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CERAMIC WEAR-RESISTANT COATING FOR ALUMINUM - PHASE I

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July 1970

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CERAMIC WEAR-RESISTANT COATING FOR ALUMINUM - PHASE I

Technical Report by

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CERAMIC WEAR-RESISTANT COATING FOR ALUMINUM - PHASE I

ABSTRACT

Initial wear test results for flame-sprayed, plasma-sprayed, and slurry-coated 6061-T6 aluminum alloy samples are reported. Optical photomicrographs of coating cross-sections are also presented. Upon final evaluation of these coatings in Phase II of the program, one will be chosen for Phase III scale-up for a coating on aluminum track shoes.

CONTENTS

INTRODUCTION

This study was begun as the first step in the development of wear-resistant aluminum components suitable to replace hardened steel parts currently in use. The program was aimed primarily at the development of track shoes since this was considered to be one of the most severe environments in which aluminum could be used.

The program was divided into three phases. Material test coupons were purchased and evaluated during Phase I. Further coupon testing and initial coated track shoe testing will be conducted in Phase II. Phase III will provide for the production scale-up of the best coating selected on the basis of the results of the first two phases. The program is a joint effort by AMMRC and ATAC with the AMMRC Ceramics Division having primary responsibility for the conduct of Phase I and II and with the ATAC Materials Engineering Branch assuming primary responsibility in Phase III. This report is intended to summarize the results obtained during Phase I.

PROCEDURE

Coatings were applied by contractors to 6061-T6 aluminum alloy by three different techniques, consisting of several different materials for each technique. The following is a list of these techniques and the materials that were evaluated for each:

1. Flame spray

   a. aluminum oxide - titanium dioxide
   b. nickel-chrome-aluminum
   c. nickel-chrome-boron
   d. tungsten carbide
   e. molybdenum
   f. aluminum

2. Plasma spray

   a. aluminum oxide-aluminum (graded)
   b. titanium dioxide-aluminum (graded)

3. Viscous slurry

   a. aluminum oxide-aluminum (1:10)
   b. aluminum oxide-aluminum (1:5)
   c. aluminum oxide-aluminum (1:3)
   d. aluminum oxide-aluminum (1:2)
   e. aluminum oxide-aluminum (1:1)
   f. silicic acid-aluminum (1:10)
   g. silicic acid-aluminum (1:5)
   h. silicic acid-aluminum (1:1)
   i. silicic acid-aluminum (2:1)
   j. silicic acid-aluminum (5:1)

k. chromium carbide-aluminum (1:1)
l. chromium carbide-aluminum (1:2)
m. chromium carbide-aluminum (1:3)
n. chromium carbide-aluminum (1:5)
o. chromium carbide-aluminum (1:10)
p. aluminum oxide (small particle)-aluminum (graded)
q. aluminum oxide (large particle)-aluminum (graded)

The graded, plasma-sprayed coatings were applied by proprietary modifications* to standard plasma spray application techniques.[1,2,3,4] The flame-sprayed coatings were applied by standard techniques,[5] however, a proprietary interlayer† was sandwiched between the aluminum substrate and the final exterior coating. A general discussion of all molten particle spray techniques is also available.[6] The viscous slurry coatings, of which detailed compositions and processing techniques‡ are proprietary, are painted on the aluminum substrate surface. Subsequent heat treatments and additional slurry applications result in a densified coating that is bonded to the aluminum.

Wear testing for initial screening of the coatings was performed on a Taber Abraser wear testing machine (Figure 1), utilizing standard helix-edged tungsten carbide abrasion wheels (Figure 2) under a 500-gram load. It was considered that these wheels would impart shear as well as compressive stresses to the coatings.

Optical photomicrographs were taken of each of the coatings evaluated in this phase of the program. Typical examples are presented, with composition identification information in Appendix A.

