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ION-PLATED COATING ON TITANIUM ALLOY. (U)
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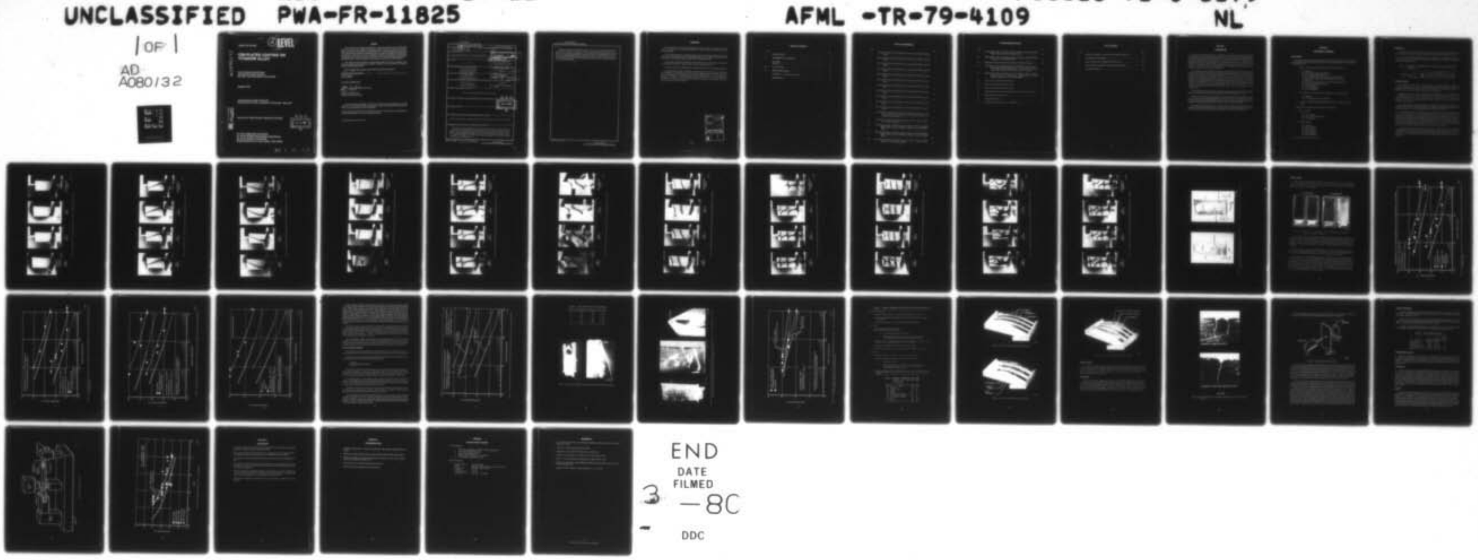

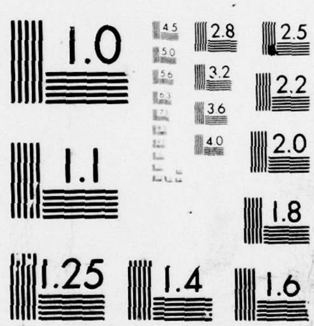

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ION-PLATED COATING ON TITANIUM ALLOY

Pratt & Whitney Aircraft Group
Government Products Division
Box 2691, West Palm Beach, Florida 33402

August 1979

Technical Report AFML-TR-79-4109
Final Report for Period 1 September 1978 through 1 May 1979

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Shiro Fujishiro
Project Engineer

FOR THE COMMANDER

Gail E. Eichelman
Chief
Structural Metals Branch
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(10) Thomas A. Eckler

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The trend to achieve higher thrust-to-weight ratios in advanced gas turbine engines has stimulated the need to develop structural components which are more oxidation resistant and possess improved mechanical properties. In an effort to meet these goals noble metals were ion-plated on Ti-6Al-2Sn-4Zr-6Mo compressor blades. These blades represent an excellent medium for evaluating ion-plating on titanium gas turbine components. The ion-plated coatings evaluated were Pt, Pt/Rh and Au.

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Holograms were used to determine the effect of the coating on the normal frequency and mode shape. In addition, a combination of stress coat paint and strain gages were used to determine if the ion-plated coating alters the stress distribution. Fatigue and notch fatigue tests were run on coated and uncoated blades conditioned by heating at 454°C (850°F) for 125 hr and then tested at 454°C (850°F). Unlike other methods of coating, the ion-plating caused an increase in the high temperature fatigue strength. The oxidation resistance of the ion-plated materials was also substantially increased.

FOREWORD

This document is the final report prepared by Pratt & Whitney Aircraft, Government Products Division, West Palm Beach, Florida under USAF Contract No. F33615-78-C-5179, Project ILIR 0099.

The work reported herein was performed during the period 1 September 1978 through 1 May 1979 and was administrated by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, with Dr. Shiro Fujishiro (AFML/LLS) as Program Manager.

Mr. Thomas A. Eckler, Pratt & Whitney Aircraft/Florida, was overall program manager and was assisted by Mr. Brian A. Manty and the technical supporting group.

The author wishes to acknowledge the contribution provided by the following individuals.

Mr. R. Workinger and Mr. P. McDaniel for their diligence in conducting the pulse plating. Mr. B. Benedict for his fatigue analysis and aid in the interpretation of the results. Dr. Keith Legg, Georgia Institute of Technology and Dr. Graham Hubler, NRL for their ion-implantation efforts. Dr. S. Fujishiro, Air Force Materials Laboratory (AFML), Structural Metals Branch of the Metals and Ceramics Division provided technical monitoring of the program and advice helpful to the success of this program.

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SECTION I

INTRODUCTION

The trend to achieve higher thrust-to-weight ratios in advanced gas turbine engines has stimulated the need to develop structural components with improved mechanical properties. Since the early 1950's the aerospace industry has met specific engineering requirements for structurally stable components through the use of titanium (Ti) alloys. A number of high-temperature Ti alloys are currently used in gas turbine engines, but service temperatures are limited to approximately 430°C (800°F) for extended service times of 500 hr or more. This limitation is due to the inherent vulnerability of Ti to oxidation and a rapid decrease in mechanical properties with increasing temperature.

The properties required to qualify a Ti alloy for high temperature applications include high modulus to density ratio, high tensile and fatigue strengths, creep resistance, and metallurgical and chemical stability in the working environment. Severe oxidation of Ti alloys causes deterioration of mechanical properties, such as post-creep ductility and fatigue strength. A number of research programs have been conducted in an effort to improve the oxidation resistance with coatings applied by electrochemical plating and thermal plasma spray. These coatings have included Al, Cr, Ni, and their alloys or slurries. The major drawback of these coatings is severe loss of the fatigue strength (References 1 and 2). Consequently, Ti alloy components coated with these materials cannot be used in fatigue-sensitive sections of gas turbine engines.

However, AFML in-house efforts demonstrated that Pt/ion-plating on Ti-6Al-2Sn-4Zr-2Mo improved the high-cycle fatigue properties significantly at 850°F (References 3 and 4).

In addition, low creep rates at high temperatures were observed on uncoated Ti alloys tested in vacuum and in argon atmosphere (References 5 and 6). This led to the investigation of ductile oxidation resistant coatings impregnated in Ti alloy surfaces. Platinum ion-plated coatings were investigated and showed improved high-temperature creep resistance (Reference 7).

This report describes the results of an 8-month effort to evaluate noble metal ion-plated coatings on Ti-6Al-2Sn-4Zr-6Mo. The best coating system was selected and applied to ninety-five 7th-stage F100 compressor blades and made available for accelerated mission testing.

SECTION II

EXPERIMENTAL PROGRAM

TEST EFFORT

Two hundred 7th-stage compressor blades were purchased from Excello Fostoria with 105 mechanically tested and 95 saved for engine testing. The mechanical testing used for these 105 7th-stage blades was:

1. *Fatigue* — All exposed at 454°C (850°F) for 125 hr before testing:

   - 9 Baseline
   - 9 Pt ion-plated airfoils with B/M roots
   - 9 Pt ion-plated airfoils and roots
   - 9 Pt ion-plated airfoils and roots with dry film lubricant
   - 9 Pt ion-plated airfoils glass bead peened after plating with B/M root
   - 9 80% Pt/20% Rh ion-plated airfoils with Au ion-plated roots
   - 9 Au ion-plated airfoils and roots
   - 9 Pt pulse-plated
   - *13 Pt ion-implanted
   - 2 Ti ion-implanted

2. *Notch Fatigue* — All exposed at 454°C (850°F) for 125 hr before testing:

   - 9 Baseline
   - 9 Pt ion-plated airfoils with B/M roots

3. *Erosion* — The blades used in the fatigue tests were also used in the erosion tests.

Ti-8Al-1Mo-1V specimens were machined for the following:

4. *Stress Corrosion*

   - 3 Pt ion-plated
   - 3 80% Pt/20% Rh ion-plated
   - 3 Au ion-plated

5. *Fretting Fatigue*

   - 6 Baseline
   - 6 Pt ion-plated
   - 6 80% Pt/20% Rh
   - 6 Au ion-plated
   - 6 Pt pulse-plated
   - 6 Au pulse-plated

*Five of these blades destroyed during conditioning.

MATERIALS

Chemical compositions of the substrate titanium alloy materials used in this investigation are listed in Table 1. These compositions were all confirmed by Pratt & Whitney Aircraft.

Chemicals used in preparing solutions in this investigation were all reagent grade materials except for the platinum electrolyte obtained from Technic Inc., under their designation "Platinum N Plating Solution."

TABLE 1. CHEMICAL COMPOSITION OF TITANIUM ALLOY SUBSTRATE MATERIALS

			Composition, (wt/%)							
Alloy	*Test*	*Heat Code*	*Al*	*Mo*	*V*	*Fe*	*N*	*C*	*O*	*H*
Ti-8Al-1Mo-1V	HSSC	BDEU	8.0	1.10	1.10	0.05	0.009	0.020	0.098	0.0033
	Fretting Fatigue	BDEU	8.0	1.10	1.10	0.05	0.009	0.020	0.098	0.0033

Vibration Analysis

Experimental vibration analysis was conducted on compressor blades to establish the frequency and shape of various modes of vibration and identify corresponding high stress areas. The analysis included: (1) holographic analysis to establish modes of vibration from 650 Hz to 24 kHz; (2) stress coat (brittle lacquer) analysis; and (3) strain-gaging.

Holographic analysis was used to identify the natural frequencies of the coated blades and corresponding mode shapes (pattern of vibration). In this analysis, laser interferometry was used to produce holograms of the coated and uncoated blades. Photographs of the reconstructed holograms show the mode of vibration the blade assumes (while fixed in a broach block) when excited at a given frequency.

The results indicate no significant differences in the various airfoils' mode shapes for all modes of vibration from first bending frequency to 24,000 Hz as a result of the ion-plating. Time-average reconstructions of the holograms are shown in Figures 1 through 11.

Various modes of vibration (usually the modes lowest in frequency: first bending, first torsion, second bending, etc.) can be determined by an electrodynamic shaker with the blade secured in a broached block attached to the shaker head. Stresscoat (brittle lacquer) analysis of the blades was conducted to establish high stress locations for the mode of interest. The blades were then strain-gaged (Figure 12) at these identified locations, vibrated at a given amplitude, and the stress ratios measured. The maximum stress location and stress ratio depend upon which mode was excited. The purpose was to identify the maximum stress location of the coated blades and the ratio of stresses at different locations for various modes of vibration.

In the first bending mode of vibration, the cracking of brittle lacquer coating on Bill-of-Material (B/M) and platinum ion-plated blades indicated no difference in the stress profile for these blades. A stress vs leading-edge blade tip double-amplitude calibration was done using strain gages at the maximum stress areas (concave leading edge and convex maximum root thickness).

