INCH-POUND

MIL-DTL-32398
9 June 2013

DETAIL SPECIFICATION

LAMINATE: CROSS-PLIED ULTRA-HIGH MOLECULAR WEIGHT POLYETHYLENE (UHMWPE) UNIDIRECTIONALLY REINFORCED PLASTIC ARMOR

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

1. SCOPE

1.1 Scope. This specification covers an ultra high molecular weight polyethylene (UHMWPE) cross-plied unidirectional reinforced plastic laminate for use in composite armor systems.

1.2 Classification. Laminates will be of the class and type specified (see 6.2):

1.2.1 Classes.

1.2.1.1 Class A. Thermoplastic polyolefin film, non-gel spun tape.

1.2.1.2 Class B. Aqueous thermoplastic elastomer resin, gel spun polyethylene fiber.

1.2.1.3 Class C. Aqueous thermoplastic polyurethane resin, gel spun polyethylene fiber.

1.2.2 Types

1.2.2.1 Type 1. Flat, low pressure (Compression molding) (500 -2000 psi).

1.2.2.2 Type 2. Flat, high pressure (> 2000 psi).

Comments, suggestions, or questions on this document should be addressed to: Director, U.S. Army Research Laboratory, Weapons and Materials Research Directorate, Materials and Manufacturing Technology Branch, Specifications and Standards Office, Attn: RDRL-WMM-D, Aberdeen Proving Ground, MD 21005-5069 or emailed to richard.j.squillacioti.civ@mail.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil/.

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2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4 or 5 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3, 4 or 5 of this specification, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-44050	-	Cloth, Ballistic, Aramid
MIL-DTL-46593	-	Projectile, Calibers .22, .30, .50, and 20mm, Fragment Simulating

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-662	-	V50 Ballistic Test for Armor.

(Copies of these documents are available online at http://quicksearch.dla.mil or at https://assist.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

ASTM INTERNATIONAL

ASTM D123	-	Standard Terminology Relating to Textiles
ASTM D412	-	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D1425/D1425M	-	Standard Test Method for Unevenness of Textile Strands Using Capacitance Testing Equipment
ASTM D1601	-	Standard Test Method for Dilute Solution Viscosity of Ethylene Polymers.
ASTM D1777	-	Standard Test Method for Thickness of Textile Materials
ASTM D2256/D2256M	-	Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method

ASTM D2563	-	Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts
ASTM D3418	-	Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry
ASTM D3776/D3776M	-	Standard Test Method for Mass per Unit Area (Weight) of Fabric
ASTM D7269/D7269M	-	Standard Test Methods for Tensile Test of Aramid Yarns
ASTM D7744/D7744M	-	Standard Test Methods for Tensile Testing of High Performance Polyethylene Tapes

(Copies of these documents are available from www.astm.org or ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.)

2.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 First article. When specified (see 6.2), a sample shall be subjected to first article inspection in accordance with 4.3.

3.2 Materials. Materials used shall be in accordance with the manufacturer's materials specifications for UHMWPE fabrics. The materials shall be capable of meeting all the operational and environmental requirements specified herein (see 4.4).

3.2.1 Fiber.

3.2.1.1 Class A fiber. The non-gel spun UHMWPE tape used shall be continuous with no point defects from bubbles or visible trapped air (see 6.5.3), and have average lot properties as specified in Table I.

3.2.1.2 Class B fiber. The gel spun UHMWPE yarn used shall be continuous filament, with no air entanglement or texturing and no added twist, and have the properties as specified in Table I. In addition, the fiber shall meet the following requirements:

3.2.1.2.1 Relative Solution Viscosity. Relative Solution Viscosity of at least 14.5 dl/g as measured by the procedure described in ASTM D1601.

3.2.1.2.2 Spin finish. Spin finish with a FTIR (Fourier Transform Infrared) signature exhibiting absorbance peaks at 950–960 cm-1, 1110-1120 cm-1, 1730-1740 cm-1 and 3300-3400 cm-1. Spin finish is removed from the yarn by Soxhlet extraction in a two-step process, first using methanol and second cyclohexane. The spin finish is collected in a single flask and the solvent is evaporated at each step using a Rotavap. A sample of the spin finish is smeared on a KBr disk using a rubber spatula and a FTIR spectrum recorded with a FTIR spectrometer.

3.2.1.2.3 Evenness. Evenness expressed as CV% less than 3.0 measured with a Keisokki Evenness Tester 80 Type C on a 400 yard length of multifilament yarn following procedure described in ASTM D1425/D1425M.

3.2.1.2.4 Fiber Signature 1. Fiber with an FTIR signature of at least 0.27 obtained from the following expression:

(A1377-A1392) / (A1368-A1392)

Sample Preparation and Analysis: Spin finish is removed from the fiber by Soxhlet extraction with methanol for 60 minutes. After the fiber is dried, a pressed film of nominal thickness (~0.001") is made by melting ~0.1g fiber sample in a hot press at 150°C for 30 seconds at a pressure of 500 psi. After quenching the film in water, an FTIR scan is recorded with an FTIR spectrometer and absorbencies obtained at 1368, 1377, and 1392 cm-1.

3.2.1.3 Class C fiber. The gel spun UHMWPE yarn used shall be continuous filament, with no air entanglement or texturing and no added twist, and have the following properties as specified in Table I.

Table I. Fiber Properties, as spun.

PROPERTIES	CLASS A	CLASS B	CLASS C
Denier per filament (DPF) nominal denier as measured by photomicrography or calculated from nominal yarn denier, filament count and fiber density	10550-11550 (denier/in)	5.4	1.75 ± 0.25
Tenacity per denier per ASTM D7744/D7744M (Class A) or ASTM D2256/D2256M (Class B) or ASTM D7269/D7269M (Class C) (gpd)	17.0-24.0	35.0 – 40.0	36.2 – 41.9
Modulus per denier per ASTM D7744/D7744M (Class A) or ASTM D2256/D2256M (Class B) or ASTM D7269/D7269M (Class C) (gpd)	1000-1500 (initial)	1275 - 1465	1268 – 1461
Elongation to break (%) per ASTM D7744/D7744M (Class A) or ASTM D2256/D2256M (Class B) or ASTM D7269/D7269M (Class C), nominal	1.9	3.3	3.4
Finish on yarn by weight (%), nominal	0.0	1.3	0.9

3.2.2 Resin.

3.2.2.1 Class A resin. The resin shall be a low linear density polyethylene adhesive. The adhesive layer will have an areal density of 0.175 +/-0.0525 oz/yd^2 and a melting temperature range as determined by ASTM D3418 of 203-230°F.

3.2.2.2 Class B resin. The resin shall be an aqueous thermoplastic elastomer with a resin content of 17.0 % ± 2.0%. The resin shall be an aqueous dispersion of a linear styrene-isoprene-styrene block copolymer along with a rosin acid modifier. The styrene-isoprene-styrene block copolymer shall contain between 10% and 20% styrene monomer and will also contain between 15% and 25% of DI Block. The Melt Flow Index of the SIS copolymer at 200° C and 5 Kg force will fall between 10 and 15 grams/10 minutes. The Tensile Strength of this polymer shall be approximately 3100-psi, as determined by ASTM D412. The Elongation at Break of this polymer shall be approximately 1300% as determined by ASTM D412. The 300% modulus of this polymer shall fall between 100 and 200-psi as determined by ASTM D412.