A specimen of each of the coatings was subjected to the following thermal treatments. Specimens were placed in a furnace at room temperature. The temperature was gradually raised to a 970 F soak temperature and held for one hour.

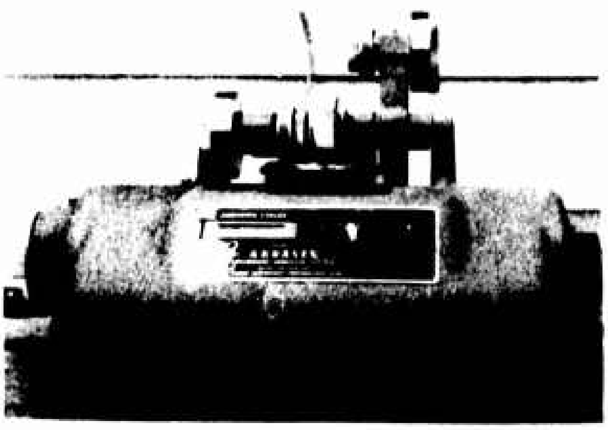

Figure 1. TABER ABRASER WEAR TEST MACHINE
19-066-487/AMC-68

Figure 2. TUNGSTEN CARBIDE HELIX-EDGED ABRASION WHEELS
19-066-257/AMC-70

*Proprietary to Monsanto Research Center, Dayton, Ohio.
†Proprietary to Metalcraft, Inc., Norfolk, Virginia.
‡Proprietary to Kaman Nuclear, Colorado Springs, Colorado.

After the soak period, the specimens were water-quenched to room temperature. Specimens were again placed in the furnace at room temperature, heated at 350 F, soaked for one hour, and then air cooled. It was considered that this thermal cycle would simulate the most severe strengthening cycle for any of the aluminum alloys considered for use as track shoes.

RESULTS AND DISCUSSION

The wear test results obtained in Phase I are summarized in Table I. Typical wear patterns for the coatings applied by flame spraying, plasma spraying, and slurry coating are evident in Figures 3, 4, and 5. Only the plasma-sprayed coatings were adversely affected by the thermal treatment. The coating warpage and crazing that resulted from the treatment on the plasma-sprayed coatings is noted in Figures 4 and 6. The crazing is particularly severe in the case of the titanium dioxide coating (Figure 6). It should be noted that although the flame-sprayed coatings were not detrimentally affected by this treatment, they were only one-fifth the thickness (0.005" as compared to 0.025") of the coatings applied by the plasma spray or the slurry techniques. This alone would tend to make them more thermal shock resistant. It should also be noted that further

Table I. WEAR TEST RESULTS UTILIZING TABER ABRASER FITTED WITH TUNGSTEN CARBIDE WHEELS

Application Technique	Material Applied	Total Weight Loss (in grams) After:		
		1,000 cycles	5,000 cycles	10,000 cycles
Flame spray	Al_2O_3 - TiO_2	0.0882	0.1367	0.1514
Slurry	SiO_2 - Al (2:1)	0.0218	0.0865	0.1636
Flame spray	Ni - Cr - Al	0.0903	0.1385	0.1742
Plasma spray	TiO_2 (graded)*	0.0575	0.1414	0.1931
Slurry	SiO_2 - Al (1:1)	0.0481	0.1425	0.2286
Flame spray	Tungsten carbide	0.1229	0.1947	0.2512
Plasma spray	Al_2O_3 (graded)*	0.0981	0.2518	0.2770
Plasma spray	TiO_2 (graded)	0.3004	0.3442	0.3783
Slurry	Cr_2C - Al (1:3)	0.1052	0.2673	0.3976
Slurry	Al_2O_3 - Al (1:3)	0.1441	0.3008	0.4012
Slurry	SiO_2 - Al (1:3)	0.1102	0.2785	0.4062
Slurry	Al_2O_3 - Al (1:5)	0.1976	0.3662	0.4701
Slurry	Al_2O_3 - Al (1:2)	0.2028	0.3889	0.5266
Slurry	SiO_2 - Al (1:10)	0.2116	0.4417	0.5733
Slurry	Cr_2C - Al (1:5)	0.1907	0.4244	0.6039
Slurry	Cr_2C - Al (1:10)	0.2816	0.4909	0.6441
Slurry	Al_2O_3 - Al (1:10)	0.2907	0.5885	0.7555
Flame spray	Molybdenum	0.2614	0.5331	0.7607
Plasma spray	Al_2O_3 (graded)	0.3836	0.6468	0.8296
Flame spray	Ni - Cr- B	0.3230	1.1416	-
Flame spray	Aluminum	1.4919	4.1069	-