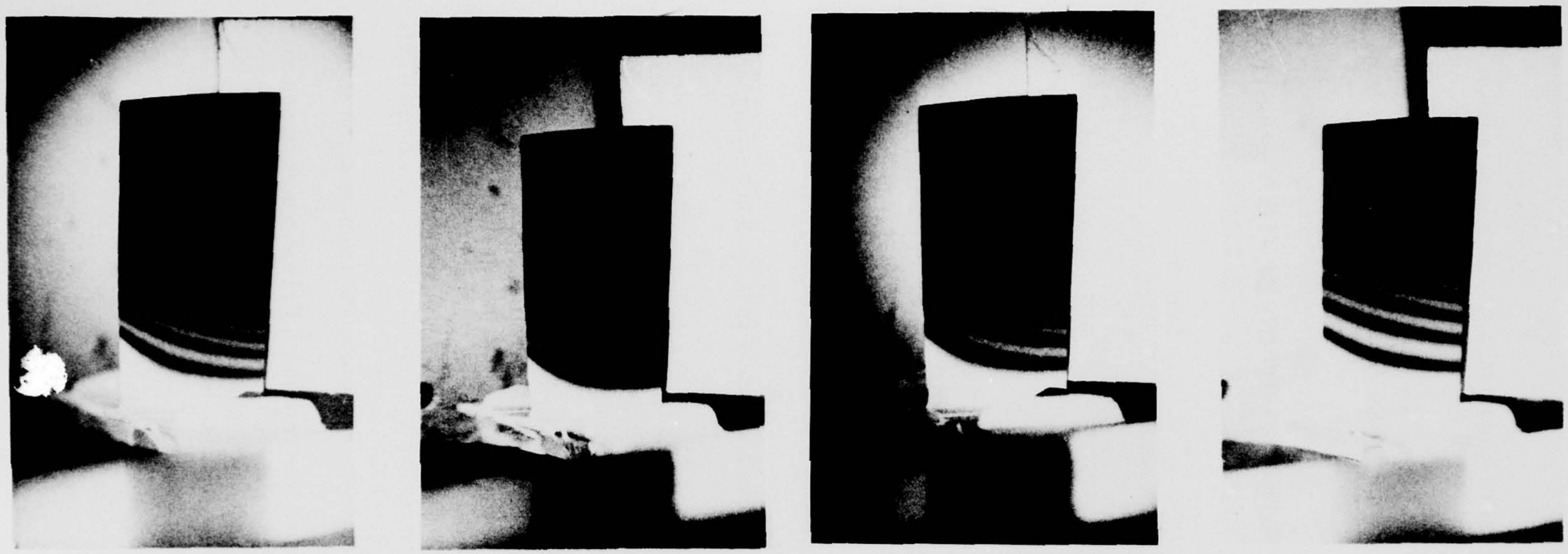


Figure 1. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades

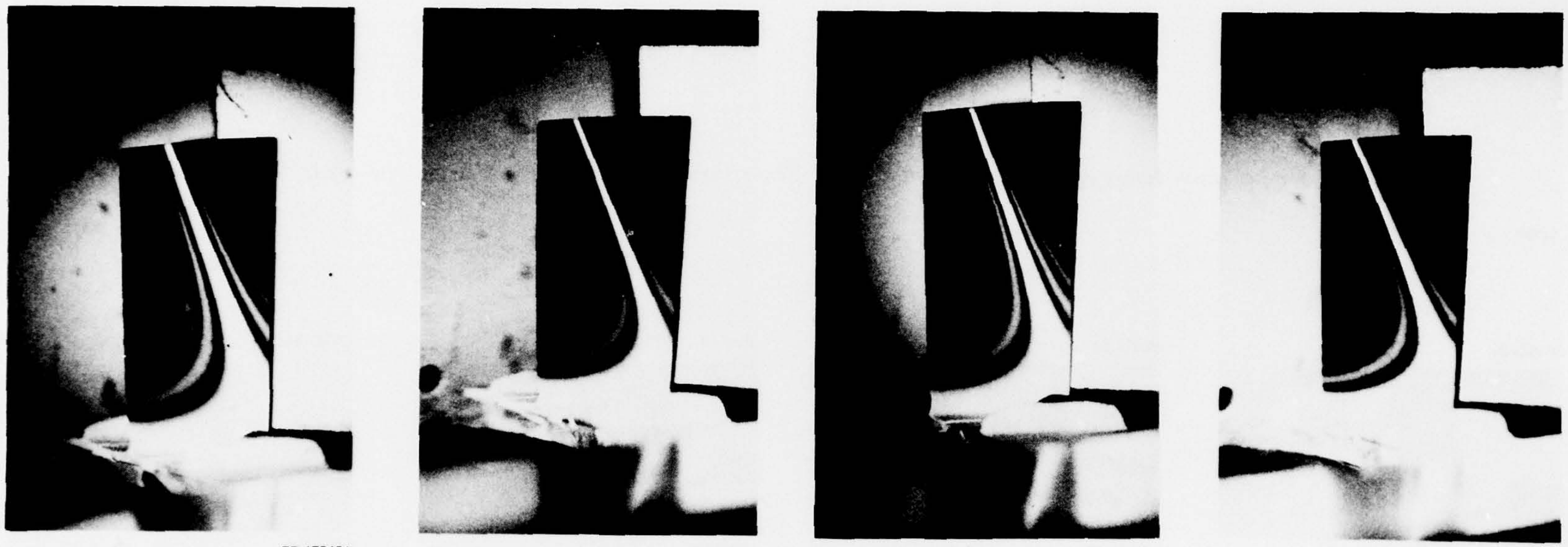
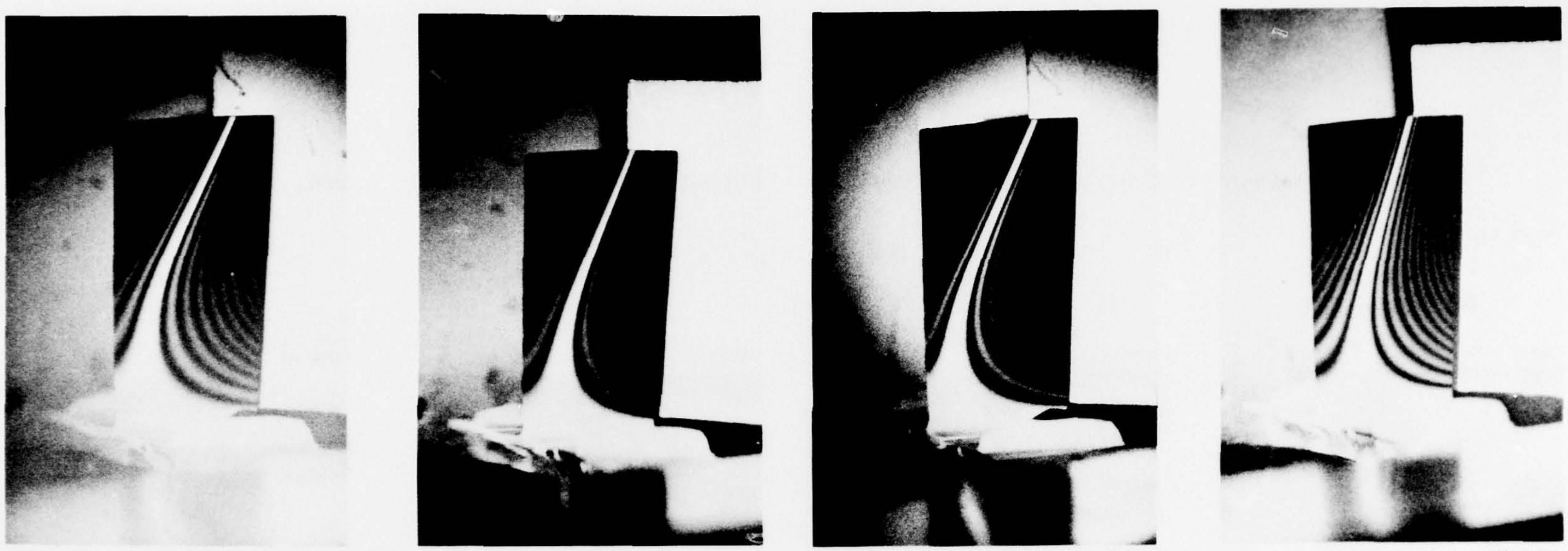


Figure 2. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades

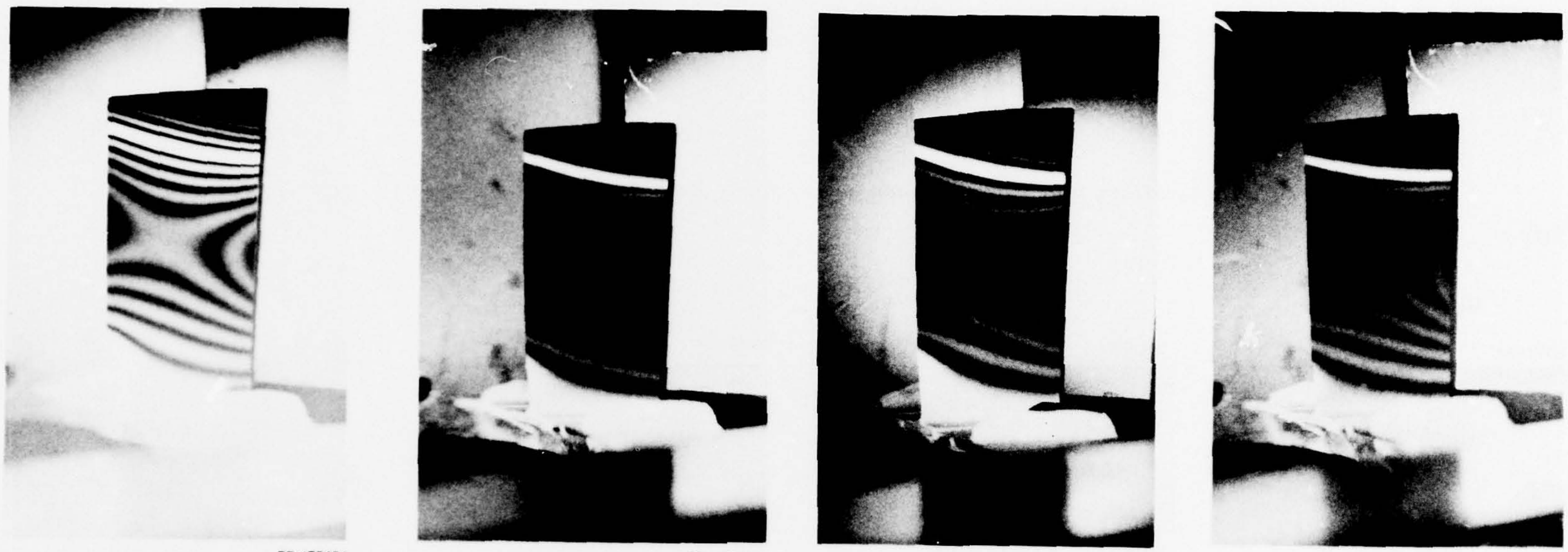


FE 175453 FE 175436 FE 175469 FE 175419

B/M 3316 Hz | Au 3281 Hz | Pt 3285 Hz | 80% Pt/20% Rh 3318 Hz

FD 166675

Figure 3. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175454 FE 175437 FE 175470 FE 175420

B/M
4830 Hz

Au
4659 Hz

Pt
4791 Hz

80% Pt/20% Rh
4606 Hz

FD 166676

Figure 4. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades

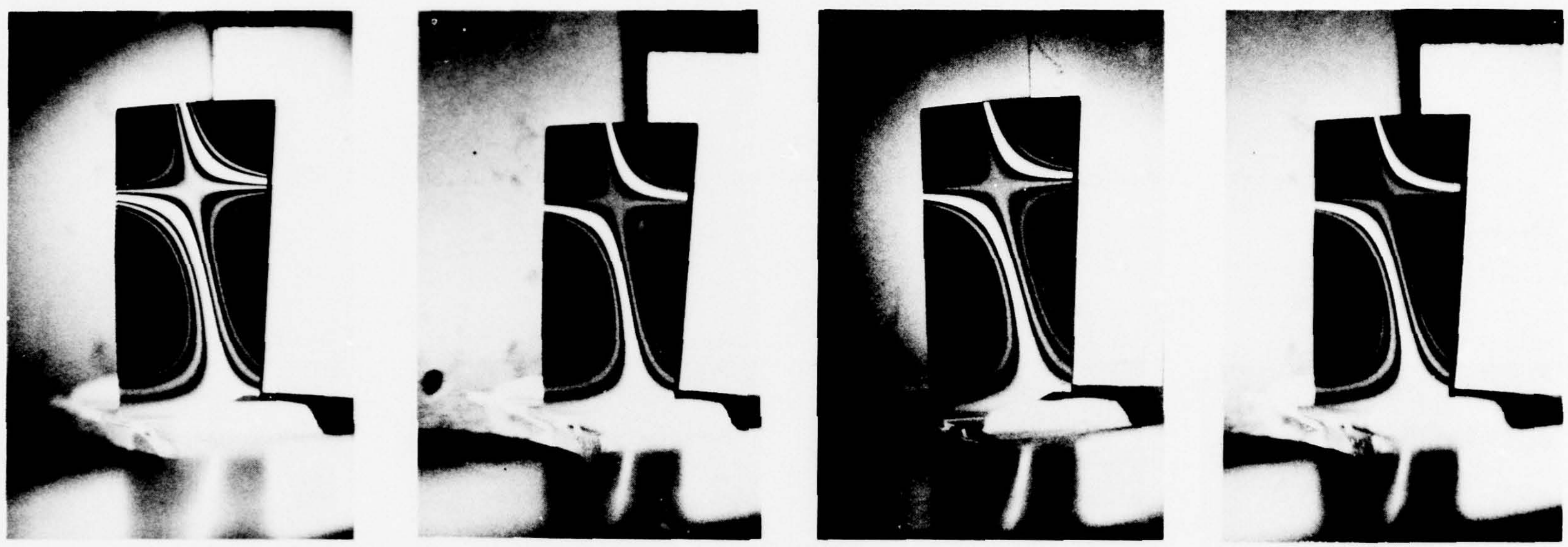
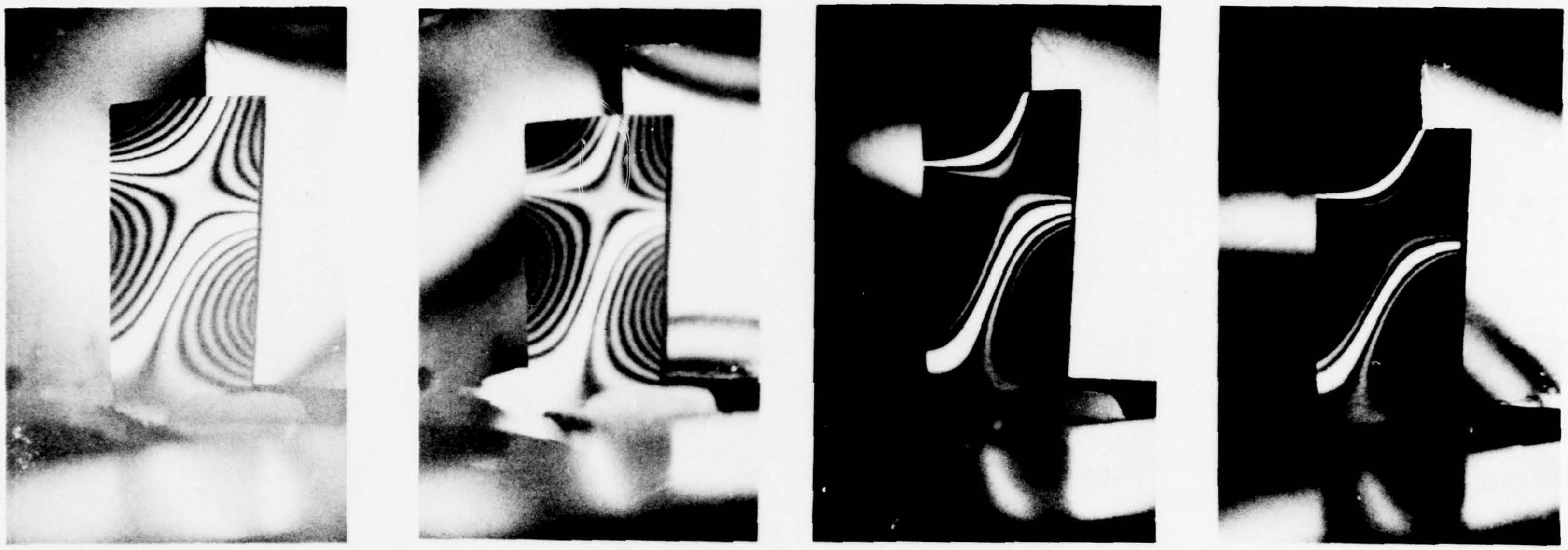


