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WEAR-RESISTANT MATERIALS FOR COAL CONVERSION AND UTILIZATION

First Progress Report, October 1979—April 1980

By
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Work Performed Under Contract No. AI05-800R20687

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U. S. DEPARTMENT OF ENERGY

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First Progress Report
October 1979 - April 1980

WEAR-RESISTANT MATERIALS FOR COAL CONVERSION AND UTILIZATION

to

R. A. Bradley, Manager, Fossil Energy Materials Projects
Oak Ridge National Laboratory

Interagency Agreement
Contract DE-A105-800R20687

Submitted by

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ABSTRACT

Studies of wear-resistant materials during this reporting period were concentrated mostly on hard coatings and surface treatments, such as chemical vapor deposited materials, thermal-sprayed materials with post-deposition laser treatments, and surface-bonded materials. Several coatings were found to have extremely good erosion resistance.

A nickel-bonded titanium diboride material was found to have extremely high erosion resistance.

An erosion data bank for existing and promising valve materials was begun. Erosion test results at six impingment angles and four particle velocities were produced.

Testing of a 6-inch ball-valve ball coated with a Cr-Ni-B coating in a laboratory ball-valve testing facility reached the half-way point; 10,000 open-close cycles in coal-ash.

INTRODUCTION

The research is organized into nine tasks: erosion and abrasion testing, laser processing of thermal-spray coatings, fabrication of valve seats by laser-processing, testing of the laser-processed valve seats in coal ash, arrangement for fabrication of letdown valve trim for test in a slurry loop facility, support to the University of California DOE program, coating of a ball-valve ball with a Cr-Ni-B alloy and testing it in coal ash, liaison to DOE contractors and others interested in wear-resistant materials for coal conversion, and preparation of a report on laser-fused thermal spray coatings.

PROGRESS REPORT

Task 1 - Erosion and Abrasion Testing

Erosion studies on a series of chemical-vapor-deposited coatings from Chemetal Corp. were made. Silicon nitride and silicon carbide coatings on graphite, and a tungsten-carbon alloy on molybdenum, all produced by the "controlled nucleation thermal deposition" method, were eroded at 30°, 45°, and 90° Angles at 170 m/s velocity with -27 μm Al_2O_3 particles. The erosion data from these tests, all taken at room temperature, are shown in tables 1 and 2. Alloy coatings CM-500, a tungsten-carbon alloy, were found to have insufficient erosion resistant to consider for letdown valve applications. But, as shown in table 2, the erosion resistance of SiC and Si_3N_4 warrants further consideration as letdown valve trim materials. The Relative Erosion Factors (REF) varied from 0.003 to 0.009 for SiC and from 0.004 to 0.070 for Si_3N_4. These values correspond to an increase in erosion resistance of a factor of 3 for SiC over a 1.5 pct cobalt/tungsten carbide cermet, and equivalent erosion resistance to the cermet for Si_3N_4. Elevated temperature erosion and thermal cycling studies will be made on the SiC and Si_3N_4 coatings in the near future to evaluate wear and adherence at temperatures to 700° C.

Erosion tests were made on several nickel-titanium diboride materials. These materials, developed by Oak Ridge National Laboratory, were hot-pressed near the melting point of nickel. Erosion data for the Ni-TiB_2 alloys are shown in table 3. The 20 pct nickel alloy had the highest erosion resistance, unlike cobalt-bonded tungsten carbide alloys, where

TABLE 1. - Erosion results on CM-500

Particle velocity 170 m/s, -27μm Al_2O_3 particles

Specimen Number	Weight loss, gm		
	30°	45°	90°
A-1	---	---	penetrated in 3-min.
A-2	---	penetrated in 3-min.	---
A-5	not penetrated in 3-min. 0.0125 gm	---	---
A-13	---	---	0.0042 gm in 1 min.
A-14	---	0.0055 gm in 1 min.	---
A-15	0.0049 gm in 1 min.	---	---

TABLE 2. - Erosion results of SiC and Si_2N_4 coatings

Particle velocity 170 m/s; -27 μm Al_2O_3 particles, test duration - 15 minutes

Specimen No.	Weight loss, gm			Volume loss, cm^3			REF 1/		
	30°	45°	90°	30°	45°	90°	30°	45°	90°
C-1; SiC	--	--	0.00020	--	--	0.000062	--	--	.009
C-9; SiC	--	0.00017	--	--	0.000053	--	--	.007	--
C-10; SiC	0.000080	--	--	0.000025	--	--	.003	--	--
C-19; SiC	--	--	0.00010	--	--	0.000031	--	--	.005
C-12; SiC	--	0.00020	--	--	0.000062	--	--	.008	--
C-16; SiC	0.000170	--	--	0.000053	--	--	.006	--	--
Si_3N_4	0.00033	0.00023	0.0015	0.000096	0.000067	0.00044	.011	.009	.070

1/ REF (Relative Erosion Factor) calculated by dividing volume loss of material by the volume loss of Stellite 6B tested in like manner.

TABLE 3. - Erosion results of ORNL hot-pressed Ni-TiB_2. Particle velocity 170 m/s, -27μm Al_2O_3 particles, 3 minute test

Alloy designation	Binder content, pct	Density, gm/cm^3	Volume loss, cm^3		REF[1/]	
			20° imping.	90° imping.	20° imping.	90° imping.
Ni-TiB_2	?	4.48	0.000104	0.000504	0.059	0.370
NT-80B	20	4.92	0.000015	0.000052	0.008	0.036
NT-85B	15	4.80	0.000030	0.000067	0.017	0.046
NT-90B	10	4.70	0.000022	0.000155	0.013	0.108
K-602 [2/]	<1.5 Co	---	----	----	0.01	0.11
K-701 [2/]	10.2Co + 4 Cr	---	----	----	0.02	0.25
K-801 [2/]	6 Ni	---	----	----	----	0.32

1/ REF calculated by dividing the volume loss of the material by the volume loss of Stellite 6B tested in like manner.

2/ Cemented tungsten carbide data shown for comparison.

the erosion resistance decreases with an increase in binder content. This suggests a strengthening and/or hardening mechanism operating in the nickel binder. Such a development could have wide-spread application for substitutes for cobalt in cemented hard materials.

An extensive erosion testing program was begun on materials that are presently used in coal conversion valves, and on some selected commercial materials that show promise for valve use. Erosion tests were made at impingement angles of 15°, 30°, 45°, 60°, 75°, and 90°. Aluminum oxide particle velocities of 70, 90, 120, and 170 m/s were used at each of the six impingement angles, giving erosion data at twenty-four combinations of conditions.