3.2.2.3 Class C resin. The resin shall be an aqueous thermoplastic polyurethane with a resin content of 18% ± 3.0%. The resin shall have the following range of physical properties.

Property	Nominal Values
Tensile strength (psi) / (MPa)	5800 / 40
100% Modulus (psi) / (MPa)	700 / 5
Ultimate Elongation (%)	1000
Blocking Temperature (° C)	110
Hardness: Konig / Sward / Pencil	25 / - / -

3.2.3 Lamina.

3.2.3.1 Class A cross-plied unidirectional lamina. The cross-plied unidirectional lamina shall consist of two (2) unidirectional reinforced plies, at 90 ±3 degrees fiber orientation relative to each other, and one fiber direction substantially parallel to the sheet machine direction. Each lamina will include 2 plies of unidirectional tapes and two layers of thermoplastic adhesive, of construction [0|adhesive|90|adhesive]. The unidirectional tape layers will be constructed from individual ribbons of monolithic UHMWPE.

3.2.3.1.1 Areal density. The Class A cross-plied unidirectional lamina shall have an areal weight of 0.023 +/- 0.0025 lbf/ft^2 [111 +/- 12g/m^2] as determined by using test articles used in lot ballistic testing per section 3.4.3. The mean lamina areal density will be the mean of the areal densities of the test articles, each divided by the number of lamina in the respective test article.

3.2.3.1.2 Thickness of the lamina. The thickness of the Class A lamina shall be 0.005 ± 0.002 inches [0.127 +/-0.05 mm] as determined by ASTM D1777.

3.2.3.2 Class B cross-plied unidirectional lamina. The cross-plied unidirectional laminate shall consist of four (4) unidirectional reinforced plies, at 0|90|0|90 ±3 degrees fiber orientation relative to each other, and one fiber direction substantially parallel to the sheet machine direction. The unidirectional cross-plied tape shall have no more than 10 clearly noticeable defects per 100 lin. yds., where defects are defined in Table II and the term “clearly noticeable” shall be interpreted to mean visible at normal inspection distance of approximately 3 feet.

Table II. Defects in Class B unidirectional cross-plied tape

DEFECTS	CONDITION	
	English Units	**SI Units**
Fill Gap	> 0.16”	> 4 mm
Warp Gap (Space between parallel fibers in the warp direction)	> 0.05” and > 63”	> 1.3 mm and > 160 cm
Consolidation Failure (Single area where both plies do not adhere)	> 0.75” x 0.75”	> 20 mm x 20 mm
Contamination (Single area containing foreign material not typical to product)	> 0.25” x 0.25”	> 6.4 mm x 6.4 mm
Resin Rich Area (Single area containing an increase amount of resin)	> 2.0” x 2.0”	>50 mm x 50 mm

3.2.3.2.1 Areal density. The Class B cross-plied unidirectional lamina shall have an areal weight of 0.0526 $\pm$ 0.0016 lbf/ft^2 [257 $\pm$ 8 g/m^2] as determined by ASTM D3776/D3776M (option C).

3.2.3.2.2 Thickness of the lamina. The thickness of the Class B lamina shall be 0.014 +/-0.002 inches [0.36 +/-0.05 mm] as determined by ASTM D1777.

3.2.3.3 Class C cross-plied unidirectional lamina. The cross-plied unidirectional laminate shall consist of four (4) unidirectional reinforced plies, at 0|90|0|90 degrees fiber orientation relative to each other, and one fiber direction substantially parallel to the sheet machine direction. The unidirectional tape shall have no more than 10 clearly noticeable defects per 100 linear meters, where defects are defined in 3.2.3.3.1 and the term “clearly noticeable” shall be interpreted to mean visible at normal inspection distance of approximately 3 feet.

3.2.3.3.1 Visual Defects for Class C material. Visual defects, or spot faults, are defects of a certain size that can be e.g. a gap, weld, stain or foreign material. A defect counts as a visual defect when it exceeds both the width and the length dimensions mentioned below, where the width and length are defined in reference to the direction of the roll length:

- Width > 2.4 inch (6.0 cm) Length > 0.24 inch (0.6 cm), or
- Width > 1.0 inch (2.5 cm) Length > 1.0 inch (2.5 cm), or
- Width > 0.08 inch (0.2 cm) Length > 2.4 inch (6.0 cm).

3.2.3.3.1 Areal density. The Class C cross-plied unidirectional lamina shall have an areal weight of 0.0526 lbf/ft^2 - 0.0555 lbf/ft^2 [257 - 271 g/m^2] as determined by Appendix A.

3.2.3.3.2 Thickness of the lamina. The thickness of the Class C lamina shall be 0.013 +/-0.003 inches [0.33 +/-0.08 mm] as determined by ASTM D1777.

3.2.3.4 Ballistic resistance of lamina before molding.

3.2.3.4.1 Class A. The ballistic resistance of lots of [0|90]-reinforced Class A lamina shall be tested on a sample from each lot, per section 4.3.2.1. The sample shall consist of two targets, each 10 plies of the [0|90]-reinforced lamina, unmolded, with external dimensions 15-inches x 15-inches, laid up so that the reinforcement is $[0|90]_{10}$. The targets may be taped around the periphery, or tack stitched in the corners, as described in MIL-DTL-44050B section 4.5.5, to facilitate handling and maintenance of registry between the layers during testing. No stitching, tape or other materials shall be in the interior of the targets where they are to be impacted. The minimum average V_{50} of the lot test articles shall be 1425 ft/s.

3.2.3.4.2 Class B. The ballistic resistance of lots of [0|90|0|90]-reinforced Class B lamina shall be tested on a sample from each lot, per section 4.3.2.1. The sample shall consist of two targets, each 19 plies of the [0|90|0|90]-reinforced lamina, unmolded, with external dimensions 15-inches x 15-inches, laid up so that the reinforcement is $[0|90|0|90]_{19}$. The targets may be taped around the periphery, or tack stitched in the corners, as described in MIL-DTL-44050B section 4.5.5, to facilitate handling and maintenance of registry between the layers during testing. No stitching, tape or other materials shall be in the interior of the targets where they are to be impacted. The minimum V50 shall be 1825 ft/s.

3.2.3.4.3 Class C. The ballistic resistance of lots of [0|90|0|90]-reinforced Class C lamina shall be tested on a sample from each lot, per section 4.3.2.1. The sample shall consist of two targets, each 5 plies of the [0|90|0|90]-reinforced lamina, unmolded, with external dimensions 15-inches x 15-inches, laid up so that the reinforcement is $[0|90|0|90]_5$. The targets may be taped around the periphery, or tack stitched in the corners, as described in MIL-DTL-44050B section 4.5.5, to facilitate handling and maintenance of registry between the layers during testing. No stitching, tape or other materials shall be in the interior of the targets where they are to be impacted. The minimum V50 shall be 1082 ft/s.

3.2.4 Recycled, recovered, or environmentally preferable materials. Recycled, recovered, or environmentally preferable materials should be used to the maximum extent possible, provided that the material meets or exceeds the operational and maintenance requirements, and promotes economically advantageous life cycle costs.

