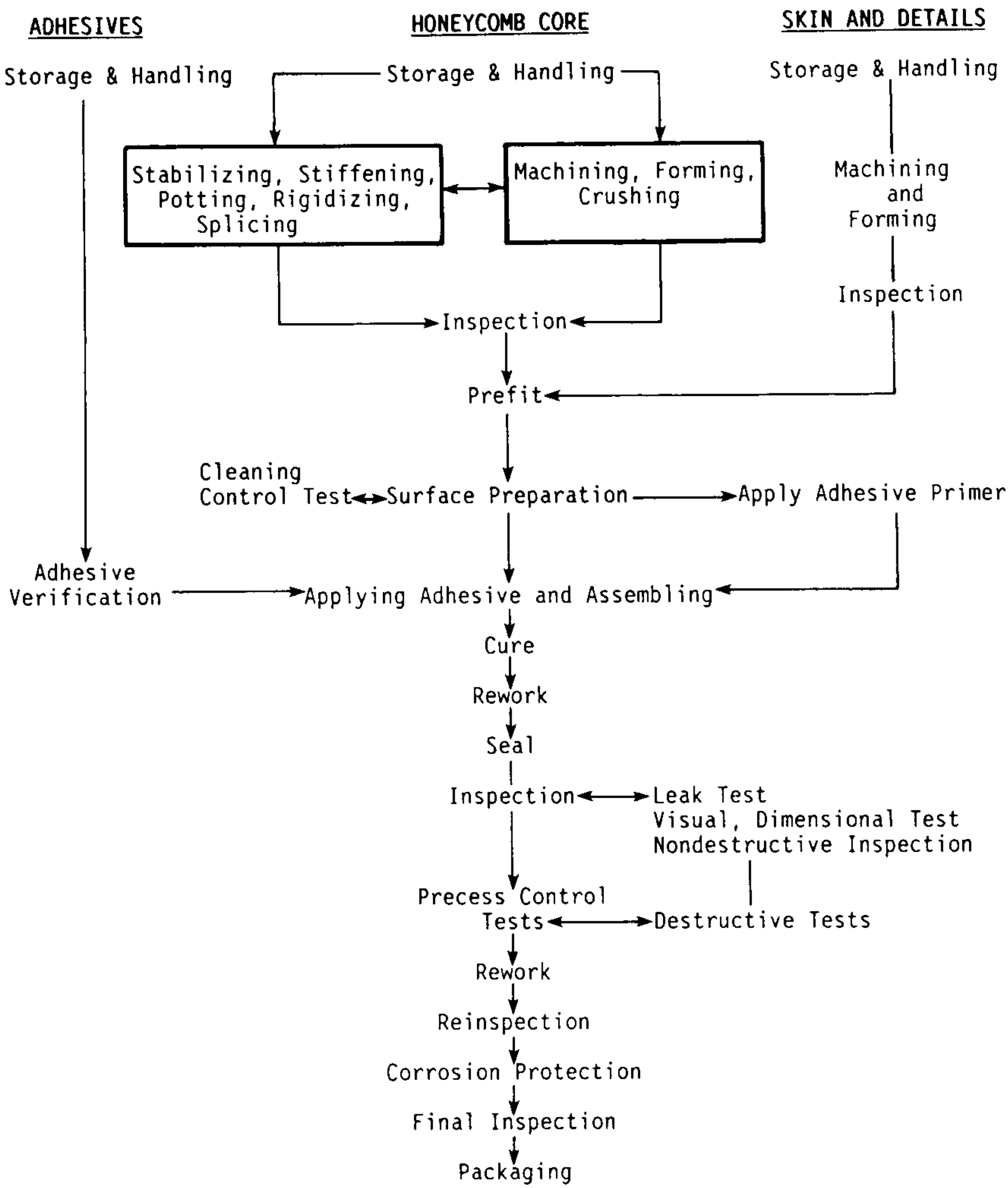
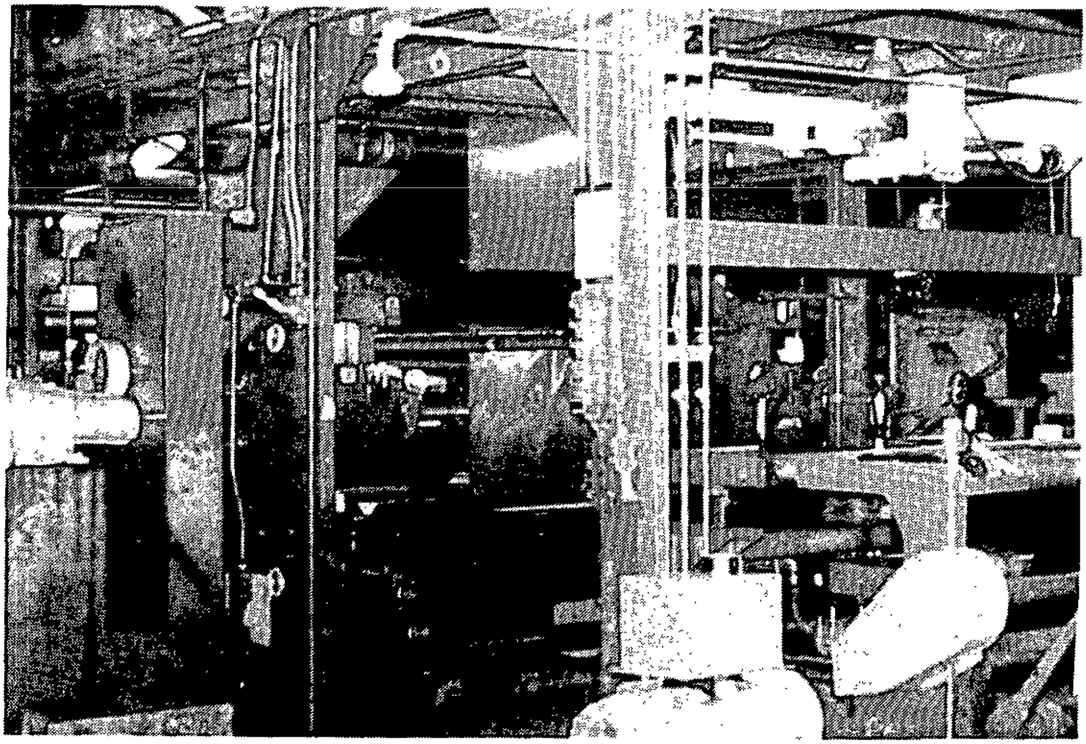
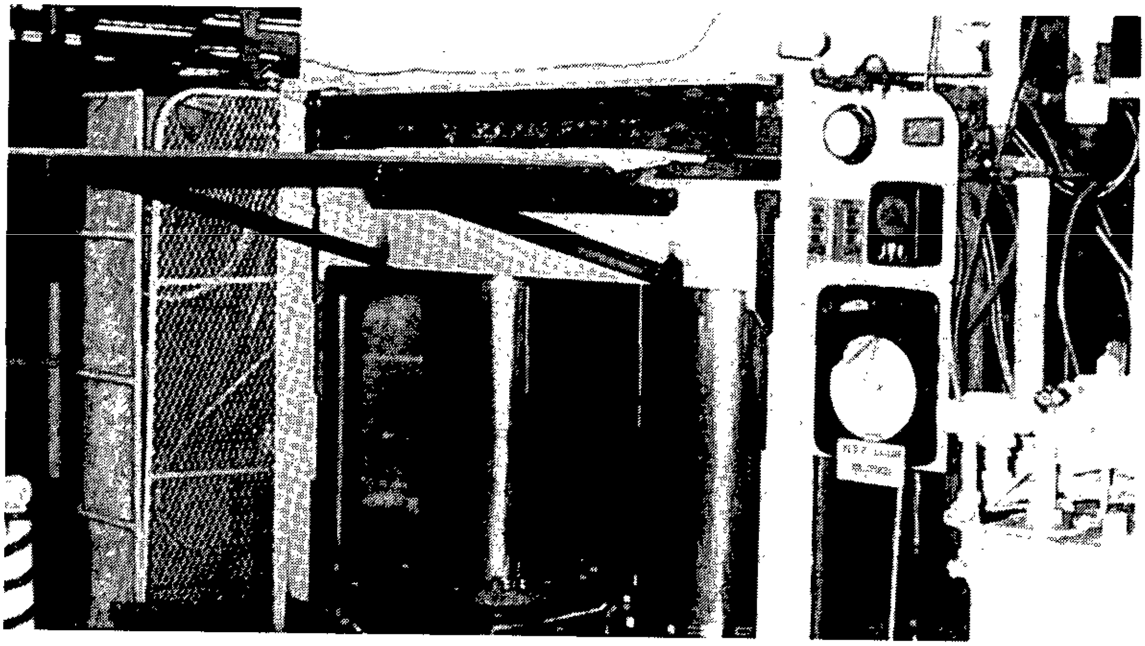



***FIGURE 5.1.1 Manufacturing process flow chart.***



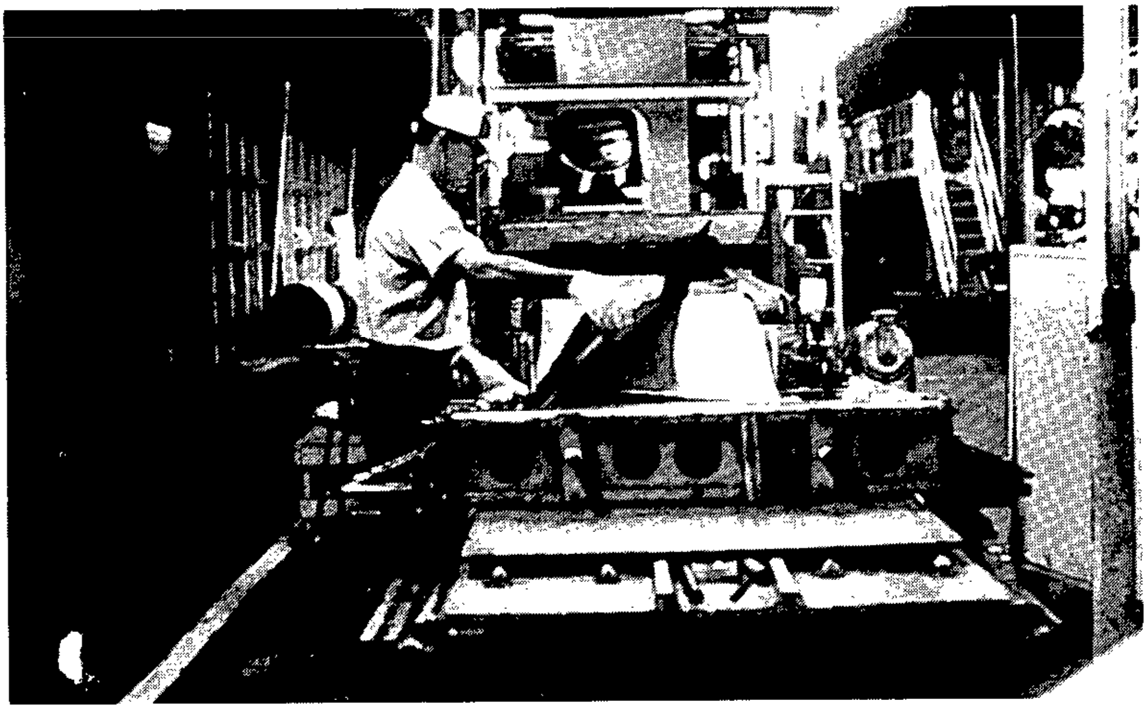
*[Photo courtesy of Hexcel]*

**FIGURE 5.2.1(a) Aluminum foil preparation-printing.**



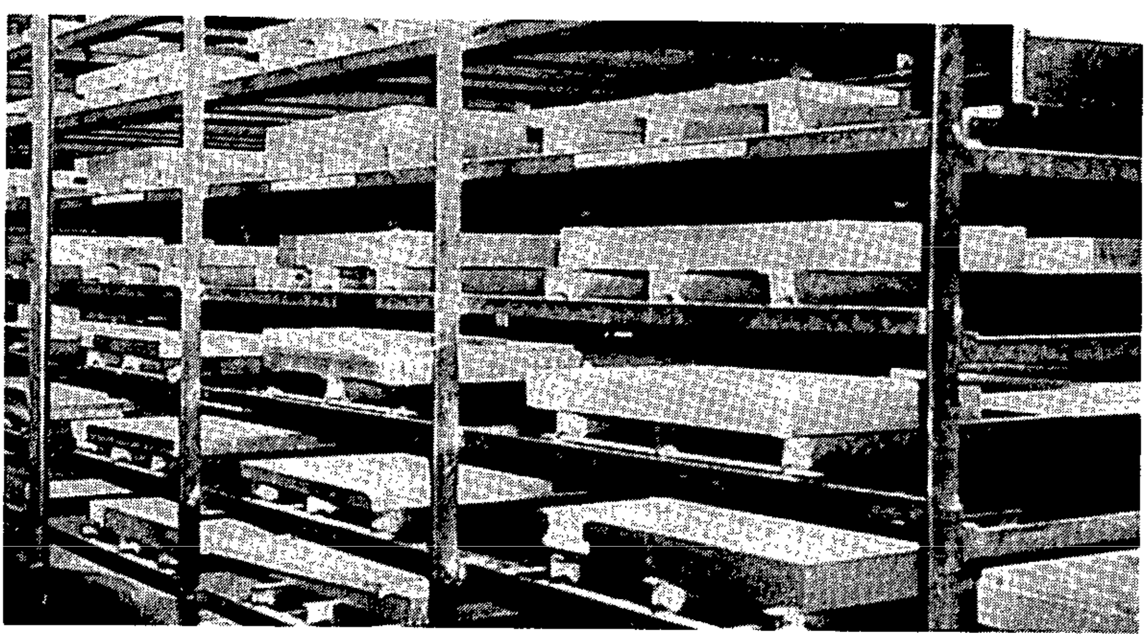
*[Photo courtesy of Hexcel]*

**FIGURE 5.2.1(b) Press cure operation.**



[Photo courtesy of Hexcel]

**FIGURE 5.2.1(c) Aluminum foil sheet lay-up operation.**



[Photo courtesy of Hexcel]

**FIGURE 5.2.1(d) Storage area for honeycomb before expansion (HOBE) after press cure.**

5.2.1.1.1 Unexpanded Aluminum Core Block. Unexpanded core block is sawed into smaller slices or wedges using a band saw. Constant thickness slices are sawed using a saw backstop set-up in relation to the saw blade.

For unexpanded shapes, templates representing the desired configuration and optimum block utilization are taped to one end of the block using double-sided tape.

**NOTE**

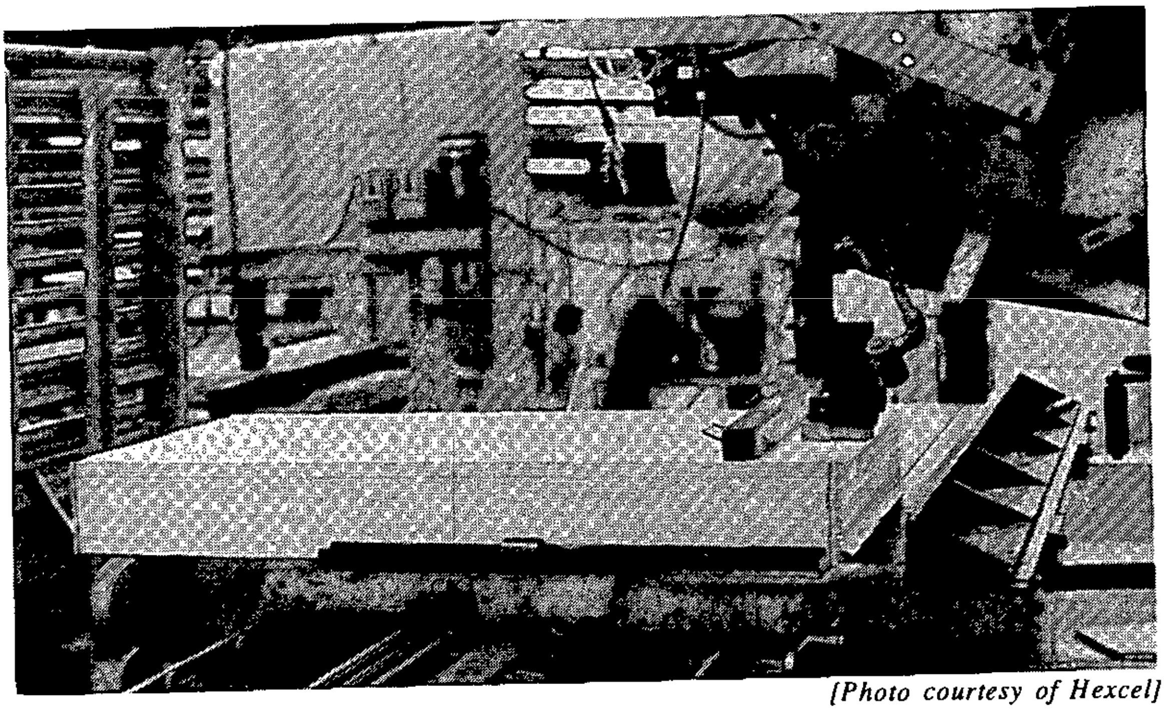
An end refers to either side of the block parallel to the surface of the sheets.

After sawing, templates are removed from the shapes by prying them apart with a hand knife. No cutting fluid is used during sawing.

See Figure 5.2.1.1.1(a) for sawing of core block. Wedge shaped machined details are shown in Figure 5.2.1.1.1(b).

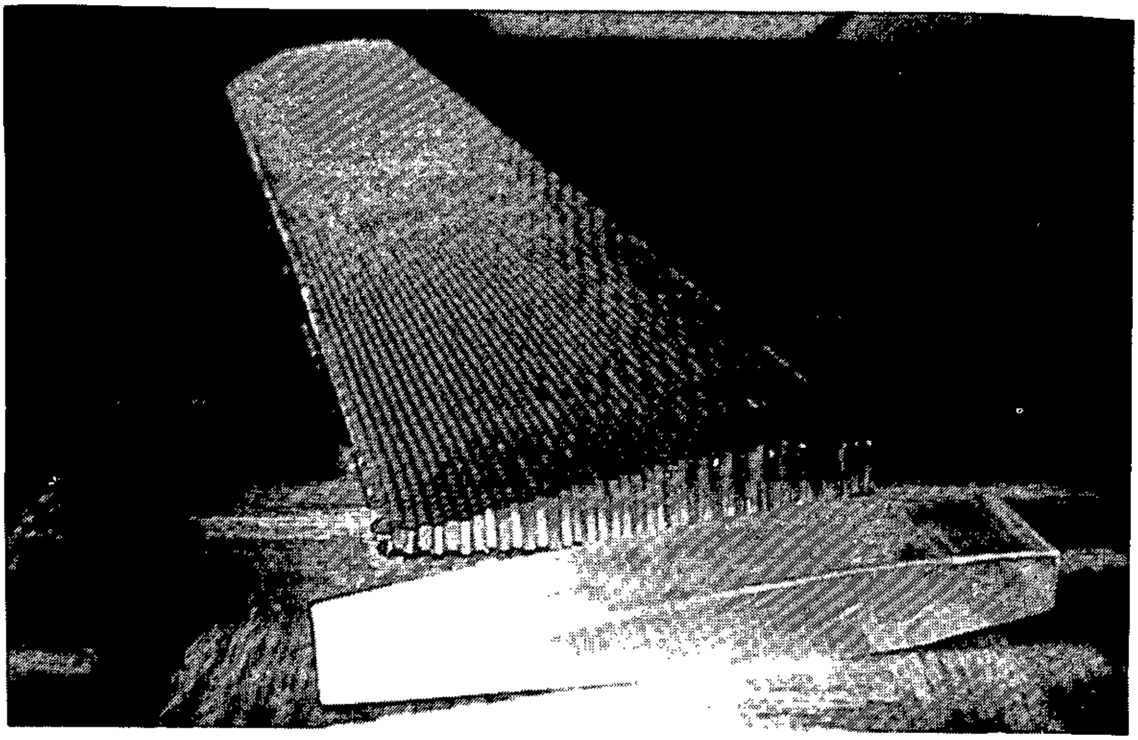
5.2.1.1.2 Core Slice. Band saws of various sizes with preset blade angles are used to cut chamfers on expanded core, slices, or details as shown in Figures 5.2.1.1.2(a) and (b). The size of the saw is dictated by the size of the cores being cut.

The core may be stabilized to the template or in fixtures using double-sided tape. Weights may also be used to secure the core onto the saw table. The core is then either automatically fed or hand guided past the band saw blade.



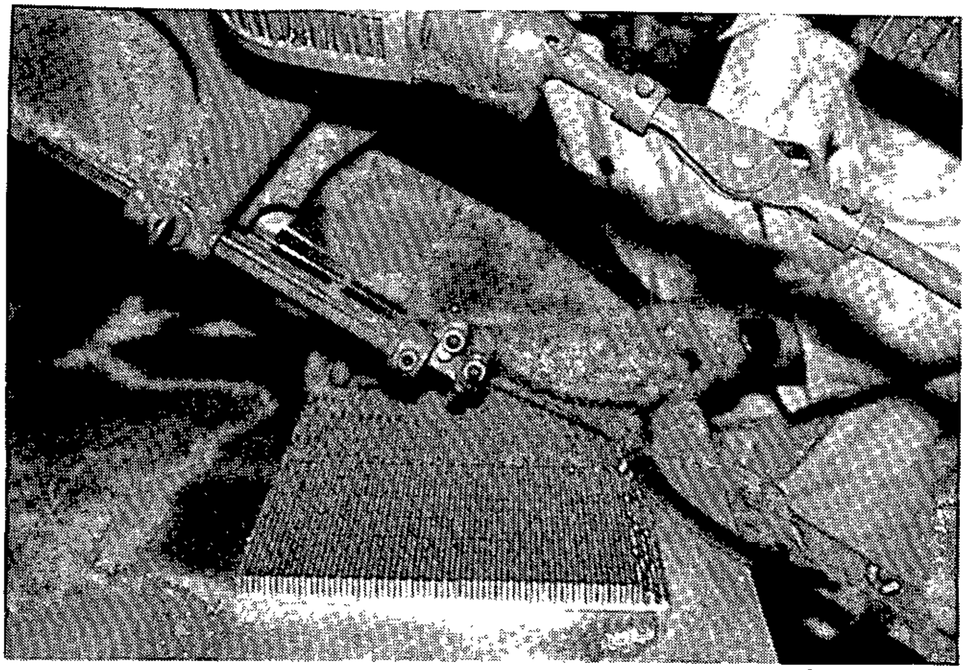
*[Photo courtesy of Hexcel]*

***FIGURE 5.2.1.1.1(a) Sawing (rough trim) of core block.***



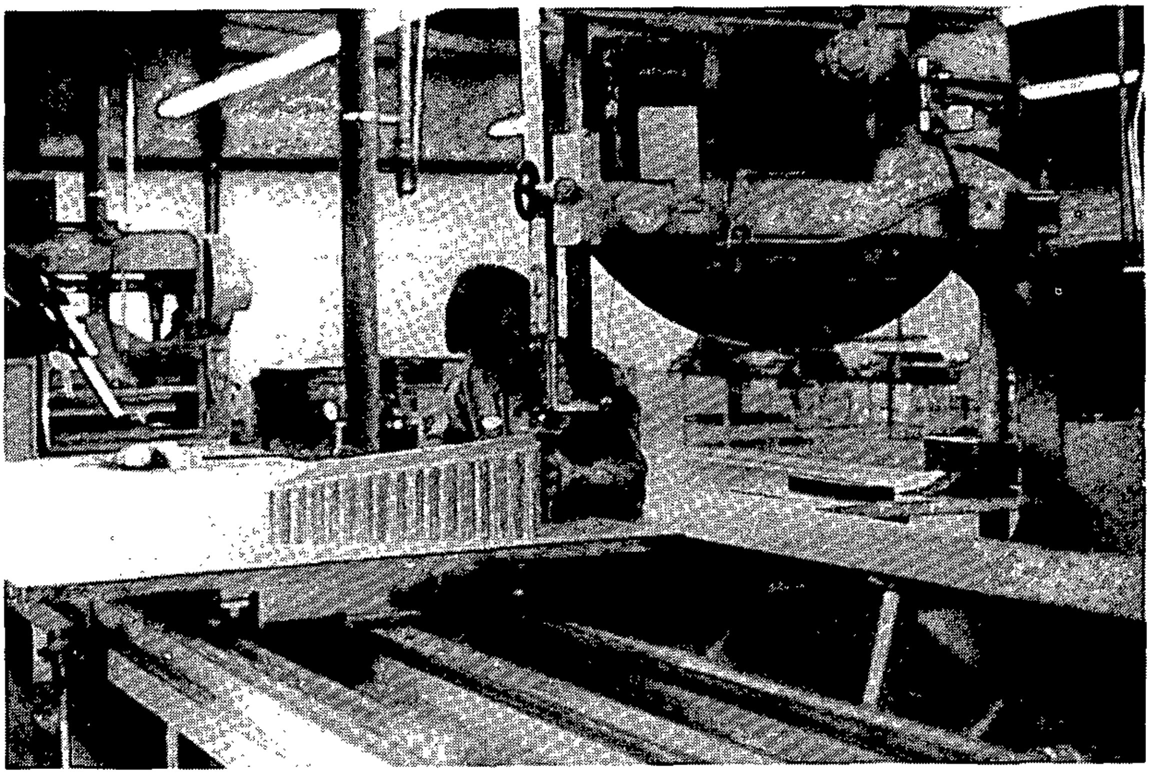
*[Photo courtesy of Hexcel]*

***FIGURE 5.2.1.1.1(b) Wedge shaped machined details–expanded and unexpanded slice.***



*[Photo courtesy of HTAC]*

***FIGURE 5.2.1.1.2(a) Core chamfering with band saw.***



*[Photo courtesy of HTAC]*

***FIGURE 5.2.1.1.2(b) Final trimming of expanded core block using band saw.***

**NOTE**

It is recommended that the core be handled with clean white gloves during processing to prevent contamination. If bare hands are used, subsequent cleaning may be necessary.

5.2.1.2 Expanding. The unexpanded core block is placed on the expander with sheets oriented vertically on the expander bed. One end of the block is secured to the expander via a fixture while the other end is being pulled away (perpendicular to the ribbon direction) creating expanded cells. The pulling force is intermittently relaxed to allow for springback. This is repeated until the specified cell count is attained.

Pins are used to one (1) separate, or pick apart, the unexpanded cells that are stuck together and two (2) align the distorted cell walls near the perimeter.

If machining has been accomplished prior to expanding the core, vacuum the expanded core to remove metal shavings and flakes. If core has been contaminated with oils, grease, etc., then vapor degrease per Section 5.4.3.2. Spray cleaning (same as steam) procedure (see Section 5.4.4.1.1) is an acceptable alternative to vapor degreasing.

5.2.1.3 Rigidizing/Stiffening/Rigidifying/Stabilizing. Two of the aluminum core's most desirable properties are its lightweight and flexibility. However, these properties also make the core difficult to handle during fabrication. Generally, the core must be rigidized with a material that is removed after machining or stiffened, or stabilized with a pourable adhesive that remains on the core.

5.2.1.3.1 Rigidizing Core for Machining. Cores are rigidized by various methods to provide the necessary support during machining. Acceptable methods include:

- Confining the core in fixtures.
- Partially filling the core cells with water, then freezing the water. After machining, the ice is melted away using hot water, and the core is then rinsed and dried.
- Partially filling the core cells with polyethylene glycol, which, contains a fluorescent "detection dye." After machining, the waxy glycol melts away. The core is then rinsed, dried with forced air, and inspected with "black light" to assure complete removal of the polyglycol residue. Refer to Section 5.4.3.1 for glycol removal procedure.
- Bonding the core surface to temporary skin (can be sacrificial skins) with adhesive.
- Bonding the end of the core block to a metal template with double-sided tape. The template can be removed by prying with a knife.
- Rigidizing is also achieved by permanently bonding the core to details per specification during partial assembly. The subassembly is then cured and ready for machining.

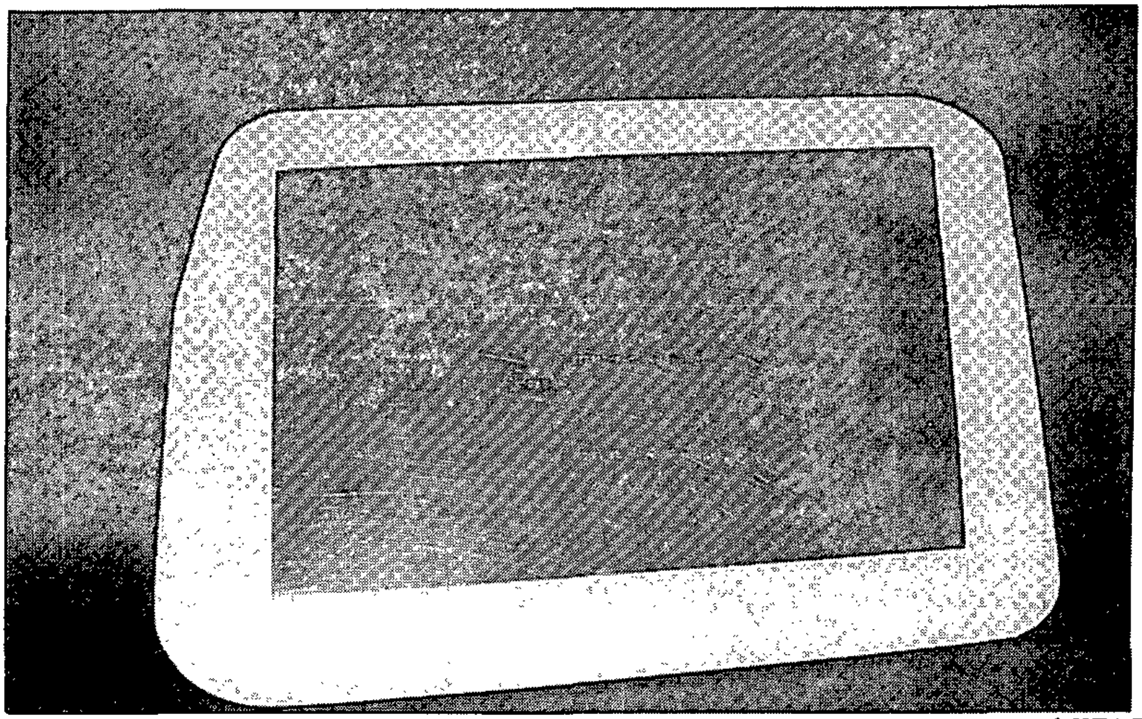
Figure 5.2.1.3.1(a) shows the application of skin to a template for core rigidizing while Figure 5.2.1.3.1(b) shows the rigidized core ready for machining.

5.2.1.3.2 Stiffening. Honeycomb core should be stiffened to prevent collapse of core cells during handling and assembly. Use the adhesive specified on the drawing or the procurement specification that has passed the receiving inspection qualification tests. The procedure for stiffening core is as follows:

1. Ensure the core is free of oily residue. Use a "black light" to inspect. If the core is determined to need cleaning, vapor degrease according to procedures given in Section 5.4.3.2.
2. Mask the core where stiffening is not required by using a template.
3. Prepare the adhesive in accordance with the manufacturer's instructions.
4. Pour the adhesive over the core in the area to be stiffened.
5. Drain the core with the cell walls in a vertical position for 2-6 minutes. Air dry and cure in a circulating air oven per manufacturer's instructions.

5.2.1.3.3 Rigidifying Local Areas. Core should be rigidified locally to prevent crushing where specified on the applicable engineering drawing. The procedure for rigidifying core is as follows:

1. Ensure the core is free of oily residue. Use a "black light" to inspect. If the core is determined to need cleaning, vapor degrease according to procedures given in Section 5.4.3.2.
2. Rigidify the core face that is not to be crushed as follows:
   a. Mask the area of the core where the adhesive is not to be applied, using a suitable template.
   b. Use the adhesive specified on the drawing or an adhesive that has passed receiving inspection tests required by the applicable procurement specification. Mix per manufacturer's instructions.



[Photo courtesy of HTAC]

***FIGURE 5.2.1.3.1(a) Application of skin to template for core rigidizing.***

c. Apply the adhesive at a 20-30 degree angle to the core cell walls to promote coverage, and apply one coat to the core face that is not to be crushed.

d. Air dry for at least 30 minutes in a horizontal position with the coated core face down to allow excess adhesive to drain.

e. Cure per manufacturer's instructions, while supporting the core to minimize contact with the core face and the supporting rack.

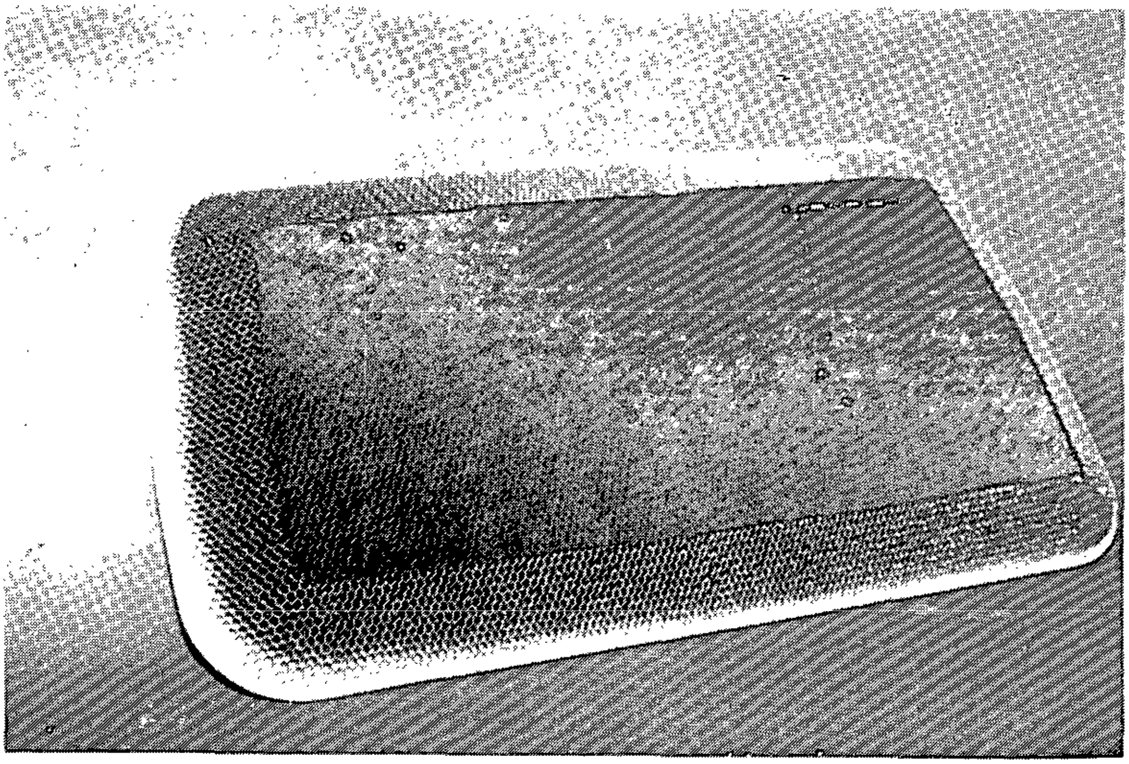
3. Pour coat the honeycomb core one section at a time, with the aid of pouring templates. **Do not** place one core section on top of another.