Figure 5. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175456 | FE 175439 | FE 175471 | FE 175423

B/M
9586 Hz

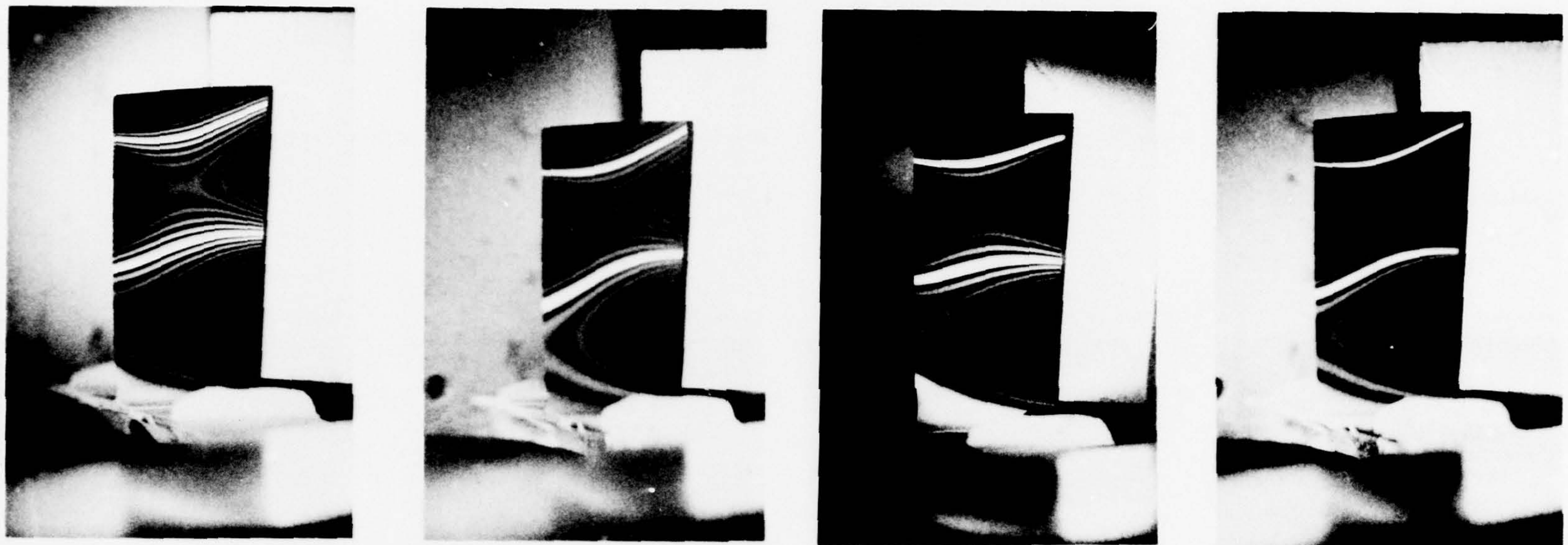
Au
9285 Hz

Pt
9530 Hz

80% Pt/20% Rh
9730 Hz

FD 166678

Figure 6. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175459 — B/M 10409 Hz

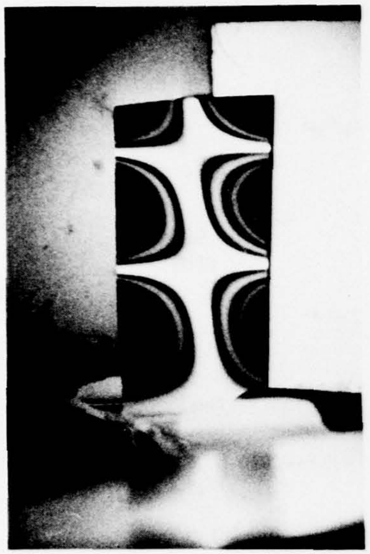
FE 175440 — Au 10052 Hz

FE 175475 — Pt 10464 Hz

FE 175425 — 80% Pt/20% Rh 10399 Hz

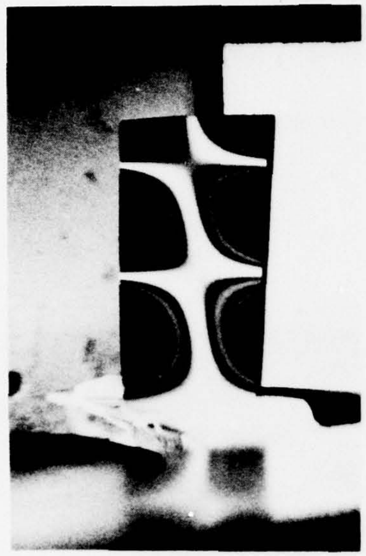
FD 166679

Figure 7. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



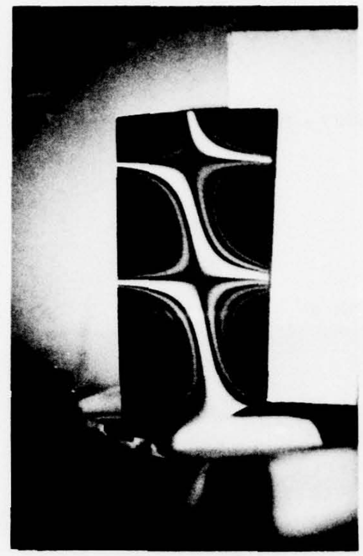
FE 175461

B/M
15541 Hz



FE 175441

Au
15355 Hz



FE 175476

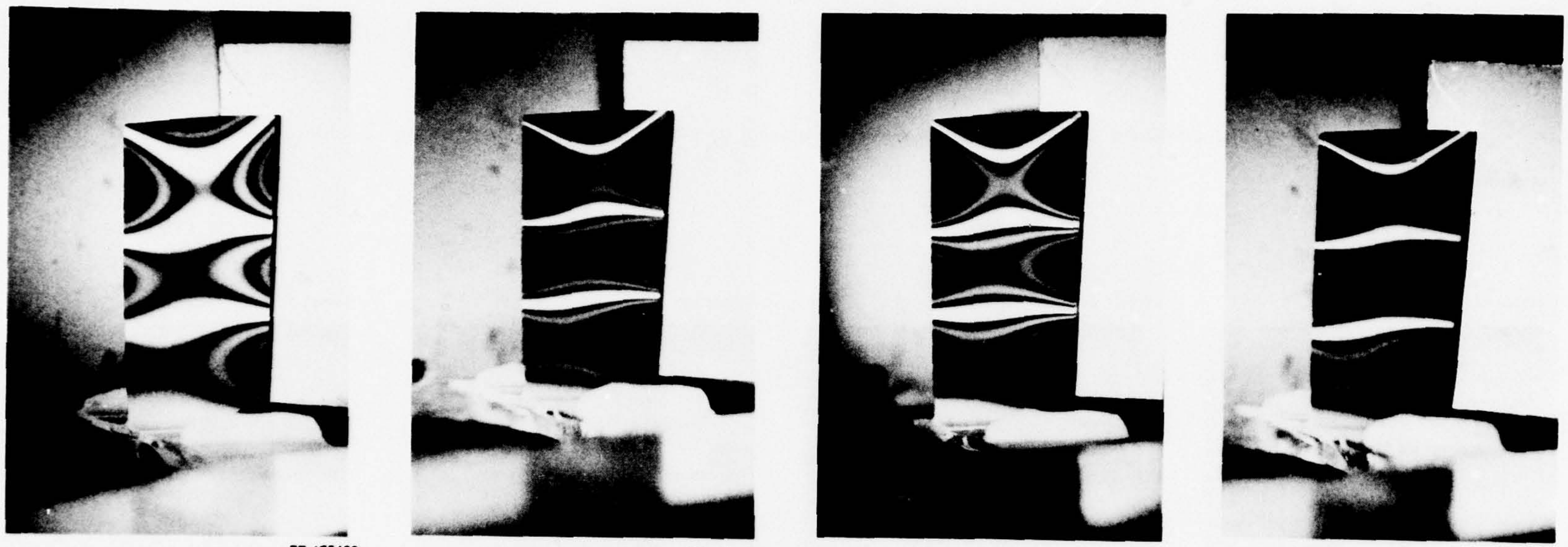
Pt
15349 Hz

FE 175427

80% Pt/20% Rh
15674 Hz

FD 166680

Figure 8. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175462 | FE 175442 | FE 175477 | FE 175428

B/M
18065 Hz

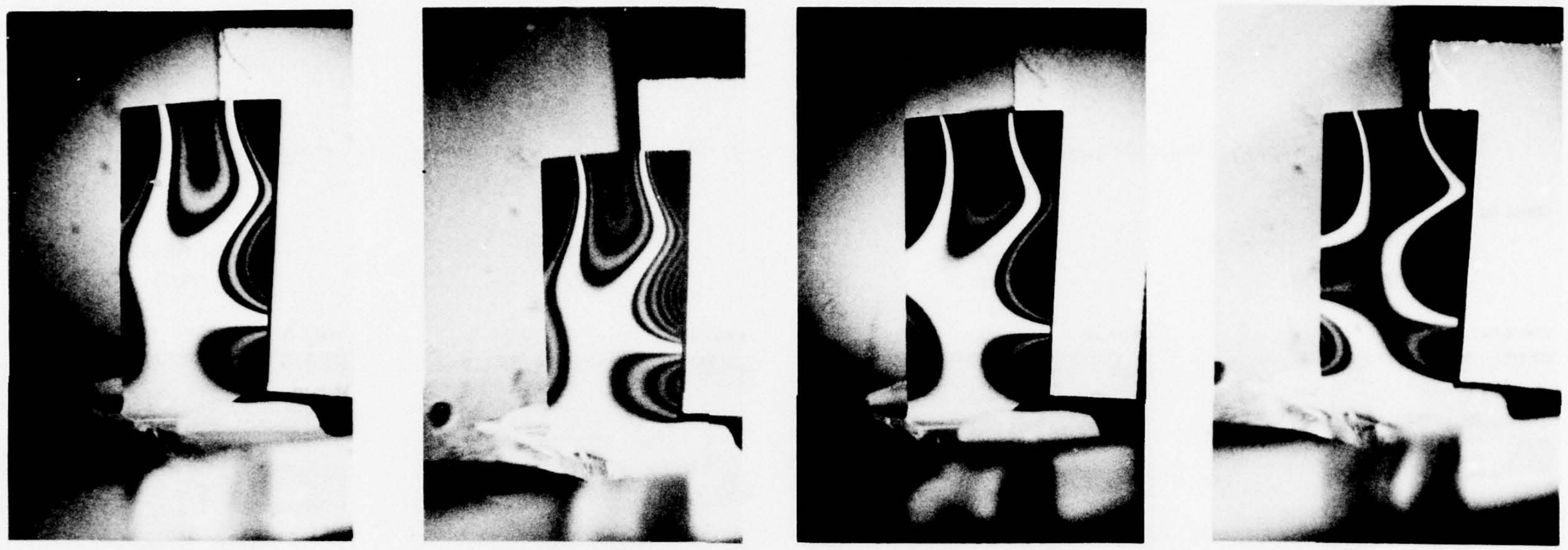
Au
17899 Hz

Pt
18055 Hz

80% Pt/20% Rh
18159 Hz

FD 166681

Figure 9. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175463 | FE 175445 | FE 175478 | FE 175431