Erosion data for type 316 stainless steel, annealed type 440-C stainless steel, heat-treated type 440-C stainless steel, cast iron alloy HC-250, stellite 6B, and 5.8 pct Co/tungsten carbide are shown in figures 1 through 12. The data are plotted to show the effect of particle impingement angle and particle velocity on erosion wear. Specific erosion wear data were calculated by dividing the volume of material removed in a three-minute test by the weight of aluminum oxide particles expended in that time period. Erosion information in this data bank should be useful to design engineers to aid materials selection for wear-prone components for coal conversion systems. Many requests have been received from valve and pump design and manufacturing people, coal conversion plant personnel and materials development laboratories for such data. Data for other materials such as boron carbide, other cemented

tungsten carbides, molybdenum, and borided molybdenum will be added to the data bank as testing progresses.

No abrasion tests were conducted during this reporting period.

Task 2 - Laser Processing of Thermal-Spray Coatings

A series of METCO[1/] flame- and plasma-sprayed coatings on type 316 stainless steel substrates were laser remelted during fourth quarter of

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1/ Specific brand names are used for identification and description only and do not imply endorsement by the Bureau of Mines.

FY 1979. Metallographic examinations of the materials were completed during this reporting period. Laser beam powers of 745, 850, 940, 1080, and 1180 watts were used at a beam-pass velocity of 8 inches/sec. Each melt zone consisted of six overlapping passes with a beam spot diameter of 0.1 inch. Initial laser-processing screening tests were made on coatings of cobalt-bonded tungsten carbide, nickel-bonded tungsten carbide, Cr-Ni-B alloys, chromium carbide, and Ni-Cr bonded chromium carbide. Metallography photographs at 200 magnification show the as-sprayed coating and the laser remelt zone for each of these materials in figures 13 through 22. Based on the visual information from the metallography results, METCO materials 36C (a nickel-chromium-bonded tungsten carbide cermet) and 19E (a chromium-nickel-boron alloy) were selected for further study. Both the 36C and the 19E materials bonded well to the type 316 stainless steel and appeared to exhibit homogeneous structure. Compositions for the METCO coatings are shown in table 4.

TABLE 4. - Compositions of METCO flame- and plasma-sprayed coatings

METCO Number	Hard phase	Composition, wt-pct										Spray powder size, μm
		Cr	Ni	Si	B	Cu	Mo	Fe	W	Co	C	
16C	---	16	67	4	4	3	3	2.5	--	--	0.5	-125 + 45
19E	---	16	64.3	4	4	2.4	2.4	4	2.4	--	0.5	-106 + 45
32C	80(WC + 12 Co)	3.5	14	0.8	0.8	--	--	0.8	--	--	0.1	-125 + 45
34F	50(WC + 12 Co)	9	33	2	2	--	--	3.5	--	--	0.5	-52 + 15
36C	35(WC + 8 Ni)	11	46	2.5	2.5	--	--	2.5	--	--	0.5	-150 + 45
70C-NS	99 chromium carbide	--	--	--	--	--	--	--	--	--	--	-106 + 30
74 SF	88 WC	--	--	--	--	--	--	--	--	12	--	-45 + 5
81 VF-NS	75 chromium carbide	5	20	--	--	--	--	--	--	--	--	-45 + 5

Specimens of type 316 stainless steel and low-carbon steel have been flame-sprayed with 0.008 inch and 0.012 inch thick coatings of METCO 19E and METCO 36C alloys. Laser remelt parameters will be optimized and bonding and microstructure studies made. Preparations are being made to laser process coatings for abrasion tests and fabrication of ball valve seats.

Task 3 - Fabrication of Laser-Fused Valve Seats

No work to report.

Task 4 - Valve Testing Laser-Fused Valve Seats in Albany Ball-Valve Tester

No work to report.

Task 5 - Letdown Valve Trim Fabrication

Arrangements to have experimental letdown valve trim parts made and tested are progressing. The principal investigator will travel to Sandia Laboratory during the third quarter to finilize the valve design and testing details. Arrangements are being made to have trim parts made of chemical vapor deposited (CVD)-TiB_2, borided Co/WC, CVD-SiC, and hot-pressed Ni/TiB_2.

Task 6 - Support for University of California, Berkeley DOE Program

No work to report.

Task 7 - Cr-Ni-B Ball Coated and Tested in Albany Ball-Valve Tester

A six-inch Pacific full-port ball-valve ball of type 316 stainless steel was flame-sprayed with METCO 19E Cr-Ni-B alloy, and a 20,000 cycle life time test in coal ash was begun in the ball-valve tester. The test was interrupted at 3,500 cycles and 10,000 cycles for inspection of the

ball and Stellite 6B seats. The condition of the ball and one seat is shown in figures 23 and 24. Abrasion scratches on the ball surface were very minor and caused no leakage problem, and the 10,000 cycle inspection showed the same condition. But the Stellite 6B coating on the seats showed moderate wear. This can be seen on the inside of the ring in figure 24. Further testing of this ball-seat combination is continuing.

Task 8 - Consultation with DOE Contractors

Many DOE contractors and others from coal conversion plants, valve manufacturing companies, universities, and laboratories have requested assistance with materials selection information and wear data. Also, a formal presentation on "Wear-Resistant Materials for Coal Conversion Components" was given at the October 9-11, 1979 Fourth Annual Conference on Materials for Coal Conversion and Utilization at Gaithersburg, Maryland.

Task 9 - Bureau of Mines Report of Investigations on Laser-Fused Thermal-Sprayed Coating.

No work to report this period.