3.3 Construction (fabrication) of the laminate.

3.3.1 Dimensions and structure. The laminates shall be of the dimensions stated in the acquisition documents (see 6.2). The laminates shall consist of the specified areal density (see 3.3.1.1 and 3.3.1.2) of resin-coated UHMWPE material reinforcement bonded together in a single molding step with heat and pressure. The laminates shall be built up from crossed plies of unidirectional reinforcement with no reinforcement gap or edge waste in any individual layer (see 4.3.3 and 4.4). If supplied as a rolled good, the nominal core diameter shall be at least 3.75 inches, to mitigate buckling.

3.3.1.1 Thickness and flatness variation.. The thickness at any point more than one inch from an edge shall not vary from the nominal thickness of the panel by more than $\pm$0.015 in. (0.38 mm) for type I and $\pm$0.030 in. (0.76 mm) for type II. Variation from flatness for each finished panel shall not exceed 0.06 inch per foot (in/ft) (5.00 millimeters per meter (mm/m) (See 4.3.3 and 4.4).

3.3.1.2 Weights and thicknesses. The unit weight or areal density of the finished Class A laminates shall fall within the ranges established by Figure 1A, the unit weight or areal density of the finished Class B laminates shall fall within the ranges established by Figure 1B or the unit weight or areal density of the finished Class C laminates shall fall within the ranges established by Figure 1C (see 4.3.2.3.2). Laminated plates should be within ±5% of the specified nominal areal density, as determined by Section 4.3.2.3.2.

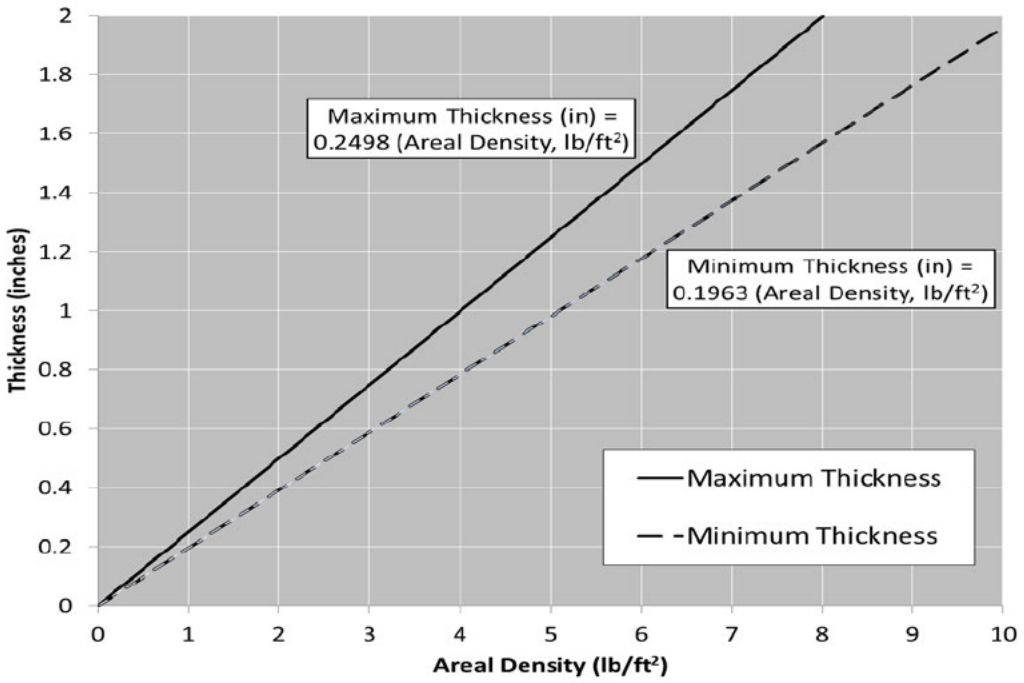

Figure 1A. Weight and Thickness Variations of the Finished Laminate for Class A.

