METRIC

DOD-STD-2136(SH)
1 OCTOBER 1981

MILITARY STANDARD

STANDARD PROCEDURE FOR THE METALLURGICAL EXAMINATION OF GAS TURBINE HOT SECTION AIRFOIL COMPONENTS FOR HOT CORROSION DEGRADATION (METRIC)

FSC 2835

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND

Washington, DC 20362

Standard Procedure for the Metallurgical Examination of Gas Turbine Hot Section Airfoil Components for Hot Corrosion Degradation.

DOD-STD-2136(SH)

1. This Military standard is approved for use by the Naval Sea Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 3112, Department of the Navy, Washington, DC 20362 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

1. This standard contains the steps in a metallurgical examination for hot corrosion degradation of gas turbine hot section blades and vanes which have been operated in a marine environment.

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FIGURES

APPENDIX

1. SCOPE

1.1 Scope. This procedure outlines the steps in a metallurgical evaluation for hot corrosion degradation of turbine hot section blades and vanes which have been operated in a marine environment.

1.2 Application. This method can be used whenever the inquiry, contract, or specification states the hot section components shall be subjected to metallurgical examination. When the evaluation is to be limited in scope or if the quantity of components is limited, portions of this procedure may be omitted on a case basis or as agreed to by the requesting and performing agencies.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. Not applicable.

2.2 Other publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

E 3 - Preparation of Metallographic Specimens.
E 407 - Microetching Metals and Alloys.

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. DEFINITIONS

3.1 Overlay coatings. Overlay coatings are claddings of corrosion resistant alloys applied to the surface of the parts. Application processes include electron beam physical vapor deposition, sputtering, hot isostatic pressing (HIP) bonding of foils, and plasma spraying. The coatings are usually MCrAlY alloys where M is either iron, cobalt, or nickel. Most of the alloys are two phase, a solid solution phase and a metal aluminide intermetallic phase. Occasionally, other metals, including hafnium or platinum, are used and yttrium is deleted. MCrAlY is used as a generic term for overlay coatings in this standard.

3.2 Diffusion coatings. Diffusion coatings are coatings applied by the diffusion of an element into the substrate (base metal). The major element used for diffusion coatings is aluminum which forms aluminide intermetallic compounds with the base metal. Precious metal layers can be applied prior to the aluminum diffusion treatment to form modified aluminides. The most important diffusion application process is pack cementation.

4. GENERAL REQUIREMENTS

4.1 Summary of method. This method consists of a standard technique for performing a metallurgical examination of gas turbine vanes and blades. There are standard plans for sectioning both vanes and blades. The procedure includes two techniques for quantifying the corrosion attack: (a) service parameters based purely on measurement of remaining coating thickness and base metal attack, and (b) corrosion mapping which defines the type of corrosion as well as provides general information on the depth of attack.

4.2 Report. A technical report shall be prepared to report the results of the metallurgical examination (see appendix herein). The body of the report shall include the following information:

(a) Gas turbine engine identification.
(b) Engine operating history, if available.
(c) Component identification. Identify the components being examined to include the base metals and coatings.
(d) General description of condition of components. Inclusion of photographs is recommended.
(e) Salt analysis results, if performed.
(f) Report results of metallographic examination including:

(1) Microscopic measurements (for each component):

a. Maximum remaining coating thickness
b. Maximum depth of attack
c. Service parameters

(2) Corrosion maps.
(3) Description of coating condition, including photomicrographs, where practical.

(g) Results of scanning electron microscope or microprobe analysis.
(h) Description and results of other analytical tests performed.

5. DETAILED REQUIREMENTS

5.1 Visual examination. Hot section components shall be examined visually and photographed. The visually apparent extent of corrosion shall be recorded. Cooling passages shall be checked for blockage using the engine manufacturer's procedure where feasible.

5.2 Airfoil washing. If the gas turbine has not been water washed prior to removal and the blades and vanes have been handled with care so as to avoid contaminating the airfoil surfaces, a salt analysis shall be conducted as follows: Airfoil surfaces shall be washed with a measured quantity of distilled deionized water. The leading edge and concave surface shall be washed separately from the convex surface. The washings shall be saved for chemical analysis of water soluble deposits. The analysis shall include at least the following ions: sodium, calcium, magnesium, potassium, cobalt, nickel, iron, vanadium, sulfate,

and chloride. The analysis shall be reported as milligrams of elements per airfoil and milligrams per square centimeter. If sufficient airfoils are available, the airfoils for metallographic examination shall not be rinsed. Collect any loose deposits and perform spectrographic or diffraction analysis.

5.3 Section components for metallurgical examination. The following procedures are a general rule for the sectioning of airfoils. Observations on a specific component will dictate the final cutting procedures. A section through the most severely corroded region should always be included in the examination. Conditions observed on individual components may also indicate sections from platforms, shrouds, or fir-trees. The requesting agency may specify other sectioning plans.

5.3.1 Blades.

5.3.1.1 Unless otherwise specified, blades shall be sectioned transversely at 10, 20, 40, 60, and 80 percent span as measured from platform.

5.3.1.2 Sections shall be mounted and polished in accordance with ASTM E 3.

5.3.2 Vanes.

5.3.2.1 Unless otherwise specified, vanes shall be sectioned transversely at 15, 50, and 80 percent span.

5.3.2.2 Sections shall be mounted and polished in accordance with ASTM E 3.

5.4 Microscopic examination. Sectioned components shall be microscopically examined and the data recorded, as appropriate, using the techniques specified in 5.4.1 through 5.4.4.