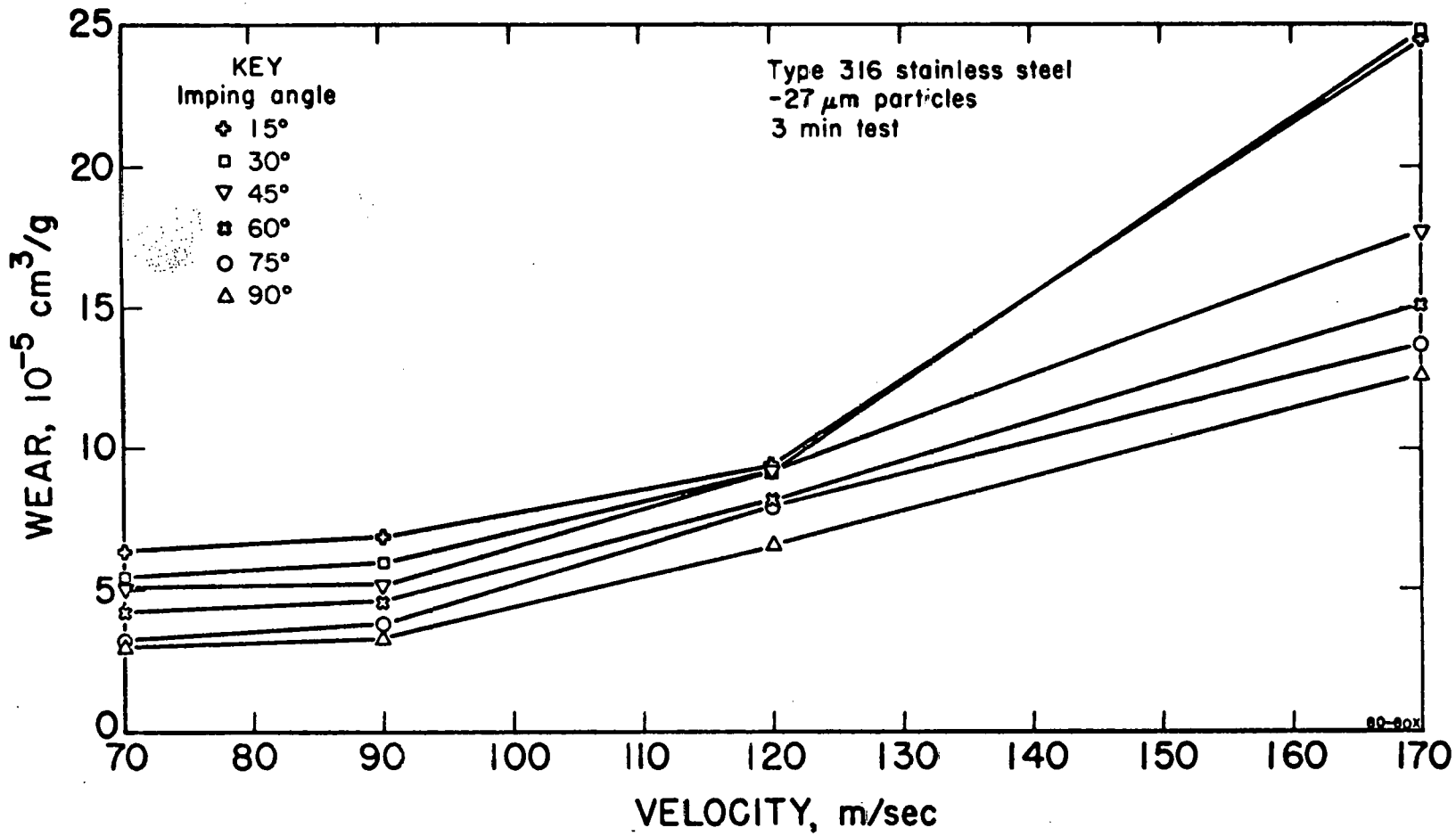


FIGURE 1.-Specific Erosion Wear vs. Particle Velocity for Type 316 stainless steel.

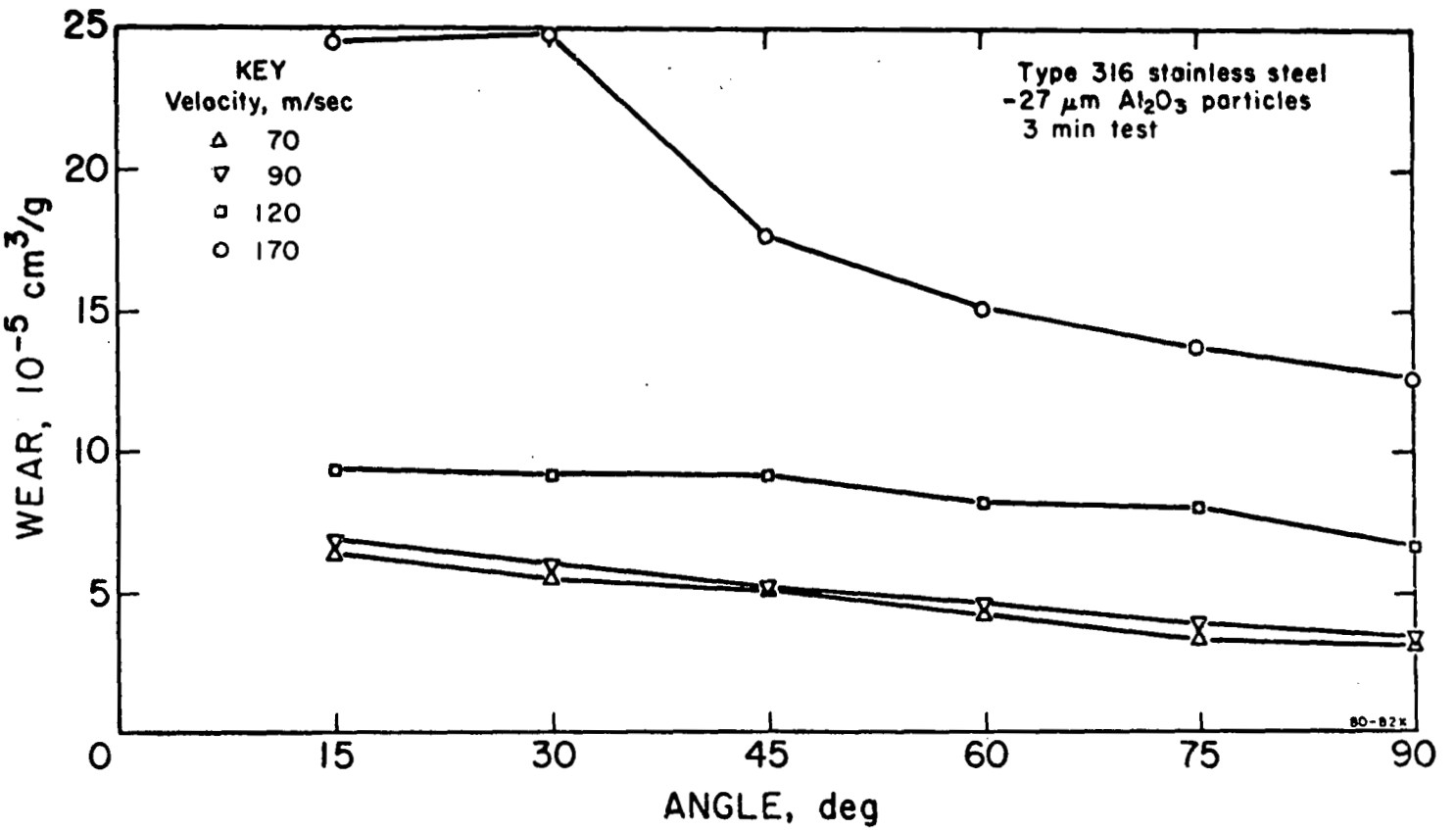


FIGURE 2.-Specific Erosion Wear vs. Particle Impingement Angle for Type 316 stainless steel.