*Thermal treatment before wear test.

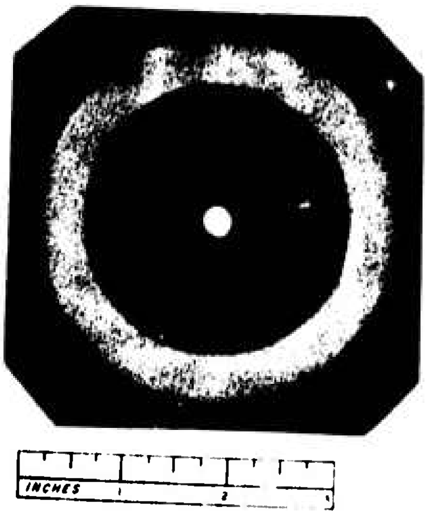

Figure 3. FLAME-SPRAYED Al_2O_3-TiO_2 COATING AFTER WEAR TESTING
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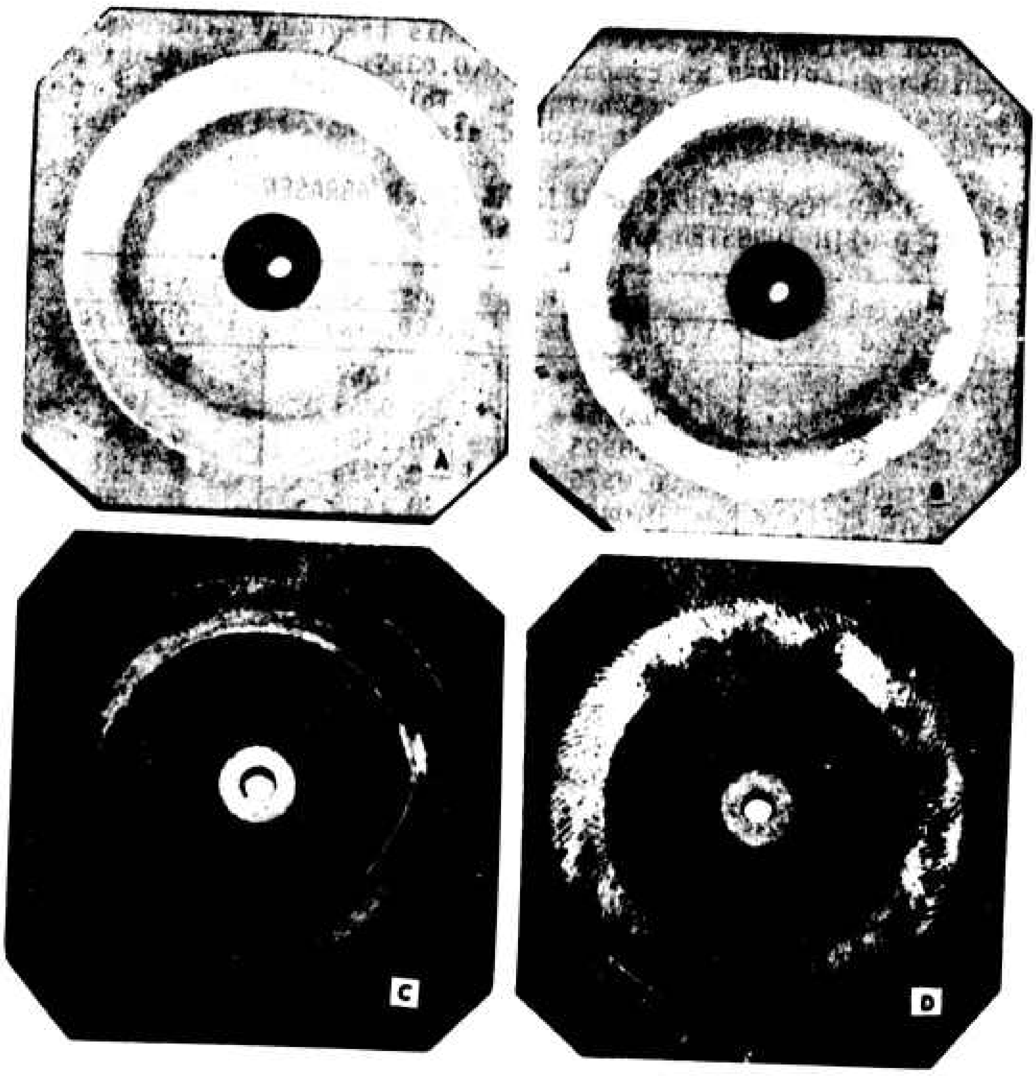