4. Coat the core in the area to be crushed making certain all cell walls are covered with adhesive. **Do not** coat the same area more than once.

5. Drain for 2-6 minutes with the cell walls in the vertical position.

6. Suspend the core on a rack with the cell walls oriented horizontally. Air dry for a minimum of 30 minutes followed by an oven dry per instructions in the part-specific material and process specification (do not cure).

7. Crush the areas specified on the drawing.



*[Photo Courtesy of HTAC]*

***FIGURE 5.2.1.3.1(b) Rigidized core ready for machining.***

**CAUTION**

Crushing of core can degrade its corrosion resistance by damaging the protective coating.

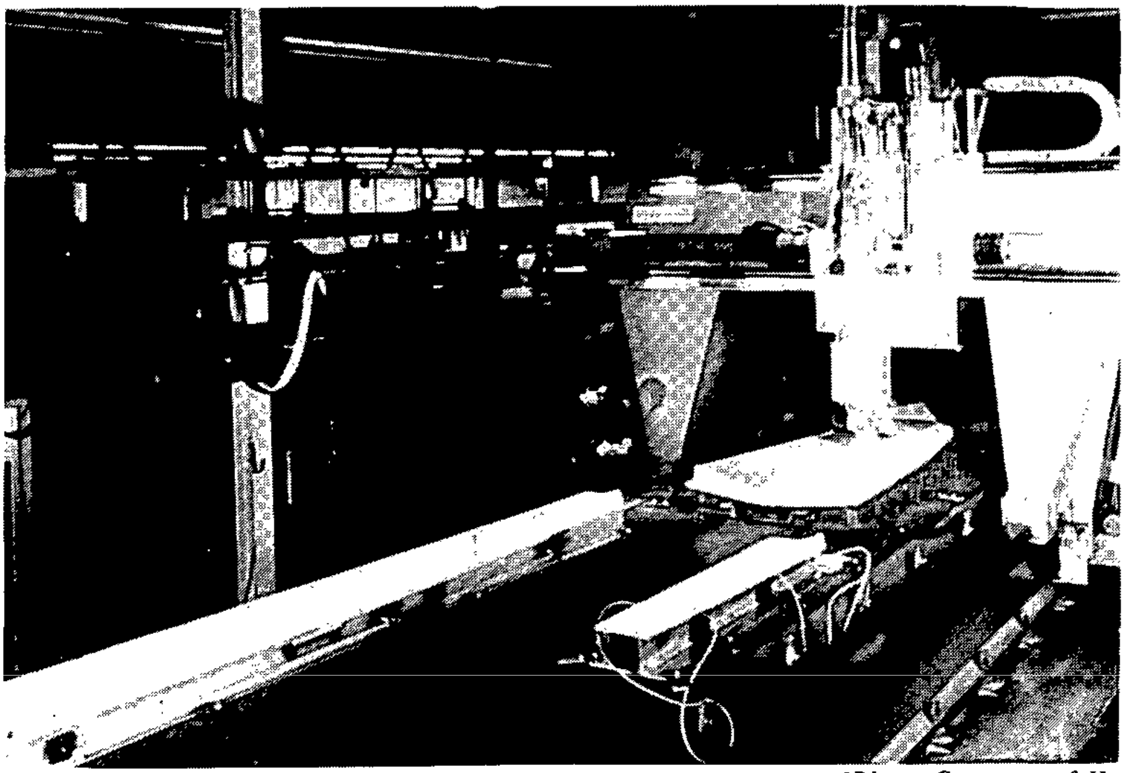
5.2.1.3.4 Stabilizing Crushed Core Areas. Stabilize core crush areas to prevent distortion after crush as follows:

1. Ensure that core is free of oily residue. Use a "black light" to inspect. If the core is determined to need cleaning, vapor degrease according to procedures given in Section 5.4.3.2.

2. Using the adhesive specified in Section 5.2.1.3.3 (Step 2b), pour coat the core in the areas to be crushed per the procedure outlined in Section 5.2.1.3.3 (Steps 3 through 7).

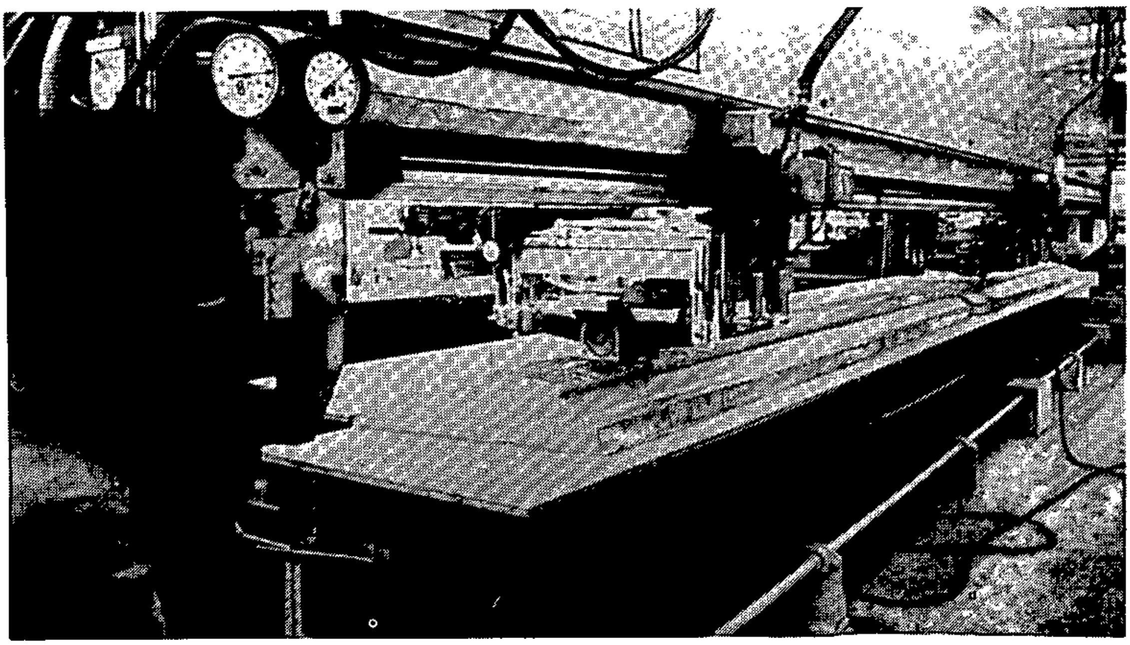
5.2.1.4 Milling. A milling operation is usually utilized to provide the core bonding surface with a finished contour. Horizontal milling, with various customized cutter sizes and shapes, is the milling mode most commonly employed. Various holding techniques are described in Section 5.2.1.3.1. Care should be taken to eliminate all contaminants from the core after machining. See Figures 5.2.1.4(a) and (b) for core milling with Numercially Controlled (NC) and beam milling machines.

Use forced, dry air to remove loose particles and dust. Use vapor degreasing procedures given in Section 5.4.3.2 to remove oily contaminants.



[Photo Courtesy of Hexcel]

**FIGURE 5.2.1.4(a) Core milling with NC milling machine.**



[Photo Courtesy of Hexcel]

**FIGURE 5.2.1.4(b) Core milling with beam milling machine.**

5.2.1.4.1 Unexpanded Core Block. The perimeter of an unexpanded core block is milled without using the stiffening procedure.

5.2.1.4.2 Expanded Core. The core perimeter and surface contour are milled with proper rigidizing methods cited in Section 5.2.1.3.

5.2.1.5 Cutting. Core details are "rough sized" by cutting off core segments using templates, hand knives, and motorized rotary cutters. Die cutting may also be used to cut the expanded core periphery to size. Figures 5.2.1.5(a) and (b) show acceptable and unacceptable burrs on core details after cutting.

5.2.1.6 Potting. Cores are potted with syntactic material to provide added reinforcement for subsequent installation of mechanical fasteners, such as bolts. The potting compound is prepared and applied as follows:

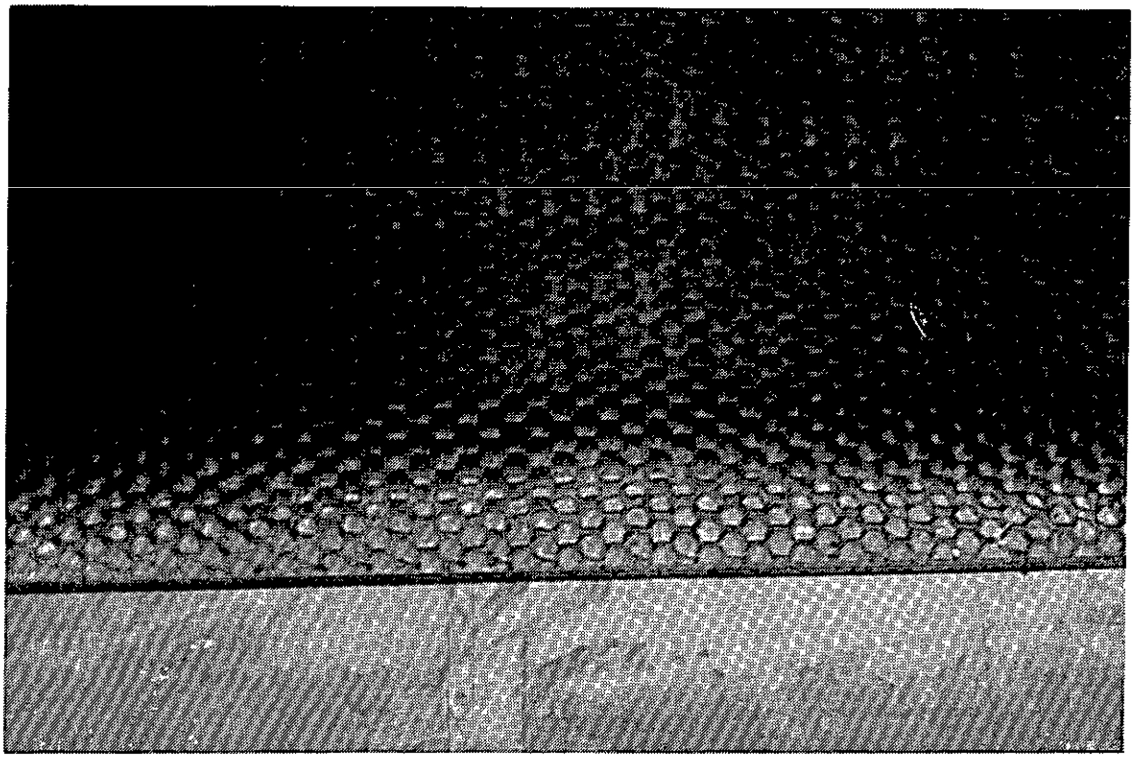
1. Clean the core before potting.
2. Allow the potting compound to reach room temperature prior to opening container(s).
3. Mix the potting compound, if applicable, in accordance with the manufacturer's instructions.
4. Apply the mixed compound using injection gun, trowel, or spatula, as applicable.
5. Cure potting material in accordance with the material supplier's instructions. Protect the core from contamination during the curing cycle using release material on both sides of the potted area and cover the core completely with nylon bagging film. Monitor the curing cycle with a thermocouple placed adjacent to the potted area.
6. Do not handle the potted part until it is cured.

See Figure 5.2.1.6 for an example of potting.

Typical potting steps are as follows:

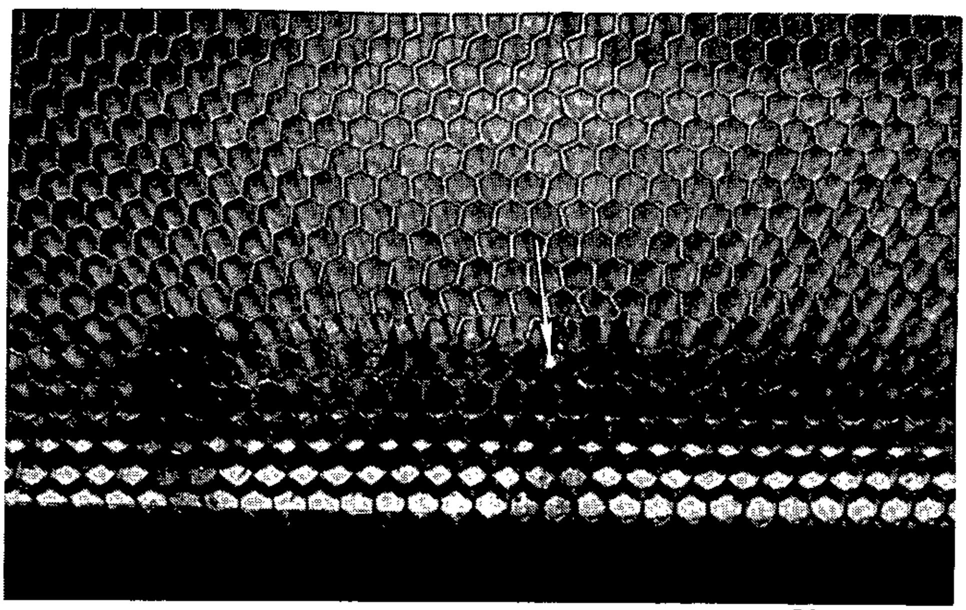
1. Remove the core area that is to be potted.
2. Clean the core before potting.
3. Use the potting compound specified in the applicable material and process specification for the part being fabricated. Allow the potting compound to warm to room temperature if refrigerated, prior to opening container(s). Mix the potting compound, if applicable, in accordance with the material supplier's instructions. Fill the core area to be potted with the compound using an injection gun or spatula, as applicable.
4. For parts requiring the curing of the potting compound prior to assembly operations, cure the compound in accordance with the material supplier's instructions. Protect the core from contamination during the curing cycle using release material on both sides of the potted area and cover the core completely with nylon bagging film. Monitor the curing cycle with a thermocouple placed adjacent to the potted area. Cure the potting compound in all other parts during the assembly cure operation.
5. The potted area is then ready for subsequent fastener installation, such as drilling.

For a structural configuration where the entrance to the potting region is smaller than the area to be potted, remove the core segment by inserting an L-shaped tool into the hole entrance. Enlarge the potting area by rotating the tool. Inject the potting material as in Step 3 above.



*[Photo courtesy of HTAC]*

**FIGURE 5.2.1.5(a) Acceptable burrs on core details after cutting.**



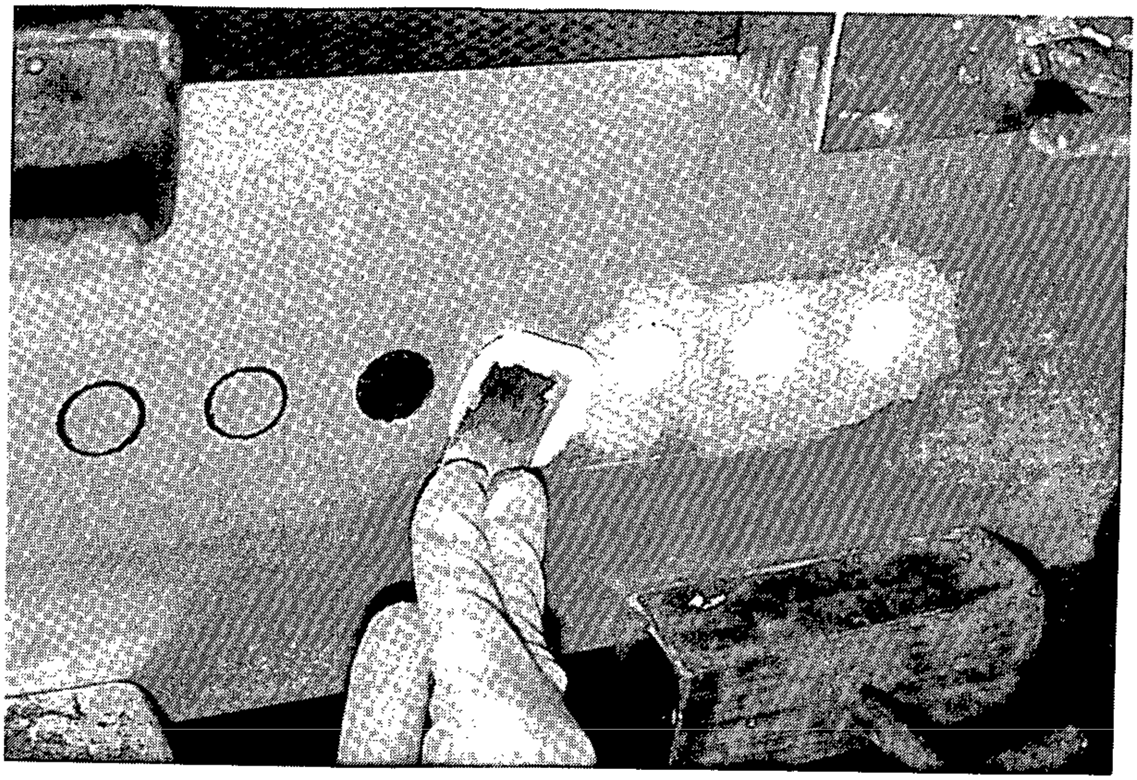
*[Photo courtesy of HTAC]*

**FIGURE 5.2.1.5(b) Unacceptable burrs on core details after cutting.**

Prefabricated potting inserts are also available for use for specific structural configurations. The general application procedure is to:

1. Place the insert into the prepared hole.
2. Inject the potting material into the fixed insert.
3. Cure in accordance with the material suppliers instructions.
4. Remove tab from the insert.

Although the core is often potted in the detail before it is bonded to the skins, Figure 5.2.1.6 shows potting of core bonded with skins.

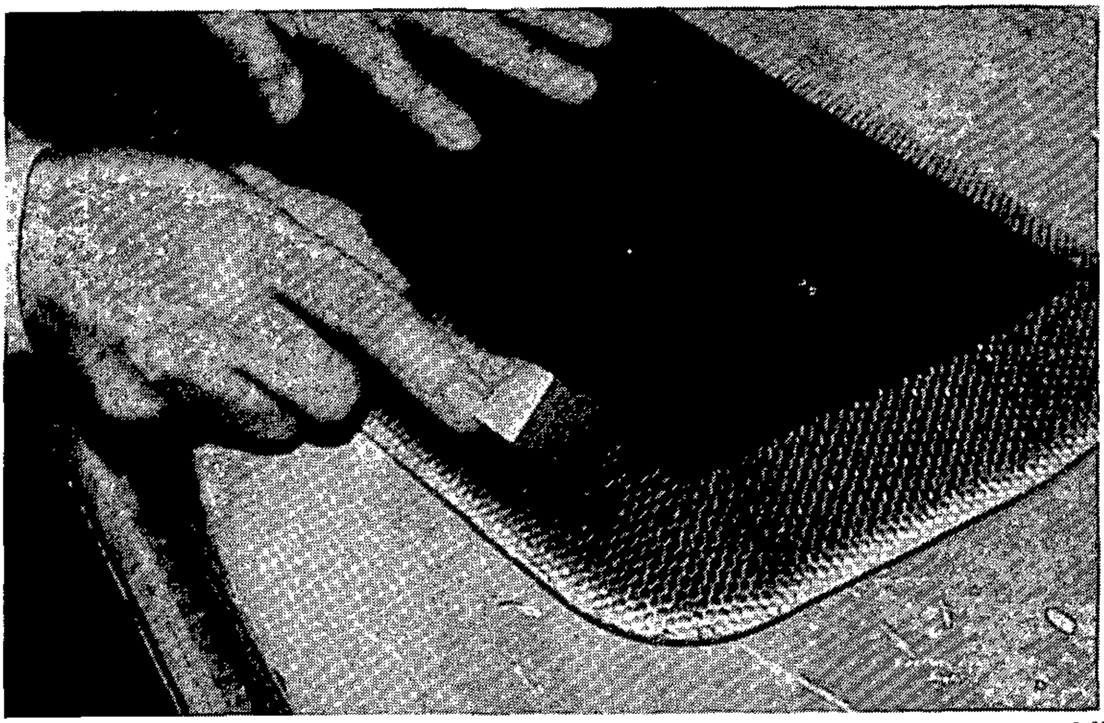


*[Photo courtesy of HTAC]*

***FIGURE 5.2.1.6 Potting.***

5.2.1.7 Sanding. Sanding is performed as the finishing operation to smooth the machined surfaces and remove burrs. Typically, it is achieved by hand sanding the part, which is firmly positioned on the work bench, with sandpaper of appropriate grit. Core sanding is shown in Figure 5.2.1.7(a). A typical sanding block is shown in Figure 5.2.1.7(b).

5.2.1.8 Splicing. Two or more pieces of core are joined together (spliced) with a foaming adhesive to allow shear loads to be transmitted from one piece of core to the other. Splicing provides a means to (1) change the load carrying capability of the core by varying its ribbon direction, (2) save weight, and (3) overcome core manufacturing size limitations. Splicing should only be performed when required or permitted by the applicable engineering drawing. Core may be spliced into a subassembly before or after machining, or during the final bonding operation.



*[Photo courtesy of HTAC]*

***FIGURE 5.2.1.7(a) Core sanding.***

The following procedure should be used to splice core into a subassembly.

1. Only splice core that has been cleaned in accordance with the procedures specified in this document. Vapor degrease aluminum honeycomb core per instructions in Section 5.4.3.2. In lieu of vapor degreasing, the following procedure may be used for handling aluminum honeycomb core prior to core splicing. This procedure is applicable only to honeycomb core manufacturers approved under MIL-C-7438. The core manufacturer must comply with the following instructions from the point of completion of fabrication of the core until the core has been packaged for shipment.

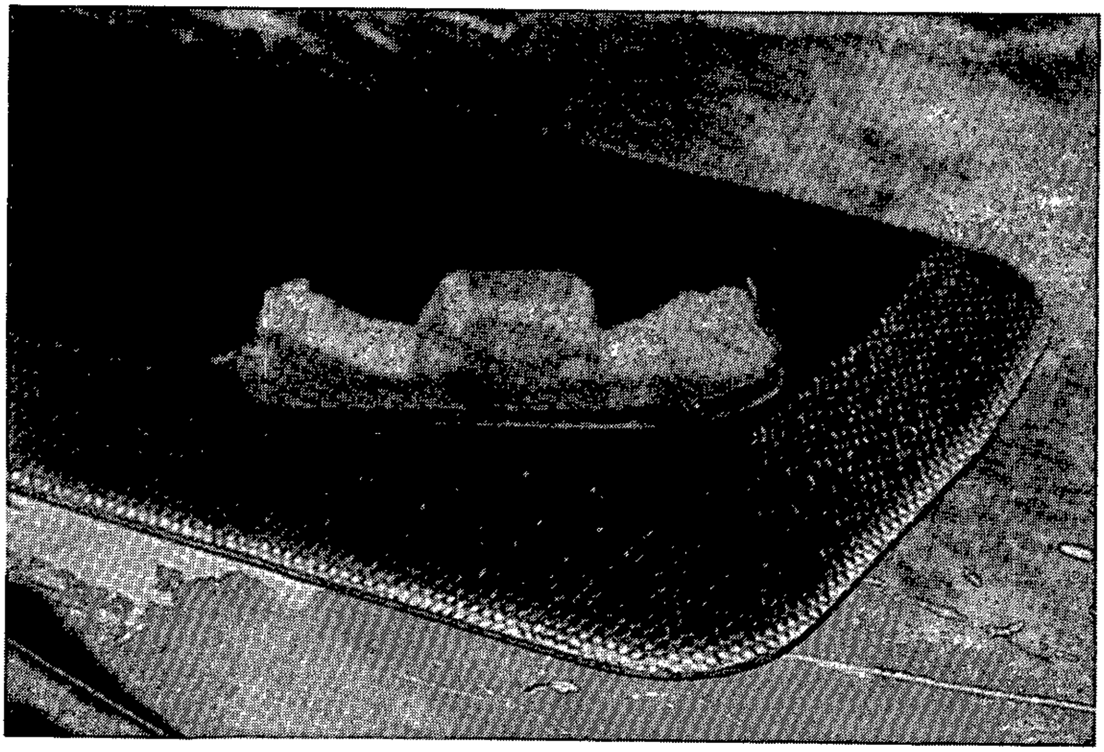
   a. Keep all working surfaces that come in contact with the core clean by either covering them with clean nonwaxed Kraft paper or wiping them with methyl ethyl ketone or isopropyl alcohol and clean cheesecloth (or an equivalent material).

   b. Wear clean, dry, white, lint-free gloves when handling core.

   c. Do not use compounds containing talc, greases, waxes, uncured silicones, or other materials detrimental to bonding in any areas where clean handling operations are in progress.

   d. Prohibit eating, drinking, and smoking in the areas where core splicing is performed.

   e. Equip air lines to machines and manufacturing areas with filters capable of removing oil, moisture, etc., from the air. Such filters should be drained and cleaned as necessary to prevent core contamination.



[Photo courtesy of HTAC]

***FIGURE 5.2.1.7(b) Typical sanding block.***

f. Use cutting tools (saw blades, milling cutters, bread knives, router blades, etc.) that are free of any contaminating substance. See MIL-C-7438 for further details.

g. Completely cover core when not working on it with either a clean, nonwaxed Kraft paper or a clean sheet of polyethylene.

2. Use only qualified splicing adhesives as required by the applicable version of the procurement specification.

3. Allow the adhesive to warm to room temperature before opening the package to prevent moisture condensation on the adhesive.

4. With a clean, sharp knife, cut the foaming splice adhesive into strips to fit the core surfaces to be spliced together. Butt joints in adhesive are permissible.

5. Remove the protective paper backing from one side of the adhesive and apply the adhesive to one of the core surfaces to be spliced together. Remove the remaining paper backing from the adhesive. Make certain the entire core surface to be spliced is covered with adhesive.

**CAUTION**

All protective paper backing must be removed because it is a foreign substance that will prevent surfaces from bonding effectively. Detection of such an unbonded area by nondestructive testing methods may be difficult.

6. Cover the cleaned, applicable core splicing fixture with a release material such as Teflon-coated glass fabric.

7. Carefully position the pieces of core into the splicing fixture. Cover the splice joint with a noncontaminating release material. Complete assembly of the splicing fixture, including tooling and weights, to hold the core pieces in proper alignment with each other.

8. Cover the core with bagging film to prevent contamination during the curing cycle. Attach thermocouples to monitor the cure.

9. Cure in accordance with the time and temperature required by the applicable procurement specification. Make certain the cure is initiated within the time allotted by the procurement specification.

10. Cool the core to 150$^{\circ}$F or lower. Disassemble and carefully remove the spliced core subassembly from the fixture to prevent damage.

11. Visually examine the spliced joint for voids and proper alignment of the various core pieces.

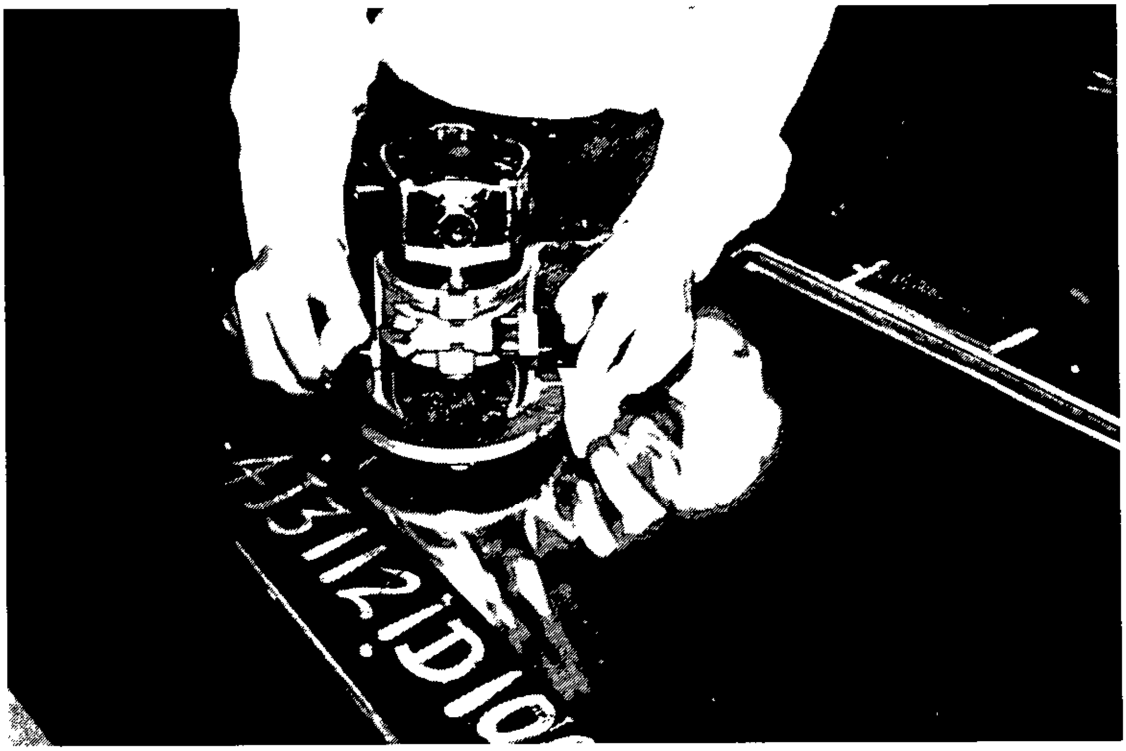
**5.2.2 Aluminum Alloy Skins and Detail Parts.** Aluminum alloy skins and detail parts are made from a wide variety of aluminum alloys including 7075-T6, 2024-T3 and 2014-T6.

Further discussion of skin materials is included in Section 4. There are many different manufacturing processes used to produce skins and detail parts for honeycomb assemblies. For the most part, these processes represent machining or forming processes. Machining operations include shearing, blanking/piercing, milling, routing (e.g., see Figure 5.2.2) drilling, grinding, deburring, sawing and cutting. The requirements for these operations are part-specific and the governing material and process specification or engineering drawing should be followed. These specifications and drawings should take into account the influence of special factors, such as:

- the sheet materials heat treated condition.
- its thickness, lamination.
- its specific application.
- the near net shape to be attained.

Unless otherwise specified in the material and process specification, parts may be formed from aluminum sheets or extrusions in the tempered condition at ambient temperature. Parts may be cooled for cold forming by chilling on dry ice or in a cold box to the temperature specified on the engineering drawing.

**5.3 Prefit.** The prefit operation is performed prior to cleaning, where all components (less adhesive) of a structural assembly are:




*[Photo Courtesy of HTAC]*

***FIGURE 5.2.2 (Hand) router cutting of skins using a template.***

- Inspected for faying surface imperfections, e.g., burrs, dents, etc.
- Assembled and checked for proper fit.

The components should be free from surface contamination that would interfere with the prefit. If necessary, preclean them by wiping with a cleaning agent (see 4.5.1) to remove surface contamination prior to prefit.

The components are mated with the adjoining surfaces using light finger pressure, approximately 1-2 pounds per square inch, and the faying surfaces are checked for mating tolerances and fit. Specific fit should meet the requirements stated in the applicable engineering drawings or specifications. Mismatches not meeting engineering drawing requirements should be reworked or refabricated per specification. Replace and prefit the components again to ensure proper fit with the rest of the assembly. Prefit inspection prior to bonding is shown in Figure 5.3.

**NOTE**

Crushing core to fit is not permitted because crushed core is not fatigue resistant in service unless properly stabilized with an adhesive primer.

**5.31 Mechanical.** The procedure for mechanical prefit is as follows:

1. Clean the surfaces of the prefit fixture by wiping with clean cloth dampened with MIL-C-87937, Type I or TT-I-735 Isopropyl alcohol.

*[Photo courtesy of HTAC]*

***FIGURE 5.3 Prefit inspection prior to bonding.***

2. Carefully assemble the components of the part into the prefit fixture.

**CAUTION**

Handle core and thin sheet metal details, such as skins, with extreme care as they are easily damaged.

3. Use calipers, feeler gauges, depth gauges, micrometers or equivalent tooling, and light hand pressure to determine the following for all bond lines. (Bond lines should consist of one layer of the film adhesive specified for the part in the applicable version of the procurement specification.)

   a. The distance between the faying surfaces in metal-to-metal joints.

   b. The distance between the core face and adjacent parts.

   c. Existence of interference fit of the core at all points of contact with internal and closure members.

4. Details should meet dimensional requirements of the applicable procurement specification. After prefit, carefully remove details from the fixture and assemble into a kit.

Part and Coupon Kitting. Test coupons (panels/specimens) as required by the applicable version of the procurement specification, including number of coupons and materials of construction, are used prefit parts of an assembly should be kitted and remain together as a unit throughout subsequent processing. Mark the parts and coupons with appropriate identification after they are prefit to assure proper fit during assembly. Cores are usually tagged with an identification plate while the edges or tabs of the skins and detail parts, including sheet metal portions of test coupons, are mechanically scribed with an identification notation.

**5.3.2 Impression (Overlay).** An imprint of the mating surfaces during a simulated bonding cycle is used to verify the acceptability of the fit of the assembly details. This imprint is also used to qualify or requalify production bonding fixtures. Verifilm interleaved between layers of Mylar (to prevent contamination of details) is placed in all joints to be subsequently bonded except the core to internal members and closure members. During the application of heat and pressure the Verifilm flows and sets. The Verifilm and Mylar films are then removed, measured, and visually examined to determine the fit of details.

Follow the procedures below to prepare an impression prefit. (See Reference 2 for further details.)

1. Assemble mechanically prefit details into the bond fixture with one layer of Verifilm, interleaved between 0.0015 inch thick Mylar in each joint to be subsequently bonded except the core to internal and closure members. Joints that are mechanically fastened prior to the actual bonding operation do not require a Verifilm check because pressure will be applied by the fastener(s), not the autoclave.

2. Complete the lay-up by placing release fabric, caul plates, if applicable, breather/bleeder materials, and thermocouples in the same amount and same location as that for an actual bonding operation.

3. Cure the assembly as indicated in the applicable version of the procurement specification. Be sure to select the type of Verifilm suitable for the intended curing temperature.

4. Carefully disassemble the details and remove the cured Verifilm and Mylar after cooling.

5. Interpret the Verifilm per instructions in the applicable procurement specification.

6. Keep the impression prefit details in a kit.

**CAUTION**

Handle core and thin details such as skins with extreme care as they are easily damaged.

**5.4 Surface Preparation.** Surface preparation procedures are performed on part components and tooling to remove contaminants and ensure proper surface treatment for reliable bonded assemblies.

**5.4.1 Bond Fixtures.** All fixtures and tooling used in the fabrication of bonded assemblies have to be kept clean to prevent contamination of part details. Adhesive squeeze-out has to be removed from bond fixtures to prevent improper fit of details during lay-up and surface damage to the completed part. All tooling surfaces that may come in contact with adhesive squeeze-out must be periodically coated with a suitable mold release to permit removal of the part and tooling details after completion of the bonding operation.

5.4.1.1 Application of Mold Release. Prior to the application of mold release, wipe all tooling surfaces with acetone. Use clean cloths to apply the solvent and to wipe the surfaces dry after cleaning.

**CAUTION**

Solvent cleaning operations must be performed in a well-ventilated area. Avoid skin contact with solvents. Acetone is a flammable solvent. Do not use near open flames, sparks or while smoking.

Select a mold release from the list of acceptable products contained in the applicable procurement specification. Apply mold release per manufacturer's instructions to all surfaces of the bond fixture that may come in contact with adhesive squeeze-out.

**CAUTION**

(1) Most mold releases are flammable. Take necessary precautions to avoid a fire such as no open flames, sparks, smoking. Apply in a well ventilated area. Avoid skin contact with mold release materials.
(2) Do not apply mold release materials of any kind (liquid, aerosol, wax, paste) in the controlled contamination areas, nor where the possibility exists of contamination of detail components of assemblies to be bonded.