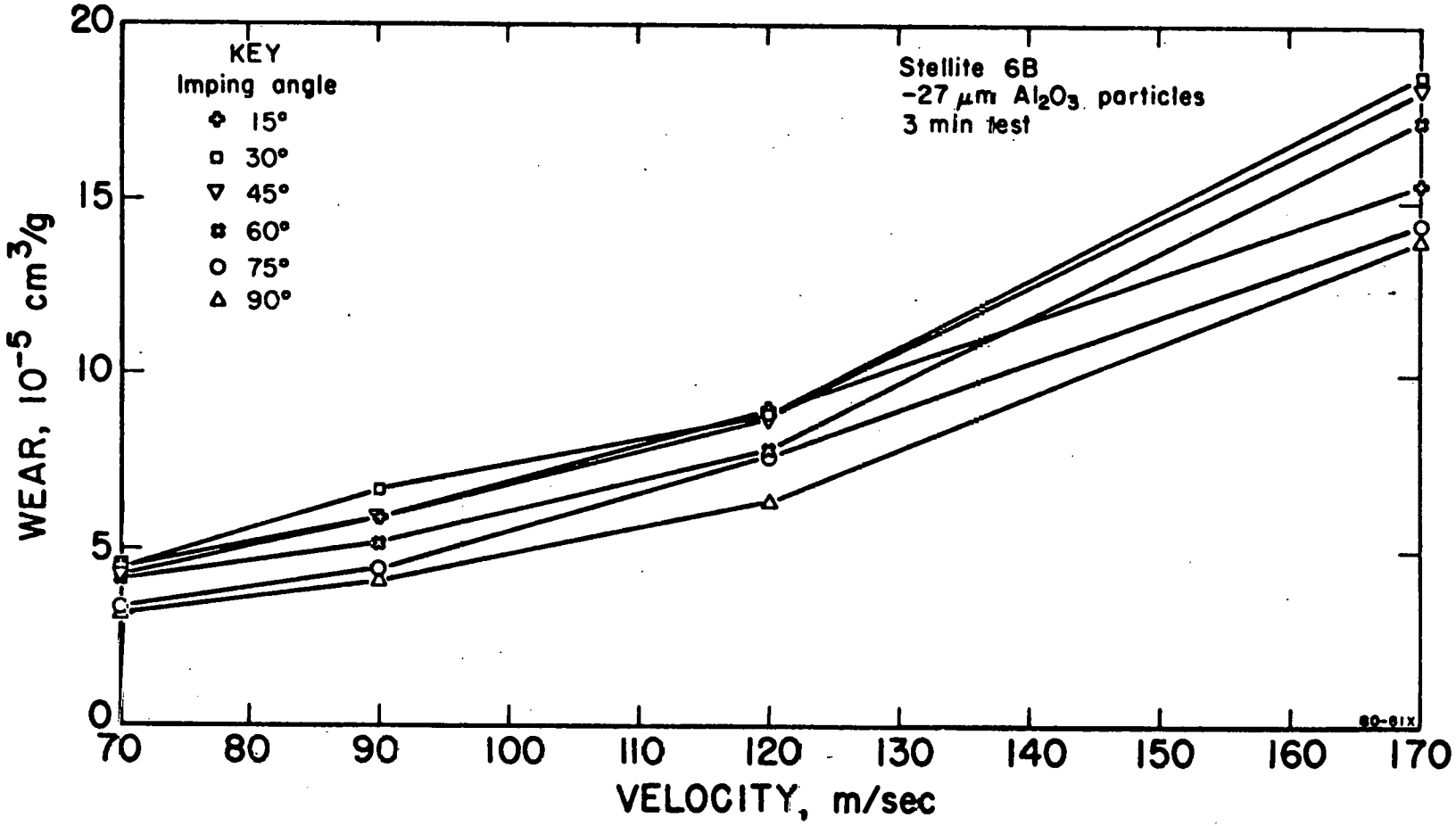


FIGURE 3.-Specific Erosion Wear Vs. Particle Velocity for Stellite 6B.