5.4.1 Quantify depth of attack. The remaining coating thickness or base metal penetration shall be measured at 5 millimeters maximum intervals around circumference of sections. A minimum of eight equally spaced measurements shall be made with the first measurement centered on the airfoil leading edge. Record maximum depth of attack at or between intervals. Calculate coating service parameter for each airfoil as follows:

$$\text{Mean parameter} = \frac{\text{Mean value of remaining coating } \underline{1/}}{\text{Maximum applied coating thickness } \underline{2/}}$$

$$\text{Variation parameter} = \frac{\text{Standard deviation of remaining coating thickness}}{\text{Maximum applied coating thickness } \underline{2/}}$$

1/ In calculating mean value of remaining coating, use value of zero for base metal loss.

2/ Where coating thickness variations exceeding 15 percent are known to exist on new components, a corrected value may be used. The basis for arriving at a corrected value shall be reported.

5.4.1.1 In addition to the service parameters, the minimum and maximum remaining coating thickness shall be reported.

5.4.1.2 The mean depth of base metal attack shall be calculated. The measured maximum and calculated mean depth of attack shall be reported.

5.4.2 Corrosion mapping technique. The maps are produced by both visual and metallographic means. Airfoils are first examined at up to 30X to produce an outline of the corrosion pattern. Metallography is performed to identify the morphology of the corrosion attack. An alpha-numeric code (e.g., A2, B3, C1, etc.) is used to describe the depth and type of corrosion attack. The depth of attack, in three general groupings, is indicated by a code letter while the type of attack is indicated by a numeral.

5.4.2.1 The depth of attack is coded as follows:

(a) Type A - Less than 50 percent of the original coating thickness lost. For this depth of attack, it is often impossible to identify a distinct corrosion morphology. Therefore, the code "A" can be used without a numeric identification of corrosion type.
(b) Type B - Between 50 and 100 percent of the original coating thickness lost with occasional areas of penetration into the base metal.
(c) Type C - Complete loss of coating and generalized attack of the base metal.

5.4.2.2 Corrosion morphologies in CoCrAlY and other MCrAlY type overlay coatings are identified as follows:

(a) Type 1 - a zone depleted of the aluminide phase occurs beneath the scale in the MCrAlY as shown on figure 1. The scale typically contains a network of oxides mixed with aluminum depleted MCrAlY.
(b) Type 2 - attack of the MCrAlY with no depletion of the aluminide phase. The scale is thick, dense and consumes the MCrAlY with no preference for either phase as shown on figure 2. The inner scale is rich in aluminum and chromium while the outer scale is rich in cobalt in cobalt based coatings.
(c) Type 3 - attack of the MCrAlY intermediate to the above morphologies. There is some depletion of the aluminide phase with one or more of the following present:

(1) A thick scale similar to that present in type 2.
(2) Depletion of chromium from the MCrAlY as evidenced by etching discoloration.
(3) Voids or spherical oxides present in the MCrAlY near the depletion zone.
(4) Aluminide phase present in contact with oxide spikes.
(5) Sulfides present in the MCrAlY prior to complete depletion of the aluminide phase.

The most frequent form of type 3 attack has the thick scale and the chromium depletion along with the aluminide depleted zone. Type B3 attack morphologies in MCrAlY type coatings are shown on figure 3.

5.4.2.3 Corrosion morphologies in aluminide diffusion coatings are identified as follows:

(a) Type 1 - a zone of alloy depletion in the coating with sulfide particles present as shown on figure 4.
(b) Type 2 - attack of the coating with no alloy depletion zone as shown on figure 5. A thick, dense scale is usually present.

5.4.2.4 Corrosion morphologies in nickel base substrate alloys are classified as follows:

(a) Type C1 - attack of the base metal with an alloy depletion zone containing metal sulfides as shown on figure 6. Grain boundary spikes of alloy depletion and sulfidation are often observed.
(b) Type C2 - attack of base metal with no depletion zone and no base metal sulfides. The scale is dense and layered as shown on figure 7.
(c) Type C3 - attack of base metal with some alloy depletion but not a distinct depletion zone. Sulfides are present in the grain boundaries and at the scale/metal interface as shown on figure 8.

5.4.2.5 Corrosion morphologies in cobalt base substrate alloys are identified as follows:

(a) Type C1 - attack of the cobalt base substrate with preferential carbide/grain boundary attack. Sulfides are present in the attacked portions of the grain boundaries as shown on figure 9.
(b) Type C2 - frontal attack of the cobalt base substrate with no preferential corrosion of the grain boundaries or carbides. Base metal sulfides are not present as shown on figure 10. A thick, dense layered scale is usually present. Carbides are frequently observed in the scale.

5.4.2.6 The corrosion maps are drawn on diagrams of the turbine airfoil using the alpha-numeric codes. The changes from one morphology to another are often gradual and no distinct boundaries occur. Special conditions, such as pitting, may also be indicated in the corrosion maps. If more than one airfoil from a specific stage is examined, corrosion maps shall be made for each individual airfoil. This is particularly important for vanes which see considerable variation in operating environment around the engine. If a comparison of corrosion maps for airfoils within a stage show a distinct pattern, a composite corrosion map for that stage may be made as shown on figure 11.

5.4.3 Photomicrographs. Photomicrographs shall be taken of significant and representative features on the turbine airfoils. ASTM E 3 and E 407 list suitable microetching procedures for bringing out metallographic features. Phosphoric acid, used electrolytically, has been found particularly effective as an etchant for the examination of gas turbine components.

5.4.4 Scanning electron microscopy. Suitable areas shall be examined in the scanning electron microscope with X-ray analyzer or electron microprobe. Compatibility of polishing materials must be insured. If samples had not been water washed previously, cutting and polishing in a non-aqueous media will prevent loss of water soluble corrosion products, such as sulfates. The extent of this analysis shall be as agreed between the requesting and performing agencies.