Air dry, heat cure (or force dry), and buff in accordance with manufacturer's instructions.

5.4.1.2 Removal of Adhesive Flash. Prior to each use of a bond fixture, carefully remove adhesive squeeze-out to prevent improper fit and damage to details. The best method is to use mechanical means such as a sharp knife, razor blade, wire brush, etc. Take care to avoid damaging the surfaces of the bond fixture details during the operation. Then wipe all surfaces using methyl ethyl ketone and clean cloths to remove any dust, oil, grease, or chips of adhesive. Follow the caution statement given in Section 5.4.1.1.

**5.4.2 Single-/Multiple-Stage Bonding.** Surface preparation of details for adhesive bonding is one of the most critical operations in the fabrication of reliable and durable assemblies. Improperly prepared surfaces will result in unbonded areas and assemblies having poor environmental resistance. Extreme care and attention to surface preparation procedures is therefore of the utmost importance.

5.4.2.1 Single-Stage Bonding. Single stage bonding (bonding of all assembly components together simultaneously) is often the preferred method because it is the least expensive. However, it requires consistently good fitting details and proper bond fixture design to produce acceptable assemblies in this manner. Surfaces for single-stage bonding should be prepared as described in Sections 5.4.3 and 5.4.4.

5.4.2.2 Multiple-Stage Bonding. Multiple-stage bonding is used when dictated by the design of the assembly. This may be because there is no practical way to assemble and cure all details simultaneously, it may be to facilitate fabrication, or it may be done when an intermediate inspection of subassemblies is desirable prior to the final bonding process.

**5.4.3 Aluminum Honeycomb Core.** Aluminum core should be thoroughly cleaned prior to bonding. All rigidizing materials used for machining purposes must be completely removed prior to the final cleaning operation because they act as contaminants and prevent bonding. Exceptions to this are "fly-away" rigidizing systems approved on the engineering drawing.

5.4.3.1 Removal of Polyethylene Glycol Rigidizing Materials. Remove gross amounts of rigidizing material (e.g., polyethylene glycol), on a heat table or oven at approximately 200°F until major amounts are removed, immerse in hot water (170 ± 10°F) until honeycomb is free of rigidizing material. Flush core with clean water via spray or hose after removal from the immersion tank (Reference 2).

An alternate, acceptable method of removing rigidizing material from the core is to steam clean until the rigidizing material is removed. Use clean steam (water only) unless it is necessary to add an alkaline agent mixed with steam as a cleaning aid. If alkaline cleaner is added, steam clean the core for 5-10 minutes without the cleaning agent after the mixture of alkaline/clean steam was used. A maximum of 100 psi line pressure and a spreader type nozzle with a 1/8 by 3-inch slot held approximately 18 inches from the core surface should be used for steam cleaning. Inspect the core with "black light" while the core is still wet with water. The presence of glycol is indicated when a fluorescing area is detected. Repeat the cleaning operation and "black light" inspection until all traces of glycol have been removed.

**NOTE**

Do not misconstrue excess node bond adhesive as glycol because it will fluoresce under the "black light" also.

5.4.3.2 Vapor Degreasing (With perchloroethylene). The final cleaning operation prior to core splicing and bonding of spliced or unspliced core details into a subassembly or final assembly, consists of vapor degreasing. The procedures are as follows:

1. Rack unspliced core details, including core required for process control test panels, in a gridded basket in a flat position so that the condensed liquid can drain readily. Do not stack one piece of core on top of another to prevent damage and prevent contaminating one core with possible contaminants on another.

2. Assure that closed cells are facing down to prevent solvent entrapment in the core.

**CAUTION**

Handle core with extreme care since it is easily damaged.

3. Vapor degrease per instructions in Section 5.4.4.1. It is permissible to spray the core with clean condensate to remove stubborn contamination (per Section 5.4.4.1.1).

4. Force dry the core at 225-250°F for 60 minutes.

**NOTE**

Drying temperature up to 350°F and drying times up to 2 hours may be necessary to completely remove the vapor degreasing fluid from thick, spliced core with closed cells. Handle core with clean dry white gloves. Take care to avoid damaging the core.

5.4.3.3 Removal of Oil Contamination. Machining core in a bonded subassembly can result in oil contamination of the core from the machine. Presence of the oil can be detected with "black light" inspection. Remove oil before subsequent bonding operations take place in the following manner:

1. Position the contaminated core so that solvent sprayed into the core will drain out. This should be done in a spray booth because the solvent (hexane) is extremely flammable.

**CAUTION**

Store hexane in a container that has been thoroughly cleaned and determined to be free of oil contamination. Exercise extreme care when handling and using hexane since it is extremely flammable.

2. Pressurize the spray gun internally with dry oil-free nitrogen to 75 psig.
3. Spray the oil contaminated area with hexane, flushing the area and allowing it to drain completely. Repeat this operation two times.
4. Allow core to thoroughly dry (30 minutes).
5. Reinspect with "black light." Repeat hexane cleaning procedure and reinspect until no trace of oil contamination is detected.

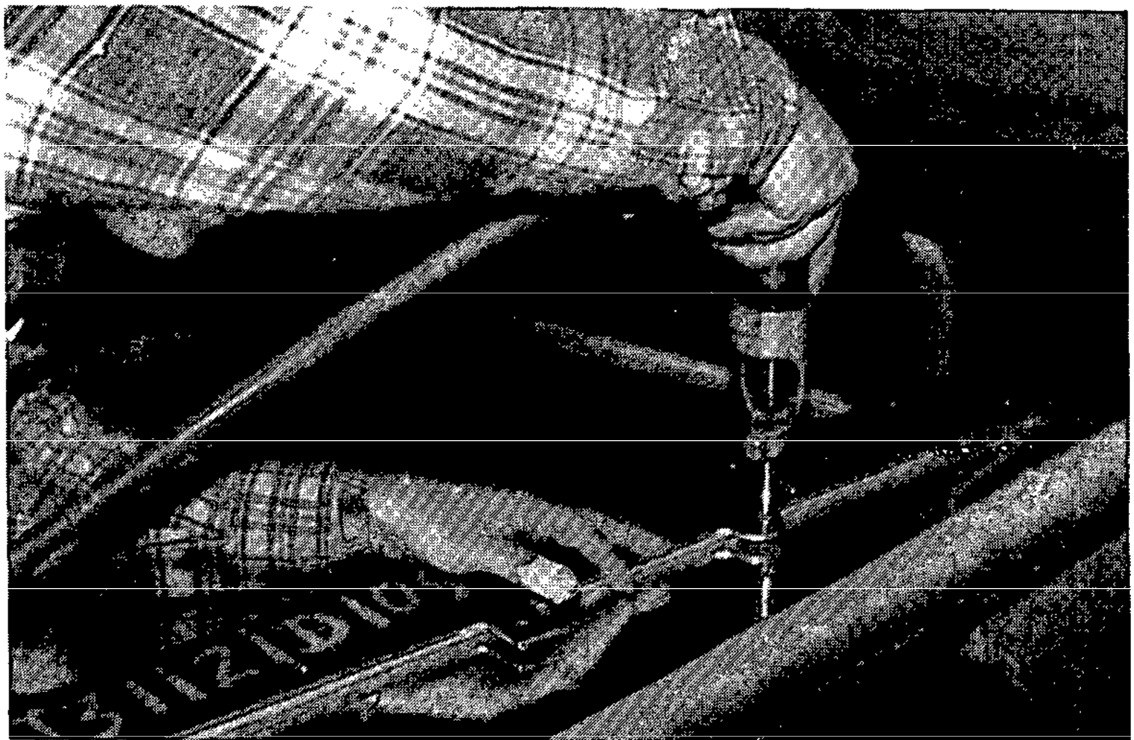
An alternate, acceptable material for removal of oil contamination without a fire hazard is aliphatic naptha, TT-N-95. This material may be sprayed from a standard spray gun, using dry, oil-free, filtered, compressed air (75-100 psig line pressure). Follow the same procedure as when using hexane, including conducting the spraying operation in a spray booth to remove the solvent vapors.

5.4.4 Aluminum Alloy Skins and Detail Parts and Precured Glass Reinforced Plastic Details. Aluminum bonding surfaces of skins, process control test panels, and detail parts, except cores, should be prepared with immersion tank cleaning with MIL-C-87937, Type I, aqueous cleaner. Parts can be racked and routed through the surface treatment tanks without delay or cross-tank contamination. Solutions that are allowed to dry on the part surface are extremely difficult to remove by rinsing. Contamination of a solution with drippings of another solution can significantly alter the solution's effectiveness in preparing surfaces for adhesive bonding. Clad and bare alloyed details can also be processed in the same manner unless otherwise designated in the procurement specification.

Handle cleaned parts with clean white gloves. Cleaned parts that are not used immediately should be protected with clean wax-free Kraft paper. Process prepared parts (e.g., priming or assembling) within the allotted time indicated in the procurement specification, or reclean them in accordance with the applicable procurement specification.

Skins and detail parts must be racked to ensure that (1) they are properly supported and protected from damage and (2) cleaning vapors, solutions, and rinse waters contact all surfaces and drain freely. One method for racking is to suspend the part at its tab with a spring clamp.

Figure 5.4.4(a) shows the process of locating and drilling holes on skin tabs to facilitate hanging on cleaning racks.



*[Photo courtesy of HTAC]*

***FIGURE 5.4.4(a) Locating and drilling holes on skin tabs to facilitate hanging on cleaning racks.***

5.4.4.1 Vapor Degreasing. Remove organic contaminants by vapor degreasing with perchloroethylene, O-T-236 solvent. Vapor degreasing cleans by removing solvent-soluble contaminants. The solvent should be heated to its boiling point, so that its vapors condense when they come in contact with the colder parts. In this manner the condensate loosens and removes soils such as grease and oils as it flows throughout the parts.

The recommended vapor cleaning procedure is as follows:

1. Use a rack to suspend parts.
2. Slowly, lower parts into the vapor zone (12 feet per minute maximum).
3. Keep parts in vapor until condensation stops. Tilt parts to remove trapped condensate.
4. Raise or withdraw parts.
5. Allow parts to cool and condensate to drain off the parts.
6. Inspect parts. Parts should be free from oils, grease, and other solvent soluble materials.

7. Repeat the cycle if necessary.

5.4.4.1.1 Spray Cleaning Procedure (same as steam). Solvent spraying should be used to augment the above vapor cycle when parts have soiled crevices or recesses that are difficult to access or remove by vapor. If necessary, individually spray the part surfaces that are difficult to access or heavily soiled, as described in Reference 4.

The cleaning cycle should comprise vapor, spray, and vapor cleaning. Spray before the parts become hot and condensation stops; spray nozzle should remain below the vapor phase.

The spraying procedure is as follows:

1. Use a rack to suspend parts.
2. Slowly, lower parts into the vapor zone (12 feet per minute maximum).
3. Spray solvent onto all surfaces of each part. Spraying pressure is normally 2-5 psi to minimize vapor loss, and 20 psi maximum. Individually flush all parts that will not drain in the racked position. Spray solvent must be from condensed vapors collected into a separate reservoir.
4. Keep parts in vapor until condensation stops. Tilt parts to remove trapped condensate.
5. Slowly withdraw the parts.
6. Allow parts to cool and allow condensed liquid to drain off the parts.
7. Inspect parts. Parts should be free from oils, grease, and other solvent soluble materials.
8. An acceptable alternative to solvent spraying is to use MIL-C-87937, Type I diluted 10 parts water to one part cleaner in a spray operation. Rinse thoroughly with clean water and inspect parts.

5.4.4.2 Anodizing. Anodizing converts the surface of the aluminum parts, extending a few thousandths of an inch into the metal, to corrosion resistant aluminum oxide. In anodizing, the part is the anode in an electrolytic circuit, and the metallic composition of the electrolytic container is the cathode.

Prior to anodizing, the surfaces of the parts must be thoroughly pre-cleaned to ensure the success of anodizing. Methods of applying anodic coatings includes batch, bulk, and the continuous strip process.

When the applicable engineering drawing requires exterior, nonbondable surfaces of bare aluminum detail to be sulfuric acid anodized (dichromate sealed) or chromic acid anodized (dichromate sealed) for corrosion protection, and the bondable, interior surfaces to be phosphoric acid anodized, use the following procedure:

1. Mask the surfaces to be bonded with a chemical milling maskant in accordance with the supplier's instructions.
2. Chromic acid anodize (dichromate seal) per MIL-A-8625, Type I, Class 1, or sulfuric acid anodize (dichromate seal). See MIL-A-8625, Type II, Class 1 for all nonbondable surfaces specified on the applicable engineering drawing.
3. Carefully remove the maskant from the bondable surfaces and apply maskant to the anodized, nonbondable surfaces.

4. Phosphoric acid anodize bondable surfaces per instructions in Section 5.4.4.2.1.

5. Carefully remove the maskant from nonbondable surfaces.

**CAUTION**

Handle with clean white gloves. Do not touch phosphoric acid anodized surfaces because they are easily contaminated and damaged.

5.4.4.2.1 Phosphoric Acid Anodizing. A common procedure for phosphoric acid anodizing (ARP 1524 and Reference 5) is:

1. Vapor degrease (see Section 5.4.4.1).

2. Alkaline clean.

3. Spray or immersion rinse in clean tap water (65-110$^{0}$F) for 2 minutes followed by a spray or immersion rinse in clean tap water (100-140$^{0}$F) for 5 minutes.

4. Deoxidize in sulfuric-dichromate solution per instructions in ARP 1524.

5. Spray or immersion rinse in 65-110$^{0}$F clean tap water for 2 minutes.

6. Spray rinse in ambient deionized water to remove tap water.

7. Inspect part surfaces for water breaks. Repeat the cycle at Step 2 if water break occurs, otherwise, proceed with Step 8.

8. Immerse parts in phosphoric acid solution maintained at 67-77$^{0}$F while executing the following:

   a. Apply DC voltage within 1 minute and raise voltage stepwise to 10 ± 1 volt in 2-5 minutes.

   b. Maintain this voltage for 20-25 minutes.

   c. Turn off current.

9. Immersion rinse parts with agitated and overflowing clean tap water for 10-15 minutes within 2 minutes of turning the current off. The postanodizing rinse water should not exceed 5000 ppm total dissolved solids after first 30 seconds of rinsing. Immediately rinse parts within 2 minutes of removing from anodizing bath.

10. Spray rinse parts with deionized water for 2 minutes.

11. Inspect part for water breaks and coverage of anodic treatment.

12. Oven dry thoroughly using 175$^{0}$F maximum clean dry air for 30 minutes.

13. Cool parts in ambient clean air for 120 minutes maximum.

    Refer to Aerospace Recommended Practice 1524 (Society of Automotive Engineers) for specific procedures for developing and maintaining a phosphoric acid anodizing solution.

14. Examine parts for the presence of anodic coating as detailed in Section 5.8.4.3.1.

**CAUTION**

Phosphoric acid anodized coating is readily damaged and soiled. Do not touch phosphoric acid anodized bond surfaces. Only edge contact with clean white gloves is allowed.

**5.4.4.3 Precured Glass-Reinforced Plastic Details.** Precured glass-reinforced plastic details need to have the surface gloss removed in order to obtain a bondable surface. Solvent wipe the bondable surfaces with a clean cheesecloth soaked in MEK (ASTM D 740) or isopropyl alcohol (TT-I-735) and immediately wipe with dry and clean cheesecloth before the solvent evaporates. The MEK should not be allowed to "drench" on FRP, as it can harm the resin system.

**CAUTION**

Use any solvent in a well ventilated area. Avoid skin contact. MEK is extremely flammable and requires the use of fire hazard handling procedures.

If the solvent is allowed to dry on the surface it must be recleaned to avoid contamination. Use one of the following procedures for final surface preparation:

1. Sand the bonding surfaces using 180 grit or finer paper to remove the surface gloss (glaze). Remove sanding residue with clean cheesecloth moistened with MEK or isopropyl alcohol. Vapor degrease parts (see Section 5.4.4.1). Dry for 30 minutes minimum at room temperature before applying adhesive. Handle with clean dry gloves.

2. Lightly vapor hone the surfaces to be bonded to remove the surface gloss (glaze). Use oil-free 120 mesh grit of aluminum oxide. If the grit is suspended in water use clean demineralized water. Dry parts thoroughly (30 minutes at 125-150$^{o}$F). If the grit is suspended in air (dry blasting) remove grit residue by vacuuming or wiping with clean cheesecloth. Handle with clean dry gloves.

**NOTE**

Compressed air used for grit blasting or air drying must be dry and oil-free.

3. Lightly sand the bonding surfaces to remove the gloss (glaze), using 180 grit or finer paper. Remove sanding residue with clean cheesecloth moistened with MEK. Repeat sanding operation. Remove sanding residue by wiping with clean cheesecloth or by vacuuming. Handle with clean dry gloves.

**CAUTION**

Sanding should only remove the gloss (glaze) and not expose fibers.

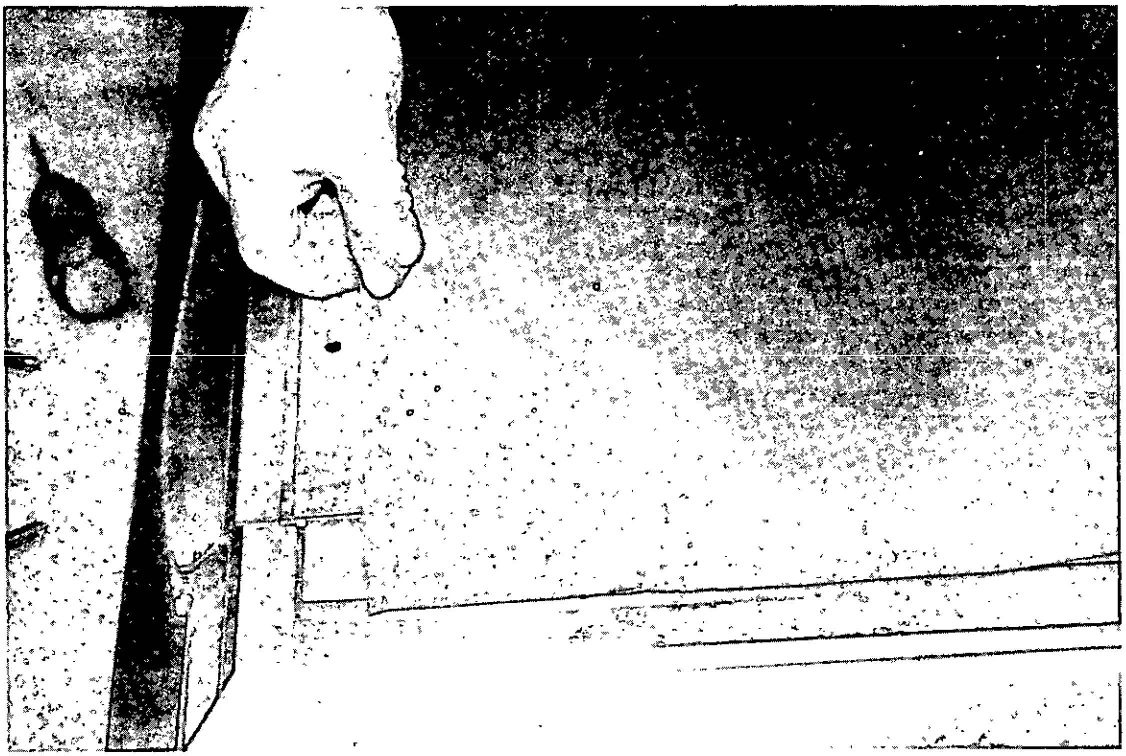
**5.4.5 Process Control Coupons (Panels/Specimens).** Process control coupons are necessary to provide assurance that the various steps in the process have been accomplished satisfactorily. Refer to the applicable, part-specific material and process specification for the type and number of process control panels/coupons required. These coupons should accompany the part they represent through all processing steps from cleaning through final bonding. The coupons should be on the BAJ where possible. The extent of further use of process control coupons should be as established by quality assurance personnel based on first article and periodic teardowns.

**5.5 Priming and Adhesive Application.** Adhesive primers are applied to cleaned part surfaces to improve bond durability and prevent contamination during handling and assembly. Both Corrosion-Inhibiting Adhesive Primers (CIAP) and non-CIAP are used for priming. CIAP are preferred over non-CIAP primers because they:

1. Yield better bond durability than standard non-CIAP primers.
2. Are more compatible with a wider variety of adhesive systems.
3. Provide longer shelf life to parts.

Refer to the applicable, part-specific material and process specification for the specific primer required for the assembly being fabricated.

Adhesives of various forms are applied to the faying surfaces of the parts with the aid of a bonding tool to form assemblies. Forms of adhesives include pastes, films, and foams. Consult the applicable version of the procurement specification for the specific adhesive required for the assembly being fabricated.



*[Photo courtesy of HTAC]*

***FIGURE 5.5 Adhesive and prepreg application setup.***

Adhesives should be applied in a controlled contamination area and cured within the specified time limit for the particular adhesive type after removal from refrigerated storage.

An adhesive and prepreg application setup is shown in Figure 5.5.

**5.5.1 Application of Primer.** Primers should be applied within the allotted time after cleaning. The time limit varies depending upon the type of surface preparation applied. Cleaned surfaces tend to oxidize, get contaminated, and absorb moisture from the air if they are exposed too long. Unprimed parts that have been contaminated or have exceeded the allotted time should be recleaned. Refer to the applicable procurement specification for specific time allotments.

Primers are toxic and flammable; they should be applied using proper protective equipment in well ventilated areas designated for primer application only. Prior to application, condition the primer as follows:

1. Bring the primer to room temperature before unsealing to avoid condensation.
2. Prepare, combine, or mix the primer components to form primer solution per manufacturer's instructions.
3. Agitate primer by mechanically shaking (e.g., using paint vibrator) or stirring to assure uniform distribution of solids.
4. Transfer the prepared primer to a coater reservoir.
5. After primer application, store and retain unused primer according to the applicable specification.

Unless otherwise specified, primers can be applied by brush, spray, or roller. The general procedure for applying a primer, regardless of the application method, is given below.

1. Support the part, e.g., using hangers and racks, such that the part surface to be primed is exposed for priming (spraying, brushing, etc.) application.
2. Apply primer to the cleaned part surface in a smooth uniform coating until the specified thickness is reached. If the primer is applied in too thin a layer, the surface will not be adequately protected from moisture penetration and corrosion. Primer applied in too thick a layer can result in weak bonds.
3. Air dry until it is tack-free.
4. Cure dry in an oven as defined in the applicable specification.
5. Check primer thickness with an Isometer or Permascope, or equal.
6. Use comparator panels to determine acceptability of the color, shine and overall appearance of the primed surfaces of the components.
7. If parts are not processed immediately, protect the primed surfaces by storing the parts in a controlled area, or wrapping or covering them with a protective covering as defined in the applicable procurement specification.
8. When both surfaces of the part are to be primed, coat and dry the first side before applying primer to the second side. Do not oven cure before coating the second side.

Spray equipment should provide continuous agitation in the container and recirculation in the hose during use. This will prevent settling of solids such as corrosion inhibitors and curing agents. MIL-HDBK-337 recommends the following equipment and conditions for the spray method:

| | |
|---|---|
| Spray gun | DeVilbiss MBC, or equivalent |
| Air cap | No. 78 |
| Needle-nozzle | AV-15-FX |
| Line pressure | 30-80 pound |
| Fluid flow | Approx. 5 fluid ounces/minute |
| Pot pressure | 1-2 psi if applicable |
| Distance from pane | 19-14 inches |
| Primer thickness | 0.0001-0.001 inch (depending on primer type) |

The roller coating equipment should also provide continuous agitation of the primer reservoir and continuous feed of uniformly viscous primer to the rollers. The conditions and procedures for primer application vary depending on primer type. Follow the manufacturer's recommendations for the applicable condition and procedure for each primer.

A primed part that is contaminated, damaged, or has exceeded the allotted storage limit should have its primer stripped and reprimed, or be recleaned and reprimed in accordance with the applicable procurement specification. The specific remedial action is dependent on:

1. The type of defect.

2. Whether the defect is incurred before or after primer cure.

3. The severity of the defect.

**5.5.2 Application of Film Adhesives.** Use the film adhesive required by the applicable version of the procurement specification. Allow adhesive to warm to room temperature before opening the sealed package to prevent condensation of water on the adhesive.

Roll out the adhesive, pull off one backing, lay detail on the adhesive and cut around the detail using scissors, X-ACTO knife or razor blade. Handle adhesive with clean white gloves. Proceed with the application as follows (Reference 6):

1. Remove the separator from one side only to permit handling and apply one layer of film adhesive, unless otherwise specified on the applicable engineering drawing, to one of the faying surfaces of all joints to be bonded with the particular film adhesive, except as noted below. Apply in a continuous sheet if possible. If splices are required, overlap 1/16 to 1/8 inch as shown in Figure 5.5.2(b). Overlapping is necessary because the adhesive may shrink during curing and leave a void if a butt joint is used. Trim flush with the detail edge as shown in Figure 5.5.2.(a). Do not scratch surfaces of details. Avoid air entrapment as much as possible. Puncture entrapped air bubbles and force out the air.

   Specific considerations for alloying film adhesives include:

   a. On wrap-around skins, apply the film adhesive to the core rather than the inner surface of the skin because it is extremely difficult to position the film adhesive properly on the skin.

   b. Film adhesive is not required on the inner surface of the spar, on edge member flanges that mate over core undercut faces, or on metal or plastic laminate surfaces that mate against the core edges because foam adhesive is required on these surfaces.

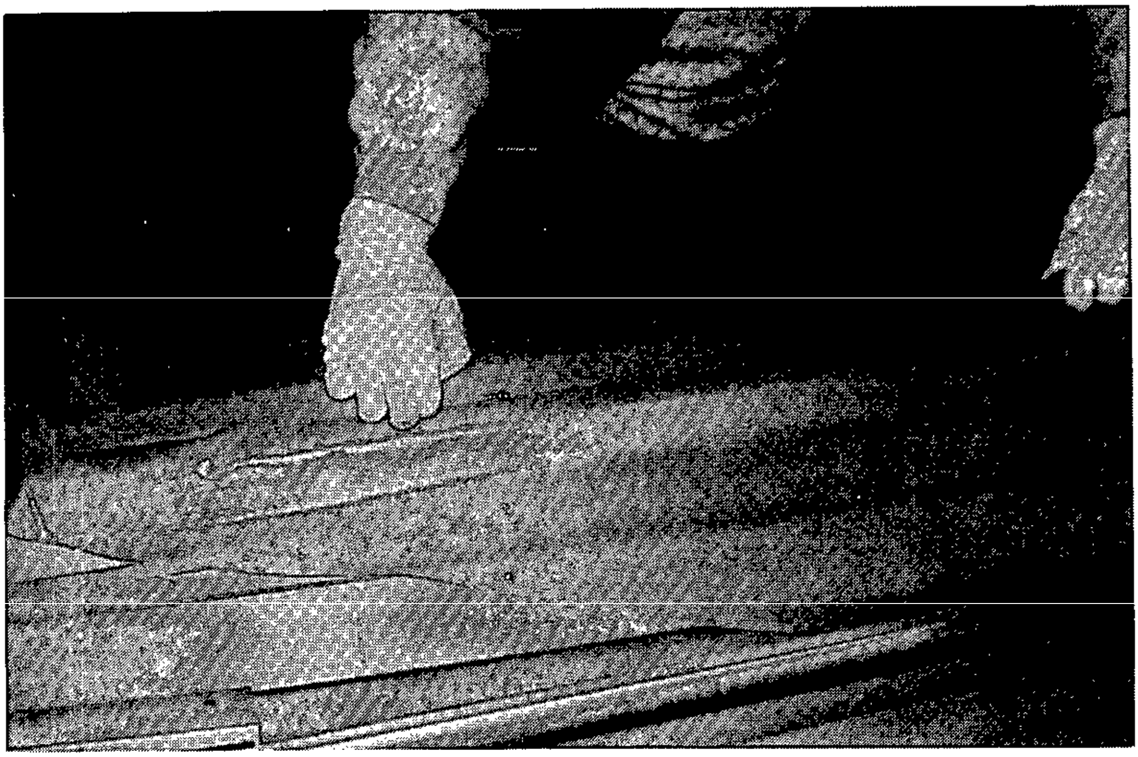
   c. A second layer of film adhesive may be applied on all crushed core areas to provide adequate bonding.

d. One or more layers of film adhesive 0.25 inch wide with the separator removed from both sides should be placed at the recessed edges of the undercut skins (chemical milling radii) or on the core to fill the gap between the doubler and the recess in the core to accept the doubler. This is required to prevent a water entry path and voids. Do not use roll of adhesive because this technique may result in air entrapment.

5.5.3 Application of Foam Adhesives. Foam adhesives are used when relatively large gaps (0.05-0.125 inch) have to be bridged to bond two surfaces together. The adhesive expands during curing to several times its original thickness. Expansion is caused by the release of a gas such as nitrogen during the curing cycle. Foam adhesives are primarily used to make core-to-core and core-to-edge member or insert bonds (Reference 7).

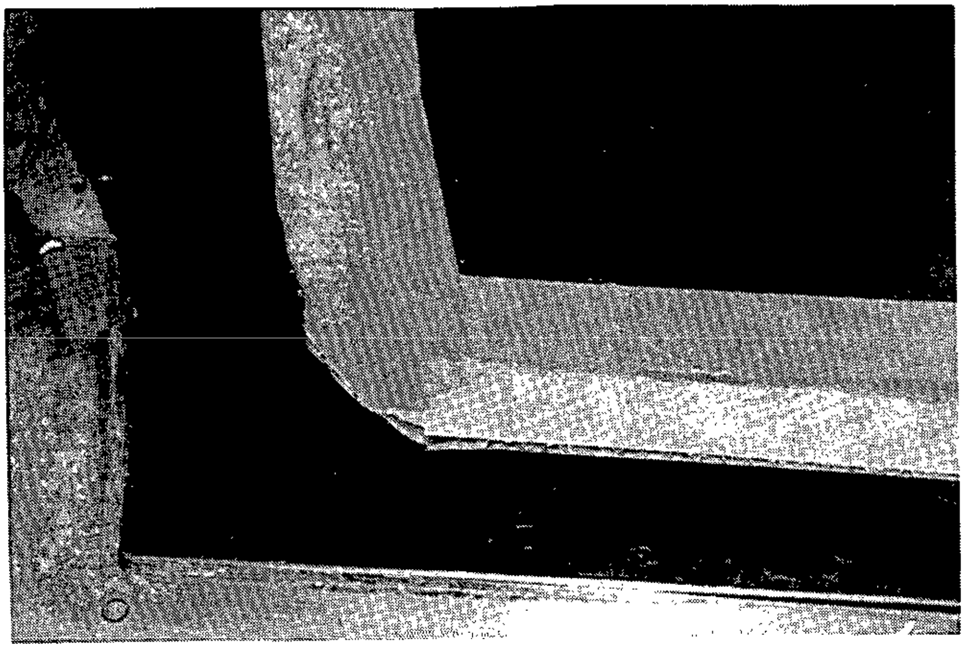
The procedure for foam adhesive application is as follows:

1. Use the foam adhesive required by the applicable version of the procurement specification.
2. Handle and cut the foam adhesive as specified in Section 5.2.1.8, Steps (3) and (4).
3. Apply one layer (or more if permitted by the applicable engineering drawing) to one of the mating surfaces of all core-to-core, core-to-edge member, or insert joints. When bonding core inside a rib cavity, apply one layer of foam on the faces of the core and force flush with the core surface. Use additional layers if permitted by the applicable engineering drawing or procurement specification.



*[Photo courtesy of HTAC]*

***FIGURE 5.5.2(a) Hand trimming (knife) of excessive adhesive and prepreg.***



*[Photo courtesy of HTAC]*

***FIGURE 5.5.2(b) Overlapping of adhesive.***

**CAUTION**

Keep foam adhesive off of metal-to-metal or plastic laminate faying surfaces because, when cured, the foam adhesive will produce a porous bond line that is significantly weaker than a nonporous bond line.

4. If permitted by the applicable engineering drawing, apply an 0.1 inch wide strip of foam at the recessed edge of undercut skins (machined or chemically milled) where the undercut is greater than 0.25 inch.

5. Leave paper separator on exposed surface of foam adhesive to simplify handling.

**5.6 Assembly and Curing.** Cleaned and prepared components are assembled using adhesives, fixtures, and support tooling. The assembly is then subjected to pressure and heat to activate the adhesives in the bond lines forming a bonded assembly.

**5.6.1 Lay-Up.** During lay-up, adhesives and bonding and support tools are used to properly align and assemble the components into an assembly for curing. This operation is to be performed with gloved hands in a controlled contamination area.

Expendable materials used to assemble the components include:

- Adhesives.
- Tacking tapes.
- Release films (fabrics).

- Breather and bleeder materials.

The nonexpendable equipment or tooling includes:

- Bonding fixtures.
- Vacuum probes.
- Thermocouples.
- Pressure support tools (e.g., caulplates, fairings, shims, etc.).
- Hand tools for cutting and trimming (e.g., knives, razor blades).
- Adhesive applicators.

The general procedure for assembly lay-up is:

1. Use adhesives and potting compound (if applicable). Let the adhesives and potting compound warm to room temperature before opening the sealed package or container to prevent moisture condensation.
2. Make certain the bond fixture has been prepared and cleaned per procedures in Section 5.4.1.
3. Lay up the assembly components into the bond fixture. Apply the adhesives required by the applicable engineering drawing to all surfaces requiring adhesive, but not previously covered in Section 5.5.2. Handle adhesives per instructions in Section 5.5.2. Straighten core cell walls with clean ice pick or tweezers (see Figure 5.6.1).

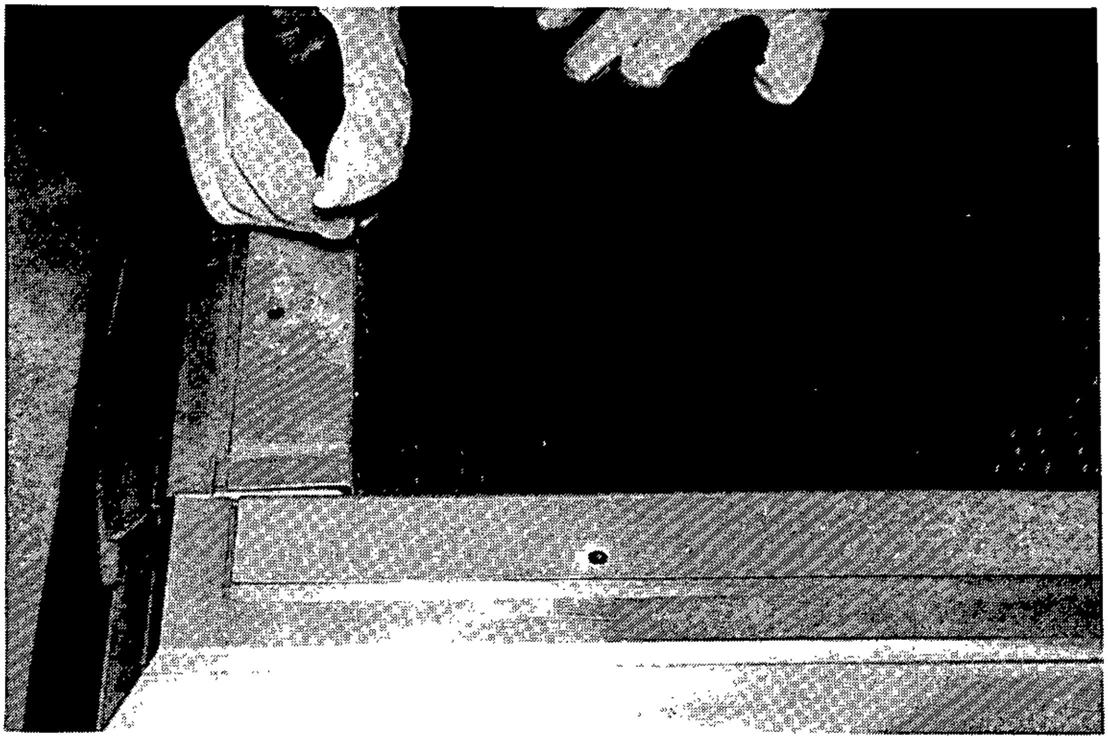
**CAUTION**

Remove all adhesive separator materials during this lay-up operation. Such materials are foreign objects that will produce unbonds, requiring repairs or scrappage of an expensive assembly.