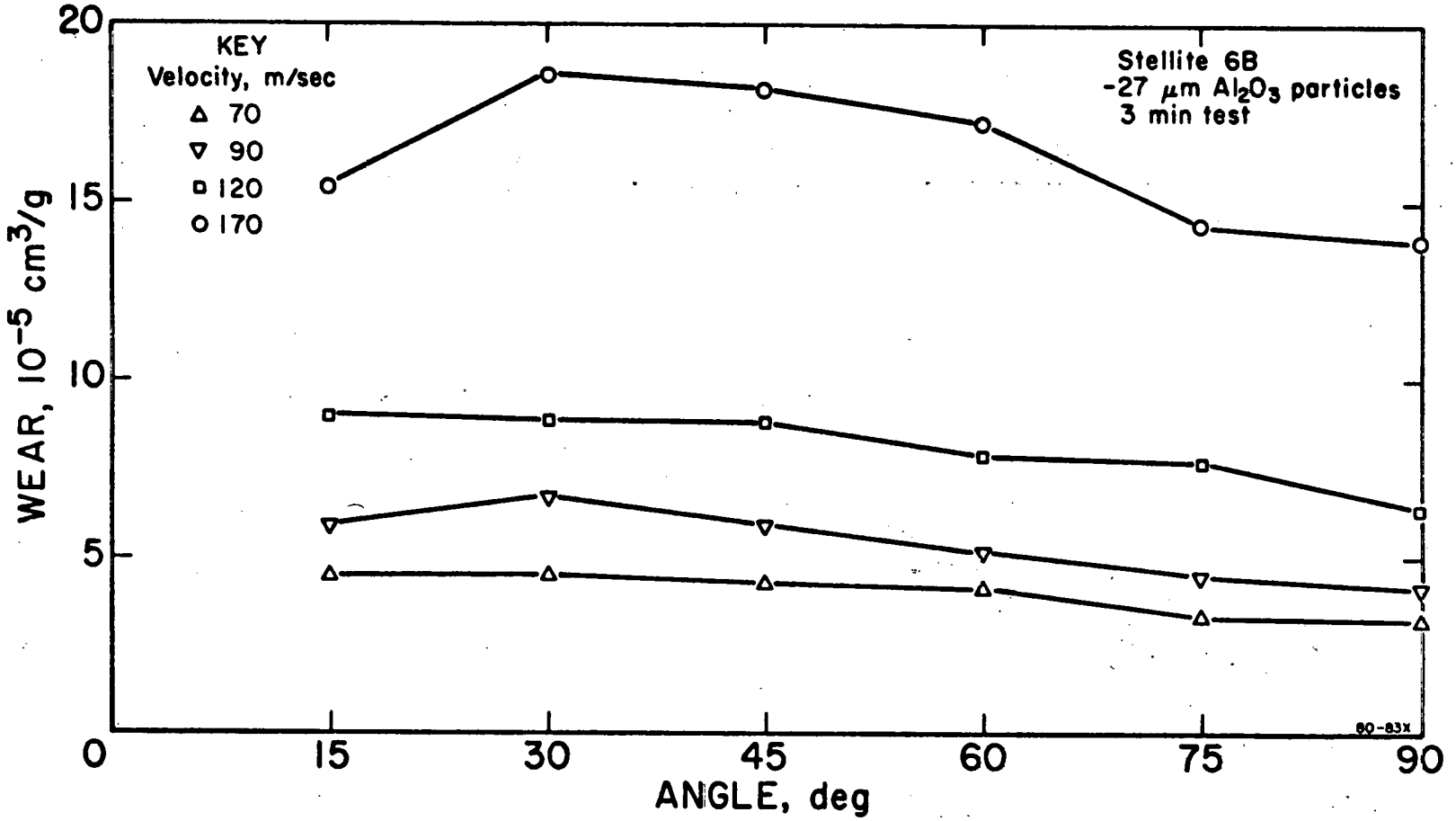


FIGURE 4.-Specific Erosion Wear Vs. Particle Impingement Angle for Stellite 6B.

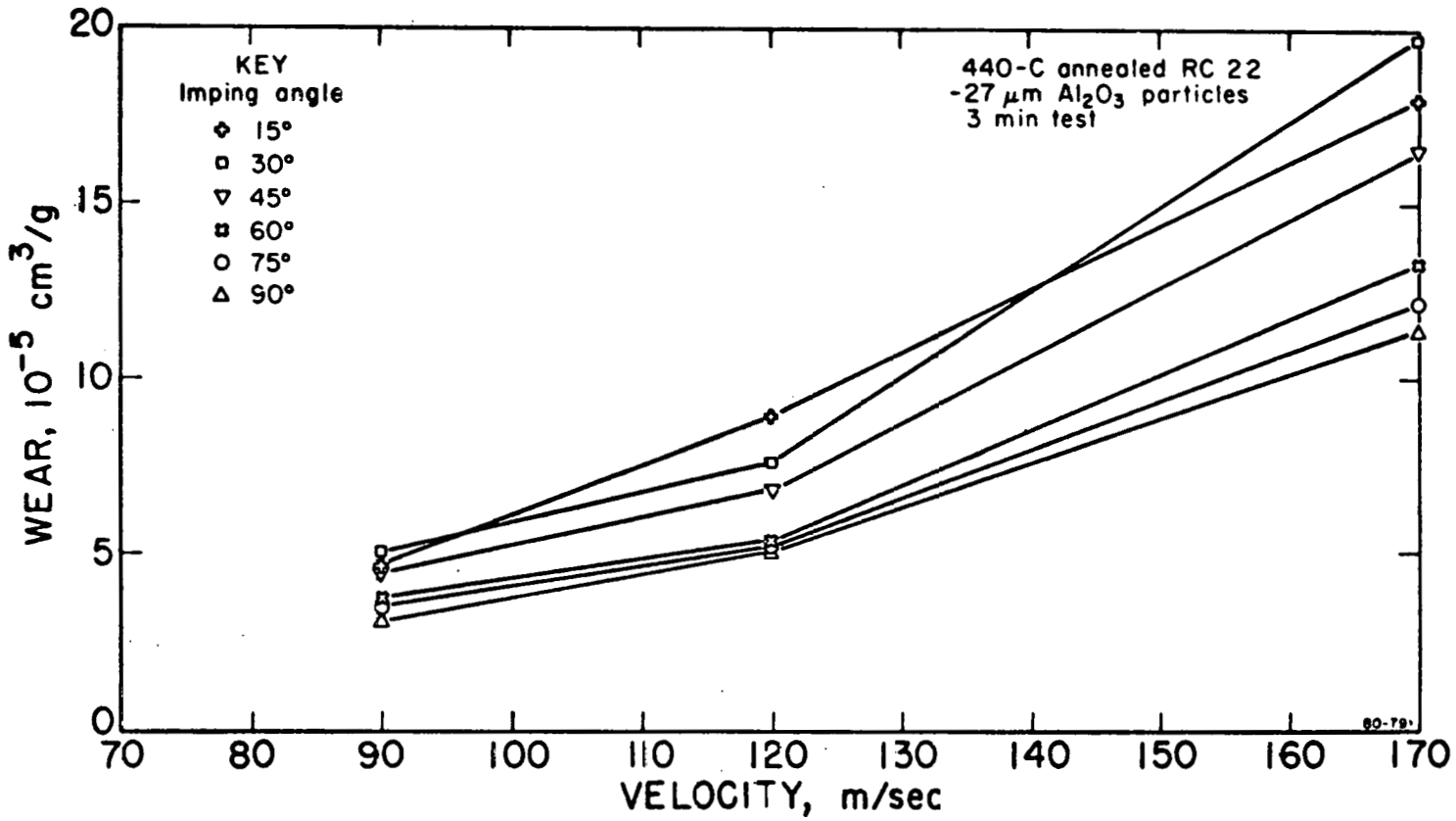


FIGURE 5.-Specific Erosion Wear Vs. Particle Velocity for type 440-C stainless steel, annealed.