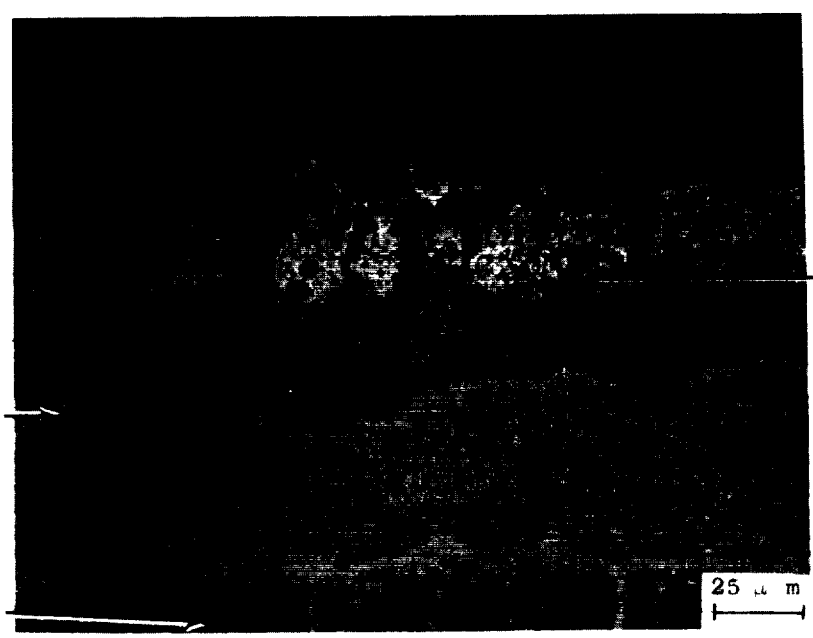
6. NOTES

6.1 Intended use. This standard is used to perform a metallurgical examination on gas turbine hot section airfoil components in order to make an evaluation for hot corrosion degradation. The standard is intended for use primarily as part of material research or development programs although the procedure can be used to evaluate components from operational engines.

6.2 Extent of examination. The agency requesting the metallurgical examination shall define the purpose of the examination and the specific tests within this standard to be performed. The number of samples available for examination shall also be specified.

Preparing activity:
Navy - SH
(Project 2835-N005)

CoCrAlHfPt COATING ON RENE' 80 SUBSTRATE

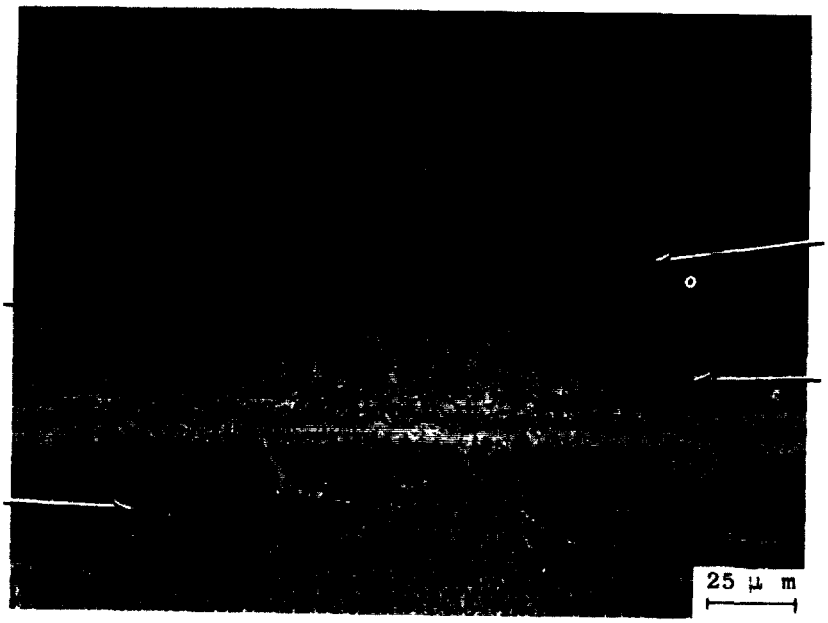


CoCrAlY COATING ON RENE' 80 SUBSTRATE

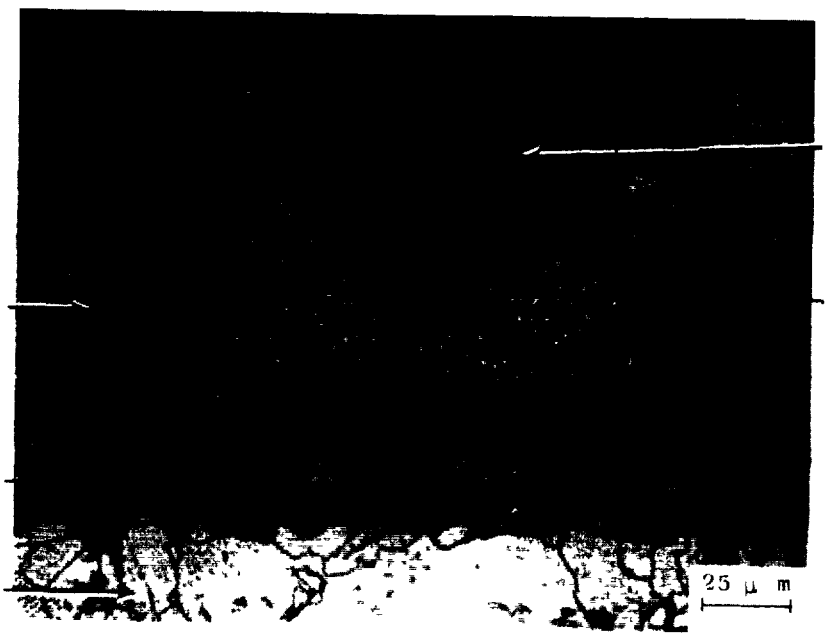
SH 12006

MAGNIFICATION: 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 1. Type 1 attack of overlay coatings.