Install potting compound if required by the drawing if not previously installed as per instructions in Section 5.2.1.6. Handle potting compound as described in Section 5.2.1.6. Lay-up glass reinforced plastic laminate components required by the applicable engineering drawing. Use the material required in the drawing, as applicable.

Use adequate tooling support to maintain the configuration and ensure that the assemblies (especially those that are wedge shaped) do not collapse under the curing pressure. Install caulplates, if applicable. Make sure surfaces of skins and caulplates are clean since small particles will cause a mark-off. Complete the bond fixture assembly.

Lay up the process control specimens in separate fixtures, if applicable, using adhesives specified in the process specification. Place the process control specimens in the location provided by the bond fixture design.



*[Photo courtesy of HTAC]*

***FIGURE 5.6.1 Core cell straightening with ice pick during lay-up.***

**NOTE**

It is preferable to lay up and cure the process control specimens on the part bond fixture. If space has not been provided, it is acceptable to lay up and cure process control specimens on a separate fixture or plate, provided its vacuum line is connected in series with the part it represents. In other words, its vacuum source should be the same.

4. If the bond fixture does not have permanently installed thermocouples, embed thermocouples in the bond line or on the fixture surface in locations previously determined by the bond fixture heat survey.

**CAUTION**

Do not allow thermocouple wires to lay on the surface of the part since this will result in a mark-off.

5. If the assembly is to be subsequently cured in an autoclave and the bond fixture is not equipped with permanently installed vacuum and static pressure ports, mount and secure the vacuum tooling onto the fixture, if applicable.

6. Cover the assembly with permeable release fabric. Place a blanket of bleeder material, on top of the release fabric to absorb adhesive squeeze-out (flash) and bleed out adhesive volatiles.

7. Cover the entire assembly with breather material. Pay particular attention to the perimeter of the assembly to provide an air path to the vacuum ports.

**NOTE**

Use sufficient breather/bleeder materials to minimize temperature differential between the top and bottom of the assembly and between thick and thin parts of the assembly.

8. Make sure all gaps and crevices are covered with bleeder/breather material (and metal strips, if necessary) to prevent the vacuum bag from being forced into these areas, which may result in bag failure during the curing cycle.

**CAUTION**

Lay-up operations must be completed with sufficient time remaining to bag and initiate cure of the assembly before the outtime for the adhesive(s) has been exceeded. Room temperature exposure of adhesives causes them to advance chemically (cure), which can lead to inadequate flow during the curing operation and weak bonds.

**5.6.2 Vacuum Bagging (When Curing in an Autoclave).** Vacuum bagging follows the lay-up operation and is performed under the same operating conditions. It consists of:

1. Sealing or bagging the assembly in a flexible, heat resistant plastic film or rubber blanket or plastic bag.

2. Drawing a vacuum on the encapsulated assembly. The vacuum bag holds the details in the proper location and permits the subsequent application of pressure via an autoclave.

Expendable materials used for bagging include (1) plastic bagging film, (2) sealing compound (vacuum bag sealing tape), (3) plastic film tape, and (4) breather material.

**NOTE**

Use only materials approved in the applicable process specification.

Nonexpendable equipment includes:

- Source of vacuum (vacuum pump).
- Sieve tubes.
- Hand-installed vacuum ports.
- Manometer.
- Vacuum gauge.
- Roller.

The vacuum bagging procedure is as follows:

1. Use vacuum bag sealing tape to form a barrier around the perimeter of the fixture base. Do not remove the protective paper from the tape until you are ready to install the vacuum bag film to permit maneuvering of the vacuum bag.

2. If not permanently installed in the bond fixture, position and secure thermocouple wires to the fixture by embedding the wires between the barrier and a strip of the vacuum bag sealing tape (remove paper separators in these areas).

**CAUTION**

Carefully remove the insulating braiding from the thermocouple wire where the wire comes in contact with the bag sealing tape. This is necessary to prevent a leak of autoclave pressure into the vacuum bag. Exercise care in stripping the braiding to avoid exposing the metal wire. If this is done, an electrical short may occur and a false or no temperature reading will be obtained. Be sure that thermocouples are not placed over the vacuum bag.

3. Position and secure vacuum tooling. Wrap and secure breather material over sharp edges and corners of the assembly and tooling (e.g., built-in vacuum ports) to prevent puncturing the bagging film.

4. Acquire and cut a piece of plastic bagging film large enough to generously cover, or completely bag the assembly, as applicable.

**CAUTION**

Handle vacuum bagging film with care to prevent puncturing.

5. Position the film over the assembly.

6. Working from the mid-section of the assembly toward both ends, remove the protective paper from the sealing tape and securely seal the film around the perimeter of the fixture base. If the part is to be enclosed in a bag, make sure the bottom of the fixture is insulated from the bagging film.

**CAUTION**

Do not allow any portion of the bagging film to cover bare metal tooling surfaces because it can cause a local hot spot and burn the bag. Insulate with breather material.

7. Pleat (install "dog-ears") and seal the excess portion of the film to prevent bridging. Bridging will result in no pressure application and possible rupture of the bag.

8. Trim off the perimeter of the bag with scissors to avoid excess bagging material hanging from the sealed edges. This will prevent the formation of "mini-tornados," (air currents that can tear open the seal and unwrap the bag during the cure).

9. If there are no permanent vacuum ports on the bond fixture, install a sufficient number of vacuum ports through the vacuum bag so that the entire assembly will be under pressure. Cut a hole in the bag, taking care not to damage the surrounding area. Assemble the vacuum port and seal its periphery completely.

**CAUTION**

Do not install vacuum ports so that they rest on the part as this will result in a mark-off on the surface of the part.

a. Install and seal vacuum caps to permit a leak check of the vacuum bag.

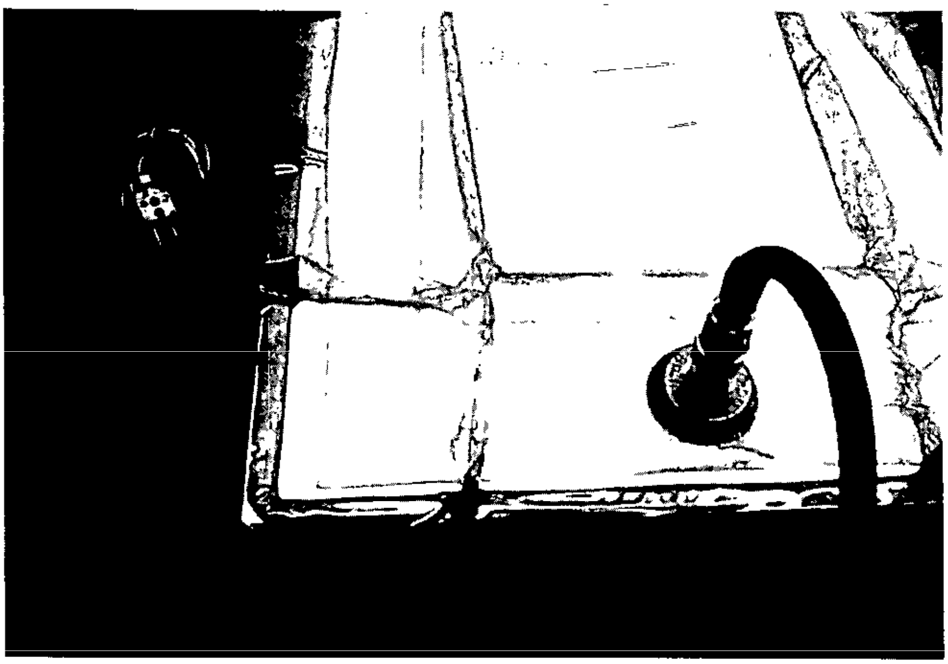
b. Attach vacuum lines and connect a manometer or vacuum gauge to the vacuum port farthest from the port through which the vacuum will be drawn.

c. Pull a vacuum on the assembly to check the bag for leaks. If the part contains core, pull 8-10 inches of mercury vacuum. This vacuum restriction is necessary to prevent collapse of the core during the leak check. Apply the vacuum slowly. As the air is evacuated, make the bag conform to the shape of the assembly and the bond fixture. Make certain the bag does not bridge any areas.

d. Isolate the part from the vacuum source. Maximum permissible leakage is one inch of mercury in a 2-minute period. If the leakage exceeds that permitted, locate and fix the leak source. Repeat the leak test and sealing operations until the bag and tool pass the leakage requirement. Detecting and fixing bag leaks before placing the tool in the autoclave can prevent costly shut-down and repair operations, and may prevent loss of the part due to blowing of the vacuum bag.

Keep bagged assemblies under 0.5-10 inches of mercury vacuum until insertion into the autoclave to prevent movement of details under the bag. Figure 5.6.2 shows a vacuum bagged part.

5.6.2.1 Bagging with a Rubber Blanket. When a rubber blanket is used in lieu of a plastic bag, check for leakage through the blanket before installation to prevent subsequent shutdown of the autoclave and repairing of the rubber blanket. Install the rubber blanket over the part, making certain no areas are bridged. Seal the bag to the tool surfaces by means of a clamping bar and clamps or a suitable system of weights. This type of pressure diaphragm may be reused.



*[Photo courtesy of HTAC]*

***FIGURE 5.6.2 Vacuum bagged part (nylon and rubber).***

5.6.2.2 Bagging Multiple Fixtures. It is permissible to place multiple bond fixtures on a large plate and cover them with a single vacuum bag, provided the tools are identical, or similar in size and shape. Bagging procedures are the same as those detailed in Section 5.6.2.

**CAUTION**

There is a risk involved with this procedure because a malfunction of the curing cycle or a leaky vacuum bag will result in rejection of every part under the bag.

**5.6.3 Curing.** Curing, through the application of heat and pressure, is the process by which the flexible, soft adhesive materials are converted to hard materials and components are bonded together.

The equipment used for this process is (1) curing devices such as autoclaves, platen presses, and cavity presses, (2) temperature and pressure controlling, and recording devices, and (3) racks for holding parts during curing in an autoclave.

5.6.3.1 Curing in an Autoclave.

The procedure for autoclave curing is as follows:

1. Curing must be initiated (application of pressure and heat) before the outtime for the adhesives, as specified in the applicable material and process specification, has been exceeded to prevent chemical advancement of the adhesive that may result in inadequate

flow of the adhesive and weak bonds. Place the assembly in the autoclave. Connect the vacuum and static port lines and thermocouples. Close the autoclave door. Pull a vacuum of 8-10 inches of mercury on the bag. Vacuum exceeding 10 inches of mercury may cause the core to collapse.

2. Cure the assembly as required by the procurement specification. The use of an inert atmosphere to pressurize the autoclave is preferred to prevent fire in the autoclave, which can result in loss of expensive tooling and parts. When the autoclave pressure reaches 5 psig, vent the vacuum bag to the atmosphere to prevent frothing of the adhesive under vacuum. Monitor the temperature, autoclave pressure, and pressure build-up inside the vacuum bag at least once every 15 minutes. Curing cycles may be run manually, by cam, or computer.

3. It may be necessary to abort (stop) the curing cycle in the case of pressure build-up in the bag greater than 5 psig (10 inches of mercury), blown bag, or loss of thermocouple readings. The adhesive system being cured influences when a curing cycle may be aborted without damage to the part.

   a. For adhesive systems curing at 225-250°F, the maximum part temperature at which the autoclave can be shut down and the load resealed for pressure leaks is 150°F.

   b. For adhesive systems curing at 340-375°F, the maximum part temperature at which the autoclave can be shut down and the load resealed is 275°F.

4. At the completion of the curing cycle, turn off the heat and cool the assemblies under at least 10 psig by letting the autoclave pressure degrade naturally to at least 200°F (hottest thermocouple reading) for 340-375°F curing adhesives and at least 150°F (hottest thermocouple reading) for 225-250°F curing adhesives. Cooling water may be used to expedite the cool down process.

5. After the parts have cooled down adequately, vent the autoclave to atmosphere, open the autoclave door, disconnect the thermocouples, vacuum and static gauge lines, and remove the bond fixtures from the autoclave.

**CAUTION**

Tools are still hot (150-200°F) so handle everything inside the autoclave with insulated gloves.

6. Remove bag, pressure diaphragm, breather, bleeder, and release materials carefully. Remove caul plates, if applicable, and disassemble the bond fixture with care to prevent damage to the part.

7. Carefully remove the part from the bond fixture, taking extreme care not to delaminate any bonds or damage any part surfaces.

5.6.3.2 Curing in a Platen Press. If the assembly is flat and all surfaces to be bonded may have pressure applied by a flat platen, a platen press may be used to cure parts. However, it is generally only used for flat, metal-to-metal bonding. The procedure for curing in a platen press is as follows:

1. Place the laid-up part on the clean press bed, cooled to at least 100°F.

2. Attach thermocouples to a recording device.

3. Apply heat and pressure as required by the procurement specification.

4. Cool parts cured at 225-250$^{o}$F to at least 150$^{o}$F under pressure; cool parts cured at 340-375$^{o}$F to at least 200$^{o}$F under pressure.

5. Separate press platens and carefully remove the bond fixture from the press.

6. Remove the part from the tooling carefully to avoid bond line damage.

5.6.3.3 Curing in a Cavity Press. A cavity press may be used to cure relatively simple assemblies by means of pressure applied through a rubber diaphragm without the need for a vacuum bag. Heat is applied through the bottom of the press. The procedure for curing in a cavity press is as follows:

1. Install the bond fixture with the laid-up part into the press cavity. Attach thermocouples.

2. Close the press and apply heat and pressure as required per the procurement specification.

3. Cool under pressure to at least 150$^{o}$F for adhesives that cure at 225-250$^{o}$F and to at least 200$^{o}$F for adhesives that cure at 340-375$^{o}$F.

4. Open the press and carefully remove the bond fixture from the cavity. Handle with care, because it will be hot.

5. Carefully disassemble the bond fixture and remove the assembly, taking care not to delaminate any bonds or damage the surface of the part.

5.6.4 Secondary Bonding. When required by the applicable engineering drawing, details such as rub strips have to be bonded to the previously cured assembly using room temperature curing epoxy adhesives.

Expendable materials include:

- Cleaning solvents (Isopropyl alcohol (TT-I-735).
- Cheesecloth.
- Adhesive mixing containers.
- Sandpapers (various grit sizes).
- Adhesives, as specified in the applicable procurement specification.
- Surface treatment materials–such as those required for manual method of phosphoric acid anodizing of aluminum in MIL-HDBK-337.
- Deionized water.
- 0.01 inch diameter nylon line.

Equipment and tools required include the cleaning tanks and solutions required for surface treatment of details to be bonded as specified in Section 5.4.4. Spatulas, C-clamps, and heat lamps are also required.

The procedure for secondary bonding is as follows:

1. Prepare the assembly surfaces to be bonded as in MIL-HDBK-337.

2. Prepare details for bonding per Section 5.4.4.

3. Allow adhesives to warm to room temperature before opening the containers to prevent moisture condensation.

4. Mix the adhesive in accordance with the manufacturer's instructions.

5. Apply a thin layer (approximately 0.01 inch) of mixed adhesive to both surfaces to be bonded, using a spatula or other suitable device. Place 0.005-0.010 inch diameter monofilament nylon line in the bond line to control the bond line thickness.

**NOTE**

A loosely woven nylon mesh material may also be used.

6. Assemble details to the part. Apply C-clamps or other device to hold details in position while the adhesive cures.

7. Cure per the manufacturer's instructions.

8. Remove clamps or other hold device. Clean off excess adhesive squeeze-out mechanically, taking care not to delaminate the bond.

**CAUTION**

Avoid skin contact with solvents, surface treatment solutions, or adhesives. Perform the above operations in a well-ventilated area. Employ fire hazard protective measures. Handle the assembly with care to avoid surface damage or bond line delamination.

**5.6.5 Post Bond Cleaning.** It is necessary to remove adhesive squeeze-out (flash) from cured assemblies when it interferes with handling, fit, or performance. Remove the residues by carefully filing or scraping with sharp tools. Use wood or plastic when practical.

**CAUTION**

Metal-to-metal bonds can be delaminated easily. Do not apply any peeling action to the bond lines when removing the squeeze-out. Handle the assemblies with care to avoid surface damage.

**5.6.6 Visual and Dimensional Inspection.** Each assembly should be visually and dimensionally inspected as required by the applicable procurement specification and in accordance with the procedures set forth in Sections 5.8.1 through 5.8.4.6.3.

**5.6.7 Rework.** A limited number of rework procedures may be performed on a bonded assembly prior to submittal for inspection. These are allowed to bring previously performed work up to quality and in conformance with the applicable engineering drawing and specifications. They include part trim, replacement of discrepant fasteners and filling-in missing sealants.

**NOTE**

Honeycomb structure can be extremely fragile. Special care may be required to prevent damage to the surrounding structure during the repair operation. Protective coverings should be placed around the reworked area where applicable.

This information does not supercede the specification design limitations for rework and repair. These limitations have been established based on the criticality of the specific part, in addition to its aerodynamic smoothness requirements and weight and balance requirements. Violation of the limits set by the governing specification may cause operational difficulties with control surface dynamics, structural deficiencies on deflection-critical parts, or structural failure. Only the responsible engineering authority may define and authorize deviations from specification-imposed limitations.

The weight of a repair becomes a major concern when it changes the mass balance of components sensitive to dynamic response, such as movable control surfaces, rotor blades, and rotating shafts. It may be necessary to rebalance the part after the rework is completed. Aerodynamic smoothness is addressed in Sections 5.7.1 and 5.8.2.4.2.1, Item (3).

Expendable materials include (1) fasteners as required by the drawing, (2) sealants (see Section 5.7.1), and (3) other expendable materials specified in Section 5.7.1.

5.6.7.1 Part Trimming. The procedure for trimming an assembly is as follows:

1. Carefully install the assembly in the appropriate trim fixture, taking care not to damage the assembly.
2. Route the part to remove excess material. Support the bonded joint on both sides to prevent delamination of metal-to-metal joints.
3. Carefully remove the part from the trim fixture.

5.6.7.2 Replacement of Fasteners and Missing Sealant. The procedure for replacing discrepant fasteners is as follows:

1. Remove the discrepant fastener with a suitable device, taking extreme care to avoid delamination of a bonded joint.
2. Install the fastener per manufacturer's instructions, applying uncured sealant as used to seal the assembly to the fastener head prior to installation.
3. Wipe off sealant squeeze-out with dry cheesecloth.

After completion of procedures 5.6.7.1 and 5.6.7.2, the quality of the rework should be evaluated and approved or rejected by responsible Quality Assurance personnel.

**5.7 Final Processing.**

**5.7.1 Sealant/Aerodynamic Smoother Application.** Sealing bonded assemblies to prevent the entrance of liquids, primarily water, is one of the most important operations in the fabrication process. Damage caused by water entry is one of the biggest problems with maintenance of bonded assemblies in service. Moisture may enter through a porous bond line. Commonly, water will enter the part after the surface has been punctured or gouged, or the edge seal has been broken by an impact. The presence of moisture may be suspected where delamination has occurred near a panel edge. The condition of the edge seals should be examined. Also, moisture entry at loose fasteners is common.

Moisture results in weight and high temperature problems, and may destroy the honeycomb part interior. The core foil is very thin and light corrosion may significantly reduce its strength. Moisture may also destroy the bond between the core and the honeycomb face sheets.

The general procedure is:

1. Whenever possible, complete all the assembly operations, such as filing, drilling, deburring, countersinking, and dimpling, before cleaning the part and applying the sealant/smoother.

2. Select the sealant required by the procurement specification. Allow the sealant to warm to room temperature before opening containers, if stored under refrigeration to prevent moisture condensation.

3. Clean the surfaces to which the sealant will be applied by wiping with cheesecloth dampened with isopropyl alcohol (TT-I-735). Take care to prevent solvent entry into any opening in the assembly. Wipe the surface dry with clean cheesecloth before the solvent evaporates. Refer to the applicable engineering drawing for areas to be sealed. This includes all openings, fastener heads into the core area, the junction of two or more details, the periphery of mechanically attached clips, and bond lines if required by the engineering drawing.

4. Mix sealant per manufacturer's instructions. Minimize air entrapment because it results in a porous sealant that is weak and may provide a leak path into the assembly.

5. Mask skin surfaces if sealant is to be applied over butt joints.

**NOTE**

DO NOT seal on top of bond lines until after the leak test has shown that the bond lines are air tight.

6. Apply sealant uniformly with sealant gun to all areas and openings to be sealed. A brush or spatula may be used if necessary. Use sealant within material's pot life as specified by the manufacturer. Follow instructions in 5.7.1.1 for each type of application.

7. Cure the sealant at room temperature until a firm rubber material is produced. Refer to manufacturer's curing recommendations. Some sealants are affected by the amount of humidity in the air, and all are affected by the temperature of the air. If heat (up to 130$^{o}$F) is needed to expedite the cure, cure at room temperature until set to prevent air pressure within the heated assembly from blowing the sealant out of the joint being sealed. Low temperatures (60$^{o}$F) slow the cure significantly.

**NOTE**

Remove maskant tape after the sealant has partially set-up so that it may flow and form a smooth edge.

5.7.1.1 Application Procedures for Specific Types of Sealing or Smoothing.

5.7.1.1.1 Faying Surface Sealing. Apply the sealant to one of the mating surfaces with a pneumatic sealing gun equipped with a fay sealing nozzle. A sufficient quantity of sealant should be applied to fill the sealant application. Install a sufficient number of clamps to pull the faying surfaces into contact and squeeze out excess sealant before installing permanent fasteners. Apply a small bead or layer of wet sealant around each fastener prior to inserting the fastener into the hole. Using a cheesecloth dampened with MEK, remove sealant that extrudes out around the fastener installation.

5.7.1.1.2 Butt Joint Sealing. Inject the butt joint with the sealant using a pneumatic sealing gun and a small orifice nozzle. Place the nozzle in or over the butt joint, and inject sealant with the gun approximately perpendicular to the surface and the line of travel. Regulate the extrusion rate so that sealant will be forced into the joint and a small bead will be left on the joint surface. After injecting the sealant, allow it to cure to a tack-free condition. Use a plexiglass scraper to trim the sealant flush with the skin surface. Fair the uncured sealant to the mold line using the spatula held at approximately 45 degrees to the line of travel. Remove the excess after it is cured with nylon abrasive pads and MEK.

5.7.1.1.3 Fillet Sealing. Apply fillet sealants with a pneumatic sealing gun by extruding a continuous bead of material along the edge of the joint. When applying the fillet, point the gun nozzle into the joint and maintain the gun nearly perpendicular to the direction of travel. Regulate the sealant extrusion rate so that a bead of sealant precedes the tip of the nozzle. Press a filleting tool against the fillet. Work out any visible air bubbles during the application life of the sealant.

5.7.1.1.4 Aerodynamic Smoother Application. The repair area should be thoroughly cleaned and dry at the time of aerodynamic smoother application. Metal parts should be cleaned with an appropriate surface preparation and dried with a clean, dry cheesecloth. Aerodynamic smoother compounds may be applied with a squeegee or putty knife. Care should be taken to force the compound down to completely fill the void and to avoid trapping air bubbles. Apply as many coatings as required to build up the depression to the skin line. Break surface air bubbles. Smooth out the entire area and eliminate local waviness. Dry the compound until it is completely hardened throughout, and then wet sand it with a fine grit sandpaper until it is completely smooth and flush with the adjacent areas. Observed irregularities in the surface should be filled by repeating the application procedure. Thoroughly clean the surface using a clean cheesecloth dampened with MEK.

5.7.2 Leak Testing. In order to determine that the assemblies have been properly sealed to prevent entry of liquids, honeycomb parts must be leak tested by immersion in hot water per Mil-A-83377. The hot water causes the air within the part to expand. If there is a leak path in the part, the expanding air will find it and emerge as a bubble. The procedure for leak testing is contained in Section 5.8.4.3.6.

The honeycomb assembly must successfully pass the leak test with no leaks before it is acceptable for production.

**5.7.3 Nondestructive Testing.** The presence of defects such as voids, unbonds, blown core, and many others in a bonded assembly can lead to failure of the part in service. Examples of these defects are shown in Chapter 3.

Nondestructive testing consists of a variety of tests that cause no harm to the bonded assembly. Tests methods such as radiography, ultrasonics, sonics and other methods are designed to detect the presence of small to large defects within bond lines and components of a bonded assembly. Trained operators are required to conduct the tests and correctly interpret the findings.

The test selection, equipment and procedures for conducting these tests, and the defect limits are specified in Sections 5.8.1 through 5.8.4.6.3.

**5.7.4 Corrosion Protection.** When required by the applicable engineering drawing or the procurement specification, adhesive bonded assemblies should be protected from adverse environments such as precipitation, fuels, oils, cleaning fluids, long term storage, and foot traffic by the application of organic coatings (paint).

Expendable materials are those required for surface preparation prior to painting, i.e., cleaning solvents, chemical treatments such as conversion coatings, cheesecloth, paints, masking tape, and gloves. Equipment and tools required are a spray booth, spray guns, mixing pots, source of oil and water-free compressed air, and solvent safety containers.

The procedure for corrosion protection of bonded assemblies is as follows:

1. Complete sealing of assembly per the manufacturer's drawing and Section 5.7.1.
2. Pretreat the surfaces to be painted as required by the applicable material and process specification.
3. Mix and apply the required organic coatings in accordance with the manufacturer's instructions and the applicable engineering drawing.

Handle assemblies with care since they are easily damaged. Avoid skin contact with cleaning solvents, surface preparation treatment materials, paints. Solvents and paints are fire hazards and should be handled accordingly. Apply solvents and paints in a well ventilated area.

**5.7.5 Identification.** Every assembly should be identified per the applicable engineering drawing, including the serial number. If required by the drawing, prepare the name plate with the appropriate information. Whenever possible, attach the name plate, in the location specified by the drawing, using mechanical fasteners or adhesive bonding, and locate the plate out of the air stream path. Cleaning solvents used on aircraft exteriors and air stream forces can cause ID plates to fall or peel off.

Rubber stamping the required information in the area specified by the drawing is another acceptable method of identification if the drawing does not specifically require a name plate.

**5.7.6 Packaging.** Package and ship the finished assemblies in containers that will preserve their physical characteristics and properties. Exercise extreme care in handling and packaging to prevent damage to the assemblies. Avoid any possible peeling action on metal-to-metal bonded joints.

**NOTE**

Packaging in compliance with contractual requirements is mandatory. Packages should be marked in accordance with contractual requirements.

**5.7.7 Disposition of Defective and/or Damaged Parts.** Parts which are damaged beyond rework shall be clearly marked "SCRAP" and disposed of at the earliest practical time. If the defect is not readily visible to the naked eye, the part should be further marked to note the type of defect.

Parts which are reworked and fail to pass inspection the second time should be considered as beyond repair, marked "SCRAP," and disposed of at the earliest practical time.

Again, if the defect is not readily visible to the naked eye, the part should be further marked to note the type of defect.

5.8 Quality Assurance.

5.8.1 Introduction. Ensuring the reliability of highly loaded aircraft structures is crucial. Today's manufacturing processes, however advanced, produce a significant number of flaws. In-process monitoring and control have become necessary using such techniques as laser-based ultrasonics.

Nondestructive evaluation is no longer limited to post-process inspection. NDE now begins with pre-process inspection of raw materials and continues through in-process monitoring and inspection after processing, in the course of service, and following repairs (Reference 8).

5.8.2 Quality Assurance Plan and Administration.

5.8.2.1 Quality Assurance. The function of nondestructive evaluation or testing is to control and maintain a desired quality level. The quality level is decided upon by management. Perfection in production is unrealistic and costly. Seeking quality assurance, management sets up a mechanism for obtaining it the quality control department. The quality control department (administration) should seek an optimum quality level, i.e., the quality level most worthwhile, all things considered. Once management has established the level of quality, production and NDE attempt to maintain this level, not departing from it excessively in either direction. NDE in and of itself cannot make a reliable, high quality product.

An effective quality assurance program should be conducted concurrent with the manufacturing and rework procedures to assure satisfactory end-item strength and durability. Materials handling should meet requirements in the applicable specifications including proper storage and adherence to shelf life stipulations. Processing steps should be carefully followed with emphasis on those items concerned with maintenance of a properly prepared bonding surface and good prefit of part details. Processing procedures should be checked at critical steps to assure specification conformance.

5.8.2.2 Administration. To achieve the maximum value from the NDE operation, it is essential that management set up proper policies for using NDE. These policies should include:

1. Statements of the aims of management for the operation of the NDE group.
2. An organization chart of the entire quality control department.
3. A description of the interrelation between the quality control department and other departments of the company (production, for one).
4. Job descriptions of each job in the quality control department.

A very clear statement should be made to all levels of supervision indicating the wishes of management concerning quality control. The details concerning the proper organization of a quality control department are beyond the scope of this document. However, achieving the quality required by the applicable procurement specification is the ultimate responsibility of management, not the quality control department or the NDE group within that department. Experience has shown, however, that production and quality control should report to management through separate channels, while at the same time establishing channels of communication directly between production and control.

5.8.2.3 Receiving Inspection and Acceptance. The receiving inspection should be part of the quality assurance department. Traditionally, receiving inspection is responsible for the inspection of raw materials such as bar stock, sheet and plate, forging, fasteners, and other detail parts. The objective of receiving inspection is to increase quality and save money by:

1. Testing incoming material to ensure that defective material on which labor would be wasted does not go to production.

2. Keeping quality and performance records for each vendor.

3. Providing the quality manager with the information necessary for the development of a well-defined and realistic quality specification.

The quality assurance department is responsible for providing the required acceptance specifications in accordance with the end use process specification and the applicable procurement specification.

Adhesives to be used in production bonding of parts are of particular concern. They must be sampled and tested in accordance with the applicable process specification for the adhesives. The faying surfaces of the test specimens should be treated by the same method and materials that are used on production parts. All bonding materials in cold storage should be allowed to warm to a temperature precluding moisture condensation before they are unwrapped. Adhesives should not be released for production unless:

1. Receiving inspection and control tests have been conducted and the adhesives found to be acceptable in accordance with the applicable process specification.

2. The adhesive has been in proper storage since receiving inspection or quality control testing.

To assure that material released to production will satisfy all process requirements, the quality control authority should perform all applicable receiving inspection tests. A summary of the types of defects that are typically encountered during Quality Assurance inspections is given in Table 5.8.4.1.1.

After receipt, storage, and testing, the quality control authority should maintain revalidation records for control of adhesives released to production. A time-out/time-in log should be maintained when adhesives are removed from refrigeration. Adhesives exposed to room temperature beyond those times noted elsewhere in this handbook should not be used.

5.8.2.4 Defect and Damage Assessment. The receiving inspection group of Quality Assurance must carefully inspect the core for any defects from core manufacture. Further, quality assurance inspections are to assess damage from handling and part assembly.

The detection of defects in a honeycomb sandwich part is important. If the damage goes undetected and the part is installed, the damage may propagate, leading to failure of the part. This, in turn, may endanger the aircraft or require a more costly repair to the aircraft.

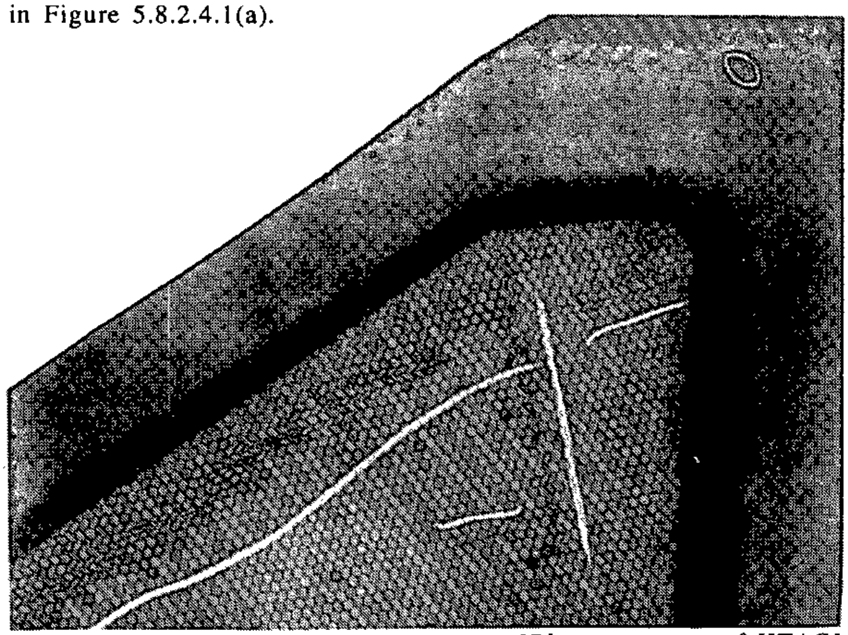
5.8.2.4.1 Honeycomb Core.

**Crushed Core.** Honeycomb core is especially susceptible to crushing from concentrated loads on the sandwich surface. A depression in the panel surface may or may not be evident where crushed core is present. If the core has been fractured the area will feel spongy to hand or finger pressure. Crushed core may also be detected by ultrasonic inspection or radiography.

There are various types of crushed core:

1. Crumpled core is core crushed in the length (L) direction.
2. Condensed core is core crushed in the width direction.

In general, where the core comes in contact with edge members in the length and width direction, some core deformation may be allowable, to a maximum of one cell width or length, but no closer than 2 inches to another similar defect. An example of an unacceptable crushed core near an edge member is shown in Figure 5.8.2.4.1(a).