B/M
21368 Hz

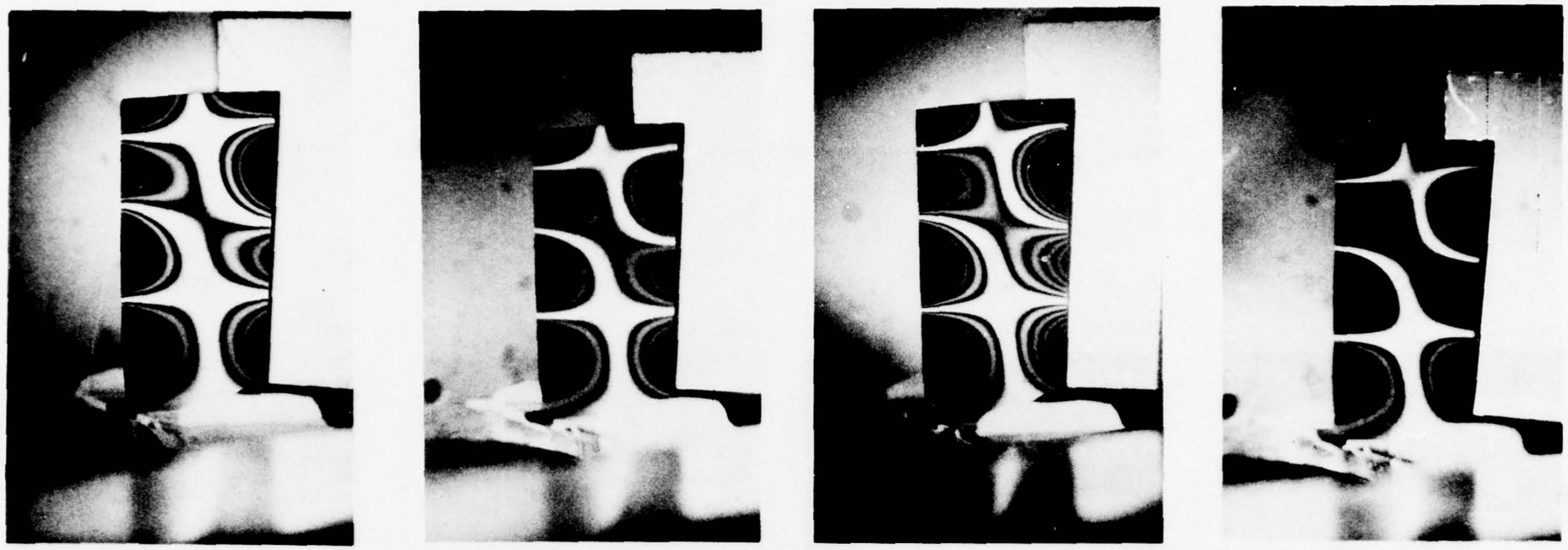
Au
21200 Hz

Pt
21179 Hz

80% Pt/20% Rh
21143 Hz

FD 166682

Figure 10. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades



FE 175465 FE 175449 FE 175480 FE 175433

B/M
23199 Hz

Au
23018 Hz

Pt
22985 Hz

80% Pt/20% Rh
23305 Hz

FD 166683

Figure 11. Reconstructed Time Average Holograms of Ion-Plated and B/M Compressor Blades

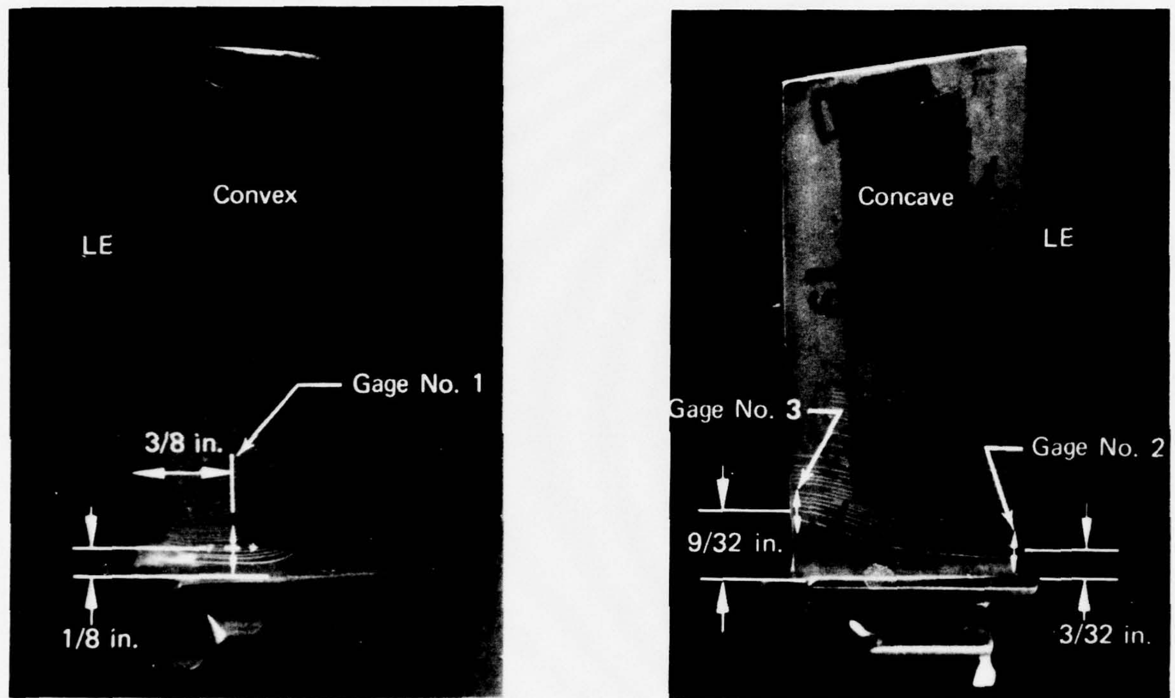
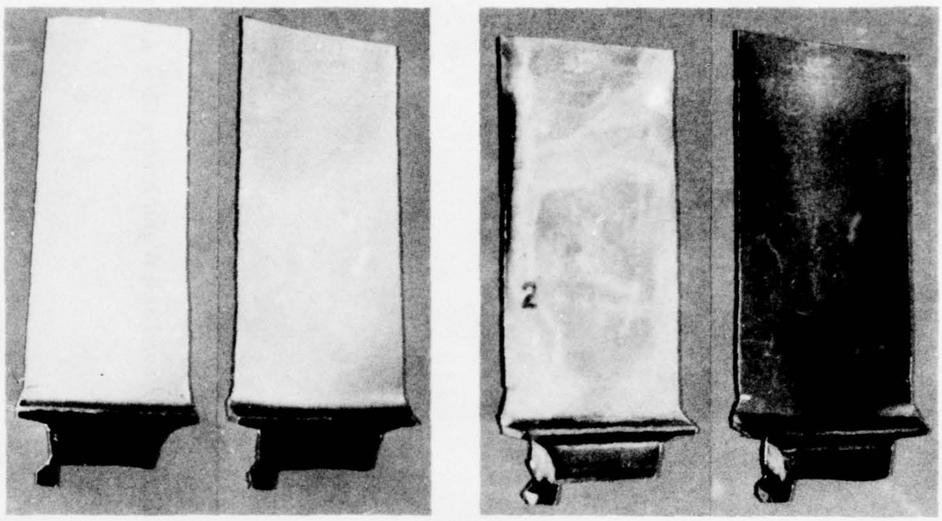


Figure 12. F100 PWA 1216 7th-Stage HPC Blade P/N 4034807 Showing Stress Coat Pattern and Strain Gage Locations and Orientations Resulting from the First Mode of Vibration

Fatigue Testing

Prior to fatigue testing all blades (B/M, Pt ion-plated, Pt pulse-plated, Au ion-plated and 80% Pt/20% Rh ion-plated) were conditioned at 454°C (850°F) for 125 hr to simulate the exposure that the blade receives in actual engine use. Figure 13 shows what a typical platinum-coated and B/M blade looks like after conditioning.

Pt Ion-Plated Airfoil — Uncoated Airfoil



FD 170749A

Figure 13. Comparison of Coated and Uncoated Titanium-Alloy Compressor Blades After Oxidation Exposure

After conditioning, four of the gold coated blades showed discoloration from oxidation of the titanium. The glass bead peened platinum-coated blades also show some discoloration in areas where the coating was removed or excessively abraded. All other blades appeared to have a satisfactory coating prior to fatigue testing. The problem with the Au ion-plated blades demonstrates the need for good quality assurance if this coating method is to be used in production.

Fatigue testing was done on compressor blades at 454°C (850°F). The fatigue strength of blades coated with either platinum, 80% Pt/20% Rh alloy, or gold, increased by approximately 30% over that of B/M blades when tested in the first bending mode of vibration.

The typical value for 10^7 cycle fatigue strength of the platinum ion-plated blades from a regression analysis curve fit is 87 ksi irrespective of root coating as seen in Figure 14. From Figure 14 it can also be seen that glass bead peening has no effect on the fatigure strength of Pt ion-plated blades. The 10^7 cycle fatigue strength of ion-plated 80% Pt/20% Rh coated blades is 86 ksi as shown in Figure 15. Figure 15 shows that gold ion-plated blades also have a typical 10^7 cycle fatigue strength of 86 ksi. This compares to 68 ksi for the B/M blades. Figure 17 shows that a 1 to 2 μ thick pulse-plated platinum coating (coated as per the Appendix) affords approximately the same fatigue enhancement as ion-plated blades.

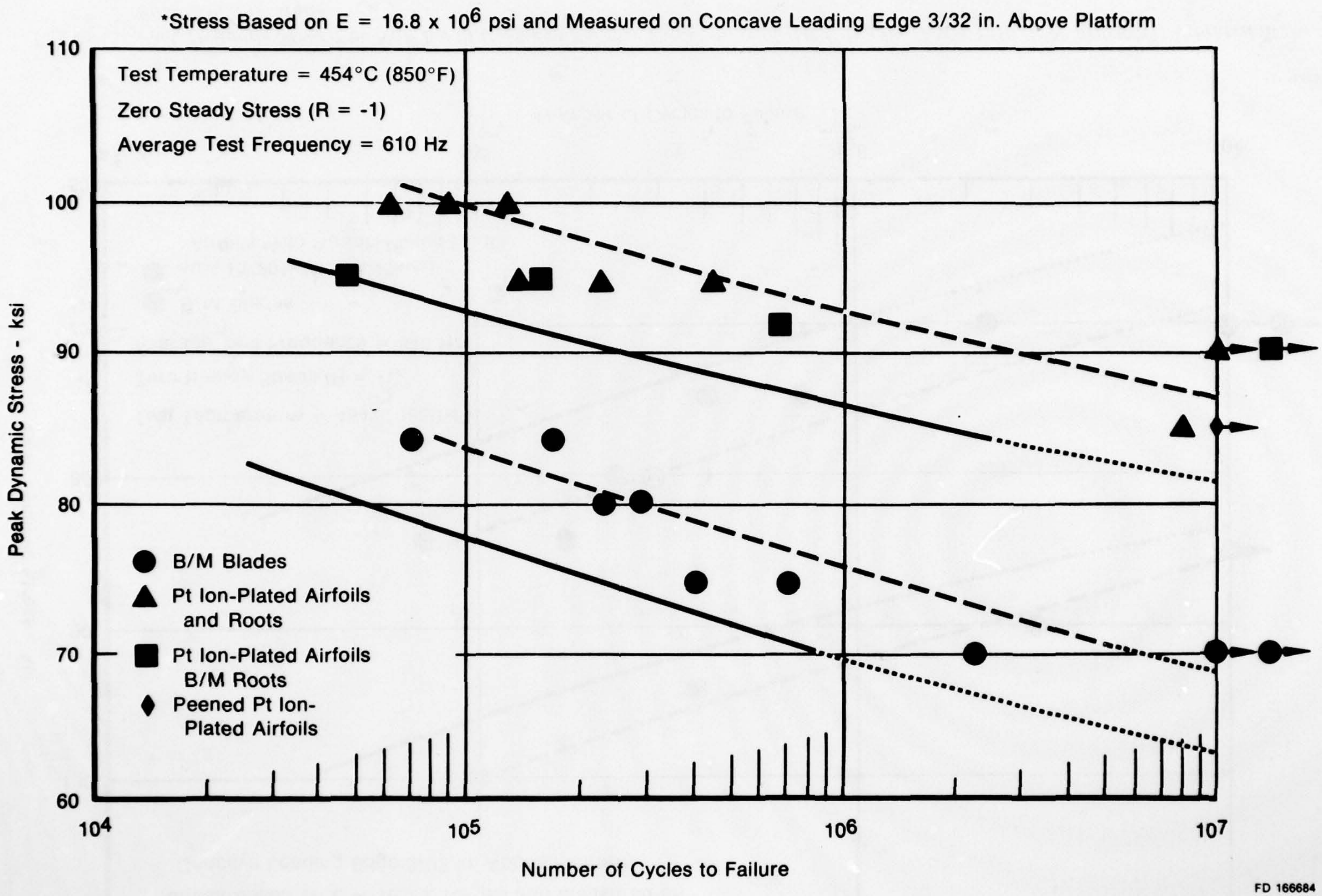


Figure 14. Peak Dynamic Stress vs Number of Cycles to Failure, F100 7th-Stage HPC Blades (PWA 1216, P/N 4040207G) Vibrated in the First Bending Mode*