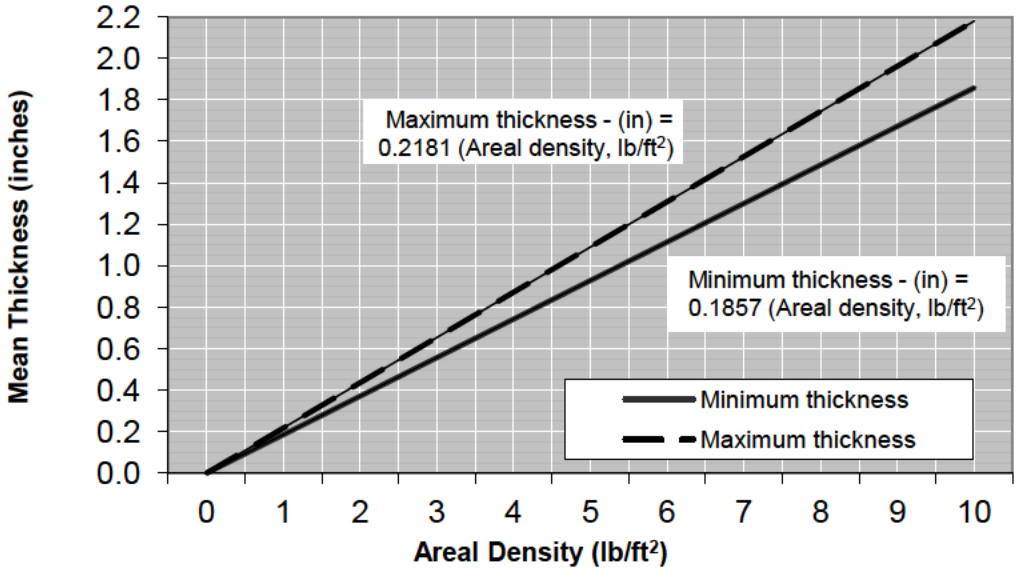

Figure 1B. Weight and Thickness Variations of the Finished Laminate for Class B

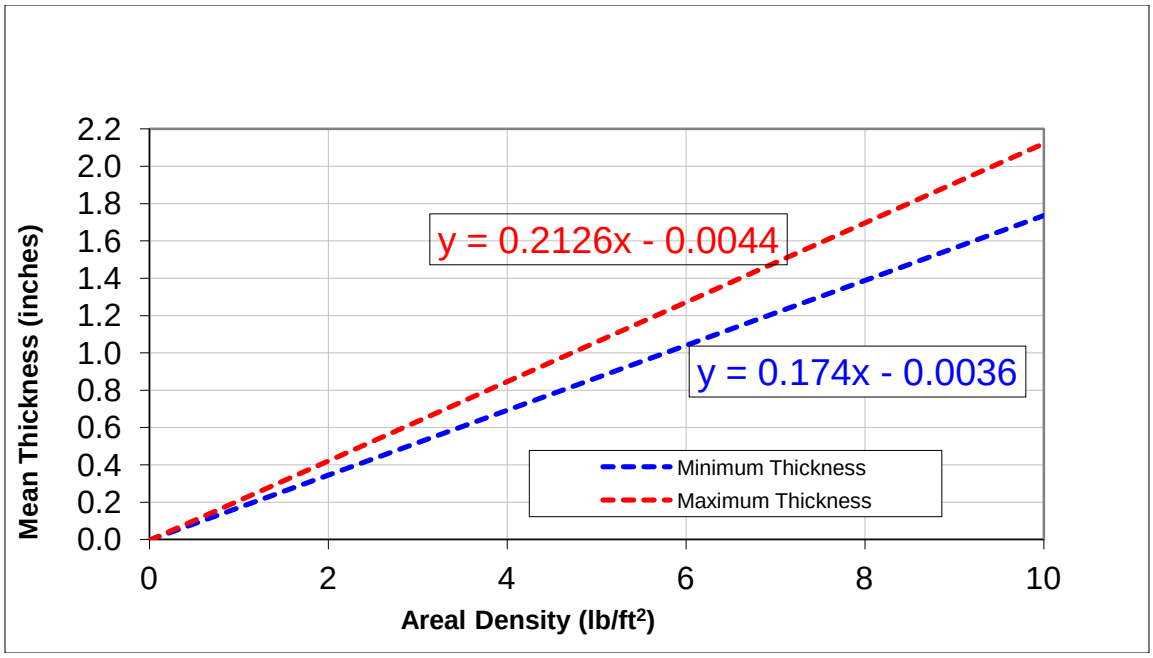

Figure 2C. Weight and Thickness Variations of the Finished Laminate for Class C.

3.3.2 Molding conditions - lamination pressures and temperatures.

3.3.2.1 Class A laminates.. The laminated panel should be laid up so that every unidirectional layer is substantially perpendicular to plies in contact with it (e.g. for three plies, the lamination schedule should be [0|90|0|90|0|90] and not [0|90|90|0|0|90]). The following conditions shall prevail during lamination processes (see 4.3.3):

For Type 1 material the molding conditions are to be determined by the molder.
For Type 2 material the molding cycle shall conform to the following details/conditions listed below:

Flat laminates shall be press-molded at 3000 pounds per square inch (psi), nominal. The class A material shall be heated such the platen temperatures are 215 ±5°F, all parts of the panel exceed 210°F for at least 30 minutes under pressure, and the panel is cooled to a platen temperature of less than 100°F before releasing pressure. An acceptable molding process meeting these requirements can be proposed by the panel manufacturer to the government quality representative for a given combination of press and panel areal density, using thermocouple data on sample panels. The government may choose to accept the proposed molding process. Otherwise, pressures indicated above shall be maintained until the following stages have been completed.

1. Pressurize preform to 150 +/-50 psi at platen temperature below 140°F.
2. Press platen temperature increased to 215 ±5°F.
3. Increase pressure to 3000 +/-200 psi gradually, in even increments, over about five minutes.
4. Dwell in accordance with schedule of Table III with platens at 215 ±5°F.
5. Cool to platen temperature of 100°F or less before laminate removal.

TABLE III. Laminating dwell times for Class A.

Laminate AD (psf)	Dwell time (minutes)
< 1.5	30
1.5 – 3.0	45
3.0 – 4.5	75
> 4.5	75

3.3.2.2 Class B laminates. The laminated panel should be laid up so that every unidirectional layer is substantially perpendicular to plies in contact with it (e.g. for two plies, the lamination schedule should be [0|90|0|90|0|90|0|90] and not [0|90|0|90|90|0|90|90]). The following conditions shall prevail during lamination processes (see 4.3.3):

For all laminates, the material shall be heated such the platen temperatures are 250±10°F, and all parts of the panel exceed 240°F for a minimum of 15 minutes under a contact pressure of less than 200 psi before the molding pressure is applied. Apply molding pressure according to the laminate Type classification and hold for a minimum of 15 minutes, then cool until all parts of the panel are less than 125°F before releasing pressure.

1. Insert material stack and preheat until centerline of panel is 240°F using a panel contact pressure of less than 200 psi.
2. Hold centerline at 240°F for a minimum of 15 minutes using a panel contact pressure of less than 200 psi.
3. Increase part pressure according to laminate Type classification; such that all parts of the panel exceed 240°F under pressure for a minimum of 15 minutes.
4. Initiate cooling cycle.
5. Cool panel until centerline is less than 125°F.
6. Release applied pressure.

An acceptable molding process meeting these requirements can be proposed by the panel manufacturer to the government quality representative for a given combination of press and panel areal density, using thermocouple data on sample panels. The government may choose to accept the proposed molding process.

3.3.2.3 Class C laminates. The laminated panel should be laid up so that every unidirectional layer is substantially perpendicular to plies in contact with it (e.g. for two plies, the lamination schedule should be [0|90|0|90|0|90|0|90] and not [0|90|0|90|90|0|90|0]). The following conditions shall prevail during lamination processes (see 4.3.3):

For Type 1 material the molding conditions are to be determined by the molder.
For Type 2 material the molder shall apply at least 2400 psi. Molder to determine maximum pressure limit.

Molding Cycle shall conform to the Chart 1 and the specific details listed below:

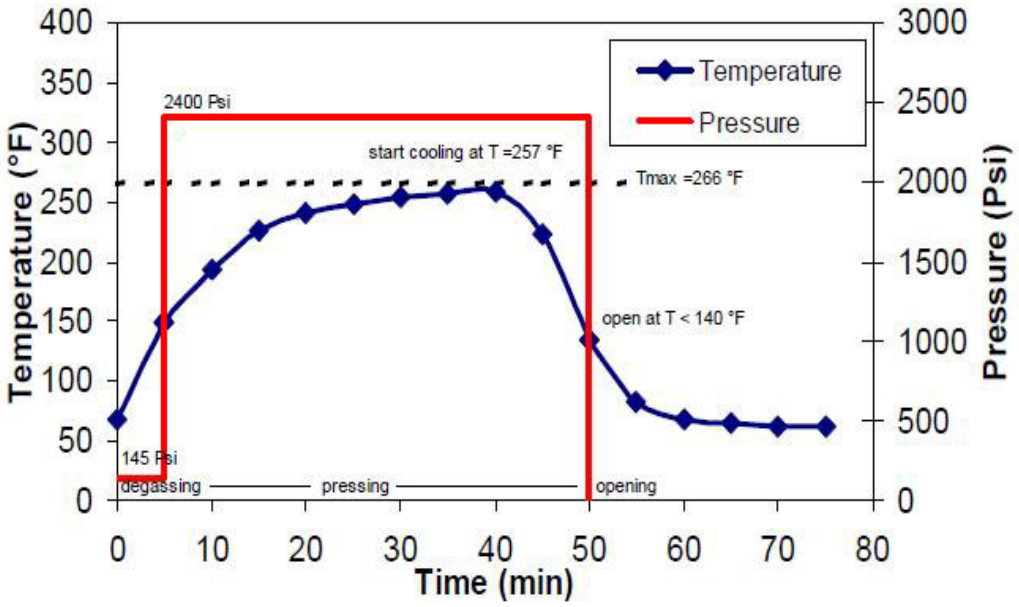

Chart 1. Molding Cycle.