CoCrAlY COATING ON RENE' 80 SUBSTRATE



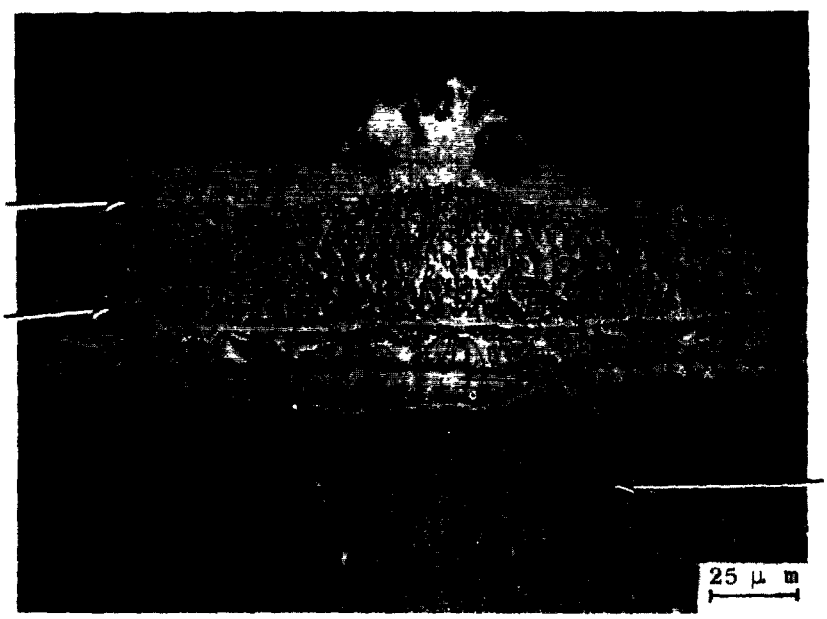
TYPE 2 PITTING OF CoCrAlY WITH Pt UNDERCOAT ON MAR-M-509 SUBSTRATE

SH 12007

MAGNIFICATION 500X
ETCHANT PHOSPHORIC ACID

FIGURE 2. Type 2 attack of overlay coatings.

CoCrAlY COATING ON RENE' 80 SUBSTRATE

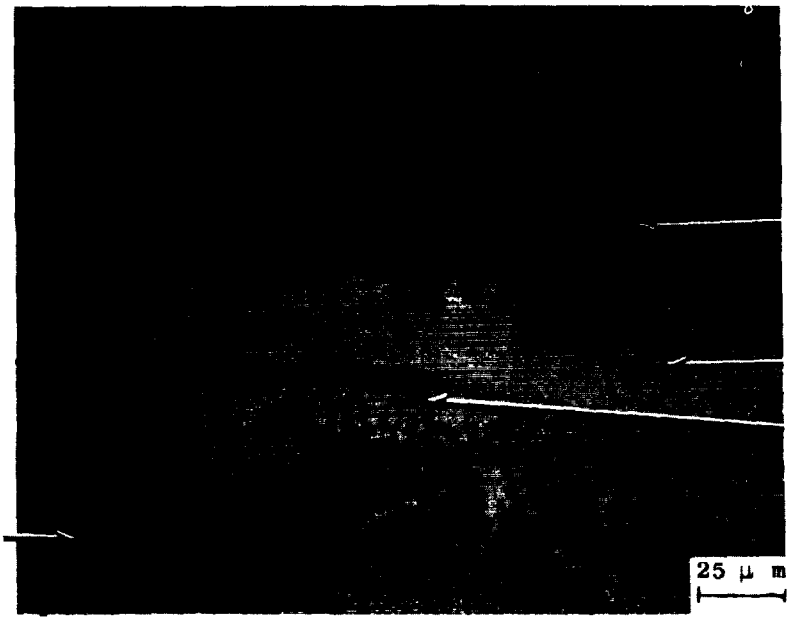


CoCrAlHfPt COATING ON RENE' 80 SUBSTRATE

SH 12008

MAGNIFICATION. 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 3. Type B3 attack of overlay coatings.



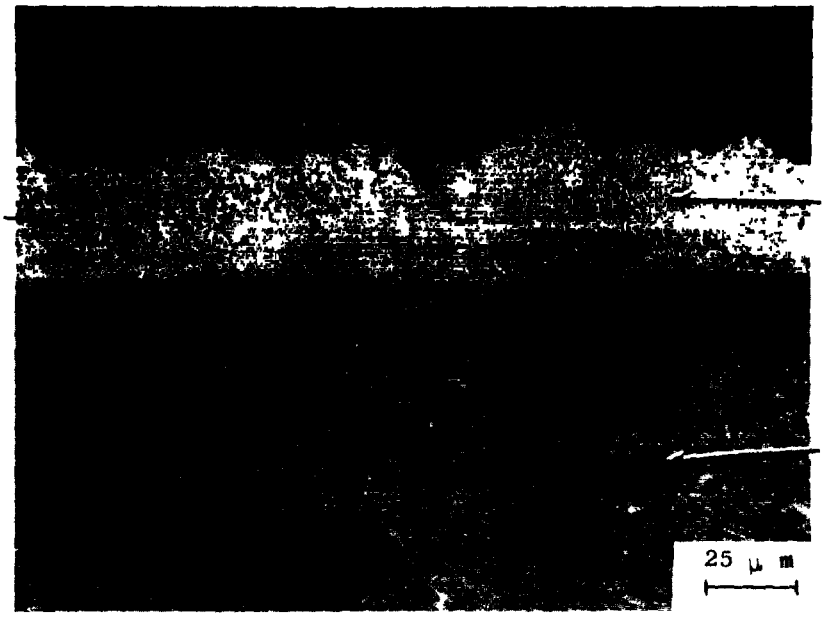
CoCrAlHfPt COATING ON RENE' 80 SUBSTRATE