*[Photo courtesy of HTAC]*

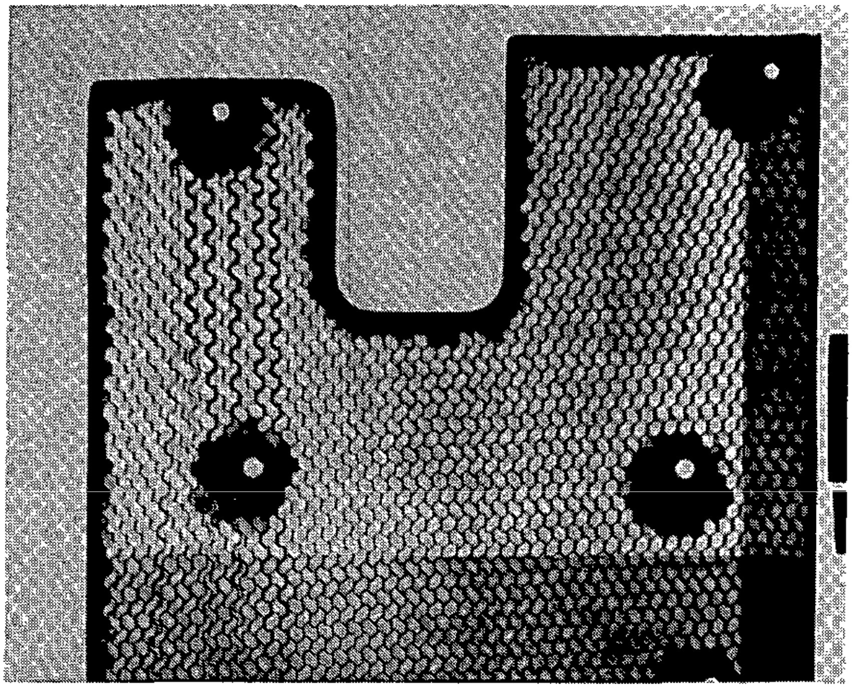
***FIGURE 5.8.2.4.1(a) Crushed core at edge member.***

**Corrugated Core Mismatched Nodes.** In general, a misalignment ratio (c/d) of mismatched cell flats less than 0.25 is desirable. Another guideline is that any square foot of assembled honeycomb core material should have no more than the following number of cells with mismatch ratios greater than 0.25.

| Nominal Cell Size, inches | Maximum Number of Nodes With Misalignment Ratio Greater Than 0.25 |
|---|---|
| 1/8 | 90 |
| 5/32 | 70 |
| 3/16 | 50 |
| 1/4 | 30 |
| 3/8 | 13 |

An example of mismatched nodes in a high density corrugated core is shown in Figure 5.8.2.4.1(b).

**Distorted Core.** Distorted core may occur during the manufacture of the honeycomb core or the assembly of a part. Distortion may be in either the length or width direction. Unless otherwise stated in the applicable drawings or specification, a core is generally considered distorted if:



*[Photo courtesy of HTAC]*

***FIGURE 5.8.2.4.1(b) Mismatched nodes in a high density corrugated core.***

1. In the width direction, the cell size varies from nominal dimensions by more than 10 percent, when measured over any 10 adjacent cells.

2. In the length direction, the cell size varies from nominal dimensions by more than +20 percent, -10 percent, when measured over any 10 adjacent cells.

**Double Foil.** Double foil is a core manufacturing defect. Double foil may be acceptable for the manufacture of parts unless otherwise stated in specifications and drawings. Although this flaw should be detected by the core supplier, the finished part inspector should be aware that it can occur and of what it looks like.

**Expanded Core Length of Bonded Cell Face.** Properly expanded core (as received or core expanded in-house) should favorably relate to the following:

| Nominal Cell Size, inches | 1/8 | 5/32 | 3/16 | 1/4 | 3/8 |
|---|---|---|---|---|---|
| Nominal Bond Length, inches | 0.072 | 0.090 | 0.108 | 0.144 | 0.216 |
| 75% Nominal Bond Lengths, inches | 0.054 | 0.068 | 0.081 | 0.108 | 0.162 |
| Max Cell Face Bonds Less Than 75% of Nominal Bond Length | 90 | 70 | 50 | 30 | 13 |

Generally, in any one ribbon, at least 80 percent of the cell face bond length must exceed the value for 75 percent of nominal bond length given above.

5.8.2.4.2 Assemblies.

5.8.2.4.2.1 External Damage to Assemblies.

External damage to assemblies includes:

1. **Scratches.** Scratches degrade the parts resistance to fatigue. Scratches that penetrate the protective coating leave the skin unprotected from corrosion. The length and depth of the scratch and the proximity of multiple scratches should be noted. The depth of some scratches can be determined with a depth gage. Scratch penetration of cladding can be determined by applying caustic soda; if the cladding has been penetrated, the base metal will turn black. The caustic soda must be removed by thorough rinsing.

2. **Dents.** Dents cause a general weakening of the part. Dents in critical areas can cause premature failure of the part. Dents can be detected visually; the diameter and depth should be measured. If a brittle adhesive was used in construction, or if the skin is thick, the area around the dent may be delaminated. Check by tapping, or inspection with ultrasonic equipment. Deep dents can be inspected for cracks with an eddy current instrument. If a crack exists, check for moisture with radiography.

3. **Improper Sealant/Aerodynamic Smoother Application.** Damage caused by water entry is one of the biggest problems with maintenance of bonded assemblies in service. Commonly, water enters the part after the surface has been punctured or gouged, or the edge seal has been broken by a bump. Moisture may enter the part through a porous bond line. The presence of moisture may be suspected where delamination has occurred near a panel edge. The condition of the edge seals should be examined.

Rework-type repairs to fix damage will be exposed to many environmental effects:

1. **Fluids**–salt water or spray, fuel or lubricants, hydraulic fluid, paint stripper, and humidity.

2. **Mechanical loading**–shock, acoustic or aerodynamic vibrations, and operating loads.

3. **Thermal cycling**–Absorbed moisture can affect repairs in three ways:

a. *Parent Laminate Blistering*. As a "wet" laminate is heated to cure a bonded repair, the absorbed moisture may cause local delamination or blisters. Prebond drying at lower temperatures, slow heat-up rates, and reduced cure temperature all diminish the tendency to blister.

b. *Blowing Skins of Sandwich Structures*. Moisture in the cells of honeycomb sandwich structures expands when the part is heated to cure a bonded repair and has developed enough pressure to separate the skin from the core, especially if the strength of the adhesive has been reduced by heat and moisture. Predrying is normally used to prevent bond line failure of this type.

c. *Porosity in Bond Lines*. As a repair is bonded to a "wet" laminate, the moisture tends to cause porosity in the bond line. This porosity can reduce the strength of the bond line. This problem can be minimized by predrying, reduced temperature cures, and proper selection of moisture resistant adhesives.

Generally, bonded repairs are not acceptable on newly-manufactured parts so thermal cycling will not be a major factor during rework.

5.8.2.4.2.2 Internal Damage to Assemblies. External damage to honeycomb parts can be detected with relative ease, but the bonded construction of the sandwich makes it more difficult to detect internal damage. There are nondestructive inspection methods that are effective for detecting both internal and external damage. These methods range from the:

1. **Tapping Method.** Tapping is a convenient and effective method of locating larger voids where the face material is thin.

2. **Ultrasonic and X-ray Methods.** Where the delamination is small or under thicker face material or multiple doublers or near fittings, the tapping method becomes less useful. For these cases, ultrasonic or X-ray techniques should be used. Ultrasonic instruments should also be used to better define the bounds of delamination in such defects as the following:

   a. Voids.

   b. Gap.

   c. Metal-to-metal bond lines.

   d. Face-to-core bonds.

   e. Splice.

   f. Crushed core.

   g. Compressed core.

   h. Buckled core.

   i. Shifted core.

   j. Blown core.

   k. Ruptured core.

   l. Split cell wall.

A listing of the types of defects commonly encountered during Nondestructive Inspection, and the inspection techniques used to detect and evaluate these defects is given in Table 5.8.4.1.1.

Normally, parts will be exposed to repeated loads (fatigue loading) during their service lives. For example, high stresses on fastener holes tend to elongate them after repeated loading. Bonded joints can develop disbonds after being weakened by environmental effects. Unrepaired delaminations tend to grow under compressive or shear loading. Any defect under these conditions could cause moisture intrusion into the assembly.

Moisture results in weight and high temperature problems, and may destroy the honeycomb part interior. The core foil is very thin and light corrosion may significantly reduce its strength. Moisture may also destroy the bond between the core and the faces. Inspection for water usually involves radiographic examination, but radiographic inspection is usually not performed unless there is a valid reason to suspect moisture. If moisture is detected, the part should be opened sufficiently to determine the extent of corrosion.

5.8.3 Mechanical Testing. Mechanical testing includes the complete range of laboratory experiments from simple component tests to full-scale component and subassembly tests. Full-scale component evaluations are generally destructive, since a common goal is to subject the part to simulated service conditions until weak spots fail. These experiments are very valuable, and expensive. Details concerning the requirements for aircraft structural component destructive testing are available from a number of sources. MIL-STD-1530 is a useful Air Force document on the subject.

The focus of this section is on simple component tests. For quality conformance and inspection, mechanical tests on simple components are essential. These tests allow engineers to determine the suitability of materials, processes, and design for the intended application. Two major causes of product failure are inadequate control of materials and poorly controlled manufacturing techniques. Mechanical tests permit differentiating between an acceptable and unacceptable material by minimizing the likelihood of the major causes of material failure.

5.8.3.1 Mechanical Test Types. Various mechanical tests have been designed to ensure the integrity of honeycomb sandwich structures. These tests evaluate various critical properties of the composite. In each case, there are acceptable limits of the properties with statistical bounds.

Tests commonly used for quality control of honeycomb sandwich composites are:

- Lap shear.
- Wedge-crack.
- Peel (T-peel and honeycomb climbing drum peel).
- Flatwise tensile.
- Beam shear.

A description of these tests is given in the following subsections. Further details are provided in Reference 9. Other acceptance tests applicable to aluminum honeycomb parts are listed in Table 5.8.3.1. These tests are tabulated with regard to their estimated sensitivity to specific types of faults.

The lap shear and wedge tests provide a means to estimate the quality of the adhesive bond in a honeycomb assembly. The lap shear test method provides a measure of the strength of the adhesive bond under mixed-mode loading. The wedge test allows Mode I loading. Although there is a shear component, this is generally quite small, which means that the normal stress primarily causes the deformation. Peel tests are used to control quality throughout the sandwich composite industry. Values obtained, provided the adhesive weight and core material are in balance, will give indications of tooling or cure problems, and of adherend surface preparation problems. It is

Table 5.8.3.1 Mechanical tests, estimate of sensitivity of standard tests to specified faults

| Core Defect | Shear Flatwise (ASTM C 273) | Tension Flatwise (ASTM C 297) | Compression Flatwise (ASTM C 365) | Compression Edgewise (ASTM C 364) | Flexure Flatwise (ASTM C 393) | Shear Fatigue Flatwise (ASTM C 394) | Drum Peel Test (ASTM D 1781) |
|---|---|---|---|---|---|---|---|
| Gap between core and edge member | N/A | N/A | N/A | High | N/A | N/A | N/A |
| Unbonded nodes | High load perp. to ribbon dir. | Low | Low | Low | High moment parallel to ribbon | High load perp. to ribbon dir. | Low |
| Core splice exceeding separation limit | Low | Low | Low | Low | Low | Low | Low |
| Gaps machined core/stepped skin | Low | Low | Low | Low | Medium moment parallel to step | Low | N/A |
| Void in foam adhesive at edge member | N/A | N/A | N/A | Low | N/A | N/A | N/A |
| Crushed core at edge member | N/A | N/A | N/A | Low | N/A | N/A | N/A |
| Mismatched nodes (corrugated) | High load perp. to bond line | Low | Low | Medium | High moment parallel to bond line | High load perp. to bond line | Low |
| Blown core | Medium | Medium | Medium | Medium | Medium | Medium | N/A |
| Incomplete edge seal | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Diagonal line of collapsed cells | Low | Low | Low | Low | Low | Low | N/A |
| Over expanded core | Medium | Low | Low | Medium | Medium | Medium | Low |
| Drilled vent hole in skin | Low | Low | Low | Low | Low | Low | Low |
| Sideways condensed core | N/A | N/A | N/A | Low | N/A | N/A | N/A |
| Incomplete core splice | Low | Low | Low | Low | Low | Low | Low |
| Nested cell (corrugated) | Low | Low | Low | Low | Low | Low | Low |
| Misaligned ribbon | Low | Low | Low | Low | Low | Low | Low |

particularly useful for this when an environmental exposure, involving both elevated temperature and high humidity is interposed between manufacture and test. It is also adaptable for use with nearly any skin material, except for very thick or very stiff skins. The flatwise tensile test is conducted to determine the tensile strength of the core or the tensile strength of the adhesive bond between the core and the face sheet of a honeycomb sandwich assembly. Finally, the beam shear test is often used to evaluate the overall sandwich performance. Values obtained using this test generally depend on the facing thickness, facing material and loading condition.

5.8.3.2 Lap Shear Strength. Test panels should be prepared from 0.063 inch thick 2024-T3 or 7075-T6 aluminum alloy, unless otherwise specified in the applicable procurement specification.

Test panels may conform to the basic dimensions of Figure 5.8.3.2 or be any suitable length and width to provide a panel that can subsequently be cut into individual test specimens having a total length of 7.5 inches minimum, a width of 1.00 inch, and a single lap of 0.500 inch. Center (overlapped) edges of all test panel sheets should be milled; sheared edges are not acceptable.

The test panels should be cleaned, processed, assembled, and cured in accordance with the procedures specified in the applicable procurement specification.

5.8.3.2.1 Specimens From Test Panels. Specimens taken from test panels fabricated in accordance with Figure 5.8.3.2 should be separated by sawing. Specimens cut from solid test panels or from assemblies should be sawed with a band saw or table saw using sharp saw blades. Extreme care should be taken in sawing to avoid chatter or overheating, which could damage the adhesive bond.

5.8.3.2.2 Specimens From Assemblies. Specimens are cut from prototype or production assemblies. Use all precautions specified in Section 5.8.3.2.1. Where part configuration permits, test specimens should be cut 1.00 inch wide. Where 1.00 inch widths are not possible, use the maximum width permitted by the part configuration. Prepare a standard 0.50 inch overlap by milling grooves in the specimen as shown in Figure 5.8.3.2.2. Use caution in setting the depth of the cut to avoid cutting into the opposite face.

If the thickness of either face is less than 0.060 inch, the face should be reinforced by bonding an 0.064 inch thick 2024-T3 aluminum stiffener plate on the exterior surface prior to milling the lap shear grooves. Prepare bonding surfaces in accordance with the applicable specification. Alternate methods of surface preparation are acceptable, provided they will produce secondary bonds that do not fail during subsequent testing of the primary bond.

5.8.3.2.3 Specimen Alignment. Care should be taken to keep the test specimen symmetrical so that the centerline of each gripped end does not vary more than 0.050 inch from the centerline of the adhesive joint to be tested (see Figure 5.8.3.2.3). Misalignments are corrected by bonding a shim in the grip area of the specimen as shown in Figure 5.8.3.2.3. Clean the bonding surfaces and the bond shim as specified above.

5.8.3.2.4 Test Temperature. Tests should be conducted at ambient temperature unless otherwise specified in the applicable procurement specification. Where tests are to be conducted at other than ambient temperature, use the following procedure:

1. Install a temperature conditioning chamber equipped with an air circulating fan or blower to completely enclose the test grips of the test machine.
2. With the test specimen in the test grips, measure the temperature of the specimen at the center of the lap area by means of a thermocouple attached to the surface. A dummy specimen having the same configuration as the test specimen may be used as an alternate

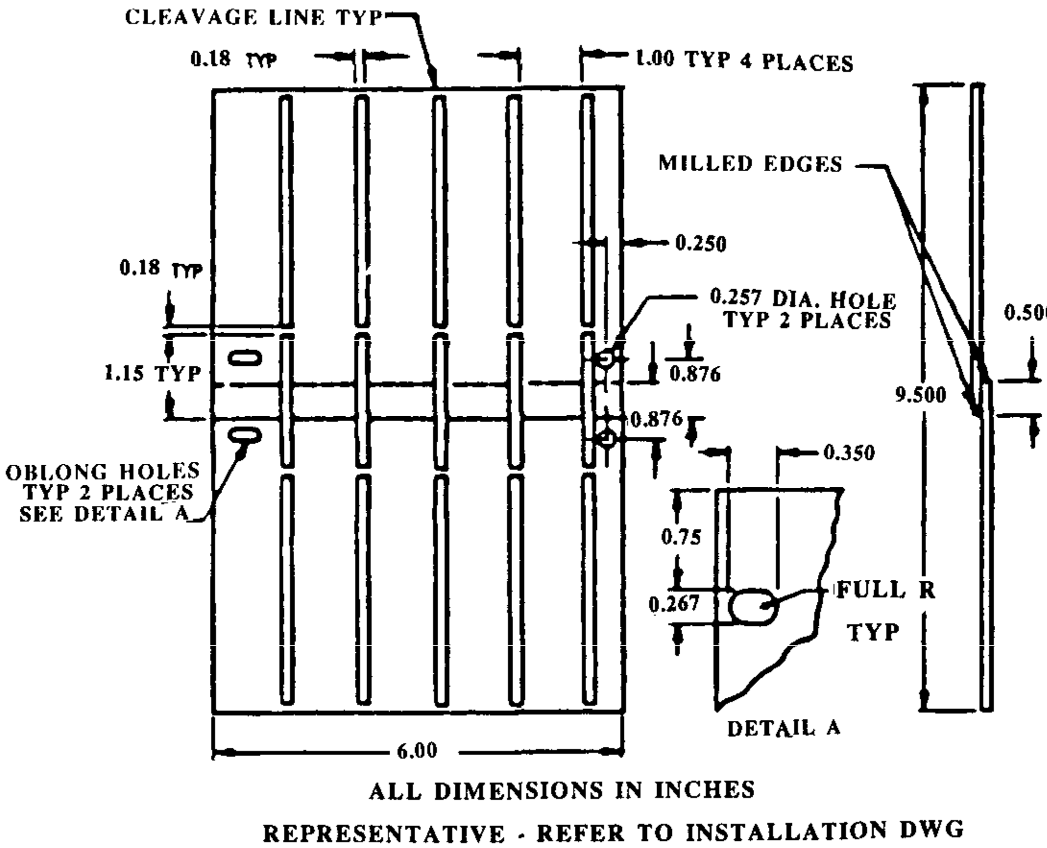



*FIGURE 5.8.3.2 Assembled lap shear panel.*

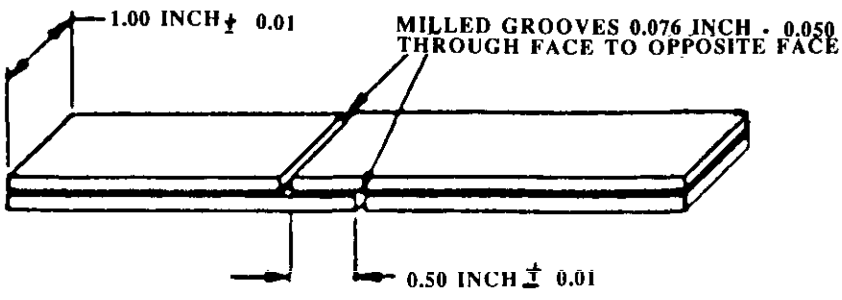



*FIGURE 5.8.3.2.2 Lap shear specimen taken from assembly.*

method of temperature measurement. The dummy specimen should have a thermocouple attached to the center of the overlap and should be located as near as practical to the test specimen during test.

3. Soak the test specimen at the required testing temperature for at least 10 minutes.

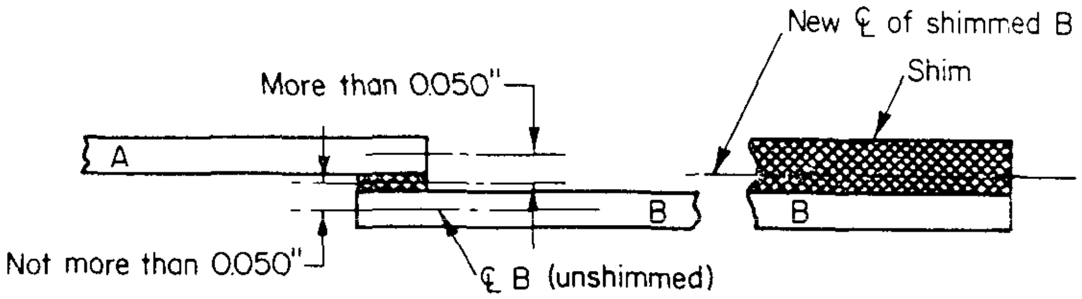



***FIGURE 5.8.3.2.3 Alignment of test specimen.***

5.8.3.2.5 Test Procedure. The test procedure should be in accordance with ASTM D 1002, or in accordance with the applicable procurement specification. The test specimen is gripped 2.0 ± 0.25 inches from each edge of the lap joint. The load should be applied at a rate of 0.030-0.035 inch per minute of head travel to failure.

The shear strength should be expressed in pounds per square inch of actual shear area calculated to the nearest 0.01 square inch. Measure the length and width of the shear area to nearest 0.01 inch. Measure the average bond line thickness to the nearest 0.001 inch by measurements of the overall thickness of the lap minus the combined thickness of the adherends.

**NOTE**

Bond line thickness measurements are not required on Quality Assurance Test Specimens.

Record the following information:

- Shear length.
- Shear width.
- Shear area.
- Load at failure.
- Shear strength.
- Bond line thickness.
- Estimated percent and mode of failure, such as cohesive (failure within the adhesive), *adhesive* (adhesive separation from metal surface), or void (lack of contact during bond).

**NOTE**

Only shear strength information is required on Quality Assurance Test Specimens.

5.8.3.3 Wedge Crack. Test panels for metal-to-metal and metal-to-honeycomb tests should be prepared from 2024-T3 or 7075-T6 aluminum alloy sheet and 7.9-1/4-40N(5052)E honeycomb core unless otherwise specified by the referencing process specification.

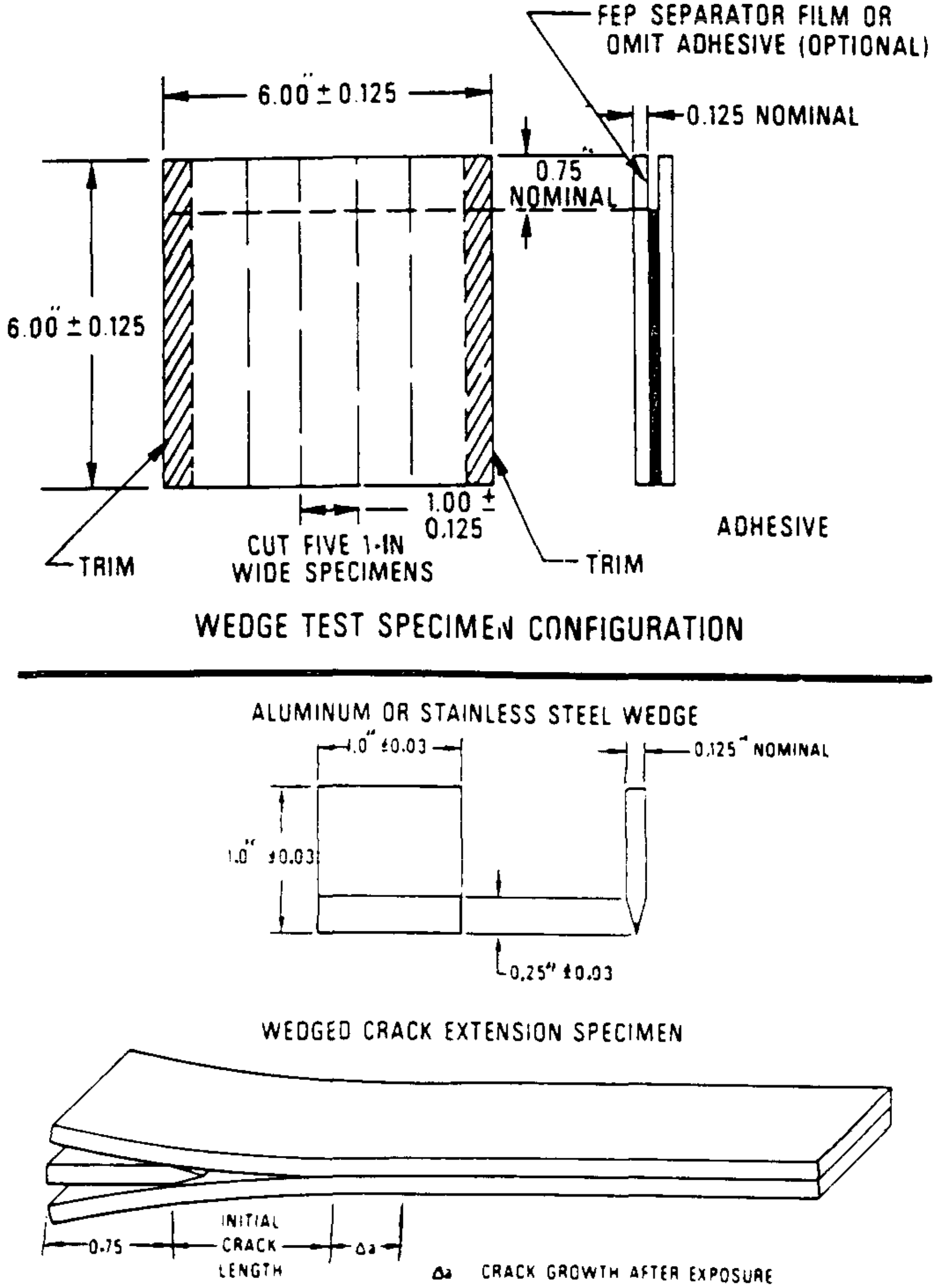



*FIGURE 5.8.3.3.1 Crack extension specimen configuration.*

This method simulates forces and effects on an adhesive bond joint at the metal adhesive/primer interface. It has proven to be highly reliable in determining and predicting the environmental durability of adherend surface preparations. This method has proven to be correlatable with service performance in a manner that is much more reliable than conventional lap shear or peel tests.

5.8.3.3.1 Test Panel Preparation. Test panels should conform to dimensions shown in Figure 5.8.3.3.1. The test panels should be cleaned, processed, assembled and cured according to the procedures specified in the applicable process specification.

5.8.3.3.2 Specimens from Test Panels. Use a minimum of five 1 x 8 inch specimens from a single assembly for each test. A satisfactory adherend thickness for a specific adhesive-adherend system can be determined by trial and error methods or approximated.

5.8.3.3.3 Test Procedure.

1. Prepare the surfaces of a piece of 6 x 8 x 0.125 inch aluminum using a surface treatment process appropriate for the test requirements.
2. Prime the faying surface of each panel, apply the adhesive, assemble the panels, and cure the adhesive as required by the appropriate specification. A 2 x 6 x 0.004 inch separation film will be inserted along one of the 6 inch wide edges of the assembly as shown in Figure 5.8.3.3.1 and the adhesive will be omitted from between the separation film and the aluminum surface.
3. Open the end of the test specimen that contains the separation film, and insert the wedge. Position the wedge so the end and sides are approximately flush with the sides of the specimen. (In any use of an auxiliary tool to open the specimen, remove the separation film or insert the wedge, do not bend the specimen).
4. Using 5-30-power magnification and adequate illumination, locate the tip of the crack, $a_o$, on the 125-μ inches finish edge of each specimen. This is the point, $a_o$, farthest from the wedge where the specimen (the adhesive primer, or adherends, or both) has separated. Mark the location on both sides of the adherend edge, using a fine stylus or scribe. If the specimen is to be used in salt spray or other environment expected to be corrosive and likely to obliterate the mark, then deepen the scribe mark with triangular file.
5. For additional accuracy, take and average readings on both sides of the specimen. Expose the wedge specimens to the environment as required by the appropriate specification.
6. Measure the initial crack length $a_o$ and the crack extension, $\Delta a$, of each specimen to the nearest 0.01 inch.

At the conclusion of the test, forcibly open the specimen and note the failure mode of the test section.

5.8.3.3.4 Interpretation of Results. Report the crack extension, $\Delta a$, and the crack extension failure mode, that is, adhesive failure at the interface or cohesive within the adhesive.

The initial crack length, $a_o$, the crack extension, $\Delta a$, and the crack extension failure mode are all functions of the adherend, surface treatment, and the adhesive/primer systems being considered. Because of these variables, the acceptance criteria for a bonded system of interest will have to be established.

5.8.3.4 T-Peel (for Metal-to-Metal). All peel tests should be conducted at ambient temperature. Maximum peeling member thickness should be 0.032 inch.

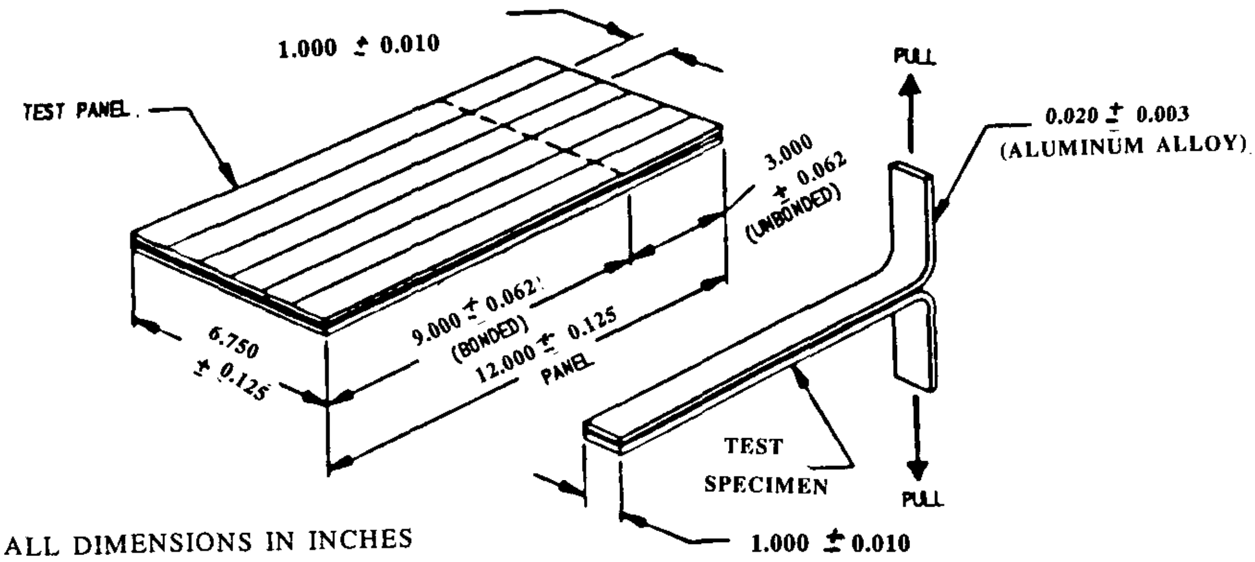



***FIGURE 5.8.3.4.1 T-peel panel and specimens.***

5.8.3.4.1 Test Panel Preparation. Test panels should conform to the dimensions of Figure 5.8.3.4.1. The test panels should be cleaned, processed, assembled, and cured according to the procedures specified in the applicable process specification.

5.8.3.4.2 Specimens from Test Panels. Cut panel assemblies into individual 1.00 inch wide test specimens, as per MMM-A-132.

**NOTE**

T-Peel testing is not applicable to specimens cut from assemblies.

5.8.3.4.3 T-Peel Test Procedure. Clamp the bent, unbonded ends of the test specimen in the jaws of a test machine with self aligning jaws and apply the load at a rate of 3 inches per minute (separation of the bond will then be 1-1/2 inches per minute). Autographically record the load versus distance peeled and determining the T peel strength over at least a 5 inch length of bond line. Note the nature and percent of failure (cohesive, adhesive, or void) and the bond line thickness.

5.8.3.5 Honeycomb Climbing Drum Peel.

5.8.3.5.1 Test Panel Preparation. Make climbing drum peel test panels/specimens per ASTM-D-1781 unless applicable specification provides other guidance. Unless otherwise specified, the test panel size should be 10 by 12 inches, with the core ribbon direction remaining parallel to the 12 inch dimension. Test panel configuration consists of 0.020 inch 2024-T3 aluminum alloy faces and 0.625 inch thick 7.9-1/4-4ON(5052) honeycomb core.

5.8.3.5.2 Specimens from Assemblies. Test specimens cut from prototype or production assemblies should be a minimum of 2.00 inches wide. The specimen length should be a minimum of 8.00 inches and should be parallel to core ribbon, if possible.

5.8.3.5.3 Test Procedure:

1. The honeycomb climbing peel apparatus is shown in Figure 5.8.3.5.3.
2. The test specimen is loaded at a rate of head travel of 3.00 inches ± 0.5 per minute.
3. The test load is autographically recorded for a distance of 6 inches.
4. The average peel load is determined from the autographic record.
5. The peel strength is calculated as follows:

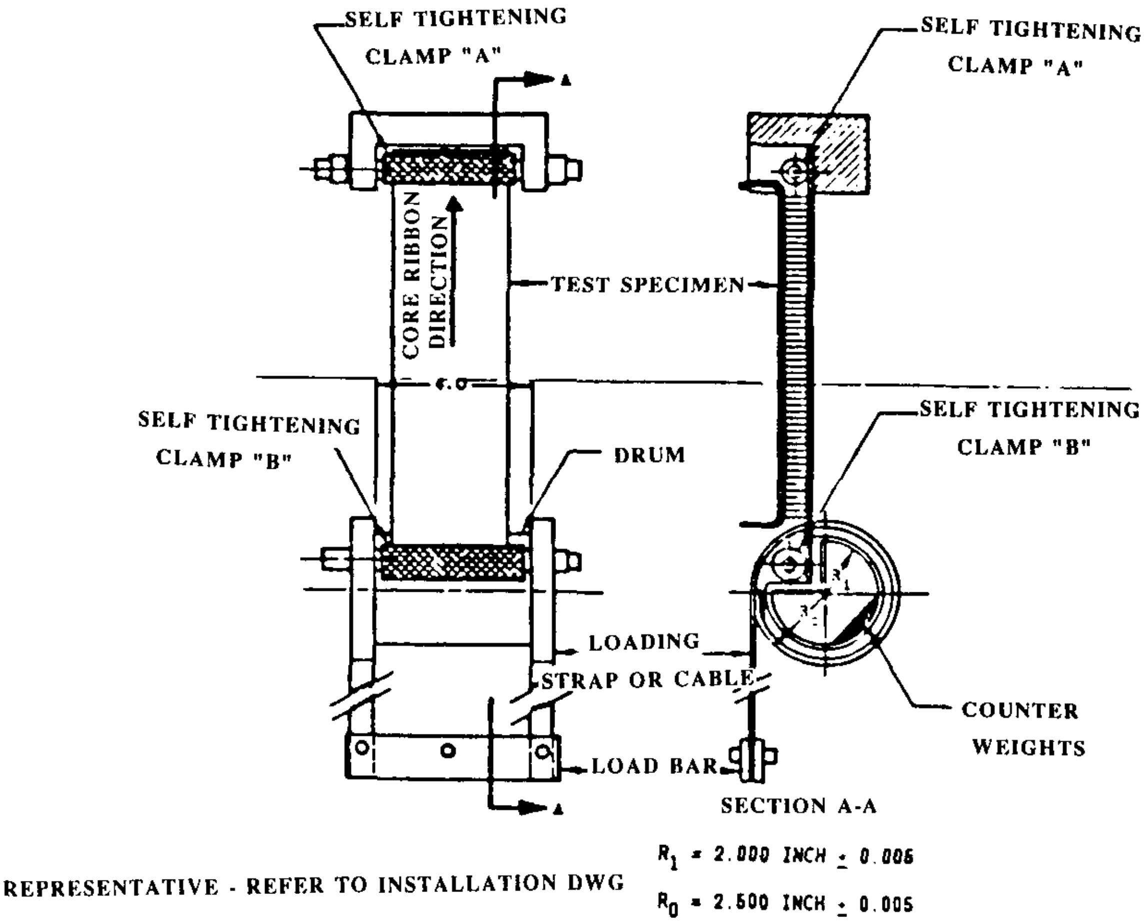



*FIGURE 5.8.3.5.3 Climbing peel test (metal-to-honeycomb specimen).*

$$Tp = (R_o - R_i)(L - C)$$

where

$Tp$ = Peel Strength, inch-pounds.

$R_o$ = Outer Radius of drum.