SPECIFIC DETAILS:

* Take at least 5 minutes of degassing at 145 psi, or other processing capabilities to facilitate satisfactory material degassing.
* Before going to high pressure the core must be well above 140°F.
* Never start cooling when the core has not reached 257°F or higher. Total dwell time to be determined by molder.
* Keep high pressure at high temperature.
* Do not open the press before the core has reached 140°F.
* Large panels may need extra precaution to assure that no air is entrapped in the plates. This can be achieved by increasing the pressure in two or three steps instead of in one step.

3.3.3 Finished laminate. The finished laminates shall consist of the specified number of plies or areal density sandwiched between single peel-plies which can be incorporated in the lamination process. Peel-plies coated with a release agent shall not transfer to the laminate surfaces. All cutting and machining of laminate panels shall be done with the peel-plies or release film intact. Wet cutting and machining procedures shall be followed by a drying process. The drying process shall consist of drying the panel in a forced draft or convection type oven in a stream of ambient air heated to 100 ±10°F (38 ±6°C) for a period of not less than four hours. NOTE: This drying requirement shall be waived if an abrasive water-jet cutter or other non-wet cutting or machining is used. Any resulting moisture film remaining on cut surface shall be removed by local heat application (heater/blower) or by using clean, dry toweling. The finished laminate shall have an adhesive sealed surface on all cut, trimmed or drilled hole edges which is applied after any required drying process. The sealing adhesive used shall have a service temperature of not less than 250°F (121°C) and meet the requirement of 3.4.2. Application of the resin shall not interfere with the peel-ply removal (see 4.3.3 and 4.3.4.1).

3.4 Performance of the finished laminate.

3.4.1 Peel-ply removal. The peel-plies and/or release plies are intended to keep panel surfaces clean and shall be easily removable by hand, without requiring heat or solvents.

3.4.2 Thermal shock resistance. The laminates shall not show evidence of delamination following a two cycle exposure to a temperature range of -65°F to 250°F (-54°C to 121°C) (See 4.3.2.3.1). Evidence of delamination is when the percent thickness change calculated from the procedure outlined in Appendix B is greater than 3%. It shall be specified in the contract or purchase order (see 6.2) that this test shall not be needed if the application of these materials does not require delamination resistance.

3.4.3 Ballistic resistance. The test projectile for this ballistic acceptance test shall be the MIL-DTL-46593 non-saboted caliber 0.30 (44 grain) fragment simulating projectile at 0° obliquity.

3.4.3.1 Class A laminates. The V_{50} protection ballistic limit as defined in MIL-STD-662 shall not be less than 1950 ft/s x ((measured area density) / (2.00-lbf/ft^2))$^{-0.5}$ for a laminate of nominal areal density of 2.0 +/- 0.1 psf.

3.4.3.2 Class B laminates. The V_{50} protection ballistic limit as defined in MIL-STD-662 shall not be less than 2043 ft/s x ((measured area density) / (2.00-lbf/ft^2))$^{-0.5}$ for a laminate of nominal areal density of 2.0 +/- 0.1 psf.

3.4.3.3 Class C laminates. The V_{50} protection ballistic limit as defined in MIL-STD-662 shall not be less than 1909 ft/s x ((measured area density) / (2.00-lbf/ft^2))$^{-0.5}$ for a laminate of nominal areal density of 2.0 +/- 0.1 psf.

3.5 Workmanship. The laminates shall satisfy visual acceptance Level I of ASTM D2563 for the following defects as defined in ASTM D2563:

a. Blister
b. Burned
c. Cracked
d. Crack, surface
e. Crazing
f. Delamination, edge
g. Delamination, internal
h. Dry spot
i. Lack of fillout
j. Wrinkles.

Reinforcement layers shall not have pleats, wrinkles, or creases. Reinforcement layers shall be free of tears, reasonably straight, and reasonably perpendicular layer-to-layer. The laminated panel should be laid up so that every unidirectional layer is substantially perpendicular to plies in contact with it (e.g. for a laminate of *N*-plies, the lamination schedule should be $[0|90]_N$, and should not be $[0|90|90|0]_{N/2}$]). Edges of the finished laminate shall be free of fraying (see 4.3.4).

4. VERIFICATION

4.1 Classification of inspections. The inspection requirements specified herein are classified as follows:

a. First article inspection (see 4.3).
b. Production acceptance inspection (see 4.4).

4.2 Lot. An inspection lot shall consist of all the laminated assemblies of one type and part number, from an identifiable production period, from one manufacturer, submitted at one time for acceptance. Unless otherwise specified in the contract or purchase order (see 6.2), the default definition of a lot shall be 30 days of production of the product or 1/12 of the average yearly production of the product, whichever is larger. Any changes in materials, composition, reinforcement architecture, the reinforcement material, the laminating resin, the laminate construction (see 3.2) or the manufacturing process including changes in the place or location of manufacture shall constitute another lot and therefore require a separate set of testing requirements.

4.3 First article inspection. When required (see 3.1), the first article sample shall be examined for compliance with the requirements and verifications in section 3 and section 4. Fiber and resin certification (see 3.2.1 and 3.2.2) shall be provided to the procuring activity by the material manufacturer. Inspection and material certification records shall be maintained by the contractor. Records shall be subject to review by the Government and shall be determined by inspection of contractor records providing proof or certification that materials conform to requirements. Applicable records shall include drawings, specifications, design data, receiving inspection records, processing and quality control standards, vendor catalogs and certifications, industry standards, test reports, and rating data. All samples shall be produced with materials and processes proposed for use on production laminates. Inspection and ballistic tests of the unmolded lamina shall be carried out by the contractor under Government surveillance, unless otherwise specified in the contract or purchase order (see 6.2).

4.3.1 Sampling for first article.

4.3.1.1 For lamina ballistic testing. Supply 2 targets as specified in 3.2.3.4.1 (Class A), in 3.2.3.4.2 (Class B), or in 3.2.3.4.3 (Class C).

4.3.1.2 For laminate ballistic testing. Supply two test samples at an areal density specified in 3.4.3 for Class A, B, or C. The size of the test sample shall coincide with the width of the product that would allow minimizing waste of material in preparation of the samples for testing. For example, for a 63 inch product, a size of 21 in. x 21 in. (534mm x 534mm) would be appropriate and for a 70 inch product, a size of 23 in. x 23 in. (584mm x 584mm) would be appropriate. Therefore, the size of the test sample shall be accordance with the following Table IV.

4.3.1.3 For all other required tests (control tests). Supply 3 test samples at an areal density specified in the contract. The test sample size shall be in accordance with Table IV. These test samples shall be used to verify the requirements of workmanship (3.5), temperature resistance test (3.4.2), peel-ply test (3.4.1), assuming the contract or purchase order does not specify that peel-plies are not required (see 6.2), and dimensions and structure (3.3.1).

Table IV. Sample Size.