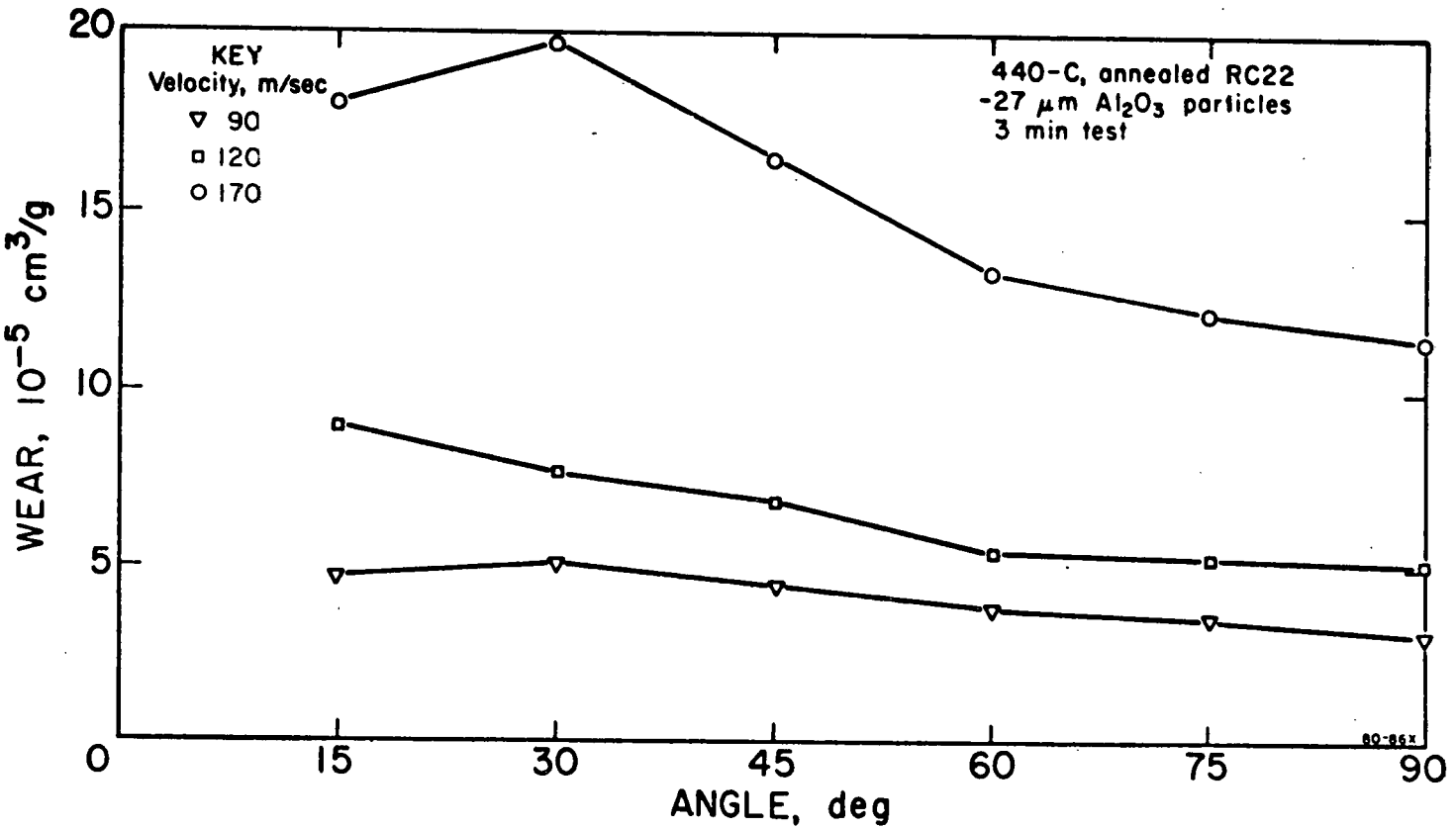


FIGURE 6.-Specific Erosion Wear vs. Particle Impingement Angle for type 440-C stainless steel, annealed.