Figure 4. PLASMA-SPRAYED COATINGS AFTER WEAR TESTING

A. Al_2O_3 without thermal treatment
B. Al_2O_3 with thermal treatment
C. TiO_2 without thermal treatment
D. TiO_2 with thermal treatment

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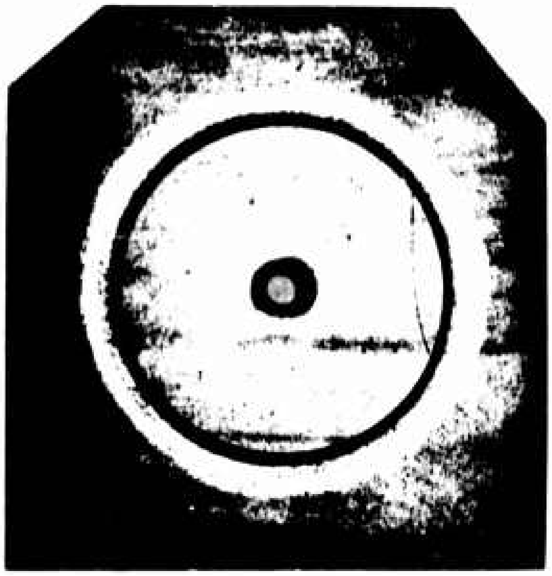