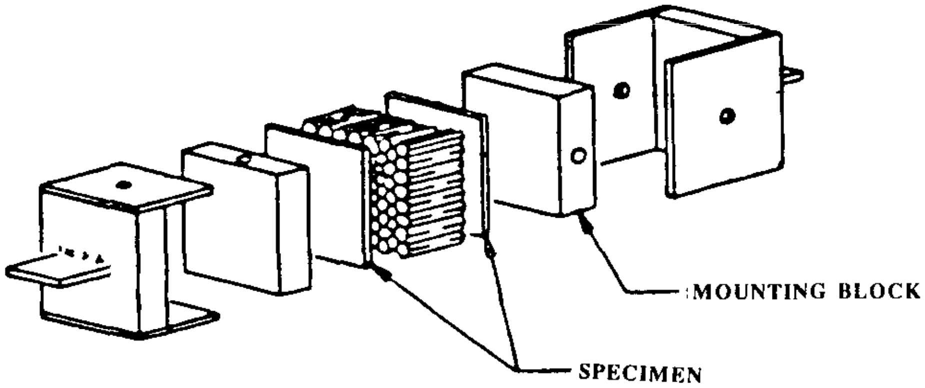
$R_i$ = Inner Radius of drum.

$L$ = Average Load, pounds.

$C$ = Correction Load, pounds.

6. Record the peel strength and mode of failure (cohesive, adhesion, void, or core).

The correction load "C" is the sum of the load necessary to overcome the weight of the drum plus the load required to wrap the peeling member around the drum. The correction load "C" may vary




(DELETE FACE SHEETS WHEN TESTING BARE CORE)

***FIGURE 5.8.3.6.1 Honeycomb flatwise tensile test.***

with each piece of equipment due to slight differences in the weight of the drum. To determine the correct value of "C," the load required to raise each individual drum is measured using a strip of metal of the same alloy, thickness and width as the facing that is peeled.

5.8.3.6 Honeycomb Flatwise Tensile Strength. Honeycomb flatwise tensile strength tests are conducted to determine the tensile strength of the core of the adhesive bond between the core and the face sheet of a honeycomb sandwich panel assembly.

5.8.3.6.1 Test Specimens. Test specimens should be 2.00 inches ± 0.01 square. Thicknesses of the core or of the sandwich facings are not critical.

Sandwich panel facings should be bonded between mounting blocks as shown in Figure 5.8.3.6.1. Facings and blocks should be manually cleaned in accordance with Reference 10 and bonded with a room temperature curing adhesive. Do not permit mounting block adhesive to extend over panel facing and onto core.

When testing the tensile strength of core, the core specimen is bonded directly to the mounting block. Bonding should be as specified in Reference 11 or equivalent, except that bonding may be accomplished in a heated platen press if desired.

5.8.3.6.2 Test Procedure. Test specimens should be loaded at a head travel rate of 0.030-0.035 inch per minute to failure. Tests should be conducted at ambient (room) temperature.

Record tensile strength in psi and mode of failure (cohesive, adhesive, void, or core).

5.8.3.7 Beam Shear Strength.

5.8.3.7.1 Test Specimen Preparation.

1. This method is limited to assemblies having a constant core thickness and is usually only used on flat assemblies.
2. Individual specimens should be cut from the assembly to a size of 8 by 3 inches. The core ribbon should either be parallel or perpendicular to the length, as specified in the process specification. Where no ribbon direction is specified, the specimen should be cut with the direction parallel to the length.
3. The test specimen should be supported for testing as shown in Figure 5.8.3.7.1. The end support plates should be 0.25 by 1 by 3 inches, machined from steel with grooves for alignment on the test apparatus. Loading surfaces should have the edges rounded to 0.06 inch radius. The reaction span should be 6 inches ± 0.01.
4. The load should be applied through round loading bars, 0.50 inch in diameter and 3 inches long, located under a pressure plate as shown in Figure 5.8.3.7.1. It is permissible to place thin narrow plates at load points to prevent local bending of the sandwich faces. Such plates should not exceed 0.250 inch in width.
5. The load should be applied at a rate of 0.015-0.020 inch per minute. Maximum load values should be obtained to determine the shear strength of the sandwich specimen. Tests should be conducted at ambient (room) temperature.
6. Calculate sandwich shear strength from the following:

$$SC = P_{max} / W (T + T_c)$$

where

SC = Shear strength, psi.

$P_{max}$ = Maximum load, pounds.

W = Specimen width, inches.

T = Specimen thickness, inches.

$T_c$ = Core thickness, inches

L,L' = Load points.

R,R' = Reaction points.

5.8.4 Nondestructive Inspection. This section contains a description of Nondestructive Inspection (NDI) methods applicable to the quality evaluation of aluminum core honeycomb sandwich assemblies and structures. These methods are directed toward the detection of defects that, if undetected, might prevent the part from fulfilling its designed function.

Typical and commonly used inspection techniques are included; however, other techniques may be equally applicable. The responsibility for selecting an inspection technique for a particular

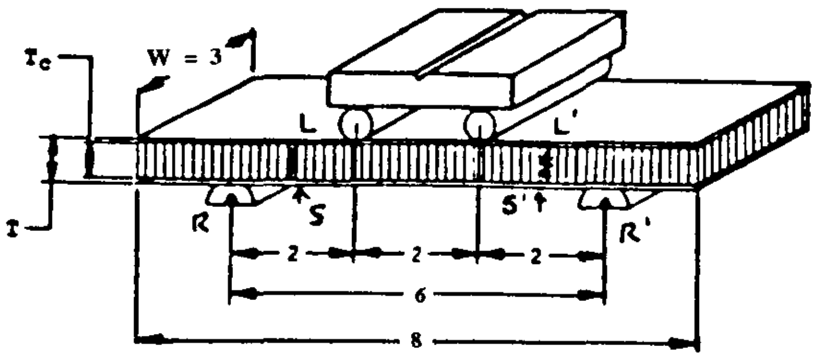



***FIGURE 5.8.3.7.1 Beam shear test.***

application rests with the using facility. However, authorization to use such a technique must come from the responsible government authority.

General NDI procedures, techniques, and terminology can be found in MIL-STD-410, SNT-TC-1, MIL-A-83376, MIL-HDBK-337 and in References 11-15. The -36 Technical Orders (T.O.s) also provide NDI instructions for inspecting airplane structures. Any deviations from these documents for a specific aircraft must be approved by the responsible engineering authority and be in accordance with the applicable procurement specification.

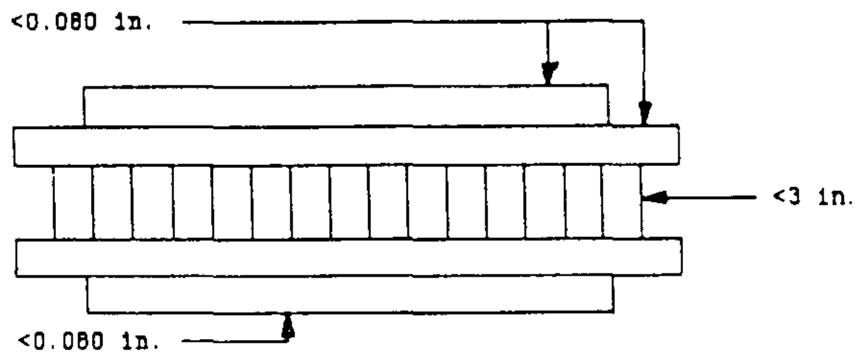
All NDI techniques are comparative; they give indications of one area being different from, or the same, as another area. The inspector uses reference standards to evaluate changes that might indicate a defect. The inspector must be familiar with the internal construction of the part to properly distinguish between indications of defects and indications of legitimate structural features. Technical training in the NDI techniques and experience in applying them are essential.

5.8.4.1 Selection of NDI Techniques. Selection of the proper NDI technique may be made with the aid of information presented in Table 5.8.4.1.1 and Figure 5.8.4.1.1. Table 5.8.4.1.1 summarizes the types of defects that are typically encountered, and the inspection techniques commonly used to detect and evaluate these defects. Figure 5.8.4.1.1 provides further guidance as to the most useful ultrasonic technique based on the probable site of the damage, the minimum defect size that must be detected and the skin thickness.

5.8.4.2 Detection of Manufacturing and Fabrication-Induced Defects.

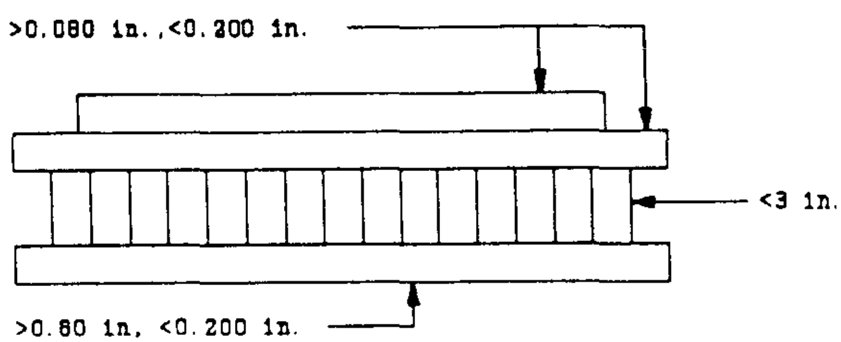
5.8.4.2.1 Manufacturing Inspection. Many mechanically damaged areas on aluminum honeycomb panels and assemblies can be detected visually; the extent and outline of the damage must be evaluated carefully. However, visual inspection should not be used as the sole means of detecting mechanical damage. If mechanical damage is identified by visual inspection the following guidelines should be used, when applicable:

1. Outline the damaged area after visual examination.
2. Verify and revise the outline by conducting a tap test.




To detect 1/2-in. dia defects in any bondline use high frequency Through Transmission Ultrasonics (TTU).

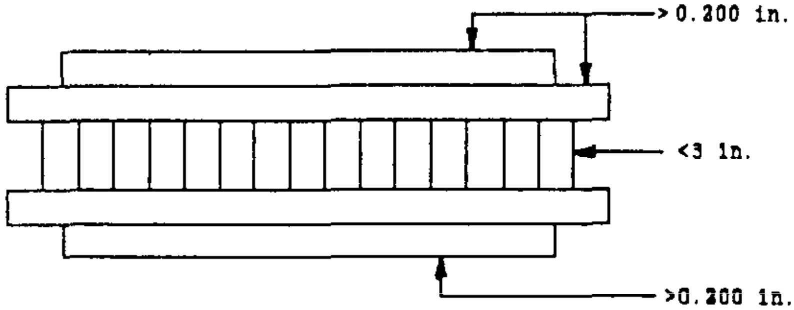
To detect 1/2-in/ dia defects outside bondlines, use portable instruments, both sides.




To detect 1-in. dia defects in any bondline, use high frequency Through Transmission Ultrasonics (TTU)

To detect 1-in. dia defects in outside bondlines use portable instruments both sides.

***FIGURE 5.8.4.1.1 Ultrasonic inspection technique selection guide.***




To detect 1-in. dia defects in any bondline, use high frequency Through Transmission Ultrasonics (TTU)

To detect 1-in. diam defects outside bondlines, use high frequency ultrasonics both sides.

To detect 2-in. diam defects in outside bondlines, use portable instruments both sides.

| Detection Site | Defect Diameter, inches | Method of Choice<br>Skin Thickness, t, inches<br><0.08 | <br><br>0.08 to 0.20 | <br><br>>0.20 |
|---|---|---|---|---|
| Near Bond line | 1/2 | Through-Transmission Ultrasonics | | |
| | 1 | | Through-Transmission Ultrasonics | Through-Transmission Ultrasonics |
| Away from Bond line | 1/2 | Portable Instruments, Both Sides | | |
| | 1 | | Portable Instruments, Both Sides | High Frequency Ultrasonics, Both Sides |
| | 2 | | | Portable Instruments, Both sides |

*FIGURE 5.8.4.1.1 Ultrasonic inspection technique selection guide. (Concluded)*

3. Verify the damaged area further by using a portable NDI instrument such as a Harmonic Bond Tester or Sondicator.

4. On metal-to-metal delaminations, the Fokker Bond Tester or an equivalent device will usually provide a well-defined outline. Careful cleaning is required to remove the couplant after inspection if this method is used.

5. If there is a visible crack in the skin, the extent of the crack can be determined by using eddy current inspection techniques.

6. If the damage is in the honeycomb section, an X-ray examination should be conducted to determine the extent of core damage and moisture in the core.

7. If the damage is in a foam-splice area, an X-ray inspection is recommended.

8. If the damage is in a multilaminate area, through-transmission ultrasonic inspection is recommended.

9. If the damage is in the multiple bond line of a honeycomb structure, through-transmission ultrasonic inspection is recommended. The exposed area must be sealed off to prevent water entry.

10. Use Table 5.8.4.1.1 and Figure 5.8.4.1.1 to select the appropriate nondestructive inspection technique.

5.8.4.2.2 Post-Repair Inspection. Post-repair inspection should be performed to ascertain that no area has been left unbonded and that no additional delamination has occurred. Figure 5.8.4.1.1 and Table 5.8.4.2.2 should be used to select the NDI technique. The inspection procedure should be

TABLE 5.8.4.1.1 Applicable inspection methods for various types of defects.

| Type of Defect | Inspection Method | | | | | |
|---|---|---|---|---|---|---|
| | Visual | Tapping | Ultrasonic | X-ray | Eddy Current | Acoustic Emission |
| External Damage | ● | ● | | | | |
| Core-to-skin Delamination | ● | ● | ● | | | |
| Metal-to-metal Delamination | ● | ● | ● | | | |
| Internal Voids | | | ● | ● | | |
| Distorted Core | | | ● | ● | | |
| Moisture | | | | ● | | |
| Skin Cracks | | | | | ● | |
| Corrosion | | | | | | ● |

TABLE 5.8.4.2.2 Post-repair defect inspection methods for metal-to-metal honeycomb sandwich.

| Type of Damage | Normally Preferred | Inspection Procedure Commonly Acceptable Alternative | Limited Alternative |
|---|---|---|---|
| Face Sheet Delamination | HF TT | LF TT<br>LF P | Resonance<br>Tapping<br>Visual |
| Back Sheet Delamination | HF TT | LF TT | LF P |
| Void, Porosity | HF TT | LF TT<br>LF P | Resonance<br>Tapping<br>Visual |
| Void in Potting | X-Ray | | |
| Core Defect | HF TT<br>X-Ray | LF TT<br>LF P | |

guided by whether or not test standards are available. The following guidelines should be followed when applicable:

1. Conduct visual inspection of the repaired area for obvious defects.
2. Conduct NDI with one or more portable ultrasonic instruments. Figure 5.8.4.1.1 and Table 5.8.4.2.2 should be used to select the NDI instrument.
3. For metal-to-metal bonded repairs (especially on narrow laminated steps), the Fokker Bond Tester or an equivalent device should be considered for the inspection.
4. If the repaired area has a foam splice in the honeycomb, X-ray inspection is recommended.
5. If the repaired area consists of multilaminated or multiple bond lines in the honeycomb area, ultrasonic through-transmission inspection is most definitive.
6. When standard defects are not available, the repaired area may be compared to an unrepaired area. The instrument readings may change because of structural changes resulting from the repair.
7. Repeat the inspection scan using various instrument settings and verify inspection results with another type of instrument.

5.8.4.2.3 Inspection Standards. There should be at least two physical standards: (1) metal-to-metal with a known void and (2) metal-core-metal with a known void. These standards provide a means to check the inspection instrument.

Test standards to calibrate and standardize bond inspection instruments are essential. An inspection technique is usually as good as the test and calibration standards. Ideally, test standards with known voids of selected sizes should closely duplicate the structure being inspected. The laminated skin should be of the same thickness, and the honeycomb core should be of the same thickness and density. Other variations such as tapered core, chemically milled skins and doublers, etc.

should be incorporated in the test standard. The void or defect should be introduced in the same bond line that is to be inspected in the structure.

5.8.4.3 Nondestructive Inspection of Core, Skins and Detail Parts. The contractor is responsible for carrying out the inspection of core, skins, and detail parts. Details of the inspection procedures should be documented with process specifications, which include at a minimum:

- Applicable documents, both military and industrial.
- Materials and equipment required.
- Inspection requirements: sequence, preparation, coverage.
- Test identification.
- Acceptance criteria.
- Marking.
- Post inspection cleaning and part protection, and part disposition.
- Disposition of rejected parts.
- Inspection control; personnel qualification, facilities, equipment calibration (including standards traceability), written procedures, data and records, safety.
- Quality assurance provisions: responsibility for inspection, responsibility for compliance.

Mechanical damage to aluminum honeycomb sandwich assemblies can often be detected by visual inspection. However, the determination of the extent of the damage (outlining the damaged area) requires further and careful examination using specialized inspection equipment.

After outlining the damaged area visually, the outline may be verified and possibly extended by a tap test. Further verification can then be performed using various types of NDI equipment. For metal-to-metal lamination, the Fokker Bond Tester can usually provide a well defined outline. If there is a visible crack in the skin, eddy current instrumentation may be used to determine the extent of the crack. Knowledge of the underlying geometry of the part is necessary. If the damage is likely to extend to the core, radiographic examination can be used to determine the extent of core damage and the possible presence of moisture in the core. Radiography is also used to detect damage in adhesive potting or foam splices. Through-transmission ultrasonic inspection can be used to inspect multiple bondlines.

Figure 5.8.4.3 provides a general comparison of the various NDI inspection techniques applicable to aluminum skin, aluminum core honeycomb parts and structures. This figure illustrates the tradeoff that generally must be considered the easiest and fastest techniques tend to be the least sensitive, while the methods requiring the greatest expertise and time to execute are generally the most sensitive. In any case, the procedure considered most appropriate for a particular situation must be approved by the responsible government authority.

The attributes and limitations of most commonly used inspection methods are reviewed in the following sections.

5.8.4.3.1 Visual Inspection of Assemblies. Nondestructive inspection by visual means is by far the oldest and most economical method of inspection. Visual inspection is performed routinely for damage assessment at all stages of production and repair. In some instances visual aids such as microscopes, bore scopes, magnifying glasses, and other optical devices are used to inspect areas for defects that are either inaccessible or cannot be seen with the unaided eye. Figure 5.8.4.3.1 shows an example of visual inspection with the aid of a flashlight and the correct angle of vision.

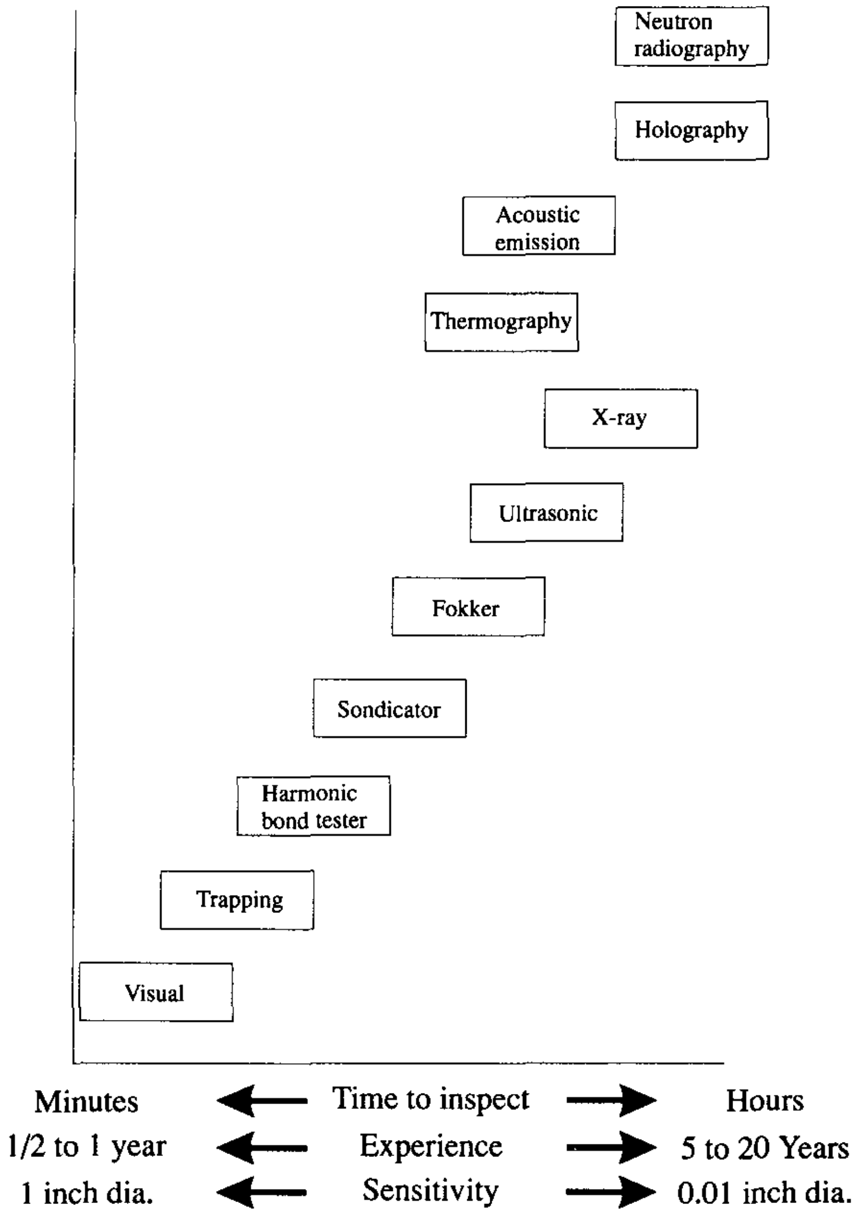



***FIGURE 5.8.4.3. General comparison of inspection techniques.***

Except in transparent materials, visual inspection is capable of finding only flaws evident at the surface; internal flaws such as delaminations or unbonds are not detectable. Tight surface cracks and edge delaminations may not be detected.

Visual inspection of honeycomb assemblies is normally performed to determine:

- Uniformity of surface.
- Continuity of adhesive flash around edges.
- Dents.

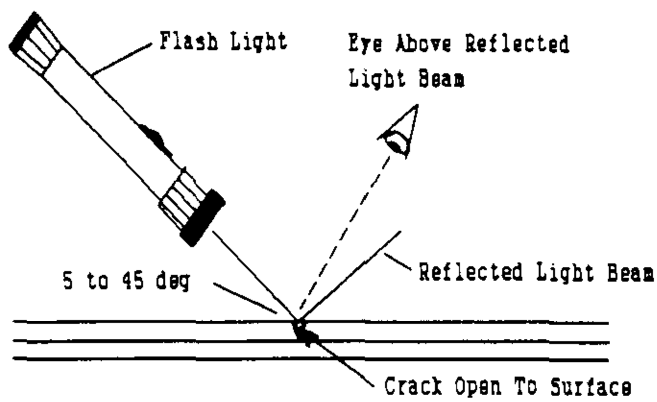



***FIGURE 5.8.4.3.1 Visual inspection of metal surfaces.***

- Scratches.
- Excessive mark-off.
- Unsealed openings into the interior of the core area.

Slippage of details during bonding should not result in excessive corner gaps, angularity of vertical leg of zee members, and mislocation of inserts or fittings.

Visual inspection is also used to examine parts for the presence of an anodic coating as follows:

- Illuminate the anodized surface with a mercury vapor or fluorescent lamp.
- View the surface through a photographic polarizing filter at a low angle (0-10 degrees).
- Acceptable surface is indicated by "interference colors," which change to a complementary color when the filter is rotated 90 degrees.

Reject the part if:

- No color is observed, or
- Abrupt differences in color of local areas are observed, except at electrical contact points, from the background color.

Personnel who perform visual inspections should have good eyesight and should be familiar with the appearance of the defects they are expected to find.

Dimensional inspection is commonly performed at the same time visual inspection is performed. Dimensional and contour inspections are performed in accordance with applicable engineering drawings. Verifilm inspection is a form of visual (and dimensional) inspection. It is used, as described in Section 5.3.2, to verify the acceptability of the fit of assembly details.

5.8.4.3.2 Tapping. Tapping inspection is a nondestructive method for detecting voids or delaminations in bonded areas. When tapping any area, use a tap hammer, (see Figure 4.6.2.12.2). A ringing sound will be produced. The tapping rate should be adjusted to produce a continuous sound so that any difference in sound tone can be detected by a trained ear. The inspection should be conducted in a relatively quiet area.

A "flat" or "dead" response is considered unacceptable. The acoustic response of a good part can vary dramatically with changes in geometry; a standard of some sort is required. The entire area of interest must be tapped. The method is limited to finding relatively shallow defects. Where multiple bond lines exist over core, the core bond cannot be evaluated. The far side bond line of a honeycomb structure cannot be evaluated; two-side access is required for a complete inspection. Surfaces to be inspected should have oil or grease removed and should be dry.

5.8.4.3.3 Ultrasonic. Ultrasonic inspection has proven very useful for detecting internal delaminations, voids, and inconsistencies in bonded structures. The method uses sound waves with a frequency above the audible range. The ultrasonic energy is induced into the part by a piezoelectric transducer (transmitter). As the ultrasonic energy travels through the part, any marked change in acoustic properties of the material will affect the ultrasonic energy, providing information about the anomaly. There are two inspection procedures: through-transmission and pulse echo.

Ultrasonic inspection is performed to detect voids, disbonds (delaminations), and excessive bond line porosity.

5.8.4.3.3.1 Through-Transmission. Through-transmission ultrasonic inspection uses two transducers: a transmitter and a receiver. The receiver is generally located at some position away from the transmitter on the other side of the material. Through-transmission provides the advantage of responding to discontinuities located through the depth of multilayer bonded structures. Voids, delamination, crushed core, or other anomalies in the structure attenuate the ultrasonic energy. When the receiver is on the opposite side of the material, the transducers must be aligned to obtain the maximum received energy. In the case of honeycomb materials, the transducer alignment must be as nearly parallel to the cell wall as possible. The inspection may be performed manually or with an automatic scanning mechanism to position the transducers. A C-scan recorder coupled to the scanning mechanism provides an accurate plan view of the anomalies producing the sound attenuation. Information about the type and depth of the defect is not available, but the size and location of the defect are accurately defined. Special care must be taken in interpreting the results since the sound beam may not always be transmitted straight through the part.

5.8.4.3.3.2 Pulse Echo. Pulse echo ultrasonic inspection normally uses a single transducer, which is both the transmitter and receiver. The method requires access to only one side of the structure. The ultrasonic energy is reflected from the surface of the anomaly and displayed with a meter or oscilloscope (CRT). The method can also be automated with a scanning mechanism and a C-scan recording made of the reflected ultrasonic energy signals. The pulse echo method is usable on materials where the signal strength is such that absorption, scattering, or reflection of sound are significantly different over good and defective areas of the part. When portable equipment is used, there is typically no permanent record of the inspection; defect indications are marked on the part by the inspector at the time of the inspection. Normally, contact inspection will find anomalies in the bond line nearest the probe only, and it cannot be used to detect anomalies in bond lines beyond the honeycomb core. Depending on the material and the particular instrument, sensitivity often decreases rapidly beyond the first bond line in laminates. If water, grease, or oil find their way into certain defects such as delaminations, these defects may become invisible to ultrasonic methods. If the surface is rough, ultrasonic inspection may not be possible.

The contact pulse echo ultrasonic method is normally used in the A-scan mode. This mode displays the amplitude of the returning signal versus time. From this mode, information about type, size, location, and depth of the defect can be obtained.

5.8.4.3.3.3 Noncontact Methods. Three noncontact methods may be used for ultrasonic inspection: immersion, bubbler, and squirter. When using the immersion method, both the part and the transducer(s) are submerged in water. For the bubbler method, the transducers are submerged in a tank, and the part is suspended at the surface of the water with the lower surface of the part wet. To ensure water contact with the part, water is continuously pumped into the tank, causing the tank to overflow. The name of the method stems from the resultant bubbling noises. The squirter method employs a dynamic water column that is squirted at the part and in which the transducer is suspended. For all three methods, the water acts as a couplant to transmit the ultrasonic energy into and back from the part.

The chief advantage of these methods is that they lend themselves to automation: they are faster than hand scanning, and they commonly produce a permanent recording of the inspection results. Disadvantages include the expense of the system, parts with defects open to the surface have to be sealed, and the systems are normally not portable.

5.8.4.3.3.4 High Frequency. High frequency (1-5 megahertz) ultrasonic inspection may be either conducted by the pulse echo method or by the through-transmission method. Several instruments are available, for example: Immerscope, Reflectoscope, Krautkramer, and Magnaflux.

Through-transmission ultrasonic inspection is one of the most reliable and sensitive methods for inspecting adhesive-bonded components, despite some disadvantages. The method requires access to both sides of the part, a continuous path must be available to conduct the ultrasonic energy through the part, and the depth of the flaw is not determined if more than one bond line is present.

Through-transmission ultrasonic inspection can be accomplished by immersing the part in water or by the use of water columns. Immersion tanks with computer controlled scanning mechanisms can be programmed to inspect complex part shapes automatically using either the through-transmission method or the pulse echo method. The record indicates the relative intensity of the ultrasonic energy beam through the part. The equipment may be set up to produce a go/no-go type recording or indicate levels of intensity. The latter may be accomplished with a multicolor recording head. Scanning rates are approximately 6 inches per second for black and white recordings and 1 inch per second for multicolor recordings.

Defect detection sensitivity is dependent upon the water jet diameter and the width of the scanning index. Typical jet diameters are from 3/16-1/4 inch. There must be no air bubbles that will cause false indications between the transducer and the part. Traverse or scan widths are typically 0.030-0.040 inch for black and white and 0.070-0.080 inch for color. The scan width (increment) should be adjusted from 1/3-1/4 of the size of the void to be detected.

5.8.4.3.3.5 Low Frequency. Low frequency (15-50 kHz) inspection units have been developed especially for honeycomb bonded structures. These units are portable and do not need a liquid or gelatin couplant between the part and the transducer. Some detection sensitivity is sacrificed compared to the high frequency through-transmission equipment.

**Harmonic Bond Tester.** The Harmonic Bond Tester is described in Section 4.6.2.12.3.2. The Harmonic Bond Tester is suitable for rapid manual checks of repaired areas. The probe size (approximately 1-1/4 inches diameter by 1-1/2 inches high) limits access to the area adjacent to vertical sections of hats and tees. The skin next to the probe must have good electrical conductivity (ideal for aluminum). Sensitivity to voids decreases rapidly for skin thicknesses over 0.060 inch and near the edges of parts.

Information about the defect type and depth is not provided. Only the near surface can be inspected. The equipment is portable. Standards are required and no recordings are made. The surfaces to be inspected should be free of grease, oil, and particulate contamination.

**Sondicator.** The Sondicator is also described in Section 4.6.2.12.3.2. The Sondicator is a pulsed ultrasonic (20-40 kHz) instrument that generates ultrasonic waves and monitors the amplitude and phase changes of the waves. The ultrasonic waves are produced by a piezoelectric transducer and are coupled into the part through a point contact. The waves are picked up by a second transducer at a fixed distance from the first. Because of the construction of the probes and the operating frequency, no couplant is required.

The advantages of this method are that no couplant is required and rapid scanning is possible. One disadvantage is its relative insensitivity to small flaws. The equipment is portable, standards are required, and no recordings are made. Surfaces to be inspected must be clean of dirt, grease, oil, etc. One-sided inspection is sufficient except for honeycomb assemblies, where two-sided access is required for 100 percent coverage. The size of the probe limits access to areas next to a vertical section of a tee or hat. Multiple bond lines and part edges will reduce the sensitivity.

**Flaw Detector.** The flaw detector works on the principle of sonic impedance in the range of 300 Hz to 8 kHz. The probe contains two piezoelectric crystals, one of which provides a continuous sonic beam. The other crystal detects changes in the phase and amplitude of the response from the part. These changes are displayed on the instrument panel.

The advantages are that the method is fast and requires no couplant; the point contact method is used. A disadvantage is its relative insensitivity. Standards are required and no recordings are made. Geometric changes will affect the results. The instrument is portable. Surfaces to be inspected should be clean of dirt, grease, and oil.

5.8.4.3.3.6 Resonance Type Instruments.

**Fokker Bond Tester.** The Fokker Bond Tester is described in Section 4.6.2.12.3.3. The Fokker Bond test works on the principle of ultrasonic resonance. The equipment consists of a hand-held ultrasonic probe attached to a variable frequency instrument. In use, the instrument is tuned to a resonant frequency over a defective area in a standard. The part being inspected is then scanned with the probe. The instrument displays the resonance amplitude and frequency. Changes in these parameters indicate the presence of defects and changes in the cohesive bond strength. Because these parameters are also affected by internal geometry changes, knowledge of the part construction and suitable standards for each area to be inspected is required. Further, a liquid or semiliquid couplant is required.

The advantages of this method are that the inspection yields some information as to the type of defect present and multiple bond lines can be inspected, but the sensitivity decreases below the first bond line, especially in heavy structures. The probe must be positively positioned during the reading and then repositioned for the next reading. It is faster than ultrasonic equipment when used with alarms. Disadvantages include the necessity for a couplant and the resultant cleanup, limited information about defect type and depth, and the relative insensitivity of the method. For honeycomb structures, two-sided access is required for full inspection; for laminated structures, one-sided access may be adequate. For multiple metal-to-metal bond lines, the probe should be in contact with the side with the thinnest outside adherend. Contact must be continuous between the probe and the adherend (no bubbles). No recordings are produced by this method, but the equipment is portable. The surface must be cleaned prior to inspection to remove obstructive surface conditions such as corrosion, blistered paint, loose dirt, etc. The instrument should be used on honeycomb assemblies only if it is successful in detecting voids in the reference standard.

**Bondascope.** The Bondascope also works on the principle of ultrasonic resonance. The equipment consists of a hand-held ultrasonic probe attached to a variable frequency instrument. In use, the instrument is automatically tuned to a resonant frequency over a defect area in a standard. The part to be inspected is then scanned with the probe. The instrument displays the resonance amplitude and the impedance phase. Changes in these parameters indicate the presence and size of defects as well as the depth of the defect. Because these parameters are also affected by changes in the internal geometry, knowledge of part construction and suitable standards for each area to be inspected is required. A liquid or semiliquid couplant is required.

The advantages of this method are that the inspection yields some information on the type of defect present, its size, and its depth. Multiple bond lines can be inspected and it is faster than ultrasonic equipment when used with alarms. Disadvantages include the necessity for a couplant and the resultant cleanup, the limited amount of information provided as to defect type, and the relative insensitivity of the method. For honeycomb structures, two-sided access is required for full inspection; for laminated structures, one-sided access may be adequate. No records are produced by this instrument and it is portable. The surface must be cleaned prior to inspection to remove obstructive surface conditions such as corrosion, blistered paint, loose dirt, etc.

**Bond Tester.** The 210 Bond Tester is another device which operates on the principle of ultrasonic resonance. The probe is placed on the surface of the part to be inspected. The transducer emits a continuous ultrasonic beam, and the frequency is adjusted to produce coupled resonance. As the part is scanned, changes in impedance are measured and monitored for unacceptable indications.

The method offers the advantage of relative ease of interpretation and low cost. Disadvantages include relative insensitivity and need for a couplant. Standards are required and no recordings are produced. The equipment is portable. Surfaces to be inspected should be clean of dirt, oil, grease, etc. Two-sided access is required for honeycomb assemblies, to achieve 100 percent coverage.

5.8.4.3.3.7 Acoustic Holography. Acoustic or ultrasonic holography employs pulse echo ultrasonic techniques and focused transducers to "illuminate" the interior of a test part with sound. Scanning the part surface produces hologram of the amplitude and position information from reflections within the part. The resulting hologram is then inserted into an optical reconstructor for viewing the interior of the part.