PRODUCT WIDTH	TEST SAMPLE SIZE
Under 63 inch	24 in. x 24 in
63 inch	21 in. x 21 in
64 inch	21 in. x 21 in
65 inch	21 in. x 21 in
66 inch	22 in. x 22 in
67 inch	22 in. x 22 in
68 inch	22 in. x 22 in
69 inch	23 in. x 23 in
70 inch	23 in. x 23 in
71 inch	23 in. x 23 in
72 inch and above	24 in. x 24 in

4.3.2 Tests for first article.

4.3.2.1 Ballistic test – un-molded panel (lamina). The ballistic resistance test shall be conducted in accordance with MIL-STD-662. Test projectile shall be the caliber 0.22 (17 grain) MIL-DTL-46593, Type 1, un-saboted fragment simulating projectile at 0° obliquity. The V_{50} protection ballistic limit reported shall be the average of two determinations made on separate assemblies of unmolded lamina. Each determination shall be a six round V_{50} ballistic limit with a maximum velocity spread of 125 ft/sec. If a panel has at least five partial penetrations at impact velocities above the required minimum V_{50}, and no complete penetrations at impact velocities below the required minimum V_{50}, then that panel test result shall be considered compliant with the ballistic test requirement, even if the range of results is greater 125 ft/s and the V_{50} cannot be determined. In such a case where a panel is determined to meet the ballistic test requirement but its V_{50} cannot be determined, the highest partial penetration velocity or the lowest complete penetration velocity, whichever is lower, shall be used to represent the panel V_{50} when averaging the result with the other panel to determine compliance of the first articles or production lot.

4.3.2.2 Ballistic test – molded panel (laminate). The ballistic resistance test shall be conducted in accordance with MIL-STD-662. Test projectile shall be the caliber 0.30 (44 grain) MIL-DTL-46593, un-saboted fragment simulating projectile at 0° obliquity. The V_{50} protection ballistic limit reported shall be the average of two determinations made on separate laminates. Each determination shall be a six round V_{50} ballistic limit with a maximum velocity spread of 125 ft/sec. (38 m/s). If a panel has at least five partial penetrations at impact velocities above the required minimum V_{50}, and no complete penetrations at impact velocities below the required minimum V_{50}, then that panel test result shall be considered compliant with the ballistic test requirement, even if the range of results is greater 125 ft/s and the V_{50} cannot be determined. In such a case where a panel is determined to meet the ballistic test requirement but its V_{50} cannot be determined, the highest partial penetration velocity or the lowest complete penetration velocity, whichever is lower, shall be used to represent the panel V_{50} when averaging the result with the other panel to determine compliance of the first articles or production lot.

4.3.2.3 Control tests for first article.

4.3.2.3.1 Thermal shock resistance test. The thermal shock resistance test shall be performed in accordance with Appendix B.

4.3.2.3.2 Determination of laminate unit weight. The unit weight or areal density of a finished laminate is determined as follows: Choose a square laminate of nominal size at least 20 in. by 20 in. (508 mm x 508 mm) and remove peel-plies (see 3.3.3) assuming the contract or purchase order does not specify that peel-plies are not required (see 6.2). Dry the panel in a forced draft or convection type oven in a stream of ambient air heated to 200 ±10°F (93 ± 6°C) until no further change of mass occurs when the panel is weighed with an error of less than 0.1% after cooling to room temperature in the standard atmosphere for testing textiles as defined in ASTM D123. Calculate the unit weight to three significant figures as follows:

$$\text{Unit Weight} = \frac{1000000\ M}{LW}\ \text{Kg/m}^2$$

Where M is the dry panel weight in kilograms measured with an error of less than 0.1%, L is the length of the panel in millimeters measured to the nearest 2 millimeters and W is the width of the panel in millimeters measured to the nearest 2 millimeters.

4.3.2.3.3 Peel-ply test. The peel-ply test, assuming the contract or purchase order does not specify that peel-plies are not required (see 6.2), shall consist of removing the peel-plies by hand (see 3.4.1).

4.3.2.3.4 Determination of laminate thickness. The thickness of a finished laminate is determined as follows: Choose a square laminate of nominal size at least 24 in. by 24 in. (610 mm by 610 mm), and remove peel-plies, assuming the contract or purchase order does not specify that peel-plies are not required (see 6.2). Measure the thickness to the nearest 0.001 in. (0.0254 mm) at least 1.0 in. (25.4 mm) in from each of the four (4) corners. Average the four (4) readings.

4.3.3 Workmanship. The laminates shall satisfy visual acceptance Level I of ASTM D2563 for the defects listed in 3.5, as defined in ASTM D2563.

4.3.4 Failure. Failure of the samples to meet the test requirements (ballistic and control) shall be cause for the Government to refuse acceptance of first article samples until the cause of failure(s) is identified, corrective action is taken by the contractor, and approved by the Government.

4.4 Production acceptance inspection.

4.4.1 Sampling for production acceptance.

4.4.1.1 Ballistic testing. The contractor shall supply two test samples at the areal density specified in 3.4.3.1 for Class A, in 3.4.3.2 for Class B, and in 3.4.3.3 for Class C for each lot of test laminate fabrication for ballistic testing at the facility specified in 6.3 unless otherwise specified in the contract or purchase order (see 6.2) to show conformance to 3.4.3. The test

sample size shall be in accordance with Table IV. The test panels shall be adequately identified as to contractor, contract number, manufacturer, and date.

4.4.2 Tests for production acceptance.

4.4.2.1 Ballistic test – molded panel (laminate). See paragraph 4.3.2.2 for test procedure.

4.4.3 Workmanship. The laminates shall satisfy visual acceptance Level I of ASTM D2563 for the defects listed in 3.5, as defined in ASTM D2563.

4.4.4 Failure. Failure of the samples to meet the test requirements (ballistic) shall be cause for the Government to stop acceptance of production samples until the cause of failure(s) is identified, corrective action is taken by the contractor, and approved by the Government.

4.5 Materials, design and construction. To determine conformance to first article and production, inspection and material certification records shall be maintained by the contractor. Records shall be subject to review by the Government and shall be determined by inspection of contractor records providing proof or certification that materials conform to requirements. Applicable records shall include drawings, specifications, design data, receiving inspection records, processing and quality control standards, vendor catalogs and certifications, industry standards, test reports, and rating data.

5. PACKAGING

5.1 Packaging. For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature which may be helpful, but is not mandatory.)

6.1 Intended use. The laminates furnished under this specification are intended for use as a component of composite armor. Since these laminates must maintain a ballistic resistance sufficient to survive under extreme battlefield conditions, under which commercial alternatives characteristically fail, the product from this specification will typically be used in military applications (military unique). However, this does not exclude the product of this specification from being used for non military applications.

6.2 Acquisition requirements. Acquisition documents must specify the following:

a. Title, number, and date of this specification.
b. Type and class (see 1.2).
c. When first article is required (see 3.1 and 6.4).
d. Production component dimensions and areal density (see 3.3.1).
e. If the thermal shock resistance test is not required (see 3.4.2).
f. If the default definition of a lot is different (see 4.2).
g. If inspection is carried out under Government surveillance (see 4.3).
h. Specify if peel-plies are not required (see 4.3.1.3, 4.3.2.3.2, 4.3.2.3.3, and 4.3.2.3.4).
i. Specify the ballistic test facility if different then 6.3 (see 4.4.1.1).
j. Packaging requirements (see 5.1).

6.3 Test samples. Ballistic test samples should be sent to: Commander, U.S. Army Aberdeen Test Center, 400 Colleran Road. Bldg. 358, ATTN: CSTE-DTC-AT-SL-V (K. Beavers), Armor Acceptance – B690, Aberdeen Proving Ground, MD 21005-5059.

6.4 First article. It is suggested that first article testing be required for every new contract especially if the possible vendor is new (has not produced this product before) or has not produced this product within the last six (6) months.