Figure 5. SLURRY-APPLIED SiO_2-Al (2:1) COATING AFTER WEAR TESTING
19-066-253/AMC-70

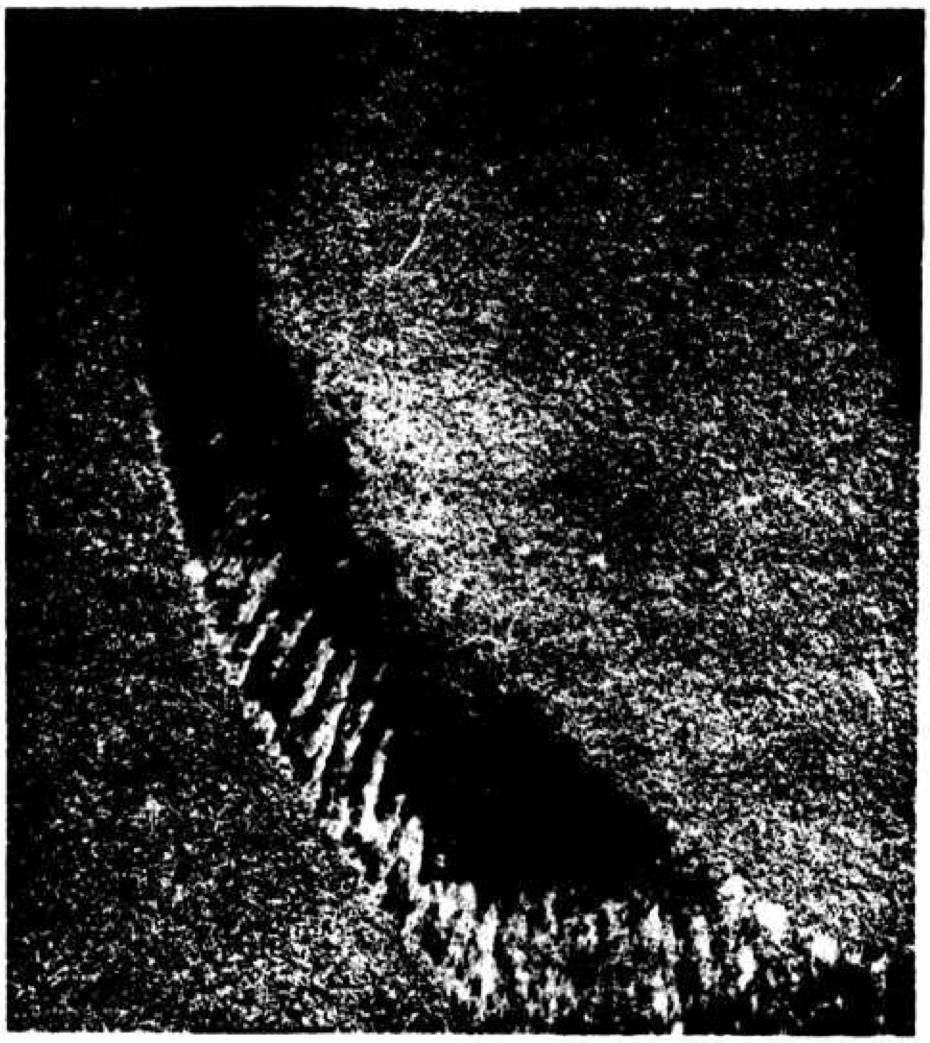

Figure 6. CRAZING OF PLASMA-SPRAYED TiO_2 COATING AFTER WEAR TESTING. Mag. 3½X
19-066-258/AMC-70

wear testing of the samples at up to 30,000 cycles could give a totally different comparative wear scale than that presented in Table I. The longer test duration may cause the thinner coatings, that presently are most wear resistant, to break down, in which case the thicker plasma-sprayed and slurry-applied coatings would prove more favorable.

CONCLUSIONS

The results for Phase I of this program, although enlightening, clearly show the necessity for the Phase II testing before the Phase III scale-up can be considered. The thinner flame-sprayed coatings which are superior at this stage of the wear testing may prove inferior to the other thicker plasma-sprayed and slurry-coated specimens when additional testing, to be conducted in Phase II, is completed.

Pull test data to determine bonding strengths of the coatings should also be included in Phase II. Although the coatings will not be subjected to tensile stress, as it is applied in this test, a measure of bonding strengths should prove valuable, especially if coupled with an impact test. An abrasion test, utilizing an abrasive grit-blasting technique to obtain a wear resistance measurement, may provide valuable information. Hard and soft anodized aluminum specimens should also be included in the wear testing program as controls.

In Phase II the effect of the heat generated by plasma spraying on the strength of the base aluminum should be determined. If it does not degrade the strength, the coating would not have to be subjected to the thermal cycle used to strengthen the aluminum base. It was this thermal cycyle that caused the warpage and crazing, with subsequent loss of bond strength. If it can be eliminated, a harder and denser plasma-sprayed coating could be applied, thus improving the wear resistance.