CoCrAlY COATING ON MAR-M-509 SUBSTRATE

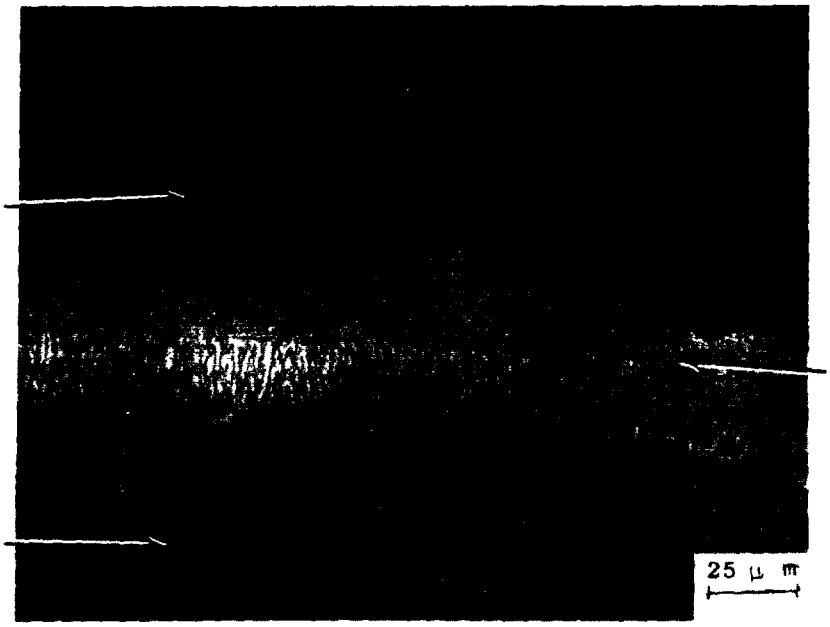
SH 12008

MAGNIFICATION: 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 3. Type B3 attack of overlay coatings. - Continued



ALUMINIDE COATING ON RENE' 80 SUBSTRATE

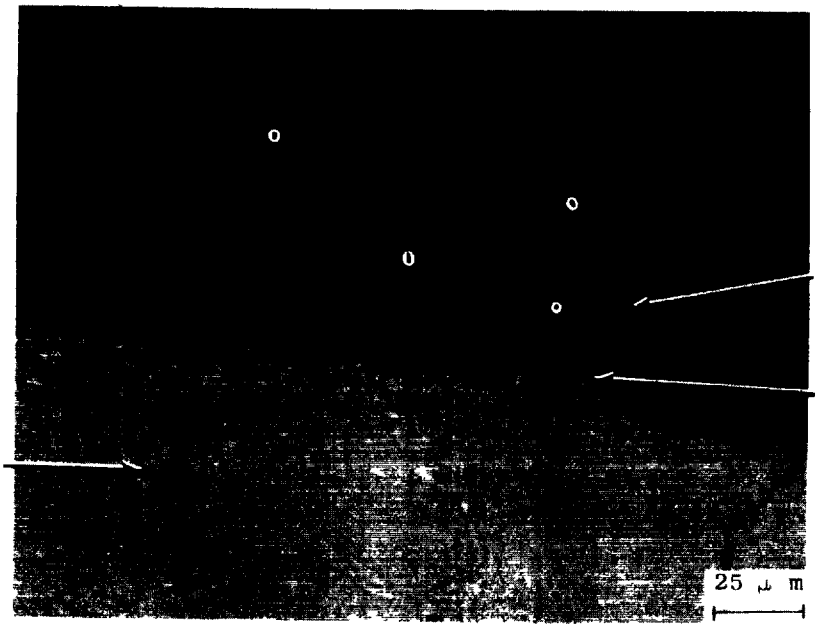


ALUMINIDE COATING ON IN-738 SUBSTRATE

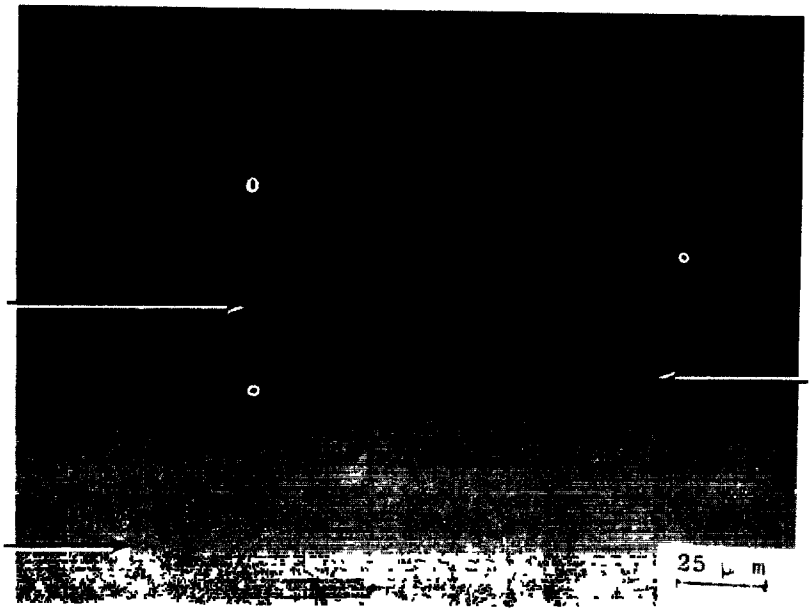
SH 12009

MAGNIFICATION: 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 4. Type 1 attack of aluminide coatings.