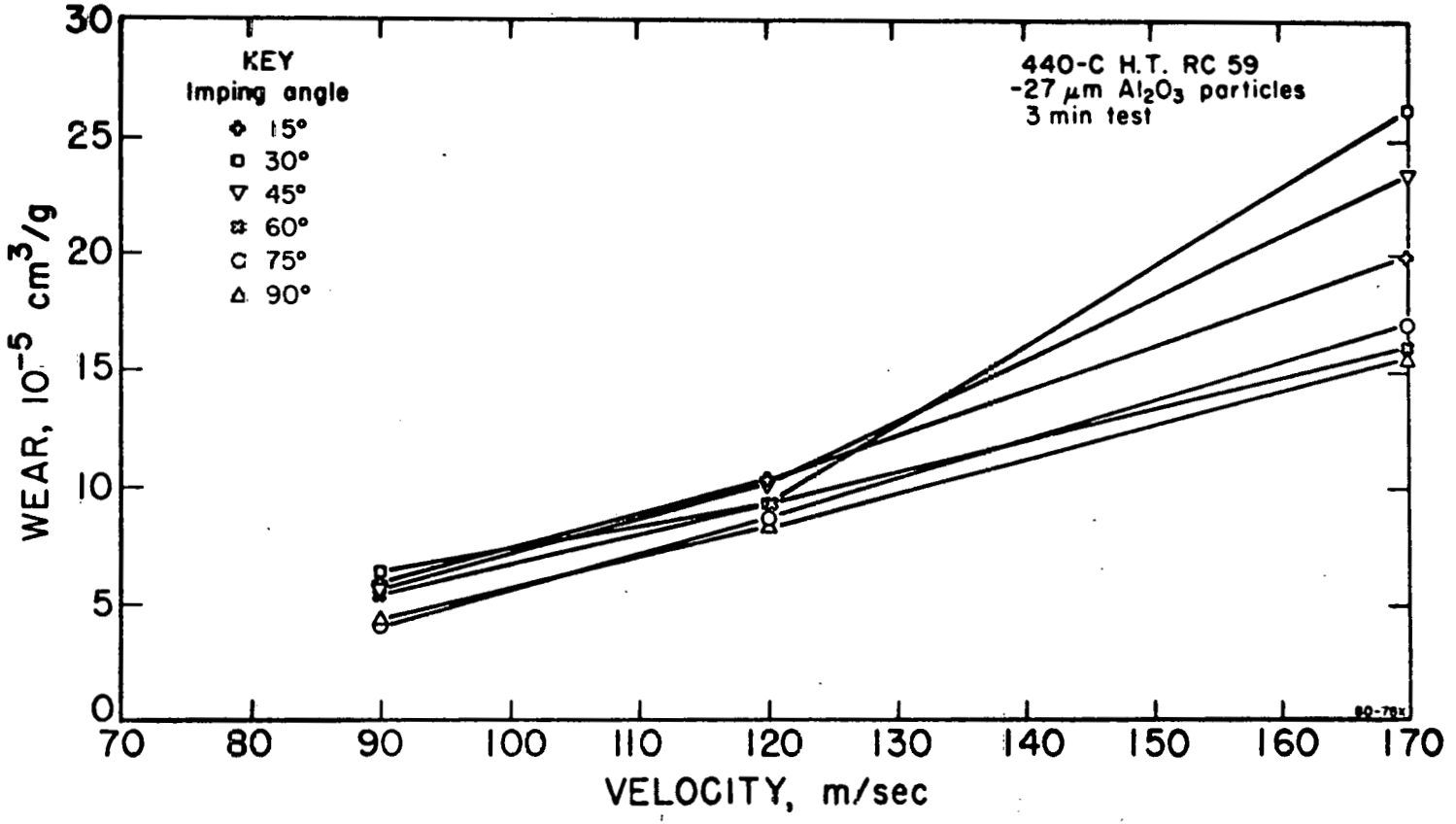


FIGURE 7.-Specific Erosion Wear vs. Particle Velocity for Type 440-C stainless steel, heat treated.

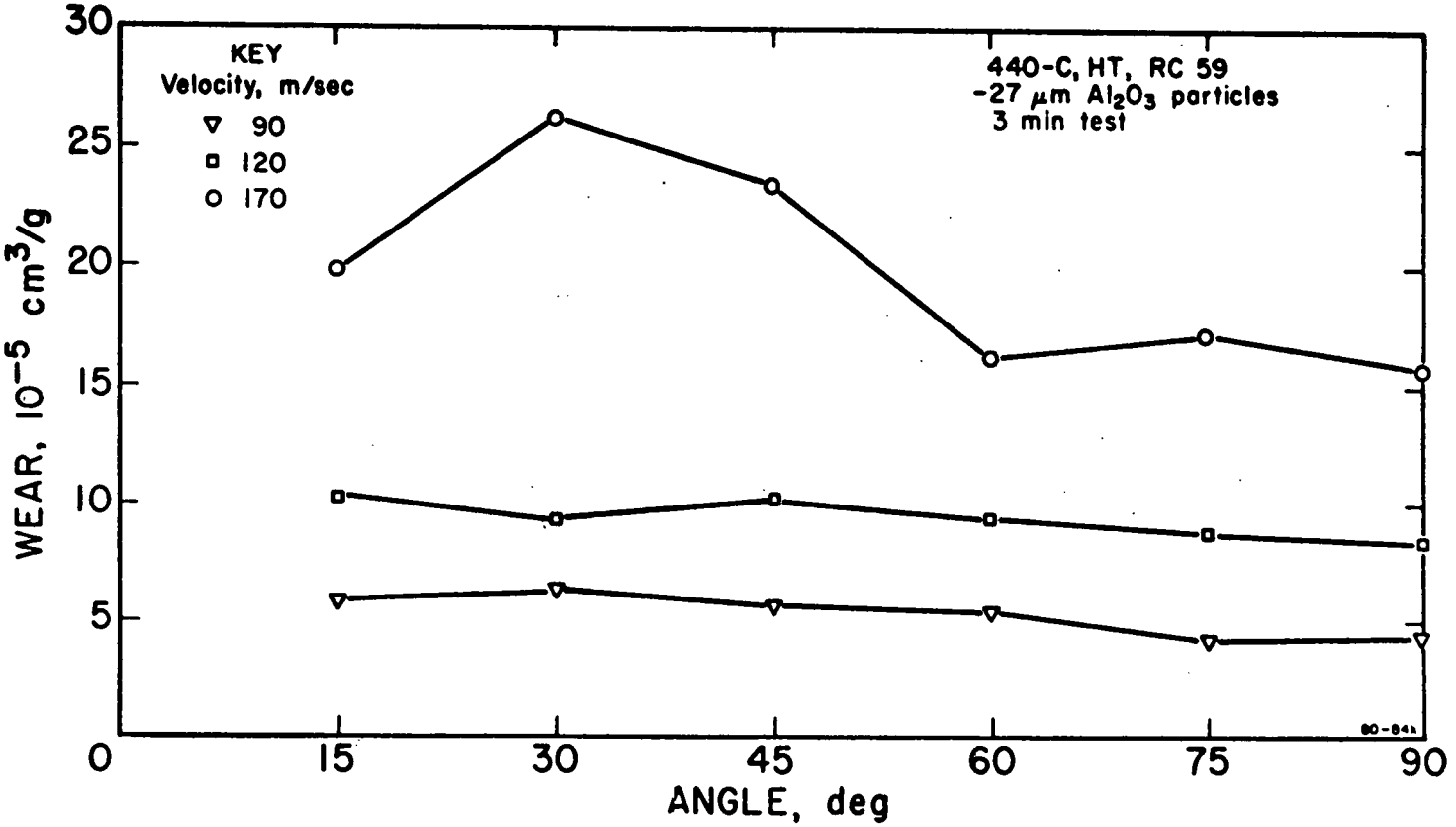


FIGURE 8.-Specific Erosion Wear vs. Particle Impingement Angle for Type 440-C stainless steel, heat treated.