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APPENDIX A

Photomicrographs of typical flame-sprayed, plasma-sprayed, and slurry-coated 6061-T6 aluminum samples tested in Phase I of the program. Micrographs were taken of the cross-section of each of the samples at the magnifications indicated. Other materials applied by each of the processing techniques possessed, respectively, similar appearances to those shown in Figures A-1 to A-3.

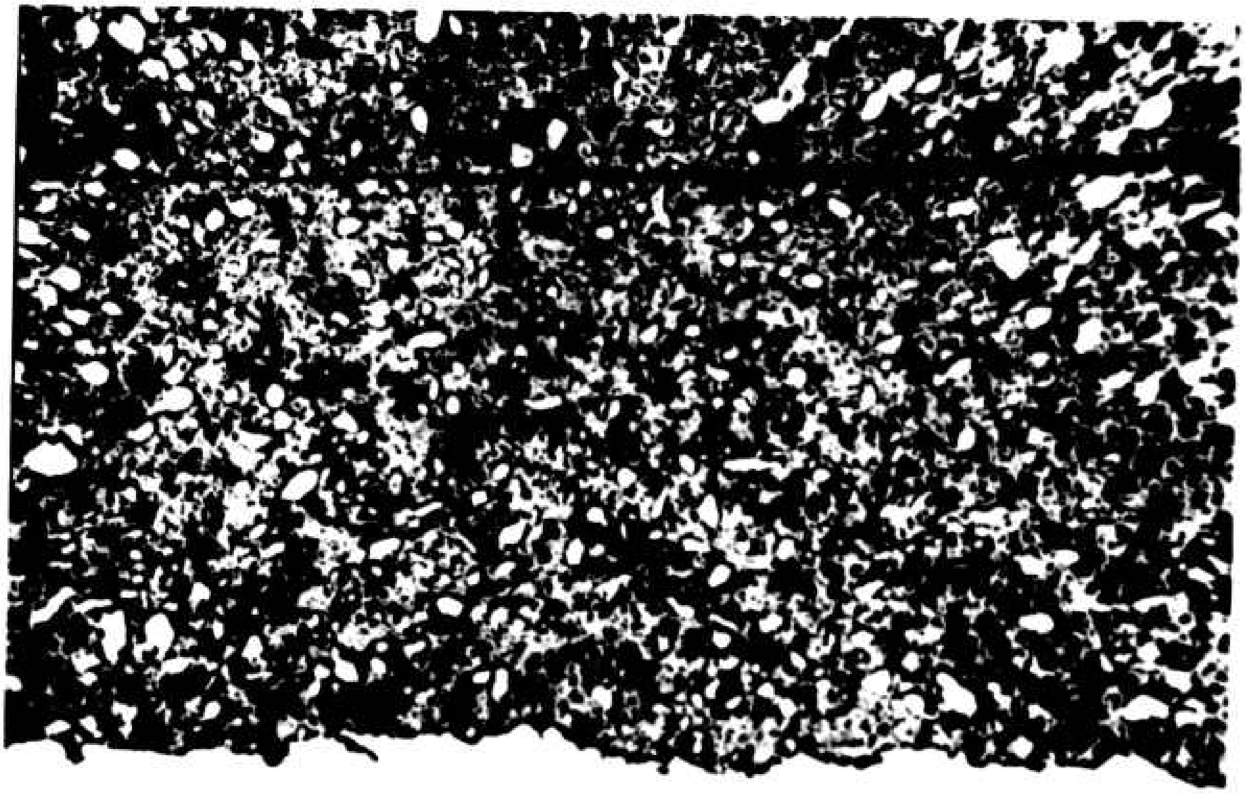
Figure A-1. FLAME-SPRAYED Al_2O_3-TiO_2. Mag. 1000X