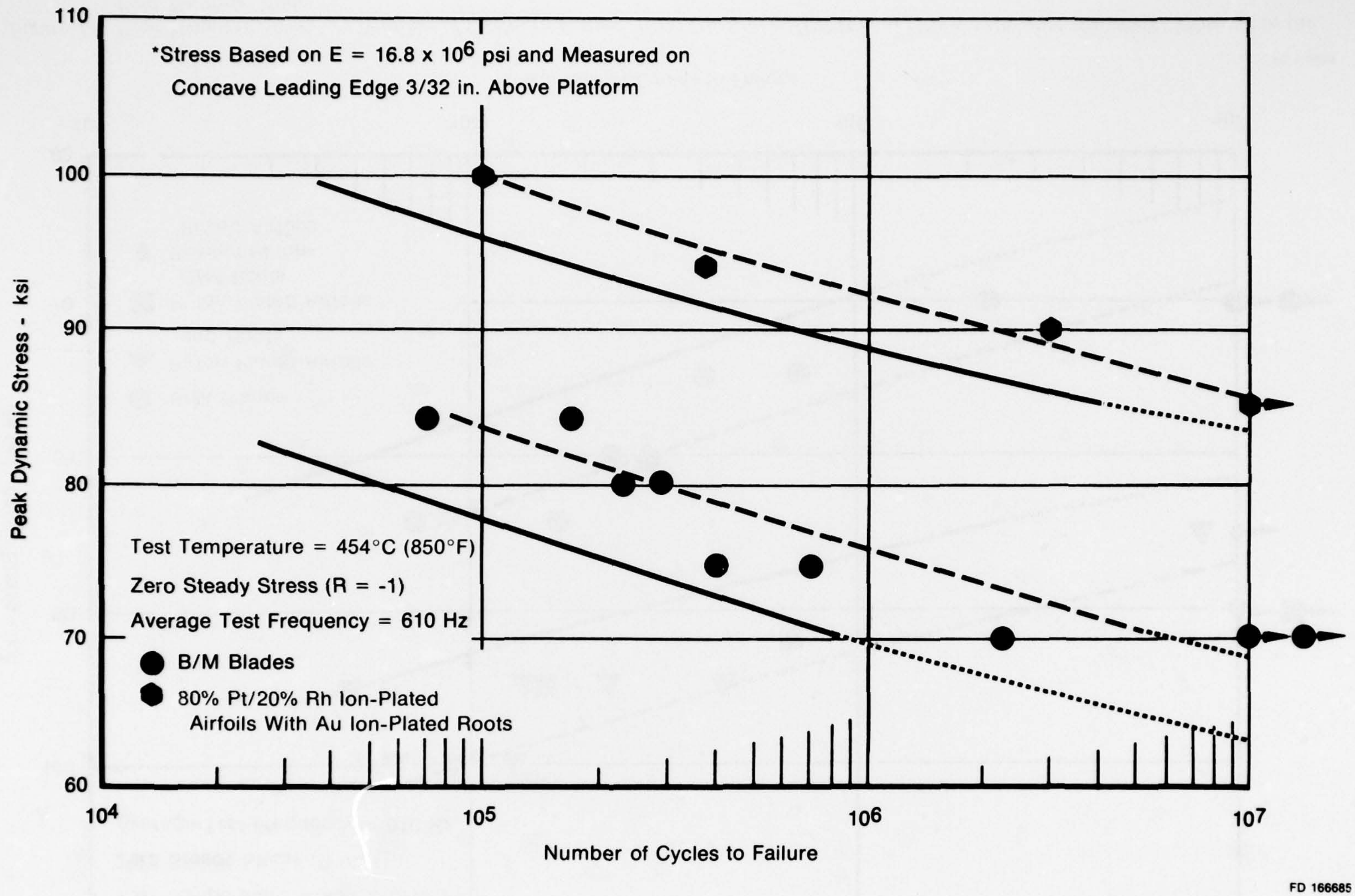
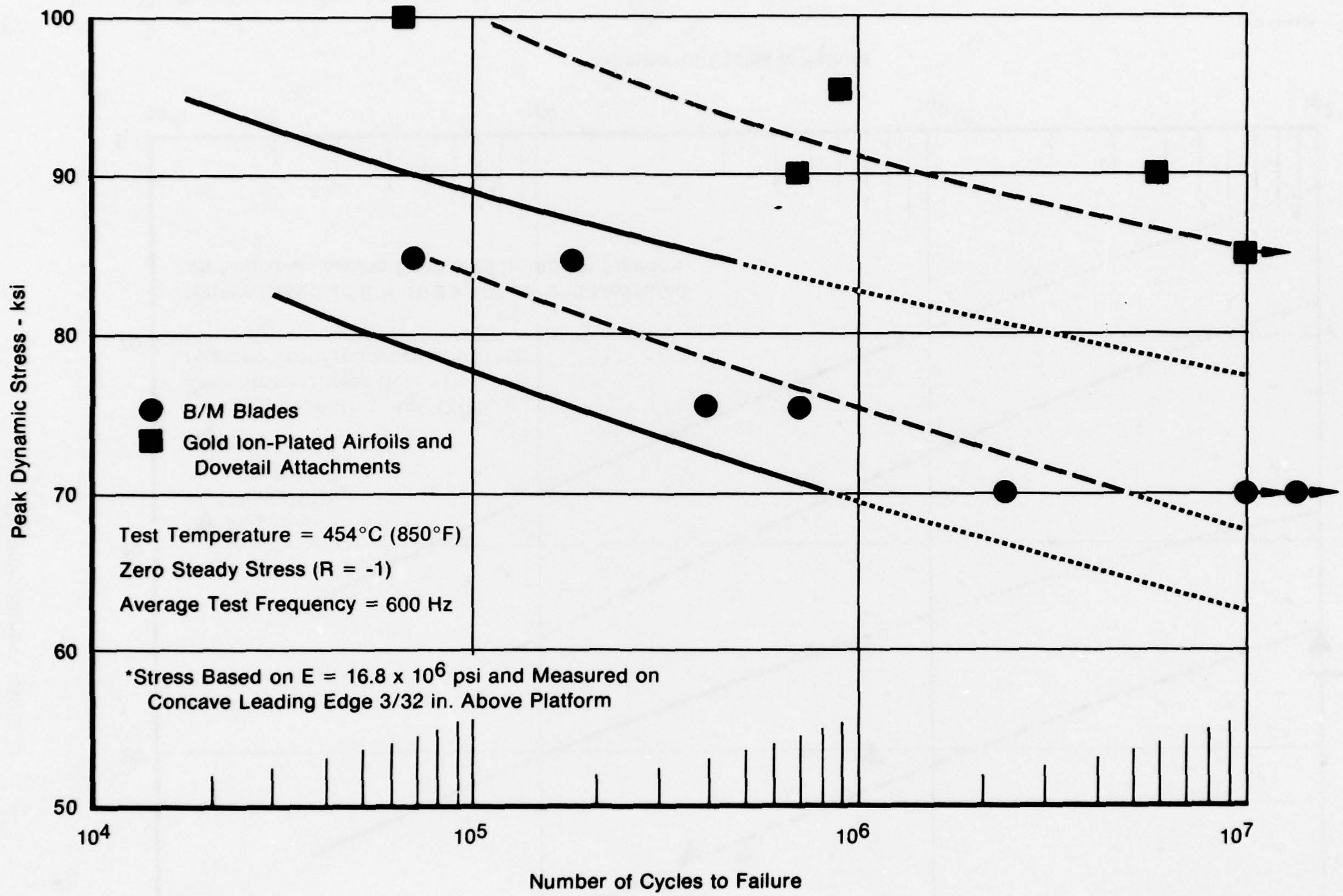


Figure 15. *Peak Dynamic Stress* vs Number of Cycles to Failure, F100 7th-Stage HPC Blades (PWA 1216, P/N 4040207G) Vibrated in the First Bending Mode*



FD 166686

Figure 16. Peak Dynamic Stress vs Number of Cycles to Failure, Compressor Blades Vibrated in the First Bending Mode*

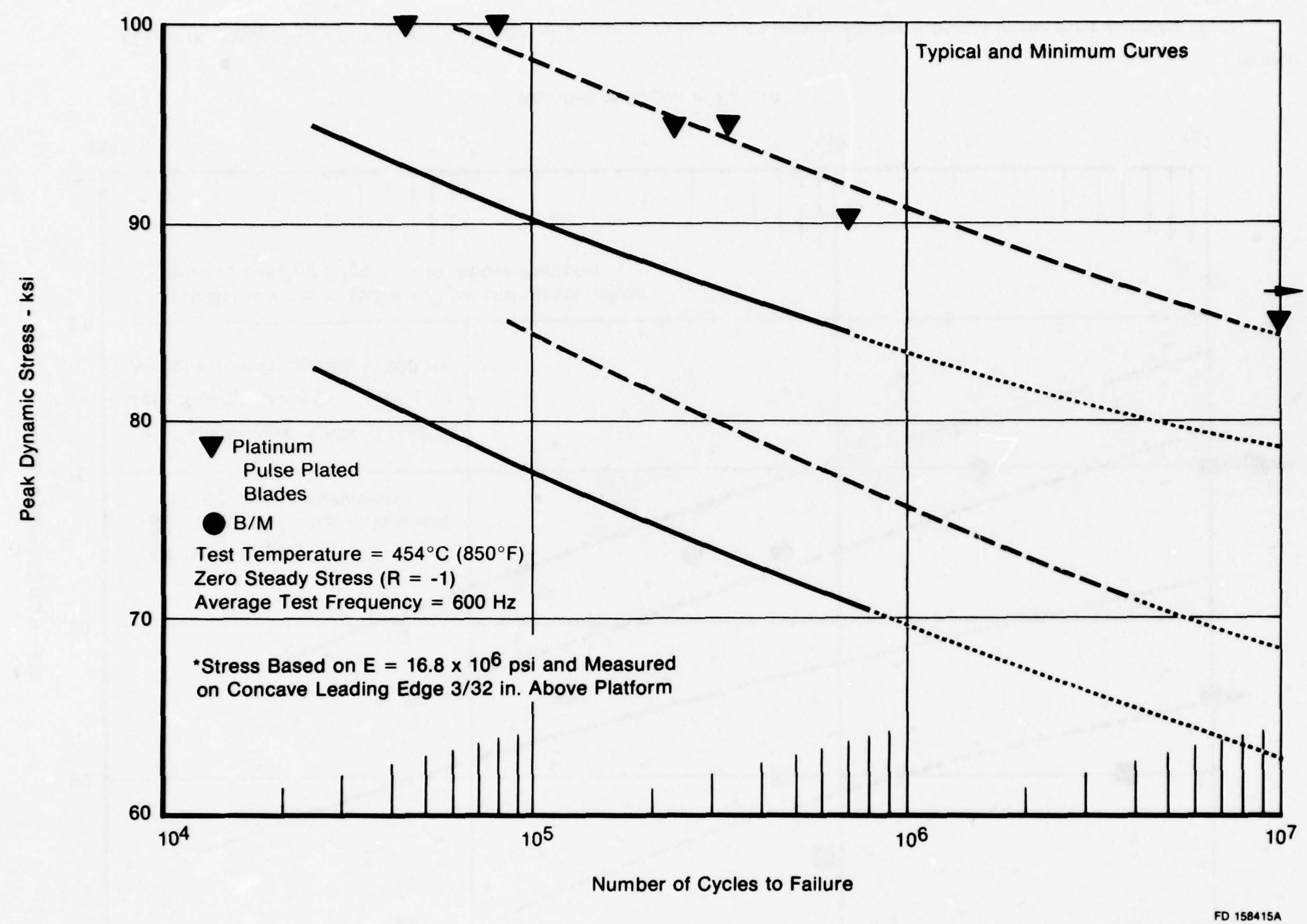


Figure 17. Peak Dynamic Stress* vs Number of Cycles to Failure, F100 7th-Stage HPC Blades Vibrated in the First Bending Mode

Figure 18 shows the effect ion-implanted Pt and Ti have on the high-cycle fatigue strength of 7th-stage compressor blades. For this test program, blades were ion-implanted as indiated in Table 2. Before fatigue testing, these blades were conditioned in the same manner as the ion-plated blades. After conditioning, the Pt ion-implanted blades showed some oxidation in the implanted region, indicating that this coating process affords less oxidation protection then ion-plated or pulse-plated Pt. Figure 18 shows that blades implanted with lower energies demonstrated only a slight increase in fatigue strength (blades 3 through 9). The two blades ion-implanted with Pt at 150 kev, 5×10^{15} ion/cm^2 appeared to perform as well as the noble metal ion-plated blades. However, with only two blades it would be impossible to draw any valid conclusions. Figure 19 shows a typical fatigue failure resulting from testing at the first mode of vibration.