ALUMINIDE COATING ON X-40 SUBSTRATE
ETCHANT: PHOSPHORIC ACID

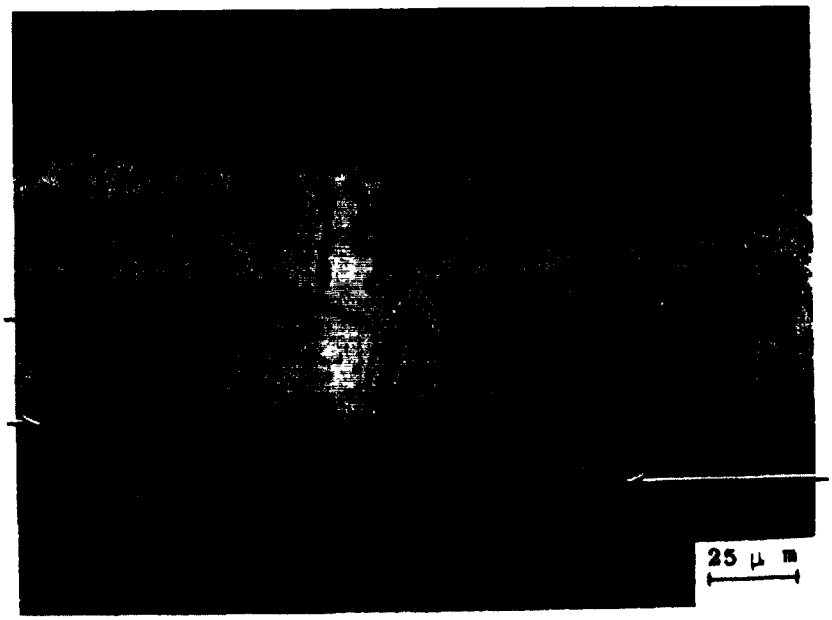


ALUMINIDE COATING ON IN-738 SUBSTRATE
ETCHANT: MARBLES REAGENT

SH 12010

MAGNIFICATION. 500X

FIGURE 5. Type 2 attack of aluminide coatings.



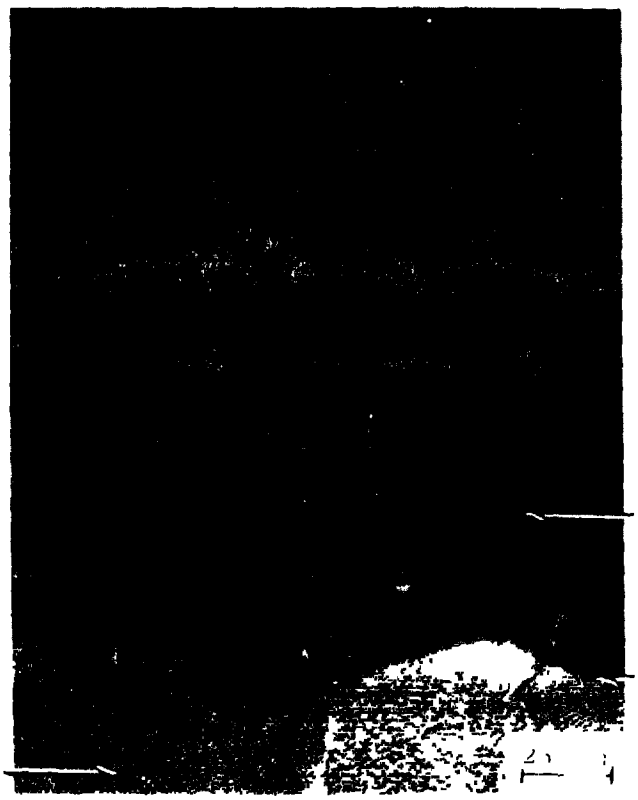
RENE' 80 BASE METAL

IN-738 BASE METAL

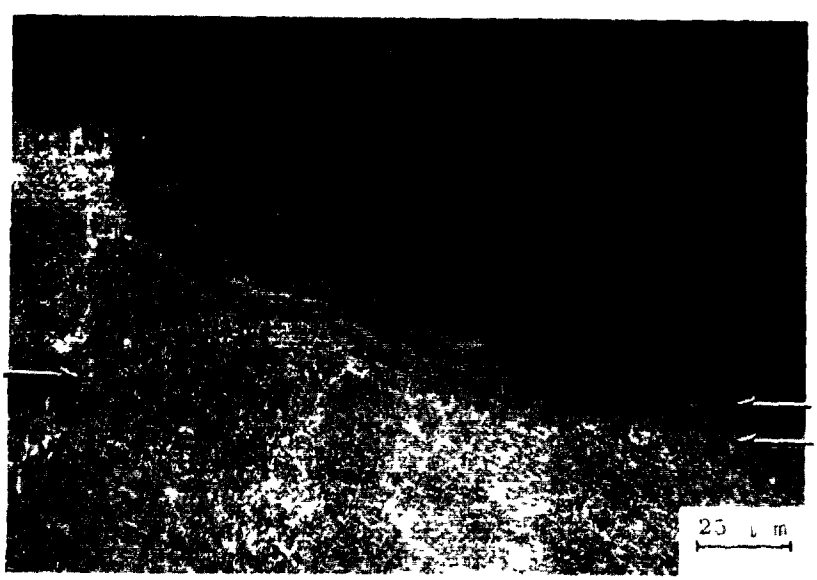
SH 12011

MAGNIFICATION: 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 6. Type C1 attack of nickel base alloys.