6.5 Definitions.

6.5.1 Lamina. Two (2) layers of wide tape cross-plied essentially 90° relative to the adjacent layer(s) for class A or four (4) layers of essentially unidirectional fibers, where each layer of fibers is cross-plied essentially 90° relative to the adjacent layer(s) for classes B and C. The layers of either tape or fiber are bonded to form a single article.

6.5.2 Fair impact. An impact is considered fair when an un-yawed fragment simulator strikes an unsupported area of the target material at a specified obliquity at a distance of at least two inches from any previous impact or disturbed area resulting from an impact, or from any crack, or from any edge of the specimen.

6.5.3. Void defects. Void defects or “visible trapped air” is not intended to describe the actual void structure inherent to the product originally tested.

6.6 Subject term (key word) listing.

Areal density (AD)
Ballistic resistance
Laminating resin
Lamination pressures and temperatures
Peel-ply
Temperature

APPENDIX A

MEASUREMENT METHOD OF DETERMINING AREAL DENSITY FOR CLASS C MATERIAL

A.1 SCOPE

A.1.1Scope. This appendix covers a procedure used to measure the areal density of Class C material. This appendix is a mandatory part of this specification. The information contained herein is intended for compliance.

A.1.2 Applicability. The requirements specified in this appendix are required. The content of this appendix is based on STANAG 2920 protocol.

A.2 APPLICABLE DOCUMENTS (Not Applicable)

A.3 REQUIREMENTS

A.3.1 Equipment. The equipment used for measuring the Areal Density of Class C material uses a scale with an accuracy of 0.05 gram.

A.3.2 Sample preparation. During the production of Class C material a sample is taken (1.6 m width and about 40 cm) at predefined intermediate and final check points. From this material three samples of 30 x 30 cm are cut. Locations are given in FIGURE A.1. The dimensions of the samples are determined by placing a steel plate of 30 x 30 cm on the UD (this flattens the UD). Then the sample is cut, using a hot knife.

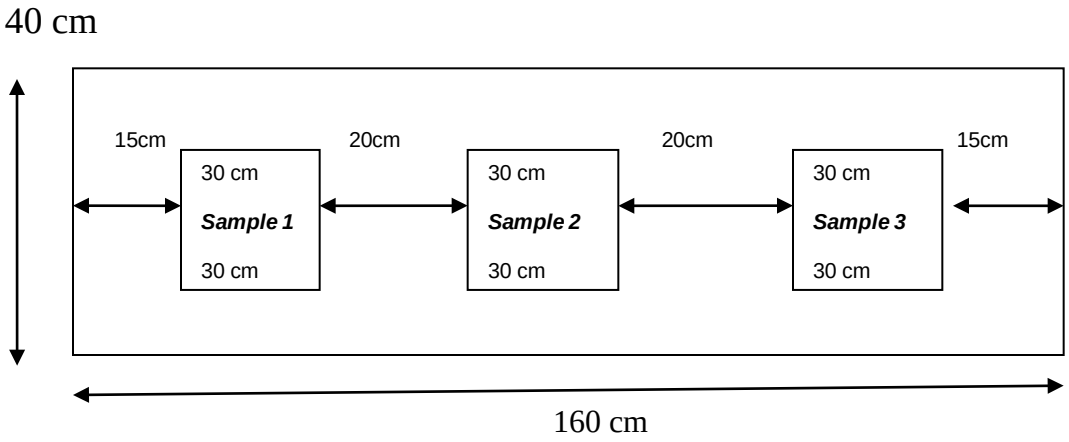

FIGURE A-1. Locations of samples in piece of Class C material

A.3.3 Procedure.

A.3.3.1 Measurement method. The scale is reset to zero, before the samples are put on the scale. All three samples are put on top of each other and the total weight of these samples is measured.

A.3.3.2 Calculation method. The measured value (in grams) is then divided by 0.27 m^2. This results in the Areal Density in gram per square meter [g/m^2]. The value is rounded off to the nearest integer whole number, no decimals are used. The value is kept constant for all boxes made until the next Area Density measurement is performed. Frequency of measurement depends on the grade. As a result each box of Class C material obtains an Area Density value in [g/m^2].

APPENDIX B

THERMAL SHOCK TEST PROCEDURE

B.1 SCOPE

B.1.1 Scope. This appendix covers a procedure used to measure the dimensional changes of materials which are exposed to extreme rapid temperature changes. This appendix is a mandatory part of this specification. The information contained herein is intended for compliance.

B.1.2 Applicability. The requirements specified in this appendix are required. The content of this appendix was taken for the most part from MIL-STD 810G, Method 503.5 Temperature Shock.

B.2 APPLICABLE DOCUMENTS

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-810	-	Environmental Test Methods and Engineering Guidelines.

(Copies of these documents are available online at http://quicksearch.dla.mil or at https://assist.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

B.3 REQUIREMENTS

B.3.1 Equipment. The equipment listed below or its equivalent shall be required to perform the thermal shock test.

1. Hot Chamber @ 275°F, Ex: Russells Technical Products, Model GD-64-5-5-AC
2. Cold Chamber @ -90°F, Ex: Russells Technical Products, Model GD-64-5-5-AC
3. Temperature Recorder w/ multiple channels, Ex: Yokogawa Mobilecorder, Model MV200
4. Thermocouple wire, Ex: Type J, 100ft
5. Micrometer, Ex: Mitutoyo, IP65, No. 389-351, Res = 0.00005
6. Transfer board, Ex: ½” Teflon sheet or ¾” plywood board, 24” x 24”
7. PPE: Safety glasses, Face shield, and insulated gloves
8. Misc: Steel Ruler 24”, Marker (Sharpie), High Temp adhesive tape, Timer, binder clips

B.3.2 Test panel. The test panel shall be manufactured as specified herein and shall be of the following size and weight; 21” x 21”, @ 3.0 psf.

APPENDIX B

B.3.3 Procedure.

B.3.3.1 Chamber preparation. Both chambers (Hot and Cold) shall be turned on and set at the following set points.

a. Hot chamber set point = 275°F/135°C
b. Cold chamber set point = -90°F/-68°C

The installation of shelving racks shall be used as needed. Note: Use of shelf racks are optional and may increase or decrease cycle times. Allow up to 1 hour for preheat/precool.

B.3.3.2 Test panel preparation and pretest measurement. Identify and place a mark on the test panel at the eight measurement locations. Each location is to be 1 ¼" from the edge and 6" from the side as shown in FIGURE B-1. Measure the thickness at each location using a micrometer. Ensure the micrometer is flat and level relative to the panel and that the panel is clean and free of debris. Record the thickness to the nearest 0.001". Measure and record the weight of the test panel. Place and center the test panel on the transfer board. Construct a five wire thermocouple harness and connect to a recorder. Use enough wire length to reach both hot and cold chambers. Attach each of five thermocouple wires to the thermocouple locations shown in FIGURE B-2. Use high temperature tape to secure the thermocouple to the panel. Additional binder clips can be used to hold the lead wires to the transfer board.

*** Safety: Always use appropriate Personal Protective Equipment while working at elevated or sub-ambient conditions. Several steps in the following sections of the procedure shall be designated in red font, which require the use of safety glasses, face shield, and insulated gloves.