Based on the fatigue, erosion, and stress corrosion results, Pt ion-plated blades were selected for notch fatigue testing. Notch fatigue testing was done on nine B/M blades and nine platinum ion-plated blades. These blades were shear notched in the most critical airfoil region to simulate engine nicked blades. A 60-deg "V" shear notch simulates the most severe type of notch other than an actual material crack. A "V" notch is shown in Figure 20. These blades were notched after conditioning at 454°C (850°F) for 125 hr.

The notch fatigue strength of the platinum ion-plated blades showed a 10^7 cycle fatigue strength of 25 ksi. This compares to 20 ksi for the notched B/M blades as shown in Figure 21. This represents a ten-fold increase in high-cycle fatigue life at high stress levels. A greater difference in fatigue strength may have been observed if the blades were notched prior to conditioning.

Stress Corrosion Cracking

Stress corrosion tests were conducted at 482°C (900°F) and 50 ksi for 120 hr using a two-point loaded bent-beam test. Table 3 lists the test procedure and Table 4 summarizes the results.

Stress corrosion specimens were made from AMS 4916 sheet stock (Heat code BDEU). The coated specimens were ion-plated with the following metals:

1. Platinum
2. 80% Platinum/20% Rhodium
3. Gold

Figures 22 through 24 show the specimens after testing. The uncoated titanium sample (No. 505) showed no evidence of cracking, but the salted sample (No. 515) cracked. These results confirm that threshold stress for cracking AMS 4916 is below 50 ksi. Figure 25A shows a cross section of typical stress corrosion cracks produced on the salted Ti-8Al-1Mo-1V specimen.

Visual examination of the platinum-coated specimens (No. 506 and 507) showed no evidence of cracking of the titanium. The platinum raised the threshold stress for cracking above 50 ksi. It also stopped both the normal oxidation of titanium and the salt accelerated oxidation (causing surface blackening) normally observed with this test.

Samples No. 509 and 510 are the 80% Pt/20% Rh coated specimens. The salted 80% Pt/20% Rh specimen also resisted stress corrosion cracking under test conditions. Both specimens reduced the normal and salt accelerated oxidation of titanium.

Photomicrographs of the gold coated specimens (Nos. 512 and 514) show no stress corrosion cracking of titanium, but a 0.1 mm (0.004 in.) thick layer of material separated from the test specimens during the corrosion test. Apparently the gold diffused into the titanium causing the titanium to oxidize and break away from the stressed specimen. The salted gold specimen did show stress corrosion cracking (Figure 25B).

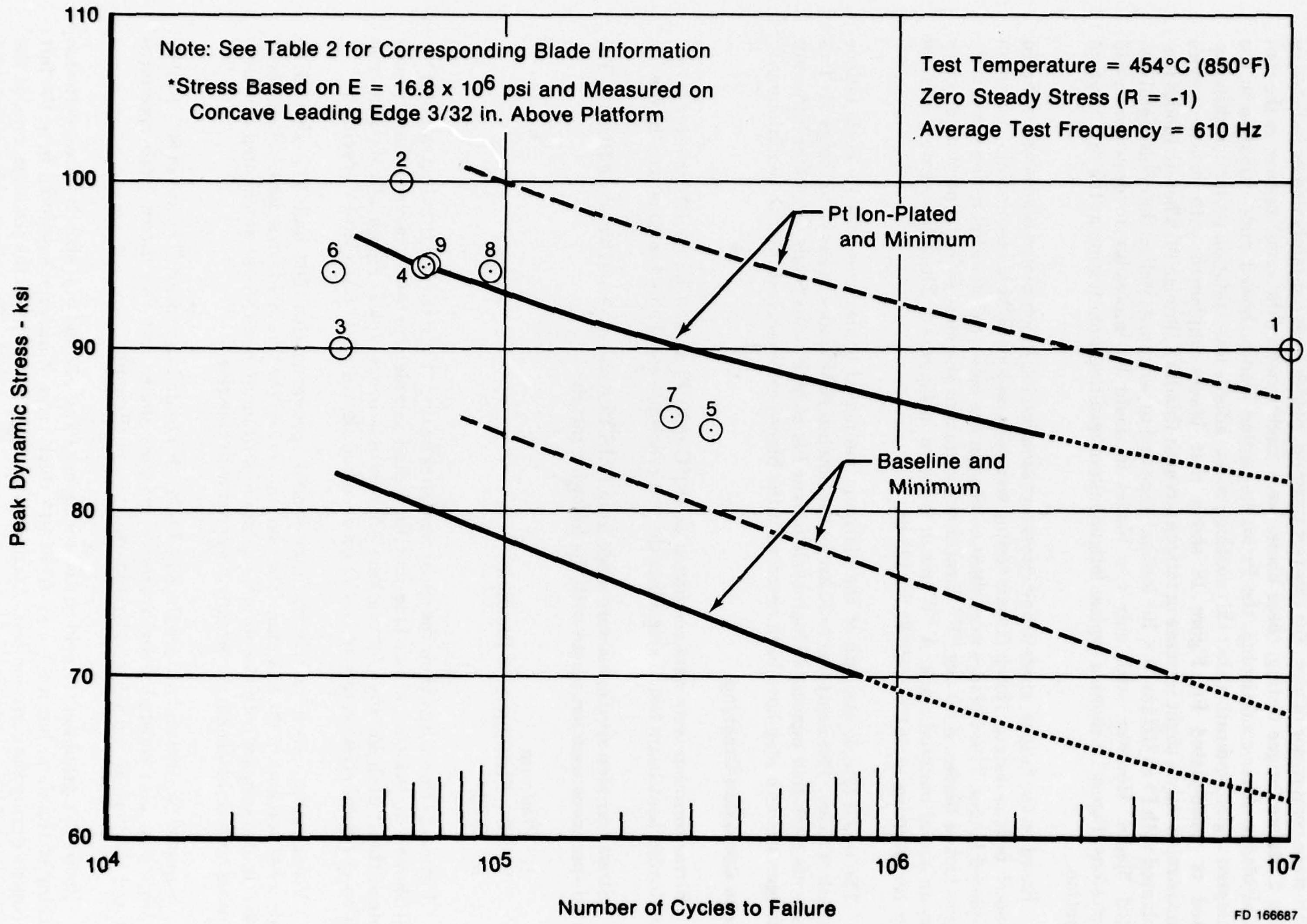
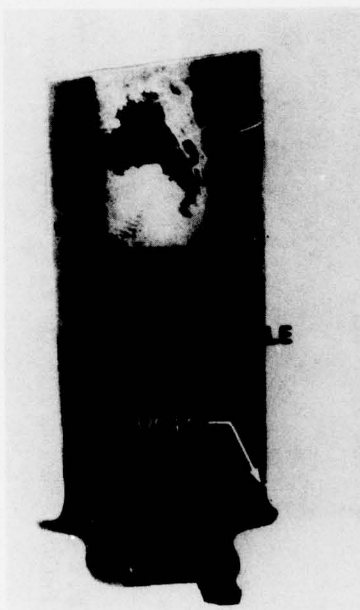


Figure 18. Peak Dynamic Stress vs Number of Cycles to Failure, Compressor Blades Vibrated in the First Bending Mode*

TABLE 2. ION-IMPLANTATION PARAMETERS

Blade No.	*Element Ion-Implanted*	*Energy kev*	*Fluence (ions/cm²)*
1	Pt	150	5×10^{15}
2	Pt	150	5×10^{15}
3	Pt	50	5×10^{15}
4	Pt	50	5×10^{15}
5	Pt	191	1×10^{15}
6	Ti	100	1×10^{15}
7	Ti	100	1×10^{15}
8	Pt	100	1×10^{15}
9	Pt	100	1×10^{15}



FAL 31131

FAL 31167
FD 93395A

Figure 19. Blade Shows Typical Failure Resulting from First Mode of Vibration

FAL 31498

FAL 31499

FAL 31502
FD 93396

Figure 20. F100 PWA 1216 7th-Stage HPC Blade P/N 4034807 With 1/32-in. Deep "V" Shear Notch on Airfoil Leading Edge 1/4-in. Above Platform Showing Typical Failure Resulting from the First Mode of Vibration

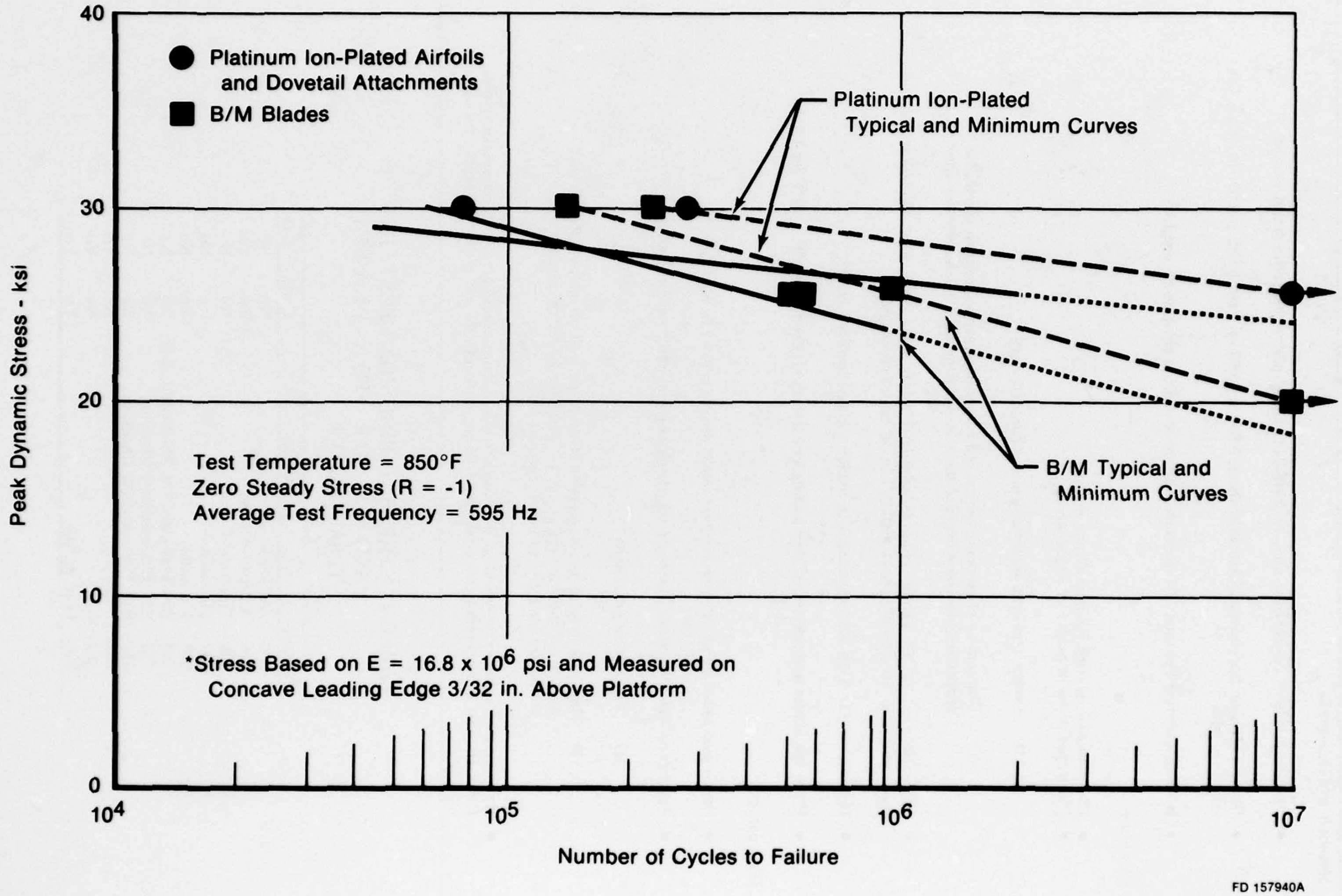


Figure 21. Peak Dynamic Stress vs Number of Cycles to Failure, Compressor Blades With 1/32-in. Deep "V" Shear Notch on Blading Edge 1/4-in. Above Platform Vibrated in the First Bending Mode*

TABLE 3. STRESS CORROSION TEST OF AMS 4916 TITANIUM ALLOYS

1. *Materials and Apparatus*

- Specimen holder: Nickel-base alloy or AMS 2424 nickel-plated 300 series stainless steel
- Stress Corrosion Specimens: AMS 4916 sheet, 5.630 ± 0.005 in. long, 0.032 ± 0.001 in. thick, 0.5 ± 0.1 in. wide
- Sodium Chloride Solution: 3% aqueous solution of sodium chloride by weight.

2. *Procedure*

- Clean specimens with Reagent Grade Freon
- Place specimens in holder at 50 ksi stress

  (1) Do not bend the specimens more than necessary

  (2) When more than one material is to be tested, each specimen should be separated from the other specimens by a minimum of 0.75 in. on each side.

- Place 50 ± μl of 3% sodium chloride solution on two other AMS 4916 specimens. Spread uniformity over an area of approximately 1 in. in center of specimen.
- Include two (2) AMS 4916 specimens in holder without surface coating.
- Place the holder and specimens into a clean circulating air oven at 900°F ± 10°F for 120 hr.