a. Overall Cross-Section. Mag. 50X

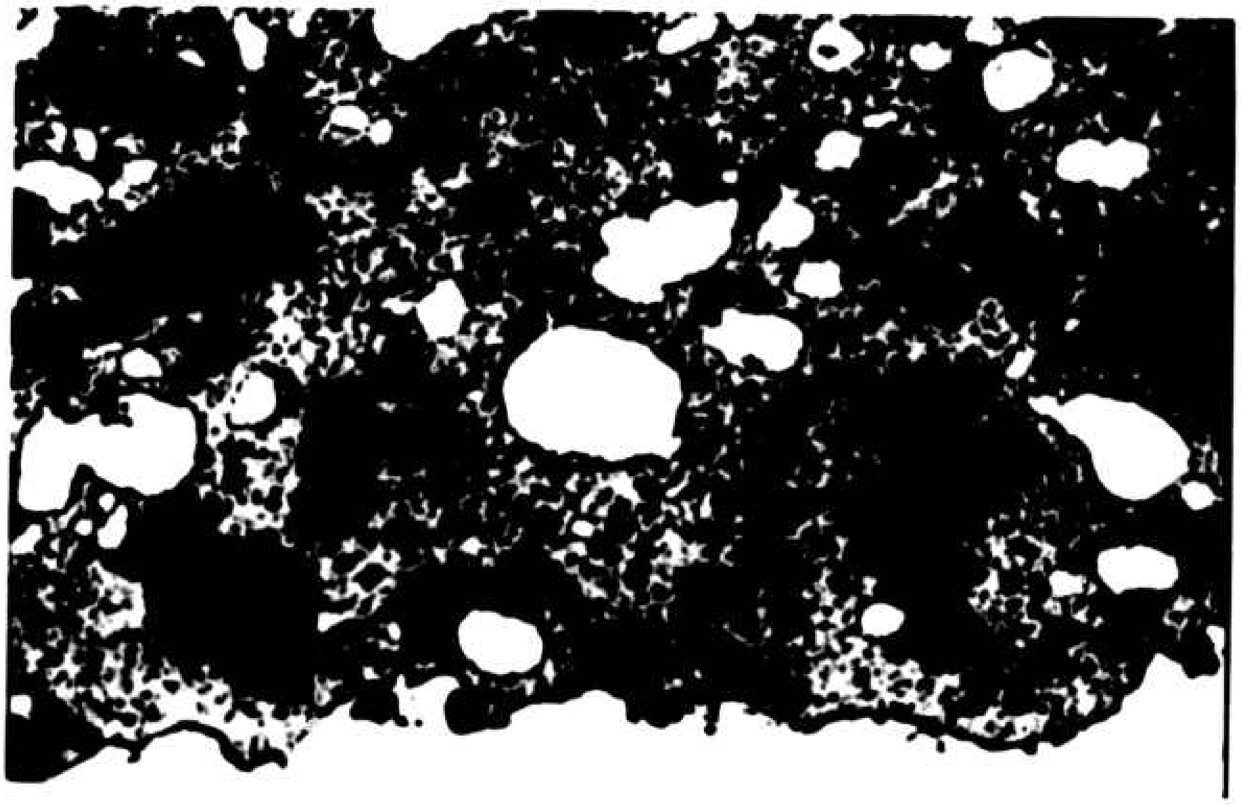
b. Al_2O_3 Rich Side of Graded Region Mag 1000X

c. Aluminum-Rich Side of Graded Region. Mag. 1000X
(black, porosity; white, aluminum; gray, alumina)