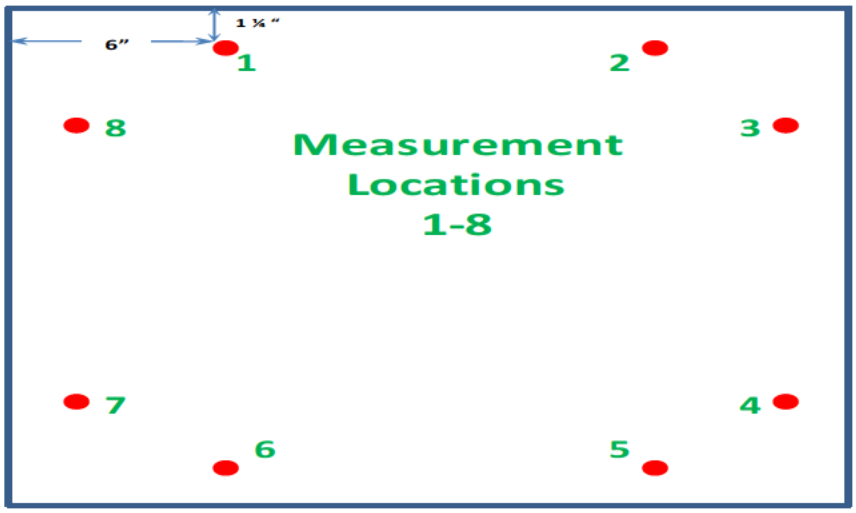

FIGURE B-1. Measurement Locations

APPENDIX B

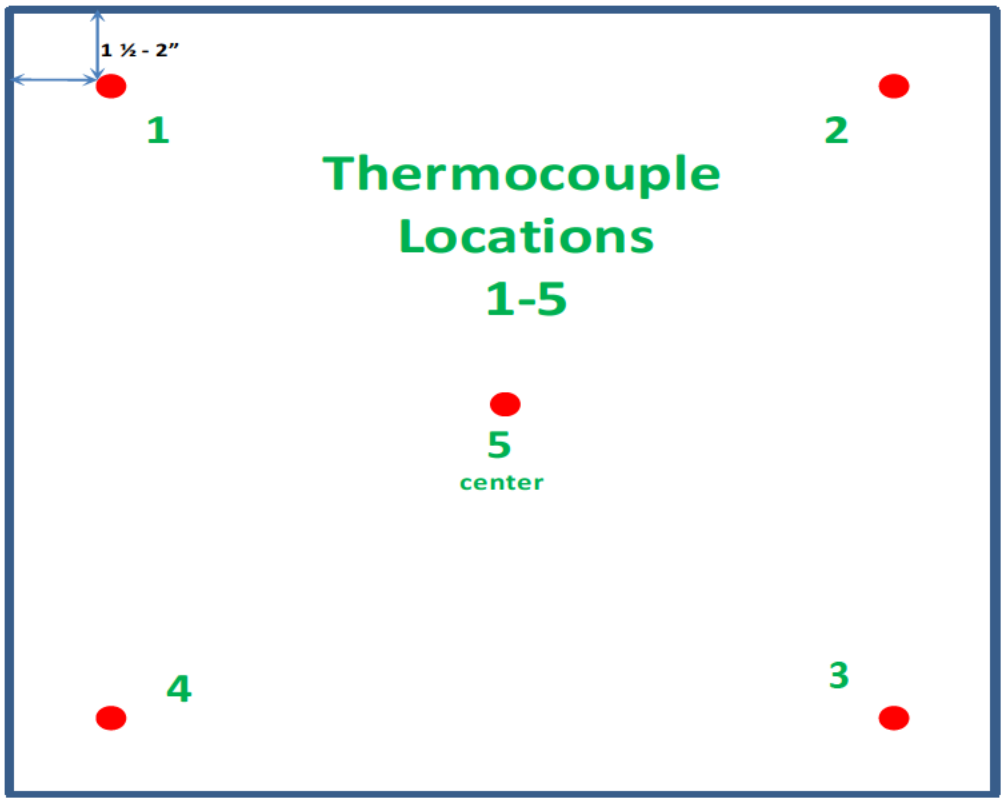

FIGURE B-2. Thermocouple Locations

B.3.3.3 Thermal cycling. Record initial temperatures of each thermocouple and inspect recorder for proper functioning. Place test panel/transfer board into center of cold chamber and begin timer. Record time and temperature of each thermocouple location at intervals of: 1 min, 2 min, 5 min, 10 min, etc. Recording interval may be adjusted based on relative ramp rate of test panel. Continue recording the temperature of each thermocouple location until one of the thermocouples reach set point = -65°F. See note 1. Transfer the test panel/transfer board to the hot chamber and record time. Transfer should be completed in 5 minutes or less. Inspect the thermocouple wires to confirm secure attachment and proper location. Record time and temperature of each thermocouple location at intervals of: 1 min, 2 min, 5 min, 10 min, etc. Recording interval may be adjusted based on relative ramp rate of test panel. Continue recording the temperature of each thermocouple location until one of the thermocouples reach set point = 250°F. Transfer the test panel/transfer board to the cold chamber and record time. Transfer should be completed in 5 minutes or less. Inspect the thermocouple wires to confirm secure attachment and proper location. Record time and temperature of each thermocouple location at intervals of: 1 min, 2 min, 5 min, 10 min, etc. recording the temperature of each thermocouple location until one of the thermocouples reach set point = -65°F. Transfer the test panel/transfer board to the hot chamber and record time. Transfer should be completed in 5 minutes or less. Inspect the thermocouple wires to confirm secure attachment and proper location. Record time and temperature of each

thermocouple location at intervals: 1 min, 2 min, 5 min, 10 min, etc. Recording interval may be adjusted based on relative ramp rate of test panel. Continue recording the temperature of each thermocouple location until one of the thermocouples reach set point = 250°F. Remove the test panel/transfer board from the hot chamber to a flat countertop and allow it to cool and equilibrate for a minimum of 8 hours in normal ambient conditions (70°F +/- 5°F, 50% +/- 20% RH).

Note 1: Thermal chambers can have uneven and irregular air flow patterns. It is the intent of the test to expose the panel to a maximum temperature of 250°F and a minimum of -65°F. Hence, when the first of the five measurements reaches the designated 250°F or -65°F, the panel should be transferred to the other environment to achieve the temperature shock and to avoid thermal soak.

B.3.3.4 Post-test measurement. Carefully remove the thermocouple wires and harness so as not to distort or damage the surface at or near the measurement locations. Measure the thickness at each location using a micrometer. Ensure the micrometer is flat and level relative to the panel and that the panel is clean and free of debris. Record the thickness to 0.001". Measure and record the weight of the test panel. Calculate the thickness change for each location and the average thickness change of the panel. The thickness change is equal to the (final thickness minus the original thickness) divided by the original thickness times 100.

CONCLUDING MATERIAL

Custodian:
Army - MR
Navy - AS
Air Force - 11

Review Activities:
Army – AT, AV, MI
Navy – SH
Air Force - 13
DLA – DH, IS

Preparing Activity:
Army - MR

(Project CMPS-2010-005)

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