3. *Observations*

- Specimens which break or show obvious cracks are considered to have failed.
- Specimens which have not obviously failed shall be removed from holder.

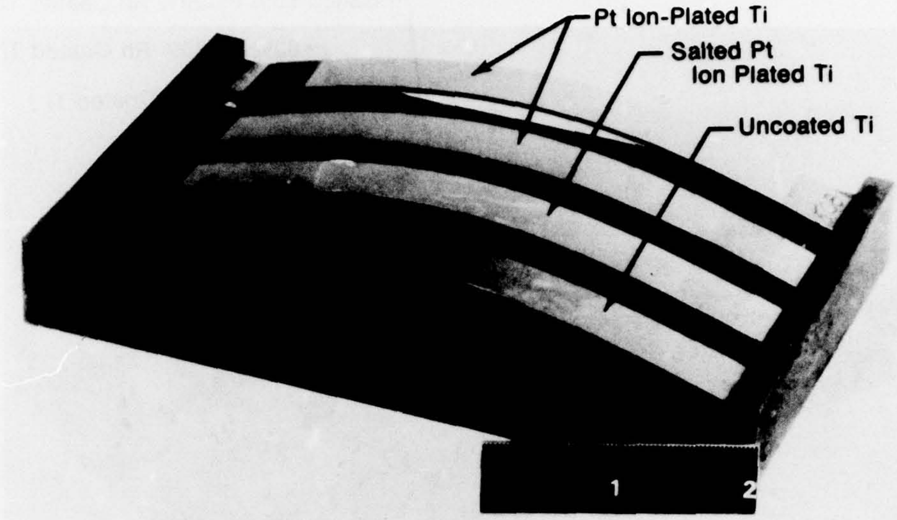
  (1) Vapor blast specimens.

  (2) Immerse in solution composed of 50 ml nitric acid, 10 ml hydrofluoric acid and 10 ml sulfuric acid at 130 to 150°F for 30 sec or until excessive red fumes are liberated, whichever comes first.

- Re-examine specimens for cracks at 10X magnification. If any cracks are noted, the specimen has failed the test (edge cracks not exceeding 0.05 in. in length do not constitute failure and are allowed).

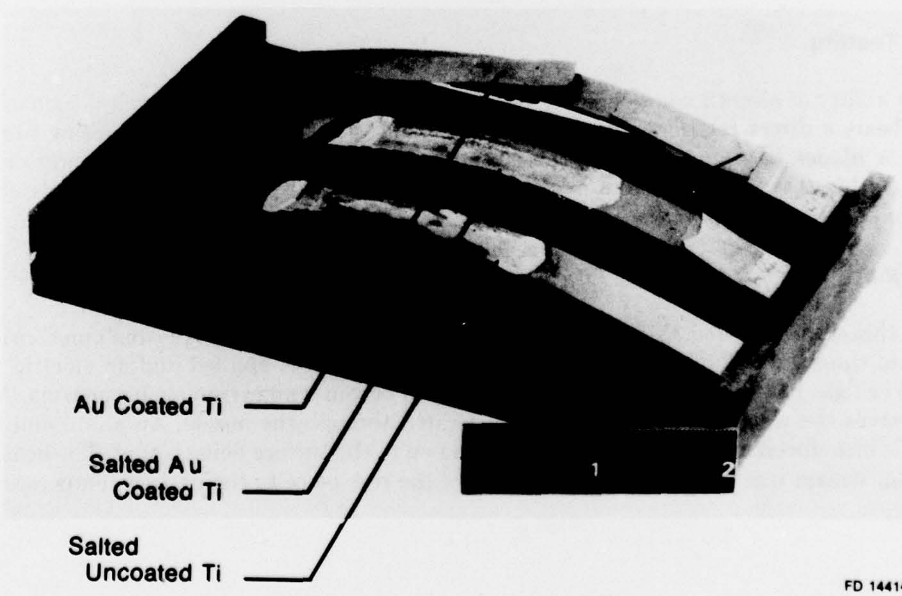
TABLE 4. STRESS CORROSION TEST RESULTS OF ION-PLATED Ti-8Al-1Mo-1V

Sample	*Coating*	*Crack*	*Pits*
505	AMS 4916	No	No
515	AMS 4916 + Salt	Yes	Yes
506	Platinum + Salt	No	No
507	Platinum	No	No
508	Platinum	No	No
509	80% Platinum/20% Rhodium + Salt	No	No
510	80% Platinum/20% Rhodium	No	No
511	80% Platinum/20% Rhodium	No	No
512	Gold	No	Yes
513	Gold	No	Yes
514	Gold + Salt	Yes	Yes



FD 144138

Figure 22. Stress Corrosion Specimens After Testing



FD 144140

Figure 23. Stress Corrosion Specimens After Testing

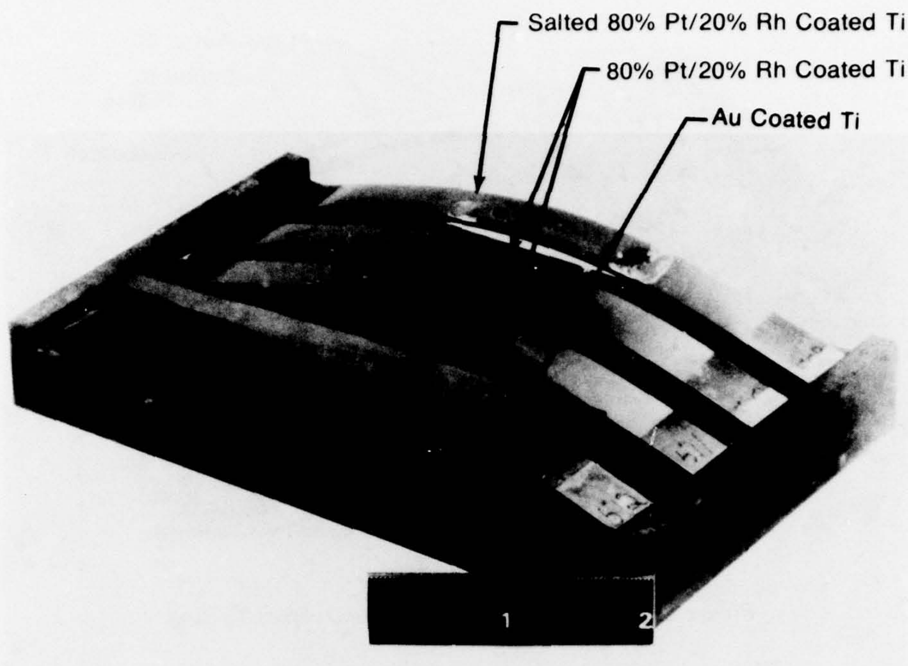


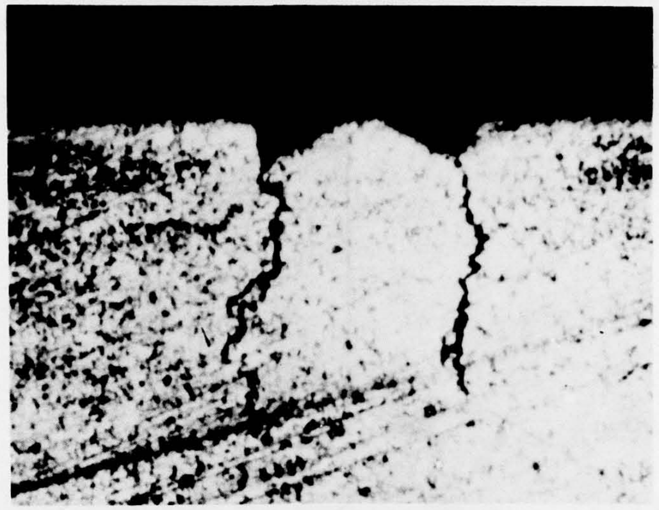
Figure 24. Stress Corrosion Specimens After Testing

Erosion Testing

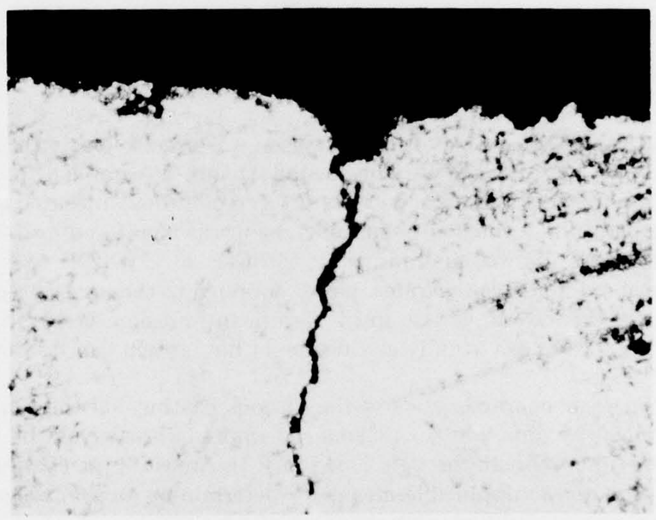
The ability of aircraft components to withstand erosion by airborne particles, such as sand or dust, bears a direct relationship to performance and life. Coatings for gas turbine titanium compressor blades have to withstand the erosion seen in that section of the compressor. The purpose of this test was to ascertain whether a 1 μ thick ion-plated coating affords erosion protection equivalent to B/M coatings.

Test Method

For this study a Metco 3MB plasma gun was used. The Metco 3MB plasma gun consists of a thoriated tungsten cathode and a copper anode. A potential is applied and an electric arc is struck. When gas passes through the arc, it ionizes and becomes an extremely hot plasma. As the plasma leaves the electrode chamber it is accelerated through the nozzle. An aluminum oxide abrasive is introduced and propelled by the plasma on to the surface being tested. The heat from the plasma stream was used to heat the surface of the test piece to the desired temperature.



A. Sample 515 - Salted Ti-8A1-1Mo-IV



B. Sample 514 - Salted Gold Coated Ti-8A1-1Mo-IV

Mag: 200X

Figure 25. Microphotographs of Titanium Specimens After Stress Corrosion Testing

The test specimens were placed in a rig which masks all but a ¼ in. diameter hole through which the plasma stream and the aluminum oxide are directed. See Figure 26.

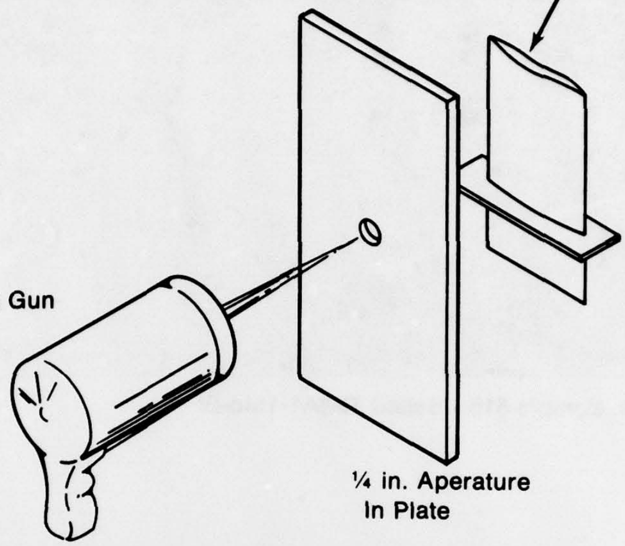


Figure 26. Plasma-Spray Erosion Test Rig

To approximate atmospheric conditions, nitrogen was used to create the plasma flame and air was used to introduce the abrasive into the plasma stream. To establish appropriate operating conditions the thermal plasma and abrasive were projected onto an uncoated titanium test piece and the surface temperature at the point of impingement was monitored by a thermocouple. The test piece surface temperature was maintained at 450°C ± 20°C (842°F ±36°F). The operating variables such as gas and abrasive flowrates, power supplied to the arc (voltage and amperage), and gun-to-work distance were varied until significant erosion occurred. By appropriate manipulation of these variables virtually any degree of hot erosion can be simulated.

The hot-erosion wear characteristics of the various coatings on the 7th-stage compressor blades were determined by directing the plasma stream and abrasive on the protective coating and determining the time to break through. Due to the thickness of the coatings (approximately 1 μ) weight losses were not an applicable means for determining erosion wear. Several methods of visual inspection were employed. For the coatings in which a distinct color change was noticeable, the first signs of breakthrough were taken as the coating life. For those coatings in which a distinct color change was not observable, two methods of inspection were employed. First, the coating was completely stripped from sections of the blade so that the plasma stream and abrasive could be directed on both the coating and the bare titanium. When the distinct line separating the two regions disappeared or faded out, the coating was assumed to have been eroded. Secondly, in those cases where examination of the specimen showed that the coating was still intact after the demarcation line had faded out, erosion runs were executed for definite time intervals. By comparison of the erosion spots, the time of breakthrough was easily determined.

Erosion Test Results

In order to stabilize the plasma stream, helium was added to the primary arc gas. The composition of the hot gas carrying the aluminum oxide abrasive (27 μ) was thus 49.6% nitrogen, 2.4% oxygen, and 48.0% helium.

The velocity of the aluminum oxide abrasive particles eroding the test specimens at 450°C (850°F) was calculated by linear displacement of the erosion marks on a plate rotating at zero and 2600 rpm. The average velocity was found to be 940 ± 170 ft/sec.