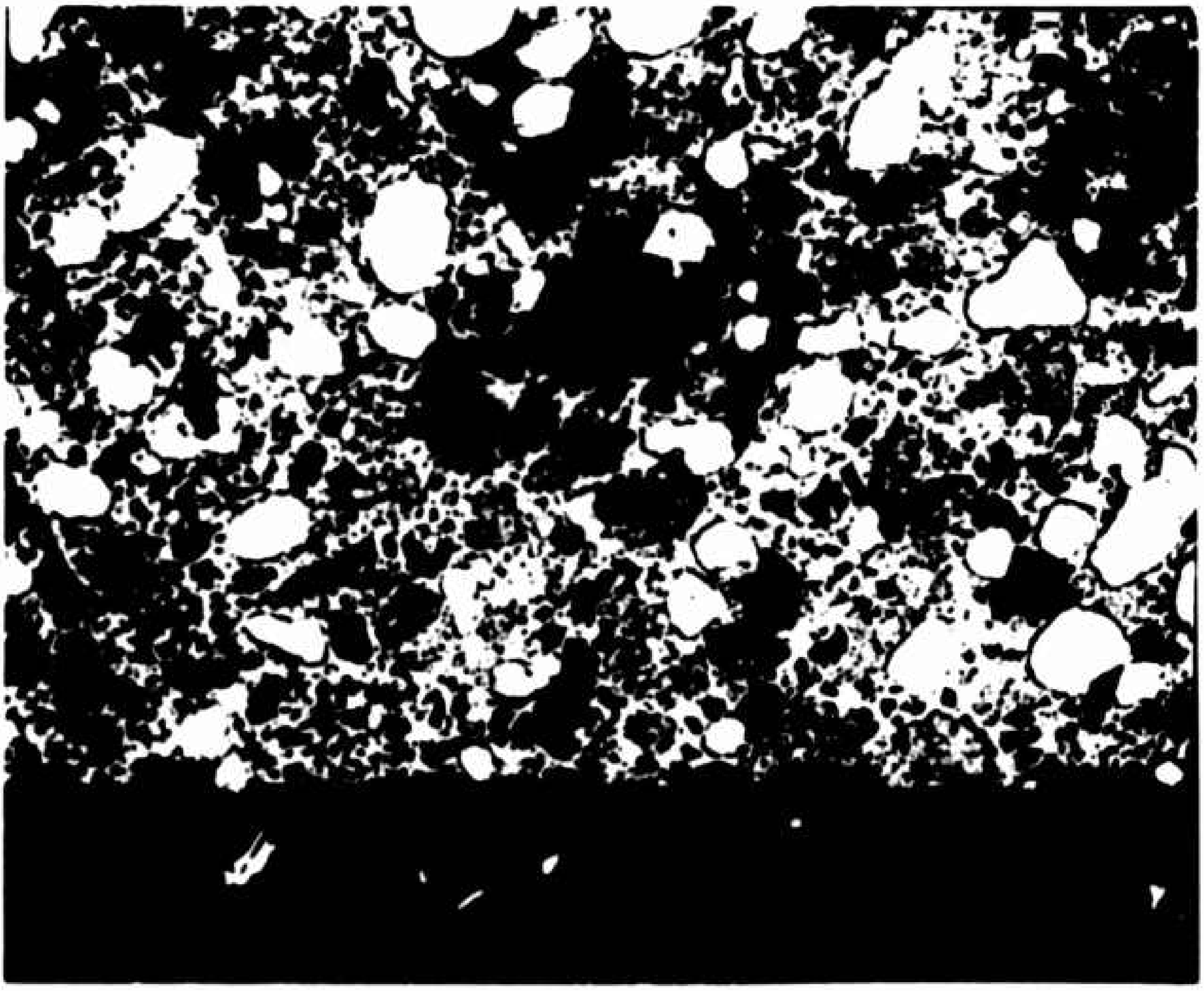
Figure A-2. PLASMA-SPRAYED GRADED Al_2O_3



a. Overall Cross-Section. Mag. 100X



b. Coating Substrate Interface. Mag. 500X



c. Region Near Coating Surface. Mag. 500X
(black, porosity; mottled white, aluminum; solid white, SiO_2; mottled gray, bonding agent)

Figure A-3. SLURRY-COATED SiO_2-Al (2:1)

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