RENE' 80 BASE METAL

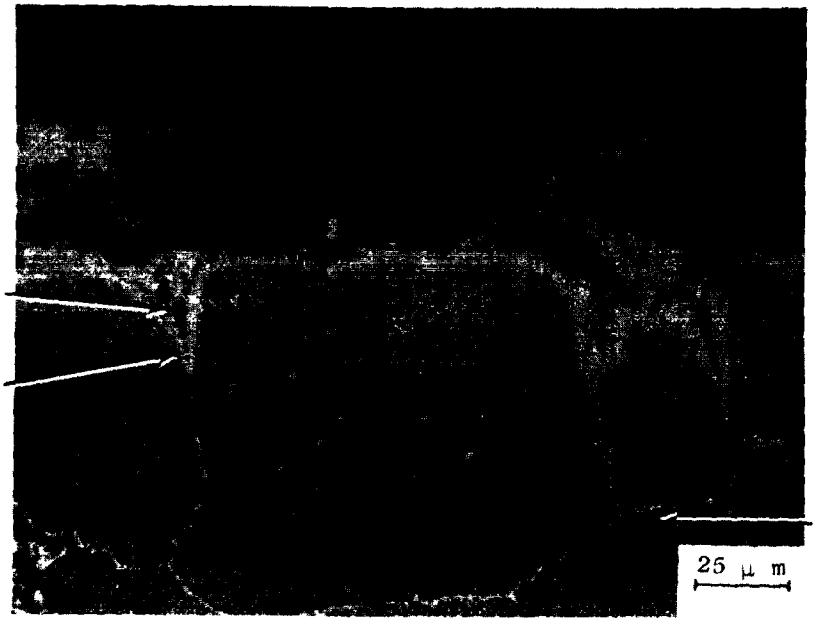


IN-738 BASF METAL

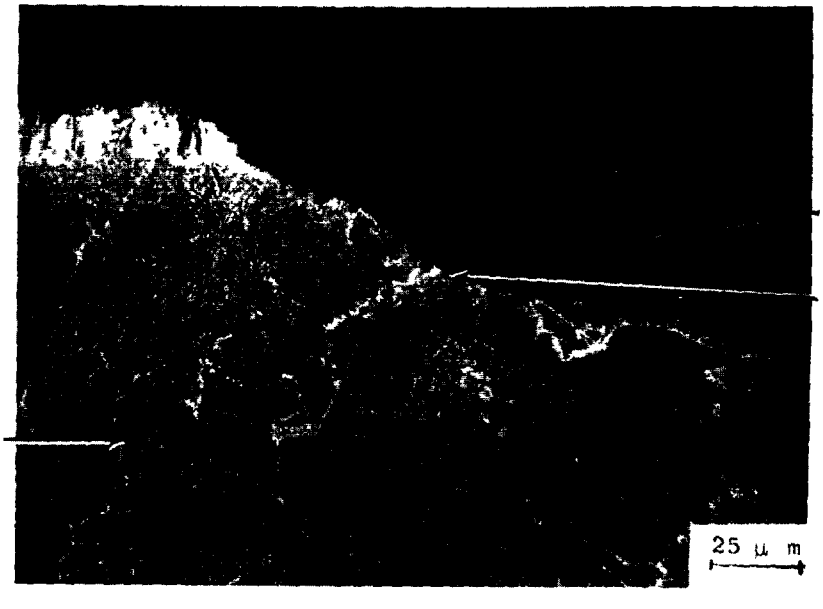
SH 12012

MAGNIFICATION. 500X
ETCHANT. PHOSPHORIC ACID

FIGURE 7. Type C2 attack of nickel base alloys.



RENE' 80 BASE METAL



IN-738 BASE METAL

SH 12013

MAGNIFICATION. 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 8. Type C3 attack of nickel base alloys.

X-40 BASE METAL

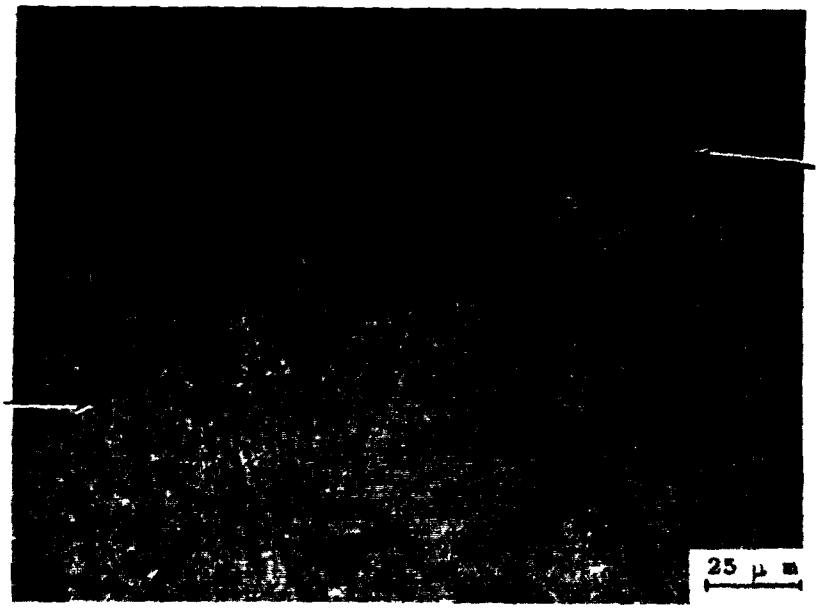
MAR-M-509 BASE METAL

SH 12014

MAGNIFICATION 500X

FIGURE 9. Type C1 attack of cobalt base alloys.