5.8.4.3.3.8 Acoustic Emission. The acoustic emission method is based on the detection of sound or stress wave signals created by a material undergoing some physical or mechanical transformation. The equipment consists basically of an amplifier and a piezoelectric sensor with a resonant frequency in the low ultrasonic range (175 kHz). The emission level is recorded on a chart or meter. A visible light indicates when a predetermined emission threshold has been exceeded.

Simple heating methods using a hot-air gun or heat lamp are used to increase emissions from active corrosion sources and to create the stresses necessary to break moisture-degraded adhesive bonds.

Actual inspection results have shown that corrosion can be detected, particularly in honeycombs, to a depth of 2-3 inches. Corrosion has been successfully monitored in 8-inch honeycomb with 3/8-inch skin.

After heating, normally 15 seconds or less is required to establish the presence or absence of active corrosion. Direct inspection cost savings of over 75 percent are claimed over comparative X-ray and ultrasonic techniques.

It is important to note that acoustic emission detects corrosion only if moisture is present and corrosion is actively taking place. If corrosion is passive, acoustic emission will not detect it.

5.8.4.3.4 Radiography. Radiography is an NDI method that allows a view of the interior of the part being inspected. The method is relatively expensive, but it provides the advantage of a permanent film record. Special precautions must be taken because of the potential radiation hazard. In most cases the part being inspected is taken to the X-ray laboratory where shielding and film processing facilities are available. However, portable equipment is available and the inspection can be performed at remote sites. To produce acceptable results close control of the process is required, including daily checks of the film processing chemicals and the use of verification standards (penetrameters). Radiation safety requirements should not be bypassed, and trained personnel who thoroughly understand the process are needed.

Representative areas commonly inspected by radiographic techniques include:

- Core splices.
- Core shear tie to closure members.
- Intersection of core and two or more closure members.
- Metal-to-metal joints.
- Metal-to reinforced plastic joints.
- Voids in foam joints.
- Chemically milled line and external detail.
- Core ribbon direction.
- Core cell size.
- Foreign objects.

If assemblies are inspected using fluoroscope radiographic techniques, all questionable areas should be radiographed using film techniques. The most distinct radiographic appearance of an anomaly occurs when the finest grain film (Type I film) and the lowest X-ray energy are used, consistent with a given specimen thickness and practical exposure time.

All radiography work should be done in accordance with the requirements of MIL-STD-453.

5.8.4.3.4.1 X-Ray and Gamma Radiography.

Conventional radiographic methods used a source of X-rays or gamma rays to detect anomalies in the part through differential densities in the material. A typical radiograph exposure setup is shown in Figure 5.8.4.3.4.1(a). In passing through the material (the part being inspected), some of the radiation is absorbed or changed. The amount of absorption is dependent upon the thickness of the material, the density of the material, and the atomic number of the absorber. The intensity of the emerging beam of radiation is recorded by the X-ray film.

The penetrameter is a small strip of the same material as the specimen and has a thickness that is a definite ratio to the thickness of the part–2 percent. If the penetrameter and the holes are clearly outlined on the radiograph, the penetrameter sensitivity is said to be 2 percent or better. Refer to

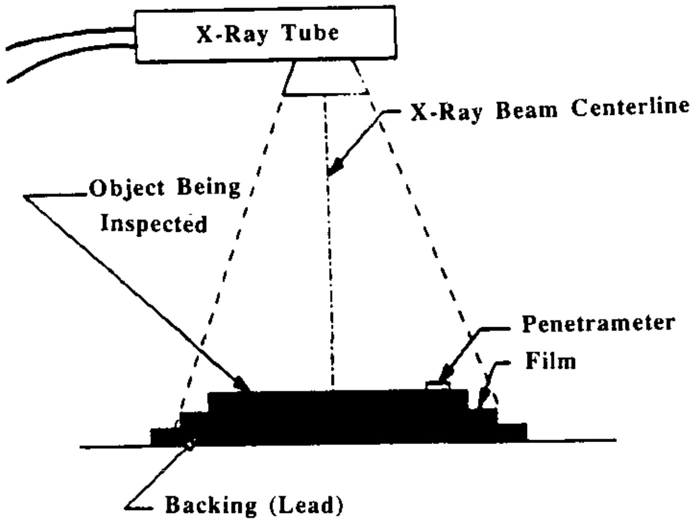



*FIGURE 5.8.4.3.4.1(a) Typical radiographic exposure setup.*

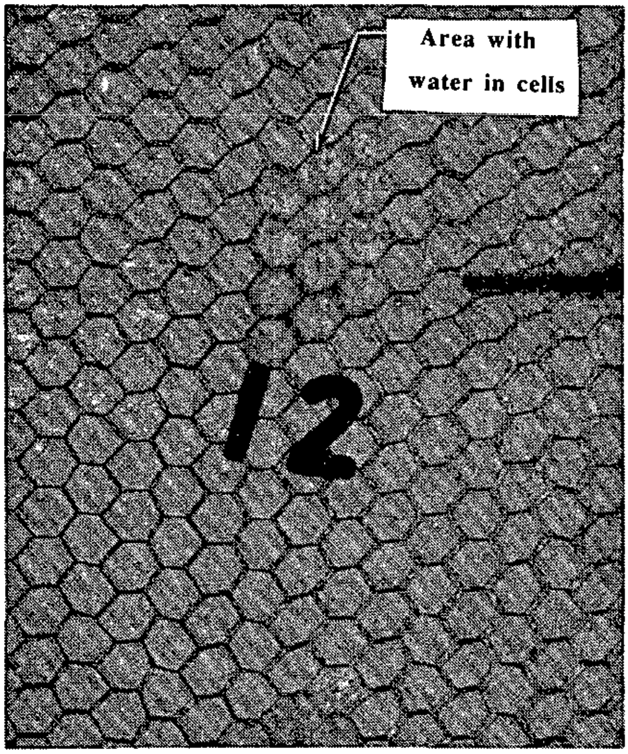



*FIGURE 5.8.4.3.4.1(b) Radiograph of cell moisture.*

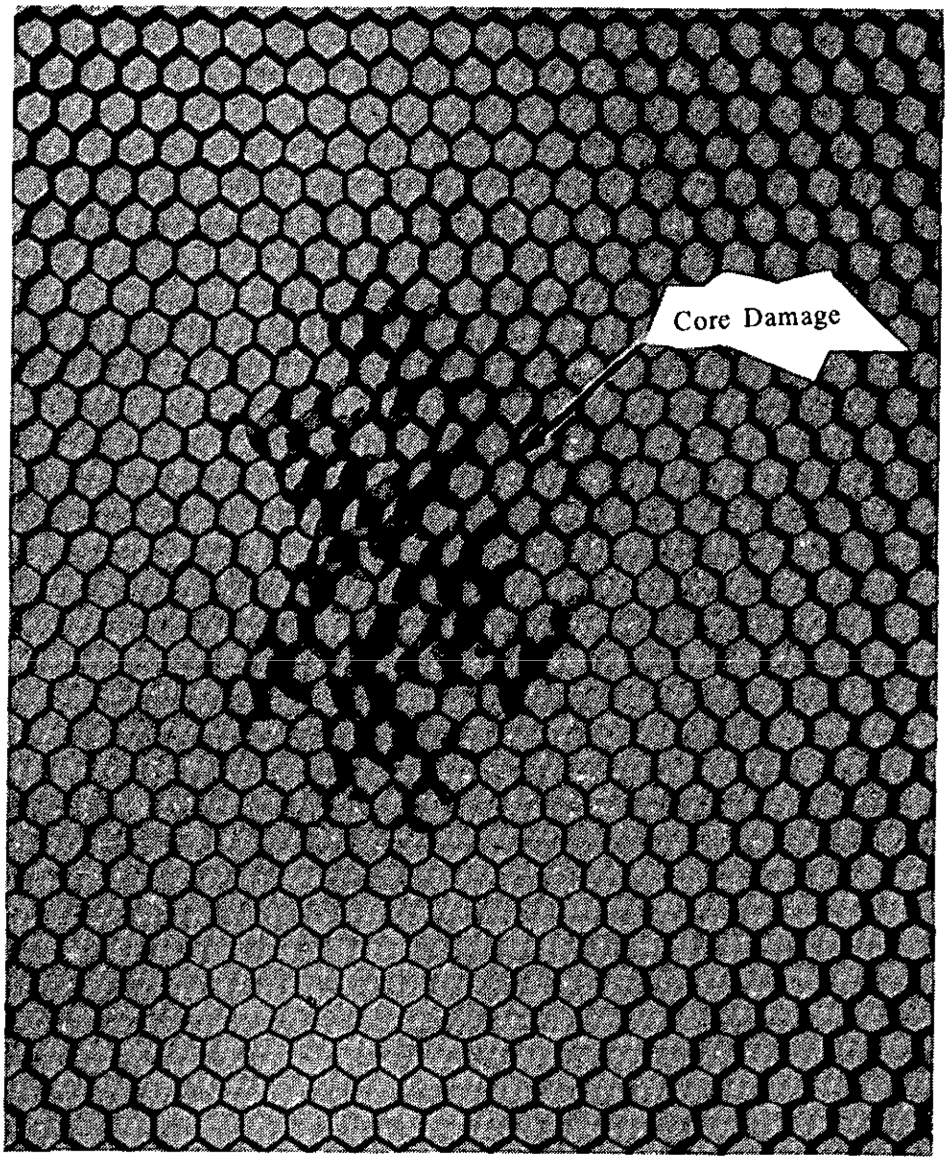



*FIGURE 5.8.4.3.4.1(c) Radiograph of crushed core.*

MIL-STD-453 for specific procedures. A penetrameter is used to indicate the quality or sensitivity of a radiograph and is not a measure of the size of a hole or cavity that may be detected.

Radiography is not the preferred method for detecting defects, such as delaminations that are in a plane normal to the radiation beam; the thickness of the delamination in the direction of the beam may be orders of magnitude less than the penetrameter sensitivity. Radiography is most effective method for detecting the presence of water in a honeycomb core cell. It is also very effective in identifying a core that has been dislocated or damaged or voids in bond lines parallel to the radiation beam direction. Various types of defects that can be detected by radiography are described below.

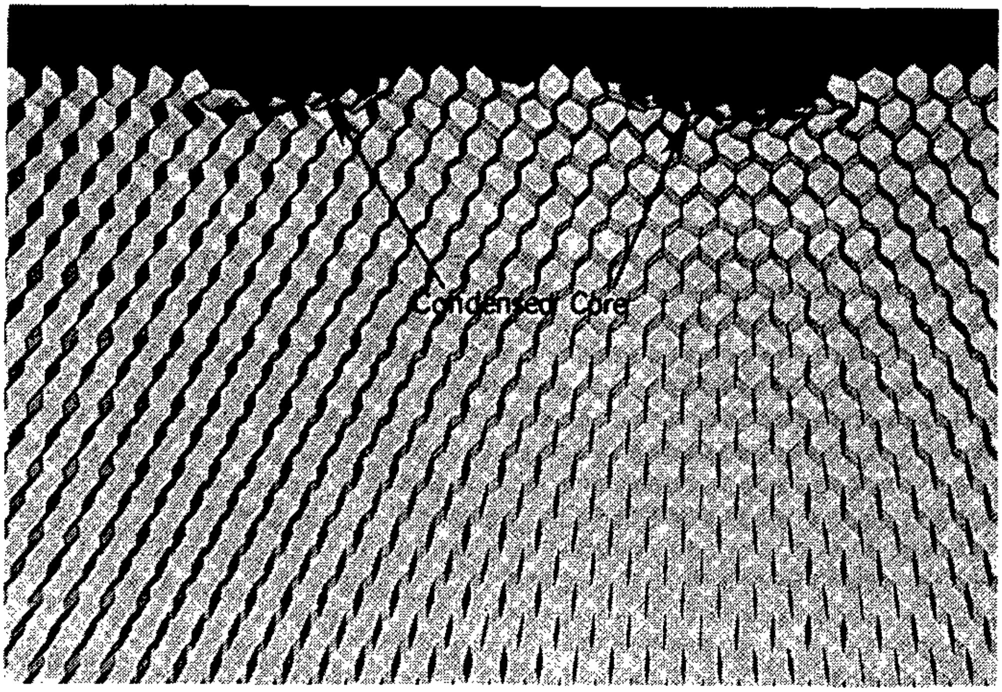



*FIGURE 5.8.4.3.4.1(d) Radiograph of condensed core.*

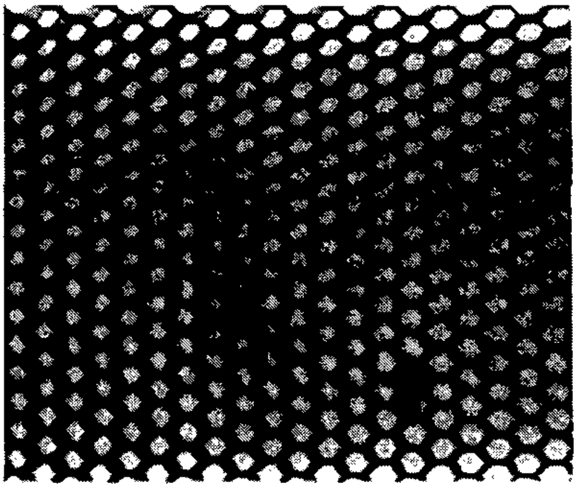


*FIGURE 5.8.4.3.4.1(e) Radiograph of node separation.*

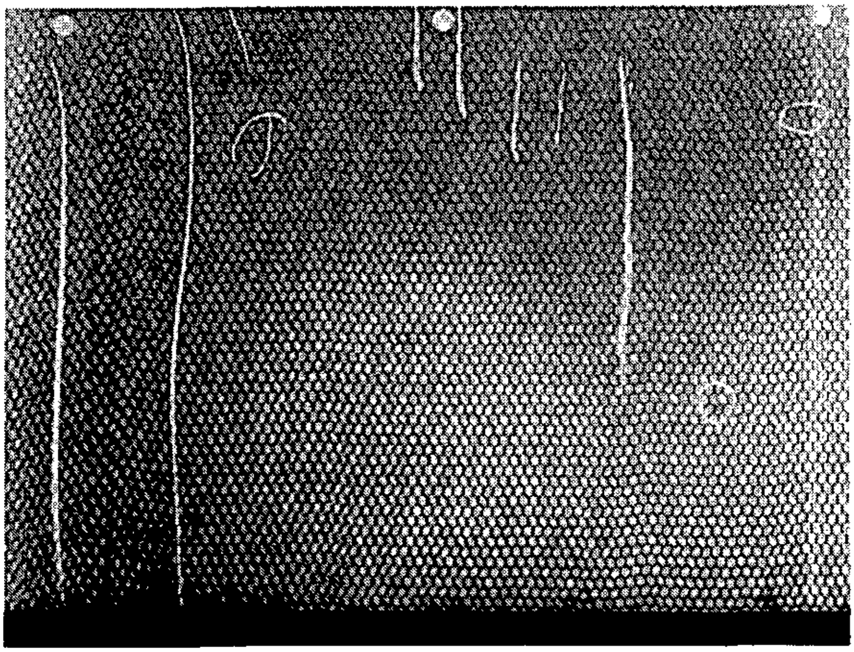


*FIGURE 5.8.4.3.4.1(f) Radiograph of blown core. (Note circled areas)*

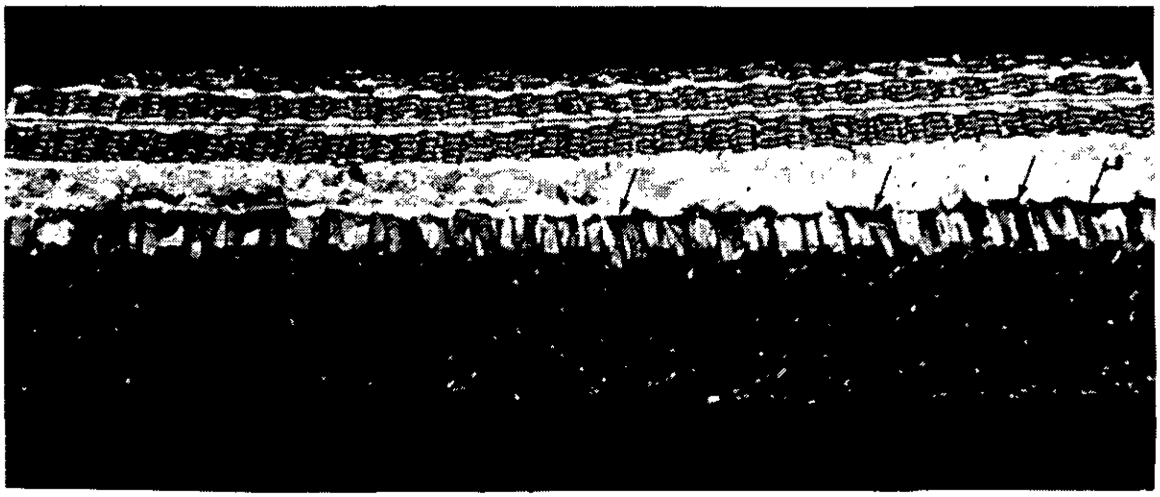


*FIGURE 5.8.4.3.4.1(g) Radiograph showing voids in foam adhesive at edge member.*

**Water in Core Cells.** Water in the core may be detected radiographically when the cells are filled to as little as 10 percent of the core height. Detection sensitivity is dependent upon the sandwich skin thickness and the radiographic technique. A problem may occur in the ability to determine whether the suspect area indicated has excessive adhesive, filler, or water. Water images usually have the same film density from cell wall to cell wall, whereas adhesive or filler images may vary

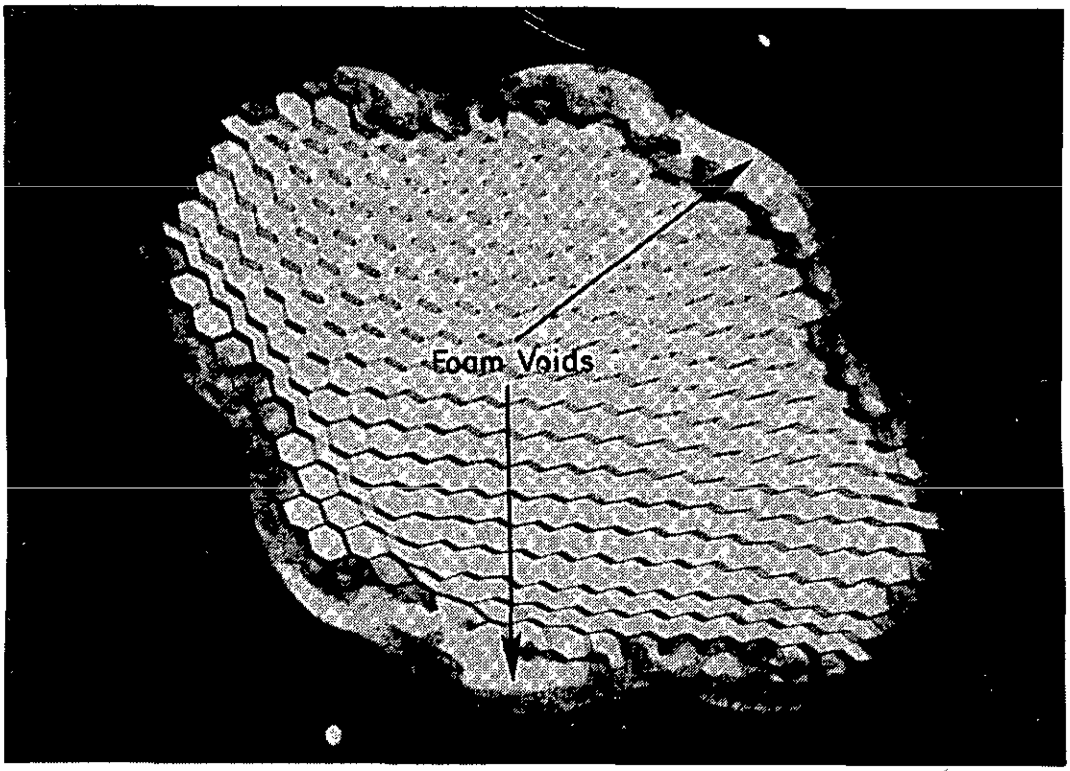



*FIGURE 5.8.4.3.4.1(h) Radiograph showing area where foam failed to fill void between fitting and core.*

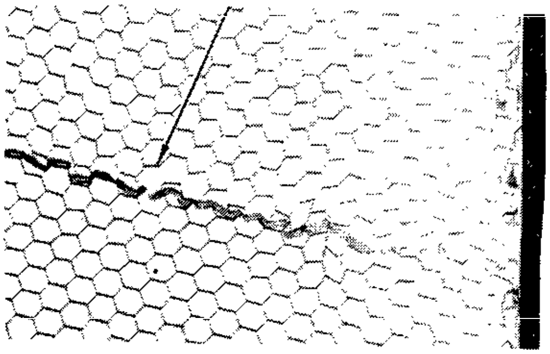


*FIGURE 5.8.4.3.4.1(i) Radiograph of failure of foam adhesive to expand into adjacent cells.*

in film density within the cell and may show indications of porosity. A radiograph of moisture in a honeycomb is shown in Figure 5.8.4.3.4.1(b).

**Crushed Core.** This condition may be associated with a dent in the skin. Crushing of the core greatly diminishes the core's ability to support the face sheets. A radiograph indicating a crushed core is shown in Figure 5.8.4.3.4.1(c).

**Condensed Core.** When the edge of the core is compressed laterally, the core is condensed. This may result from bumping the edge of the core during handling or slippage of details during bonding. Figure 5.8.4.3.4.1(d) shows a core that has been condensed by excess expansion of the adhesive at the core-to-fitting splice.

**Node Separation.** This condition is the separation of the foil ribbons at the nodes, which this usually occurs during core fabrication. It may also result from pressure build-up in cells as a result of vacuum bag leaks or failure, which allows the pressurizing gas to enter the assembly. A radiograph of a failure of this type is shown in Figure 5.8.4.3.4.1(e).

**Blown Core.** Blown cores occur after a bag break or as a result of a sudden change of pressure in the curing cycle. The pressure change produces a side loading on the cell walls that can either distort the cell walls or break the node bonds.

Radiographically,

1. Single cell damage usually appears to be round or elliptical with a partial node-bond separation.

2. Multicell damage usually appears as a curved wave front of core ribbons that are condensed together as shown in Figure 5.8.4.3.4.1(f).

This condition is most likely to occur at the part edge, in an area close to the external surface where the greatest effect of a sudden change in pressure occurs. The condition is most prevalent where there are leak paths, such as gaps in the closure ribs to accommodate fasteners, or in chemically milled steps in the skin where the core may not be fit properly. This condition is readily detected with radiography when the X-ray beam centerline is parallel to the core cell walls. When associated with skin-to-core unbonds, the condition is detectable with pulse echo and through-transmission ultrasonics.

**Voids in Foam Adhesive Joints.** Flaws in core-to-core or core-to-fitting foam joints can results from any of the following conditions. Radiography is used to detect many of these.

1. The foam adhesive can slump or fall leaving a void at an edge member as shown in Figure 5.8.4.3.4.1(g). This particular condition is most readily detected with ultrasonic techniques.

2. The core may be cut too small and the foam does not expand uniformly to fill the excess area. This condition is clearly shown in Figure 5.8.4.3.4.1(h).

3. The foaming adhesive can fail to expand and surround core tangs. This is shown in Figure 5.8.4.3.4.1(i).

5.8.4.3.4.2 Low Voltage Radiography (25-50 kV). The linear attenuation coefficient of a given material is a function of the energy of the X-ray beam. As the potential on an X-ray tube is lowered, the X-rays produced do not penetrate as well. This phenomenon provides an advantage when radiographing thin and low density materials. The lower the kV used, the higher will be the image contrast of the radiograph. This is the reason that the lowest possible kV should be used consistent with reasonable exposure times. For parts with large variations in material thickness, a higher kV may be used (sacrificing image contrast) to inspect the part with only one radiograph.

Considerable work has been done on bond line inspection techniques and the development of accompanying inspection standards. Other than a dense adhesive, additional items that are important to accomplishing bond line inspection are:

1. Low X-ray kV.
2. High-contrast film.
3. An experienced machine operator and film interpreter.

Examples of types of defects that can be successfully detected in filled adhesives using proper procedures are shown in Figures 5.8.4.3.4.2(a)-(c).

**Metal-to-Metal Flaws.** Disbonds of this type can occur when the core is slightly higher than a closure member, when there is a lack of pressure tooling, or when air is trapped in the adhesive prior to cure. This type of flaw is readily detected by low kV X-ray techniques [see Figure 5.8.4.3.4.2(a)]. If the flaw is the result of insufficient pressure, the adhesive will be porous, as indicated by dark spots on the radiograph. The lower the kV or the thicker or denser the adhesive, the higher will be the resolution of the flaw image. In general, the flaw size detectable by radiography is smaller than that detectable by ultrasonics.

**Skin-to-Core Voids at Edges of Chemically Milled Steps or Doublers.** This condition occurs when the adhesive bridges or forms a gap at the edges of chemically milled or laminated steps or shoulders. On a radiograph, voids show as a dark line or an elliptically shaped dark image.

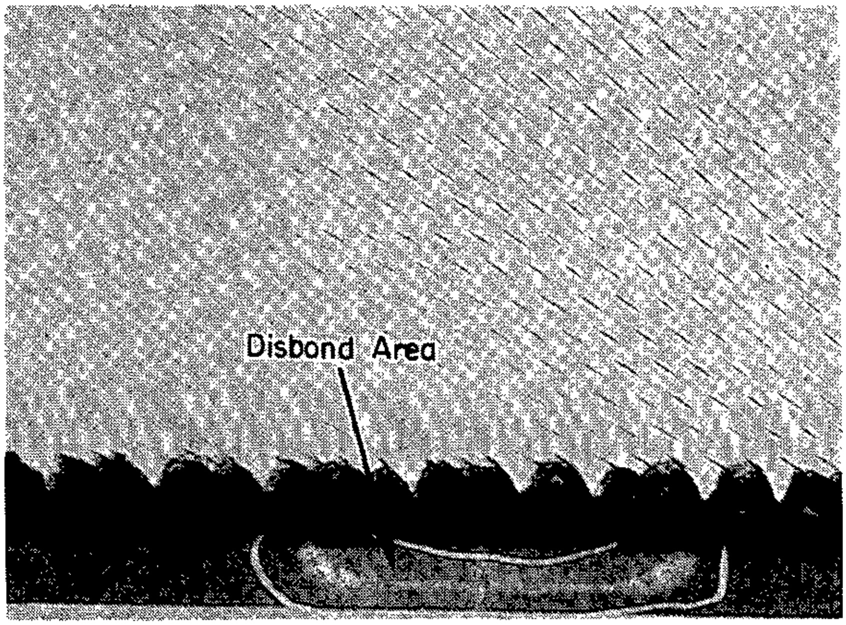



*FIGURE 5.8.4.3.4.2(a) Radiograph of metal-to-metal disbond in adhesive bond line.*

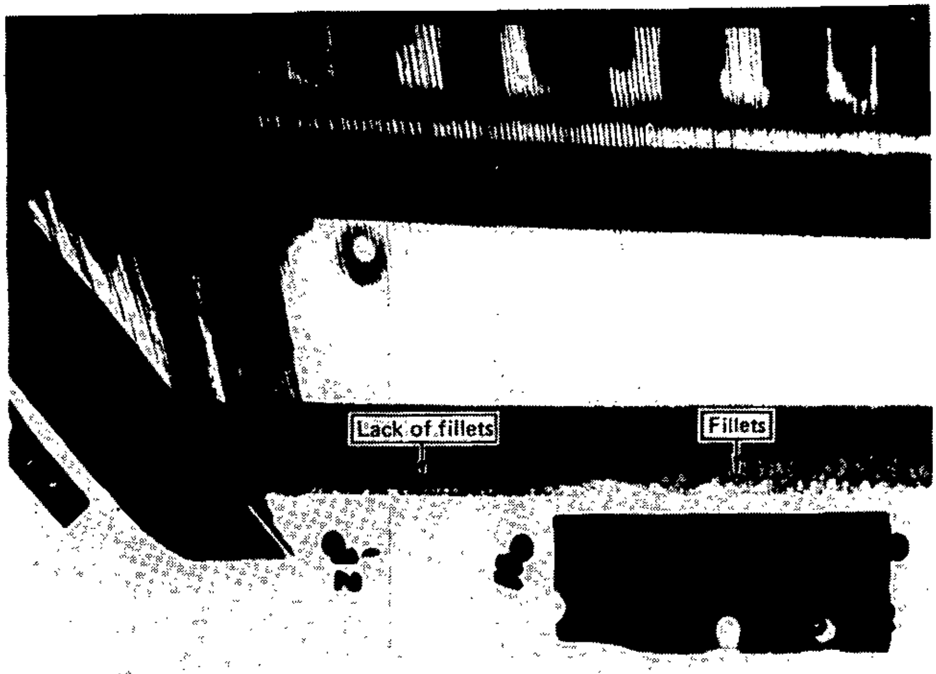



*FIGURE 5.8.4.3.4.2(b) Radiograph showing lack of filleting.*

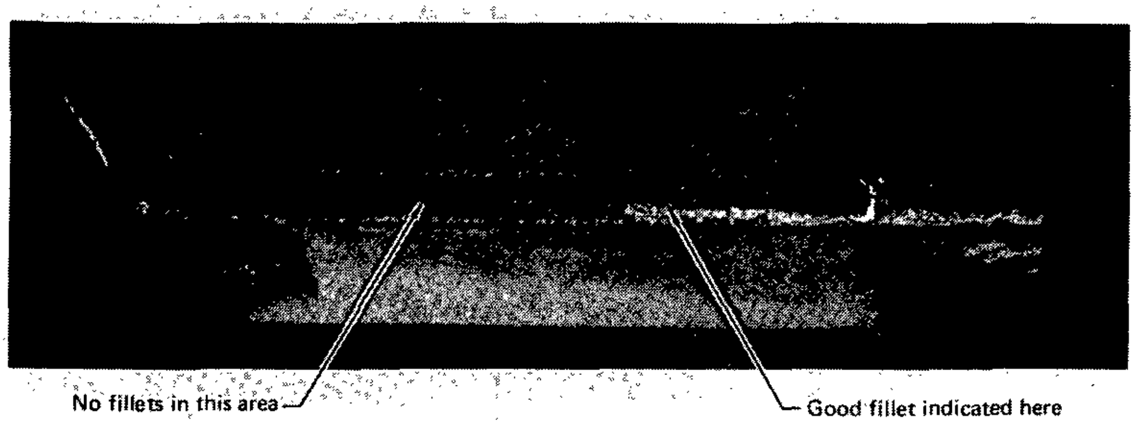
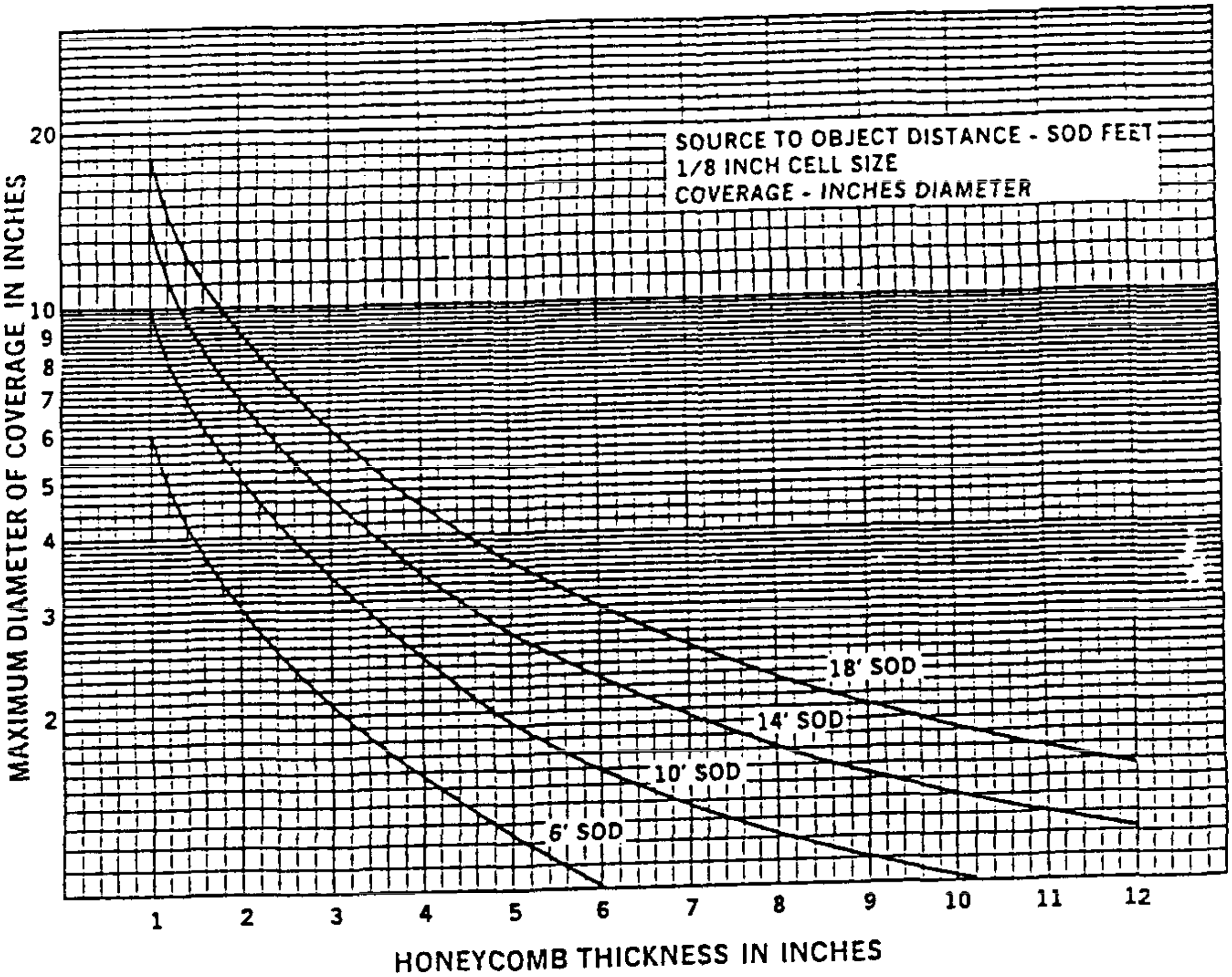



*FIGURE 5.8.4.3.4.2(c) Destructive inspection verifying radiograph indications.*

**Missing Fillets.** As pressure is applied during the bonding cycle, adhesive fillets are formed at the edges of each honeycomb cell. If pressure is not maintained properly or the adhesive is outdated or weak, no fillets will be formed. Missing fillets are detected by directing the X-ray beam at an angle of approximately 30-45 degrees to the centerline of the core or closure web. The fillets appear as dark semicircles or hexagons in a gray matrix, with the cell walls forming intersecting white lines. Lack of fillets is indicated by lack of semicircles or hexagons [Figure 5.8.4.3.4.2(b) and (c)].




**NOTE**

This chart gives the amount of usable film coverage for 1/8-inch cell size honeycomb with four different source to object distances. When a different cell size or source to object distance is encountered. The maximum diameter of coverage, D, in inches shall be:

D = 2 C (SOD) / 3t

when

*t* = *honeycomb thickness (inches)*

C = cell size (inches)

SOD = source to object distance (inches).