The various coatings eroded and their lives as determined by time until breakthrough are shown in Table 5. All specimens were tested at a 90-deg angle to the plasma stream.

TABLE 5. HOT EROSION TESTING

Coating	*Thickness*	*Time to Breakthrough*	*Protection Relative to NiCd*
Nickel-Cadmium	13 micron	2 to 5 sec	1
Platinum-Pulse Plated	1 micron	2 to 5 sec	1
Gold Ion-Plate	1 micron	2 to 5 sec	1
Platinum Ion-Plate-Peened	1 micron	1 to 1.5 min	20
80% Pt/20% Rh Ion-Plate	1 micron	1 to 1.5 min	20
Platinum Ion-Plate	1 micron	1.5 to 2 min	30

Fretting-Fatigue Testing

Fretting is of particular concern because of its occurrence in the dovetail joints comprising the blade-to-hub attachments of turbine engine components. Fretting in this blade root area results in localized effects that can ultimately result in fatigue failure. Fretting-fatigue can be defined as a reduced-cyclic stress life due to premature crack initiation at the area of surface-fretting damage.

Test Method

In this investigation, testing utilized a P&WA/Florida-developed rig which assesses fretting-fatigue. The fretting-fatigue test rig (Figure 27) produces fretting wear simultaneous with high-cycle fatigue. The fretting is produced at the midspan point of a cantilevered bar, the test specimen, which is forced to vibrate by means of an electromagnet. Vibration is restrained by two pins forced against the bar by a hydraulic ram. This force on the bar, together with the vibration, permits a small amplitude of motion in the loaded area producing fretting. The loading and stress on the bar are at a maximum at the edge of the pins closest to the deflected end of the bar. Fatigue failures follow this line of maximum fretting and occur from multiple origins along the fretted region.

Results

All fretting fatigue specimens were made of Ti-8-1-1 sheet stock. The baseline and coated specimens were run at 454°C (850°F). Figure 28 shows the fretting-fatigue curve for uncoated and coated Ti-8-1-1. Uncoated Ti-8-1-1 has a runout stress (10^7 cycles) of 29 ksi. The Pt and Au ion-plated specimens appear to have slightly lower fretting-fatigue strength. The ion-plated 80% Pt/20% Rh does not show this pattern. From Figure 28, the pulse-plated Pt and Au appear to have a higher fretting-fatigue strength. This supports the indication of poor adhesion of pulse-plated coatings based on the erosion testing. More testing should be undertaken before any conclusions can be drawn about the fretting-fatigue resistance of ion-plated noble metal coatings.

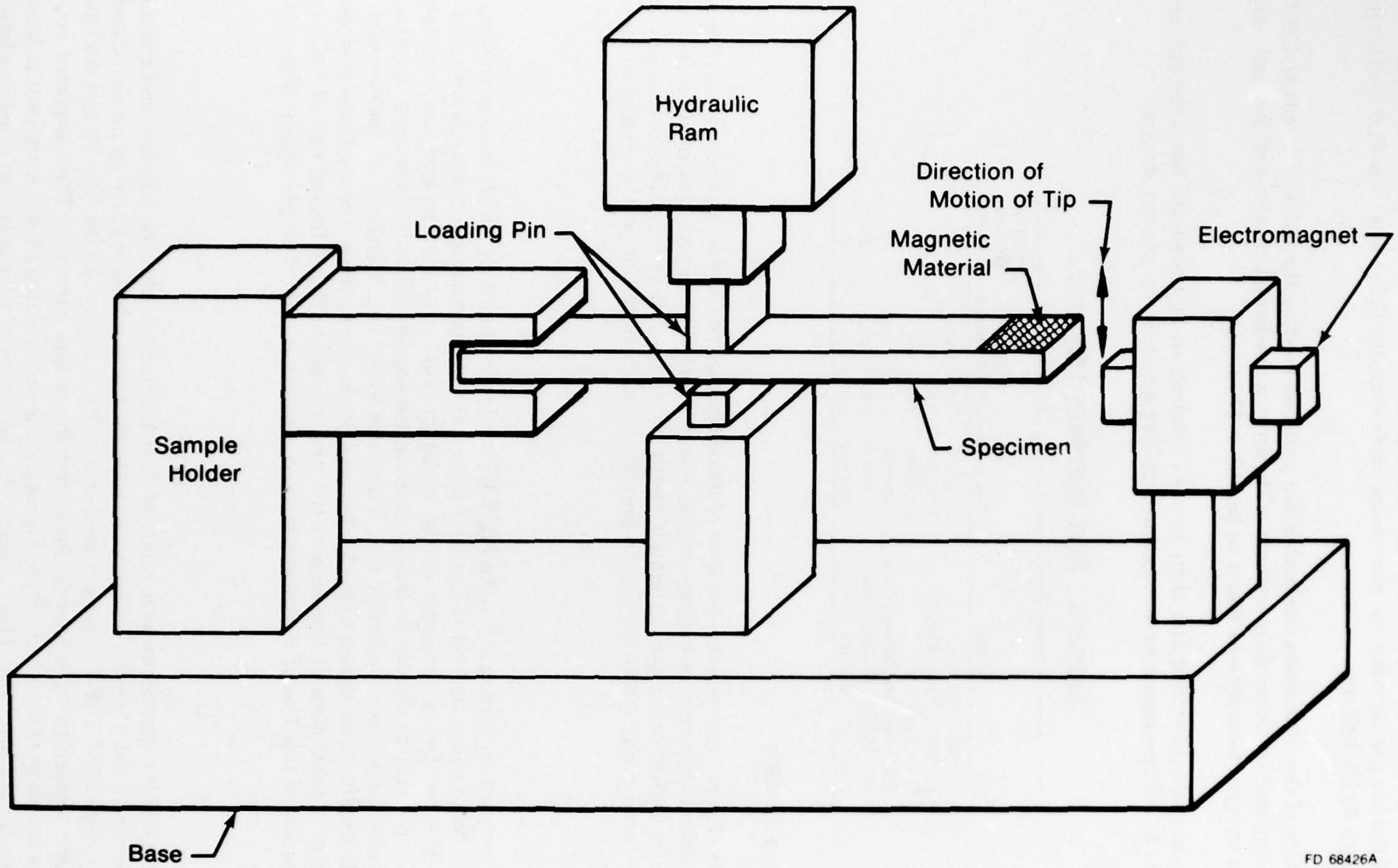


Figure 27. Fretting-Fatigue Test

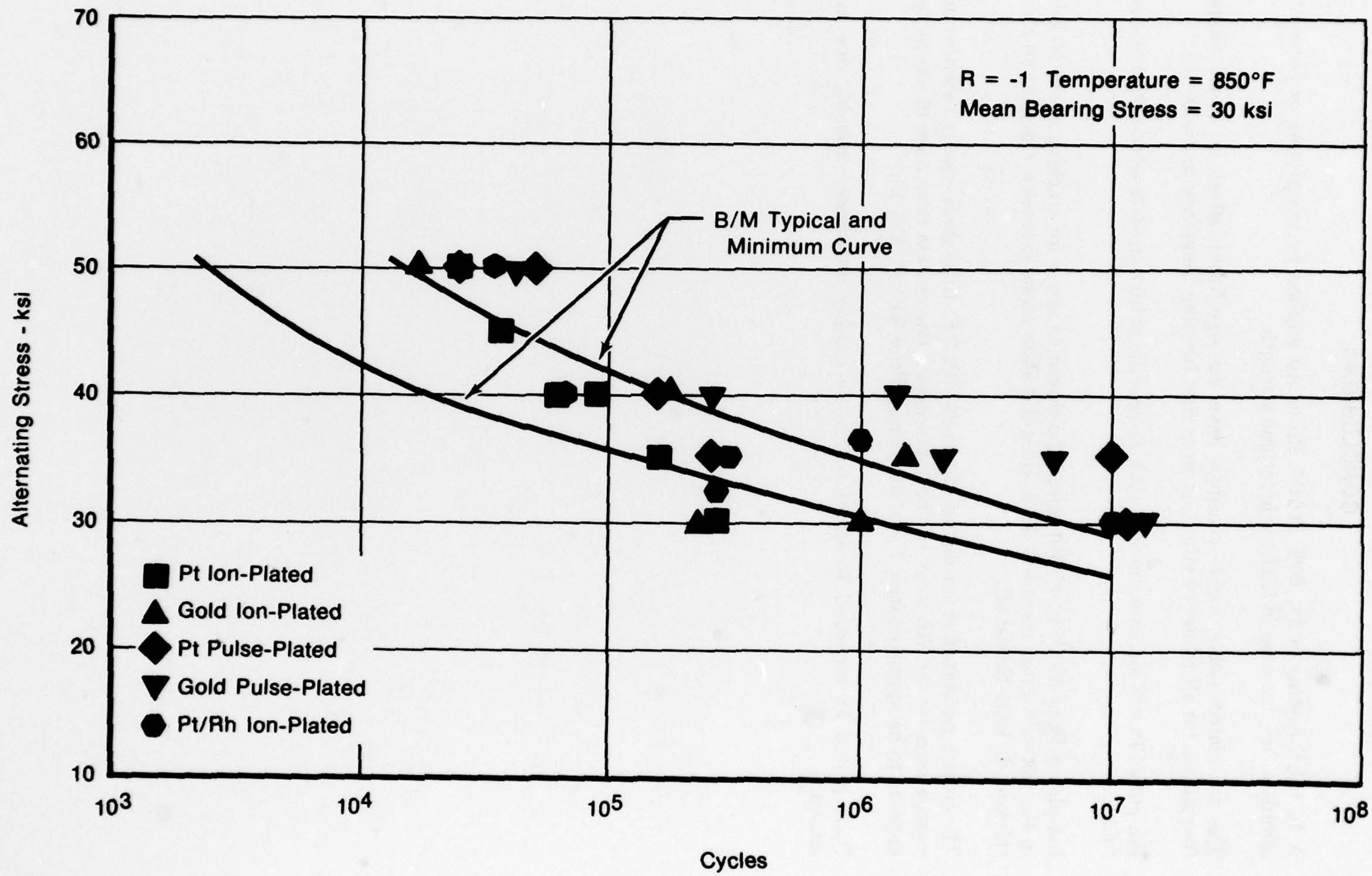


Figure 28. Fretting-Fatigue Results of Ti-8-1-1 (AMS 4916)

SECTION III

CONCLUSIONS

1. A 1μ thick coating of Pt, 80% Pt/20% Rh or Au applied by ion-plating or pulse-plating affords a 30% increase in high-cycle fatigue strength.

2. The ion-plated noble metal coatings have no significant effect on mode shapes or frequencies for all modes of vibration from first bending frequency to 24,000 Hz.

3. Ion-plated Pt will increase the high-cycle fatigue life at high stress levels on FOD blades ten-fold.

4. Ion-plated Pt or 80% Pt/20% Rh raised the threshold stress for cracking above 50 ksi used in the hot-salt stress corrosion tests. Gold did show stress corrosion cracking and a 4-mil thick oxide layer flaked off.

5. The erosion resistance of ion-plated Pt and 80% Pt/20% Rh is great enough to withstand the erosion seen by the 7th-stage of the compressor. The erosion resistance of ion-plated Au appears to be approximately 5% of ion-plated Pt or 80% Pt/20% Rh.

6. Pulse-plated Pt appeared to afford very little erosion resistance, probably due to poor adhesion.

SECTION IV
RECOMMENDATIONS

1. Establish a design study to ascertain the engine parts that would be benefited by Pt ion-plating.

2. Establish a coating thickness quality assurance program based on Beta backscattering.

3. Evaluate ion-plating as a method for applying a thin base coat under other coatings to protect the mechanical properties of Ti.

4. Evaluate the use of ion-plating using metal other than Pt.

5. Evaluate ion-plating using base metals other than Ti.

APPENDIX

PULSE-PLATING PLATINUM

Solution Makeup

1. Fill a liter tank halfway with 66°C (150°F) distilled water
2. Stir in 340 g/l ammonium nitrate
3. Stir in 43 g/l sodium nitrate
4. Add 319 ml/l of platinum "N" concentrate
5. Fill-up balance with distilled water.

Plating Parameters

Current Density:	50 to 60 amps/ft^2
Anode:	Platinum or platinum-coated cobalt or titanium
Temperature:	88 to 96°C (190 to 205°F)
Voltage:	2 to 3V
Current Efficiency:	20 to 30%
Pulse Cycle:	3 ms ON — 3 ms OFF

REFERENCES

1. Levy, M. and J. L. Morrosi, "Army Materials and Mechanics Research Center," Technical Report 76-4 (1976).

2. Groves, M. T., NASA Report CR-134537 (1973).

3. Fujishiro, S. and D. Eylon, Thin Solid Films, *54* 309 (1978).

4. Fujishiro, S. and D. Eylon, U. S. Patent No. 4,137,370, January 1979.

5. Hall, G. S., S. R. Seagle, and H. B. Bomberger, AFML-TR-73-37 (1973).

6. Fujishiro, S. and D. Eylon, 105th AIME Annual Meeting, Abstract Book, p. A14, Las Vegas, Nevada, February 1976.

7. Fujishiro, S. and D. Eylon, "Scripta Metallurgica," 11, 1011 (1977).

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