X-40 BASE METAL

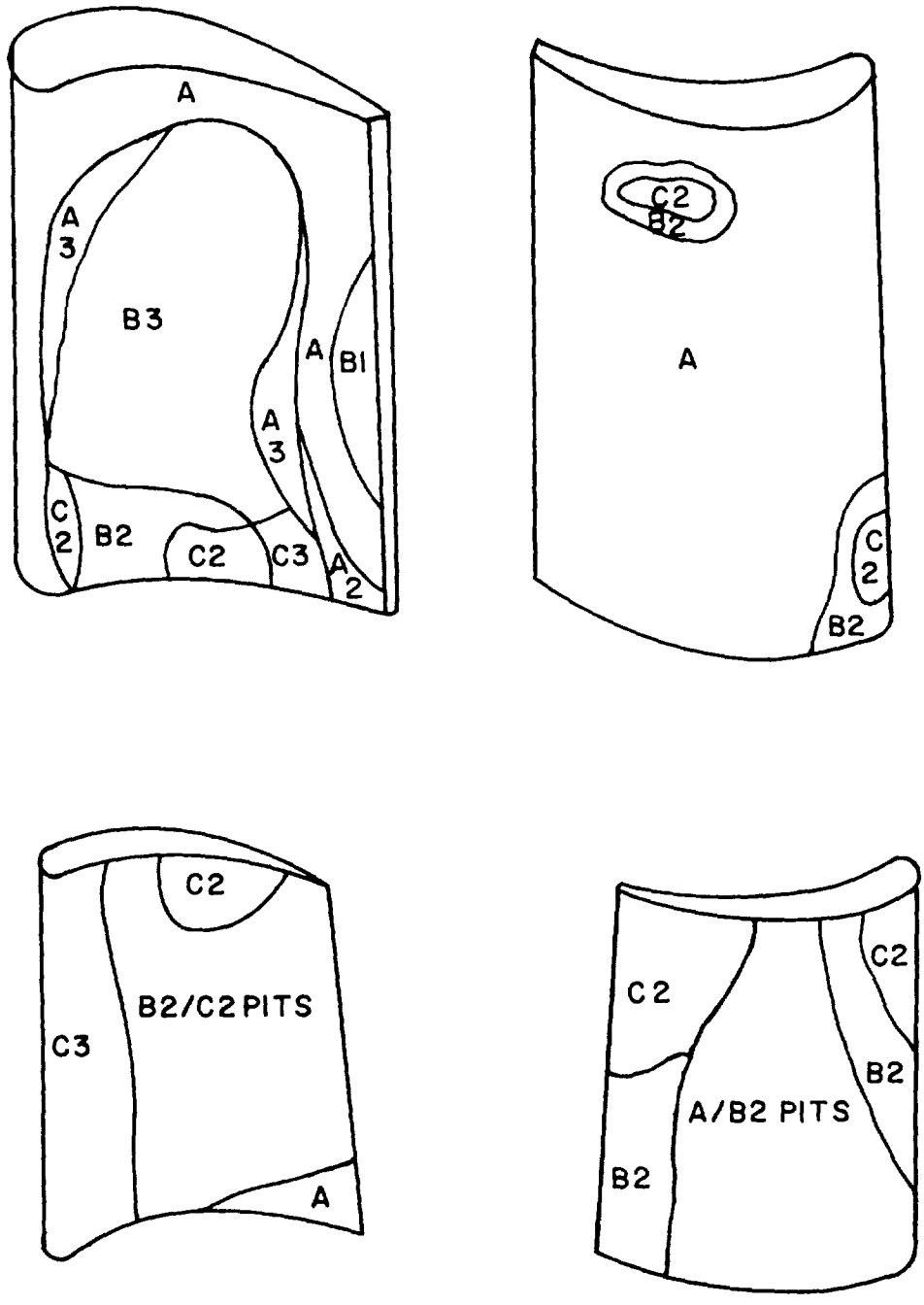


MAR-M-509 BASE METAL

SH 12015

MAGNIFICATION: 500X
ETCHANT: PHOSPHORIC ACID

FIGURE 10. Type C2 attack of cobalt base alloys.



SH 12016

FIGURE 11. Examples of turbine airfoil corrosion maps.

APPENDIX
DATA REQUIREMENTS

10. DATA

10.1 Data requirements. When this standard is used in a contract which incorporates a DD Form 1423 and invokes the provisions of 7-104.9(n) of the Defense Acquisition Regulation (DAR), the data requirements identified below will be developed as specified by an approved Data Item Description (DD Form 1664) and delivered in accordance with the approved Contract Data Requirements List (DD Form 1423) incorporated into the contract. When the provisions of DAR-7-104.9(n) are not invoked, the data specified below will be delivered by the contractor in accordance with the contract requirements. Deliverable data required by this standard is cited in the following paragraph:

Paragraph	Data requirement	Applicable DID	Option
4.2	Report, technical	UDI-S-23272	Final report or interim and final report

(Copies of data item descriptions required by the contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

10.1.1 The data requirements of 10.1 and any task in the standard required to be performed to meet a data requirement may be waived by the contracting/acquisition activity upon certification by the offeror that identical data were submitted by the offeror and accepted by the Government under a previous contract for identical item acquired to this standard. This does not apply to specific data which may be required for each contract, regardless of whether an identical item has been supplied previously (for example, test reports).

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

OMB Approval
No 22-R255

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