***FIGURE 5.8.4.3.4.4 Maximum coverage of radiographs for honeycomb structure.***

TABLE 5.8.4.3.4.5 Radiographic equivalence factor relative to aluminum.

| Material | Energy Level, kV peak | | | | |
|---|---|---|---|---|---|
| | 10 kVp | 20 kVp | 50 kVp | 100 kVp | 150 kVp |
| Aluminum | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 2XXX and 7XXX Aluminum | | | 1.4 | 1.2 | 1.1 |
| FM 300 Adhesive | 0.16 | 0.28 | 0.45 | | |
| Fiberglass | | | 0.35 | | |
| Graphite/Epoxy | 0.06 | 0.06 | 0.07 | | |

5.8.4.3.4.3 Radiation Sources. Only tube type radiation sources should be used. The source should be capable of producing the voltages and quality levels necessary for the inspection of aluminum honeycomb parts (particularly the lower voltages). The focal spot size should be determined in accordance with Section 5.8.4.3.4.5 to produce radiographs of acceptable geometric sharpness.

5.8.4.3.4.4 Radiation Beam Geometry. Select the minimum distance from the object being radiographed to the source of radiation using the following relationship:

$$d = Ft/U_g$$

where

d = Source to object distance.

F = Physical size of the radiation source (spot size).

t = Object to film distance.

$U_g$ = Allowable geometrical unsharpness.

For honeycomb sandwich sections, the $U_g$ permitted is 0.0075 inch.

The maximum coverage per radiograph for film methods is shown in Figure 5.8.4.3.4.4. Note that this is for a source-to-film distance of 72 inches. If the source-to-film distance is less than 72 inches, compute the maximum diameter of coverage using the equation given in Figure 5.8.4.3.4.4.

5.8.4.3.4.5 Radiographic Equivalence Factors Relative to Aluminum.

Table 5.8.4.3.4.5 tabulates radiographic equivalence factors for several materials that are frequently encountered in connection with the inspection of honeycomb parts.

5.8.4.3.4.6 Film and Film Processing. Radiographs should be produced on Type 1 or Type 2 films as defined by ASTM E 94. Type 1 film should be used if viewing for interpretation is to be performed at 2X or greater.

TABLE 5.8.4.3.4.7 Quality level of inspection.

| Radiographic Quality Level | Penetrameter Designation | Penetrameter Thickness | Penetrameter Hole Diameter | Equivalent Penetrameter Sensitivity |
|---|---|---|---|---|
| 00 | 1-1T | 1% | 1T | 0.7% |
| 0 | 1-2T | 1% | 2T | 1.0% |
| 1 | 2-1T | 2% | 1T | 1.4% |
| 2 | 2-2T | 2% | 2T | 2.0% |
| 3 | 2-4T | 2% | 4T | 2.8% |

Film inventories should be maintained on a first-in, first-out basis. Film storage facilities should protect the unexposed film from light, penetrating radiation, excessive heat and humidity, and damage from fumes.

Film holders or cassettes should be consistent with the kV used (care should be exercised using cardboard or fibrous cassettes below 50 kV).

Films should be processed only in the chemistry designed for the particular film, and the manufacturer's instructions should be followed closely. Careful attention must be paid to the proper maintenance of automatic processing equipment. The radiographs should be consistently uniform and free from blemishes such as scratches, roller pressure marks, water spotting or streaks, static marks, halation, and fogging.

For manual processing, a log should be maintained to show the number and sizes of films processed (film area).

5.8.4.3.4.7 Penetrameters. A penetrameter or image quality indicator is a strip of metal of the same material as the part being inspected, in this case, aluminum. The thickness of the penetrameter is normally 1 or 2 percent of the thickness of the part being inspected. In the case of honeycomb parts, the thickness of core is ignored in determining the penetrameter thickness.

The penetrameter has three holes: one whose diameter is equal to the thickness of the penetrameter, a second twice the thickness, and a third four times the thickness of the penetrameter. These holes are referred to as the 1T, 2T, and 4T holes.

The penetrameter will have lead numbers indicating either (1) the thickness of the penetrameter in mils, or (2) the thickness of the material being inspected for which the penetrameter thickness is 2 percent. The penetrameter may or may not have lead letters indicating the material of the penetrameter: Al for aluminum.

There are five radiographic quality levels of inspection, as shown in Table 5.8.4.3.4.7.

To obtain a quality level of 00, the penetrameter placed on the part must be 1 percent or less of the thickness of the part and the 1T hole must be visible on the radiograph. Generally, a 2 percent penetrameter should be used for honeycomb parts. This requires that the penetrameter be 2 percent or less of the thickness of the honeycomb skins (front and back), and that the 2T hole be visible on the radiograph.

The penetrameter should be placed at the least advantageous position on the radiograph: at the outer edge of the cone of radiation, and on the source side of (on top of) the part so that the geometric unsharpness is at it greatest.

It is important to remember that penetrameter sensitivity, 1 or 2 percent, is an indication of the ability of the radiographic process to show a difference in material thickness and detail definition. Penetrameter sensitivity is not a measure to the smallest flaw that may be detected. Details of penetrameter construction are contained in MIL-STD-453C.

If the inspection specification for the part permits, wire penetrameters may be used. These penetrameters have a series of wires of graded diameter. Further information about wire penetrameters is contained in ASTM E 747-90.

5.8.4.3.4.8 Screens, Backing, and Masking. Lead or lead-oxide intensifying screens should be free from scratches, wrinkles, and surface streaks of low atomic number. Screen identification that appears on the radiograph is recommended. The screen should be maintained in intimate contact with the film. For radiographs made at:

| | |
|---|---|
| 0-100 kV | No front screen is required, and a 10 mil back screen should be used. |
| 100-200 kVA | 5 mil front screen should be used with a 10 mil back screen. |
| 200-300 kVA | 10 mil front screen should be used with a 10 mil back screen. |

For 25-120 kV, Kodak Ready Pack or equivalent may be used provided the Ready Pack is in intimate contact with a backing material (1/8 inch lead). For 100-200 kV, Kodak Lead Pack or equivalent may be used.

All radiographs made at constant potential or above 50 kV should be backed with at least 1/8 inch of lead.

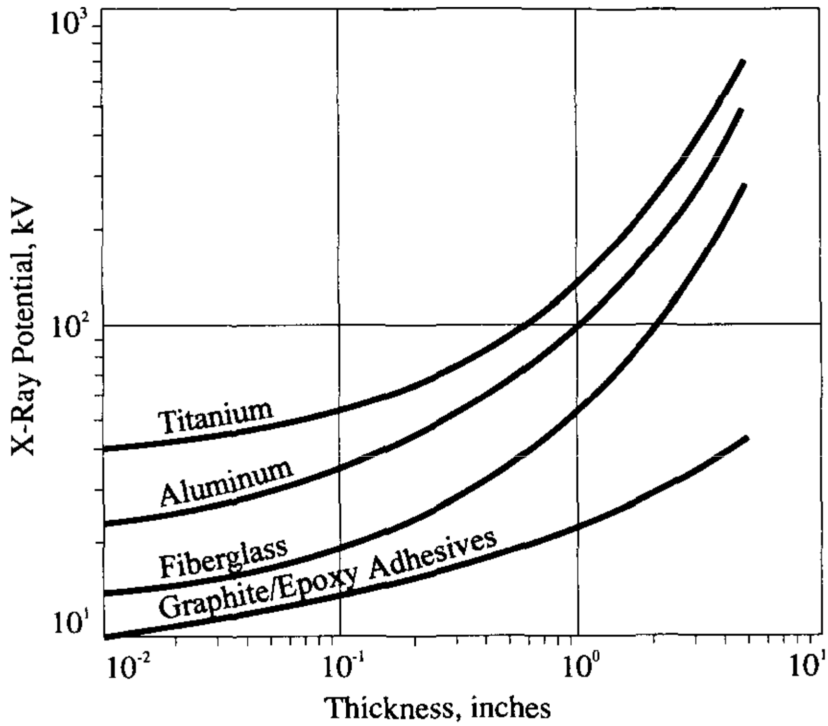
Shot and foils may be used for masking. Shot should be a mixture of diameters to provide a uniform density. Foils should be free from nicks and wrinkles. Lead salt solutions should be used only with the approval of the facility quality assurance authority. Masking should be completely removed prior to subsequent processing.

5.8.4.3.4.9 X-Ray Potential. Radiographs should be taken at the lowest practical voltage, consistent with exposure time. Figure 5.8.4.3.4.9 shows recommended X-ray potentials for various thicknesses of honeycomb structures. Note that the thickness shown in Figure 5.8.4.3.4.9 is the total thickness of skins + caps + flanges + adhesives, BUT NOT THE CORE OR FOAM ADHESIVES.

5.8.4.3.4.10 Viewing Facilities and Illuminators. Background illumination should be approximately the average brightness of the image to be interpreted. No direct light or reflection from external objects should appear on the radiograph, monitor, or screen being interpreted. For nonfilm methods, the brightness of the viewing screen should be in the range of 3-6.5 candelas per square meter during interpretation.

A magnifying glass from 3-10× may be used. A 7× optical comparator with a film contacting reticle is recommended for sizing flaws.

Illuminators should be a variable light source capable of transmitting at least two foot-candles through a radiograph with a film density of 4.0 at the viewing surface (minimum of 100,000 candelas per square meter at the viewing surface). The level of illumination should be uniform over the entire viewing surface. Opaque masks or a variable aperture should be provided to reduce the




Thickness = Skins + Caps + Flanges + Adhesive

***FIGURE 5.8.4.3.4.9 Recommended X-ray potential.***

viewing area. A cooling system should be provided so that the film is not damaged after 10 minutes of continuous contact with the viewing surface.

5.8.4.3.5 Image Processing and Other Enhancement Methods. Conventional radiography is an analog form of imagery. Before the image can be processed and enhanced, it must be converted to a two-dimensional grid of numeric values. This function is performed by a picture digitizer. The picture digitizer samples the light intensity at points across the radiographic image into a numeric gray scale, commonly with 8 bit resolution or 256 gray levels. Scanning two dimensional microdensitometers are very accurate, but take minutes to scan a useful film area. For many applications, photometric and geometric accuracy can be sacrificed for lower cost and higher scan rates. Image processors contain video rate analog-to-digital (A/D) converters from the output of a standard television camera. The TV image is converted to a 512 × 512 array of 1 byte (8 bit) words. Higher accuracy and resolution is available. The image processors can store one or two images for transfer to computer memory. The image data may come directly from a TV camera without the film stage as real-time radiography (fluorography). The state of imaging hardware is changing quickly, and a description of available devices is beyond the scope of this document.

Image enhancement uses a wide range of techniques that are usually mathematically straight-forward. Several different pictures may be combined to improve the visibility of otherwise obscure image features by suppressing random noise. The digitized image may contain 256 intensity or gray levels. The eye can only distinguish a much smaller number of shades of gray. The image contrast can be enhanced by selecting a narrow range of gray level and expanding the displayed intensities.

$$\begin{matrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{matrix}$$

Smoothing

$$\begin{matrix} 0 & 0 & 0 \\ 1 & 0 & -1 \\ 0 & 0 & 0 \end{matrix}$$

Differentiate X Direction

$$\begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{matrix}$$

Differentiate Y Direction

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix}$$

Approximate Laplacian

$$\begin{vmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{vmatrix} + \begin{vmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{vmatrix}$$

Edge Detector

3 X 3 FILTERS

***FIGURE 5.8.4.3.5 Image enhancement filters.***

A common input/output function of an image enhancement routine is a linear function, but other functions are readily implemented. False color enhancement is possible.

TV frame summing is a means of suppressing random noise. Another method is referred to as "leaky-bucket" averaging, where the resulting image after equilibrium is reached is a geometrically weighted sum of past TV frames. For static objects, leaky-bucket averaging does not reduce noise as effectively as frame summing.

Small blemishes or irregularities in the target layer of the TV tube are enhanced when random noise has been reduced by frame summing. This is a problem with real-time radiography where the TV tube blemish can be read as a component defect. The displaced difference method can remove these artifacts. Two TV pictures of a component are required, with the component displaced laterally between images. The artifacts are not displaced. A third image is computed by subtracting the displaced image pairs.

Enhancement techniques, in which the value of neighboring pixels is considered, necessarily change the spatial frequency content of the picture. Many spatial operations that may be applied to pictures. Spatial filtering with small filters (3 X 3) requires an order of magnitude more computation than point-by-point enhancement methods. For larger filter sizes, the computational requirements increase.

If a picture is badly affected by random noise, a smoothing (low-pass) filter will reduce the noise. The visibility of lines and edges may be enhanced by a high-pass filter. Five commonly used 3 X 3 filters are shown in Figure 5.8.4.3.5.

5.8.4.3.6 Leak Test. A leak test is performed by submerging the part in approximately 170°F water for 2 minutes and observing it for air bubbles along bond joints. The leak area should be marked while the assembly is under water. All air bubbles are not necessarily leaks; entrapped air on the outside surface of the part may appear to be a leak. Air bubbles can travel along the part surface before coming to the water surface; carefully determine the source of the bubbles. Remove the panel and dry immediately by wiping with cheesecloth or other absorbent material. The area around a leak should be wiped quickly to prevent water being sucked into the assembly as the part cools.

The inspection facility will require a mechanism to lower and raise the assembly from the water. Bonded honeycomb assemblies float.

A leak test should be performed after fastener installation and sealing. Leaking parts may be retested after a resealing operation only one time, unless otherwise stated by the procurement specification.

Equipment requirements for leak testing are reviewed in Section 4.6.2.14.

5.8.4.3.7 Optical Holography. Optical holography is a method of recording the amplitude and phase of the optical wave fronts reflected from an object such that, when reconstructed, these wave fronts have the relative amplitude and phase of the original wave fronts. Three-dimensional properties are contained in the image of reconstructed wave fronts.

In practice, a stress is applied to the part and a hologram made of the stressed area. Slight movement of the surface being viewed by holography during stressing may be detected and show a defect in the bonded part.

The main limitation of optical holography is the necessity to isolate the part and inspection system from extraneous movement.

5.8.4.3.8 Eddy Current. The eddy current inspection method is applicable to parts and materials that are electrically conducting. The anomalies may be either physical or metallurgical.

In eddy current inspection, an alternating electrical current in a probe coil has a corresponding magnetic field that penetrates the material being inspected. This alternating magnetic field induces an electrical current (eddy current) in the electrically conductive material. The flow of the eddy current is affected by the geometry (including physical anomalies) and the conductivity (the metallurgical state) of the material. The eddy current in turn has a corresponding magnetic field that causes currents to flow in a pickup coil. Information about the state of the material being inspected is contained in the current in the pickup coil. A single coil may be used to generate eddy currents in the material being inspected and to pick up the magnetic field being generated by these eddy currents. In this case the state of the material being inspected is contained in the impedance of the probe coil.

The technique is most effective for detecting anomalies near the surface of the part the higher the frequency, the less the depth of penetration (skin effect). The primary advantages of the eddy current method are (1) it can detect irregularities concealed by paint or dirt embedded in a crack and (2) it does not require a couplant. The eddy current method is generally used to detect three types of defects:

1. Cracks.
2. Faying surface and intergranular corrosion.
3. Heat damage.

Cracks commonly occur at fastener holes in panel edges. Typical locations of fastener cracks are shown in Figure 5.8.4.3.8.

Fasteners holes may be inspected from the surface with the fastener installed or the hole may be inspected with the fastener removed. With the fastener in place, more gross cracks with a minimum length of 1/4 inch may be detected. Cracks may be detected to a depth of 0.2-0.3 inches below the

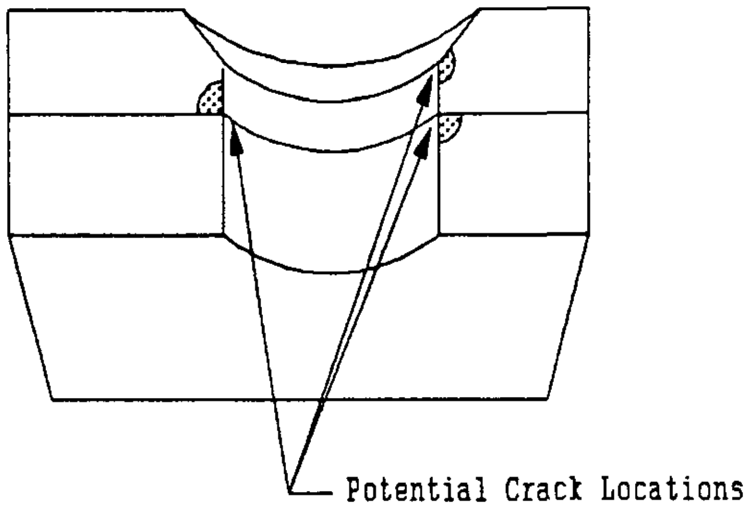



*FIGURE 5.8.4.3.8 Typical fastener crack locations.*

surface, depending on the operating frequency of the particular instrument used. With the fastener removed, cracks with lengths as short as 0.030 inch may be reliably detected.

Because the eddy current method is sensitive to metal grain structure and electrical conductivity, it may be used for the inspection of interface corrosion under body skins and to detect damage to the metal caused by high heat exposure.

The major limitation lies in the small size of the eddy current coil. The small coil must be scanned over the area of interest, and in practice the inspection area is 3/16 inch in diameter. The time for inspecting each point may vary from 30 seconds to 5 minutes depending on the type of reading and instrument being used. For large surfaces, this means long inspection times. Other limitations are that the specific nature of the anomalies may not be clearly identified and the inspection of ferromagnetic metals is sometimes difficult.

5.8.4.3.9 Dielectric Measurements. The degree of cure of composite patches may be monitored during curing. Two metal conductors are placed on the surface of the composite so that the patch is between them. Free molecules act as dipoles; and, as the cure progresses, the free molecules attach to the polymer chains and no longer act as dipoles. The inductance drops as the cure progresses, and the cure is complete when the inductance no longer changes.

A similar method measures the resistance, which increases to a steady state level when the cure is complete. Conductors may be inserted into the patch from one side only, requiring access to only one side.

These methods are low cost, do not require special training, and are portable.

5.8.4.4 NDI Set-Up and Calibration Methods.

Ultrasonic Inspection Equipment. Reference standards are required for calibrating ultrasonic inspection equipment prior to, during, and at the completion of inspection sessions. For contact techniques, reference standards containing defects are required. For squirter or immersion ultrasonic techniques, reference standards with and without defects are required.

TABLE 5.8.4.5.2 Acceptable ultrasonic inspection techniques. (See Figure 5.8.4.5.2)

| Scan Plane Number | Acceptable Ultrasonic Inspection Techniques | | |
|---|---|---|---|
| 1 | Either | (a)<br>(b)<br><br>(c) | Pulse-echo angle beam contact technique on each skin, or<br>Pulse-echo straight beam contact technique on each skin (not a ringing method), or<br>Through-transmission squirter, immersion, or contact technique. |
| 2 | Either | (a)<br><br>(b) | Pulse-echo straight beam contact technique on each skin (not ringing technique), or<br>Through-transmission squirter, immersion, or contact technique. |
| 3 | WARNING | | Pulse-echo ringing contact technique. This technique is only effective for the detection of separation between the contacted adherend and the adhesive layer. In general, rigorous compliance with acceptance class flaw sizes cannot be met. Also, ringing tests generally are not effective on composite types adherends. |
| 4 | Either | (a)<br><br>(b)<br>(c) | Pulse-echo straight beam contact technique monitoring the thickness of the doubler, or<br>Immersion reflector plate technique, or<br>Through-transmission squirter, immersion or contact technique. |
| 5 | Refer to technique 1 above. If these techniques fail to have sufficient penetration power to detect the reference defect in the reference standard, then an immersion technique may be used. | | |
| 6 | Pulse-echo straight beam contact technique monitoring the thickness of the doubler or tripler. | | |
| 7 | Through-transmission contact, or immersion technique. | | |

Standards should be representative of each structurally different area of the part. Additional standards may be required if different geometries or materials affect the test parameters. Preferred reference standards are samples of the parts being inspected with known and well documented naturally occurring defects.

Scan rates should be no faster than those used to clearly detect the defects in the reference standards. The scan index should be small enough to insure detection of the minimum dimensions of the defects. Indications that are suspected of being due to water noise or other spurious sources should not exceed the limits of any flaw size acceptance criteria.

During the inspection of the parts, the reference standards should be periodically scanned to determine if the response from reference defects continues to trigger alarm mechanisms or produce the required indications in recordings. Recalibrate at least once every two hours and after the equipment has been shut down. Observe the reflection from the entry surface of the part to further check the functionality of the equipment.

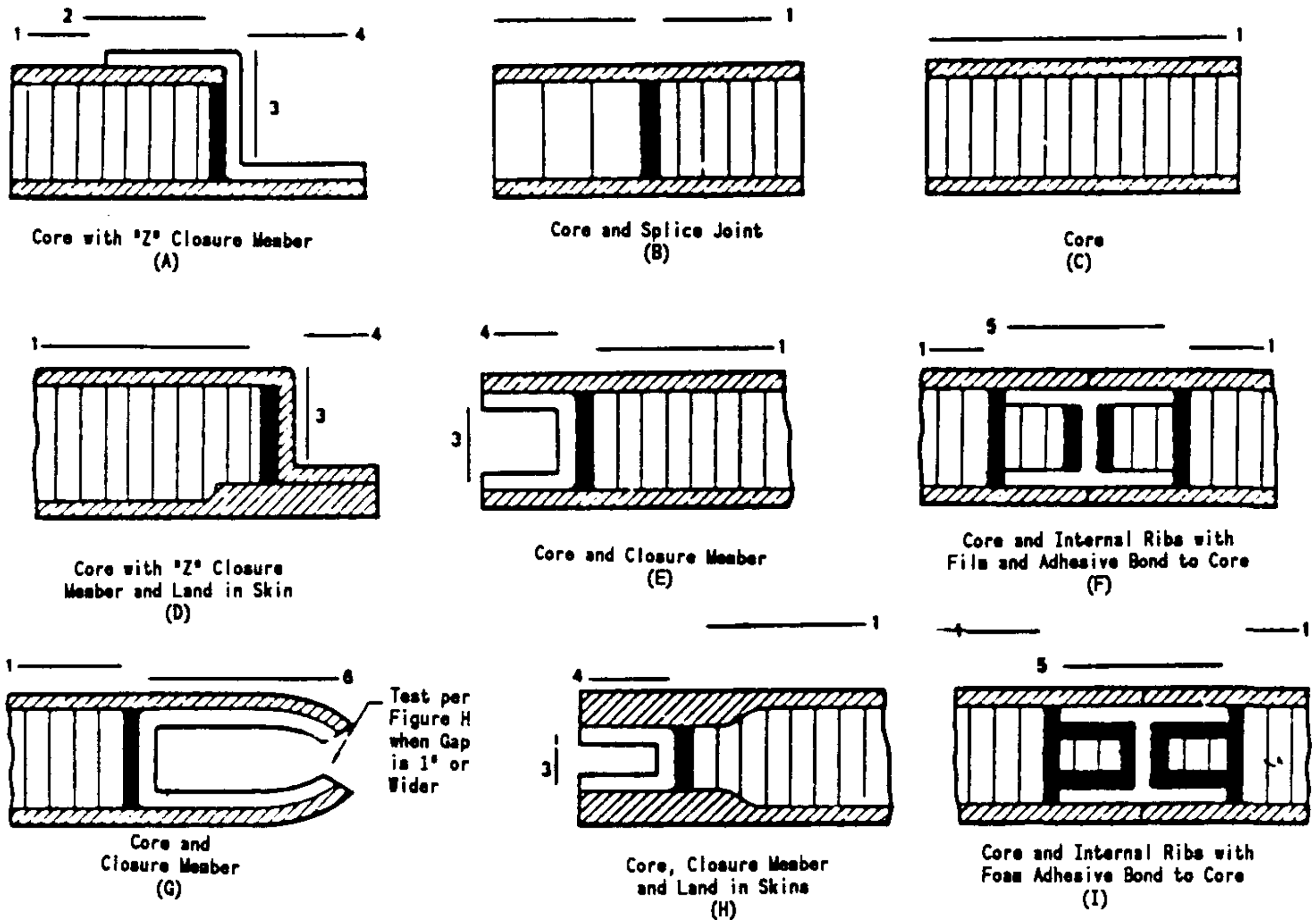



*FIGURE 5.8.4.5.2 Typical ultrasonic inspection techniques and scan planes.*

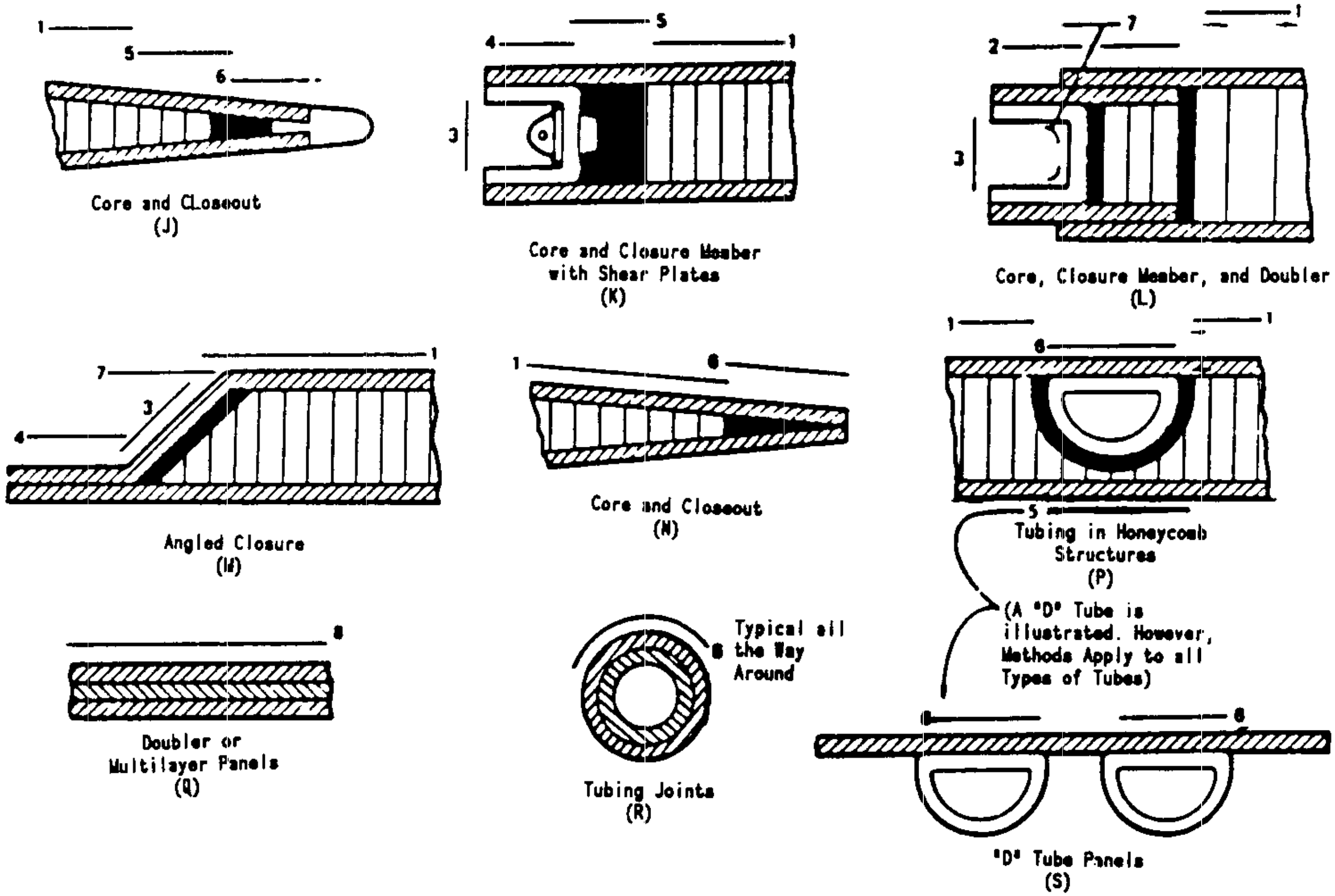



*FIGURE 5.8.4.5.2 Typical ultrasonic inspection techniques and scan planes. (Continued)*

5.8.4.5 NDI Procedures. Nondestructive inspection should be performed according to a detailed written specification for the individual part. A copy of the NDI procedure should be available to the inspection personnel while the inspection is being performed.

5.8.4.5.1 Radiographic NDI.

Radiographic nondestructive inspection should be conducted in the areas of:

1. Core splices.
2. Core shear tie to closure members.
3. Intersection of core and two or more closure members.

If the parts being inspected are samples, the sampling procedures of MIL-HDBK-106 should be used. Under these procedures an average outgoing quality limit (AOQL) = 7.5, f = 1/2 and k = 5 should be used. The plan should be truncated such that the maximum number of parts of a given lot which may be passed with inspection equals ((2/f) - 1), where f is the sample rate at any level. Sampling should start at the 100 percent sampling level.

If samples are inspected using fluoroscopic techniques, all questionable areas should be radiographed using film.

If excessive leakage is recorded during an autoclave bond cycle or during press bonding, the part should automatically be 100 percent radiographically inspected for core or core splice damage.

5.8.4.5.2 Ultrasonic NDI. Minimum ultrasonic inspection techniques may be selected from those shown in Figure 5.8.4.5.2. The ultrasonic techniques indicated by the numbers adjacent to the various part configurations are further defined in Table 5.8.4.5.2. The parts shown in Figure 5.8.4.5.2 all have parallel skins; however, the techniques are also applicable to parts with non-parallel skins.

5.8.4.5.3 Tapping. Tapping inspection is used in areas where test methods such as radiography and ultrasonics are not applicable to assure that voids do not exist. Tapping (sonic) inspection may be used to inspect skin-to-core bonds with skin thicknesses up to 0.080 inch.

Tap hammer specifications are reviewed in Section 4.6.2.12.2.

5.8.4.5.4 Rejection. A part should be rejected if the limits established by the applicable part drawings and specifications are exceeded. Refer to 5.6.7 for assemblies requiring rework. For assemblies beyond rework limits, dispose of the assembly per 5.7.7.

5.8.4.6 NDI Personnel Qualification and Certification. The effectiveness of the various NDI techniques for inspecting honeycomb panels and assemblies depends upon the proper application of the technique by trained and qualified inspectors. MIL-STD-410D outlines the qualification and certification requirements for NDI personnel, but it does not cover the requirements applicable to honeycomb panels and assemblies. Until these requirements are incorporated in MIL-STD-410, the responsibility to ensure that inspectors are qualified rests upon the users of these techniques. It is recommended that an NDI Level III inspector, as defined in ASNT Document SNT-TC-1 or MIL-STD-410, determine the type of technique to be used and write the detailed honeycomb parts and assemblies inspection procedure. A Level II inspector should perform the examination and evaluate the results of the examination to determine the repair requirements or acceptance or rejection of the repaired parts.

Guidelines for a proper training and qualification program, including specific qualification requirements, are contained in MIL-STD-410 and the American Society for Nondestructive Testing Recommended Practices SNT-TC-1 and supplements. The qualification requirements as written in these documents are specific to the inspection of metal parts by various techniques. The documents should be used as guidelines for establishing a qualification program and qualification requirements the inspecting of honeycomb parts during manufacture or rework and repair.

A list of qualified and certified nondestructive inspection personnel should be maintained, indicating qualification and certification level for the various nondestructive inspection techniques. Nondestructive inspection personnel should be requalified and certified every 2 years.

5.8.4.6.1 Government and Air Force Standards. The following specifications and standards are applicable to nondestructive inspection of honeycomb assemblies. The issue numbers of these specifications and standards should be those specified in the applicable procurement specification, which will probably be the issue listed in the Department of Defense Index of Specifications and Standards and its supplements:

| | |
|---|---|
| MIL-I-6870 | Inspection Program Requirements, Non-Destructive: For Aircraft and Missile Materials and Part |
| MIL-A-9067 | Adhesive Bonding, Process and Inspection Requirements for |
| MIL-Q-9858 | Quality Program Requirements |
| MIL-I-45208 | Inspection System Requirements |
| MIL-A-83376 | Adhesive Bonded Metal Faced Sandwich Structures, Acceptance Criteria |
| MIL-A-83377 | Adhesive Bonding (Structural) for Aerospace and Other Systems, Requirements for |
| MIL-STD-105 | Sampling Procedures and Tables for Inspection by Attributes |
| MIL-STD-410 | Nondestructive Testing Personnel Qualifications and Certification |
| MIL-STD-453 | Inspection, Radiographic |
| MIL-HDBK-337 | Adhesive Bonded Aerospace Structure Repair |

5.8.4.6.2 Industry Standards.

5.8.4.6.2.1 ASTM E 94–Standard Guide for Radiographic Testing. This standard guide has been approved for use by agencies of the Department of Defense (DoD) as part of Federal Test Method Standard No. 151b. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

This guide covers satisfactory X-ray and gamma-ray radiographic testing as applied to industrial radiographic film recording. It includes statements about preferred practice, without discussing the technical background that justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject. This guide covers:

- Materials to be inspected.
- Radiographic techniques and production methods.
- Radiographic film selection, processing, viewing, and storage.
- Maintenance of inspection records.
- Available reference radiograph documents.
- Interpretation and acceptance standards.
- Safety practices.

A copy of this document may be obtained from:

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

It is also contained in the Annual Book of ASTM Standards.

5.8.4.6.2.2 American Society for Nondestructive Testing SNT-TC-1A. This document provides guidelines for establishing a qualification and certification program. These guidelines have been developed by the ASNT to aid employers in recognizing the essential factors to be considered in qualifying personnel engaged in the following test methods:

| | |
|---|---|
| Radiographic | Neutron radiographic |
| Magnetic particle | Leak testing |
| Ultrasonic | Acoustic emission |
| Liquid penetrant | Visual |
| Electromagnetic | |

5.8.4.6.3 Company Standards.

5.8.4.6.3.1 The McDonnell Douglas Corporation, Process Specification 21240 (Reference 16). Non-destructive Testing Personnel Qualification and Certification. This specification establishes minimum requirements for training, qualification, examination, and certification of personnel. This specification meets and exceeds the requirements of MIL-STD-410. Subcontractors and vendors of McDonnell Douglas performing nondestructive testing according to this specification may not use MIL-STD-410 in lieu of this specification. Nondestructive testing methods covered by this specification include:

| | |
|---|---|
| BLT, bubble leak testing | NRT, neutron radiography |
| ET, eddy current | PT, penetrant |
| HT, holography | RT, radiography |
| IRT, infrared thermal | ULT, ultrasonic leak testing |
| MT, magnetic particle | UT, ultrasonic testing |
| MSLT, mass spectrometer leak testing | |

# 6.0 NOTES

6.1 Intended Use. This handbook is intended to present information on the manufacture and inspection of adhesive bonded, aluminum honeycomb sandwich assemblies for aircraft. It was developed specifically to be used as a reference guide that provides information useful in meeting specification requirements for individual parts.

6.2 Subject Terms (Keyboard) Listing:

APPLICABLE DOCUMENTS

QUALIFICATION

MATERIALS

CONSUMABLE MATERIALS

HONEYCOMB CORE REWORK

INSPECTION LIMITS

SURFACE PREPARATION

CURE CYCLE MALFUNCTION

SPECIMEN RETENTION

**CUSTODIAN:**

Air Force - 99

**PREPARING ACTIVITY:**

Air Force - 82

**AGENT ACTIVITY:**

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