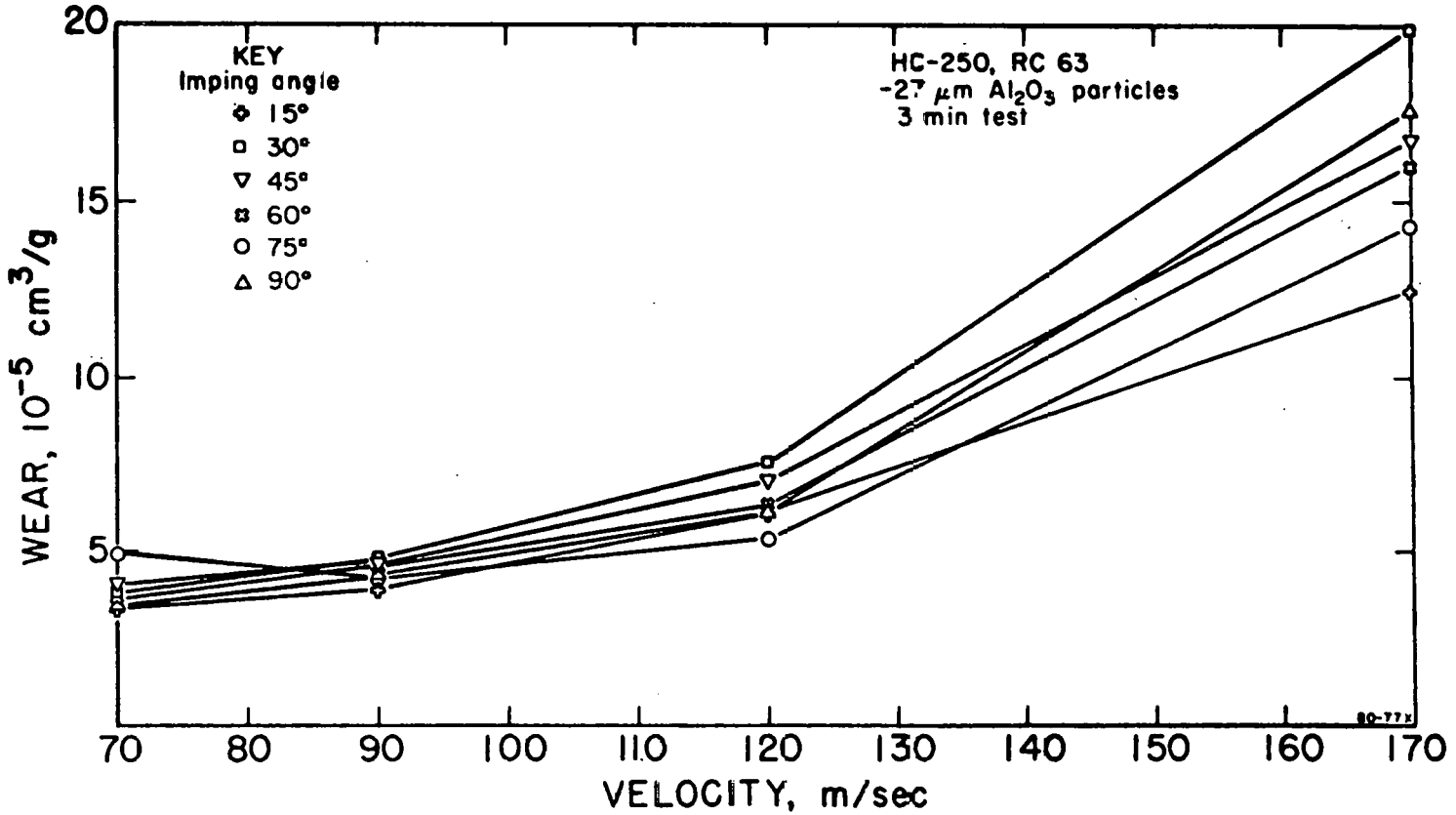


FIGURE 9.- Specific Erosion Wear vs. Particle Velocity for HC-250.

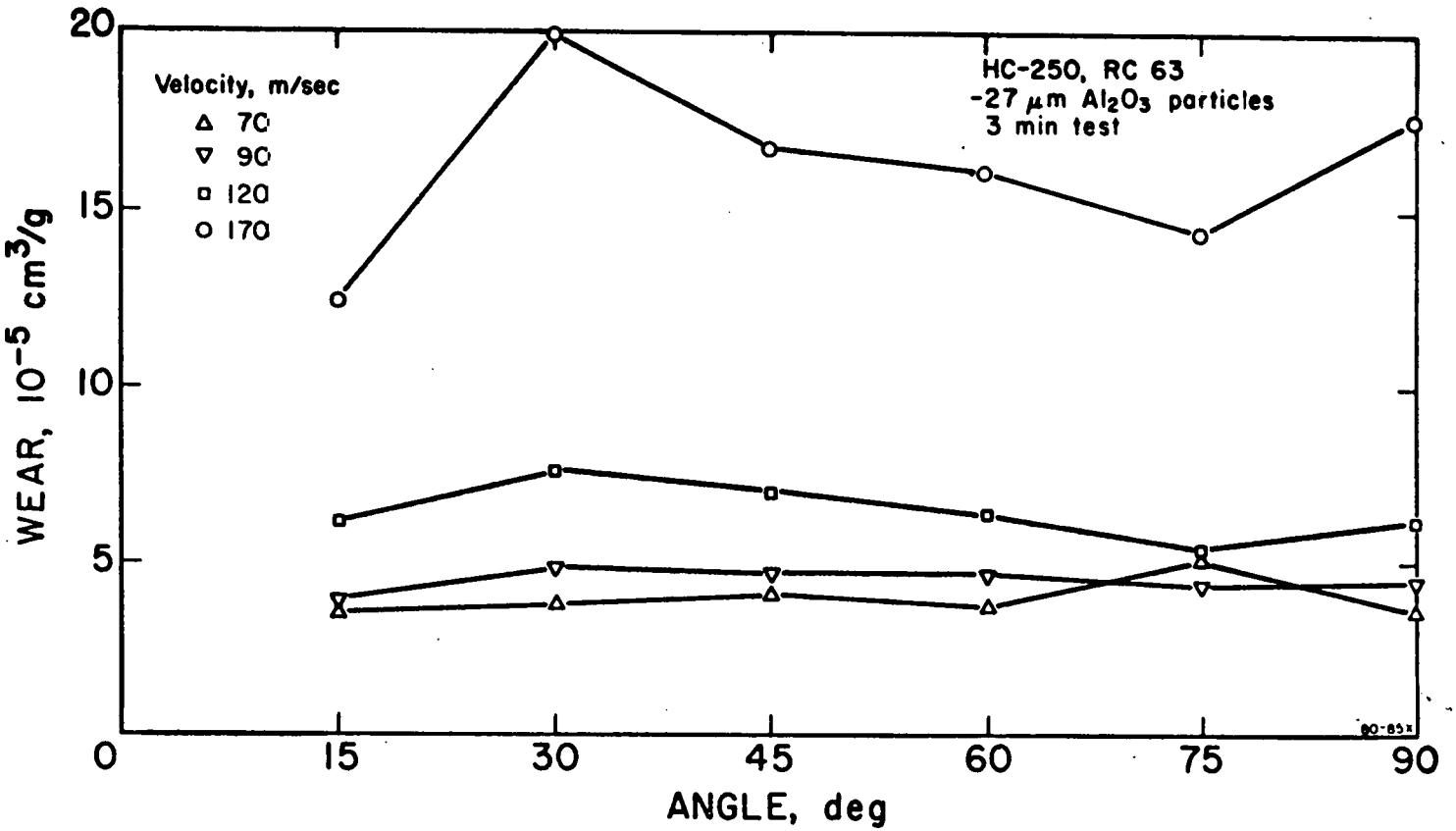


FIGURE 10.-Specific Erosion Wear vs. Particle Impingement Angle for HC-250.

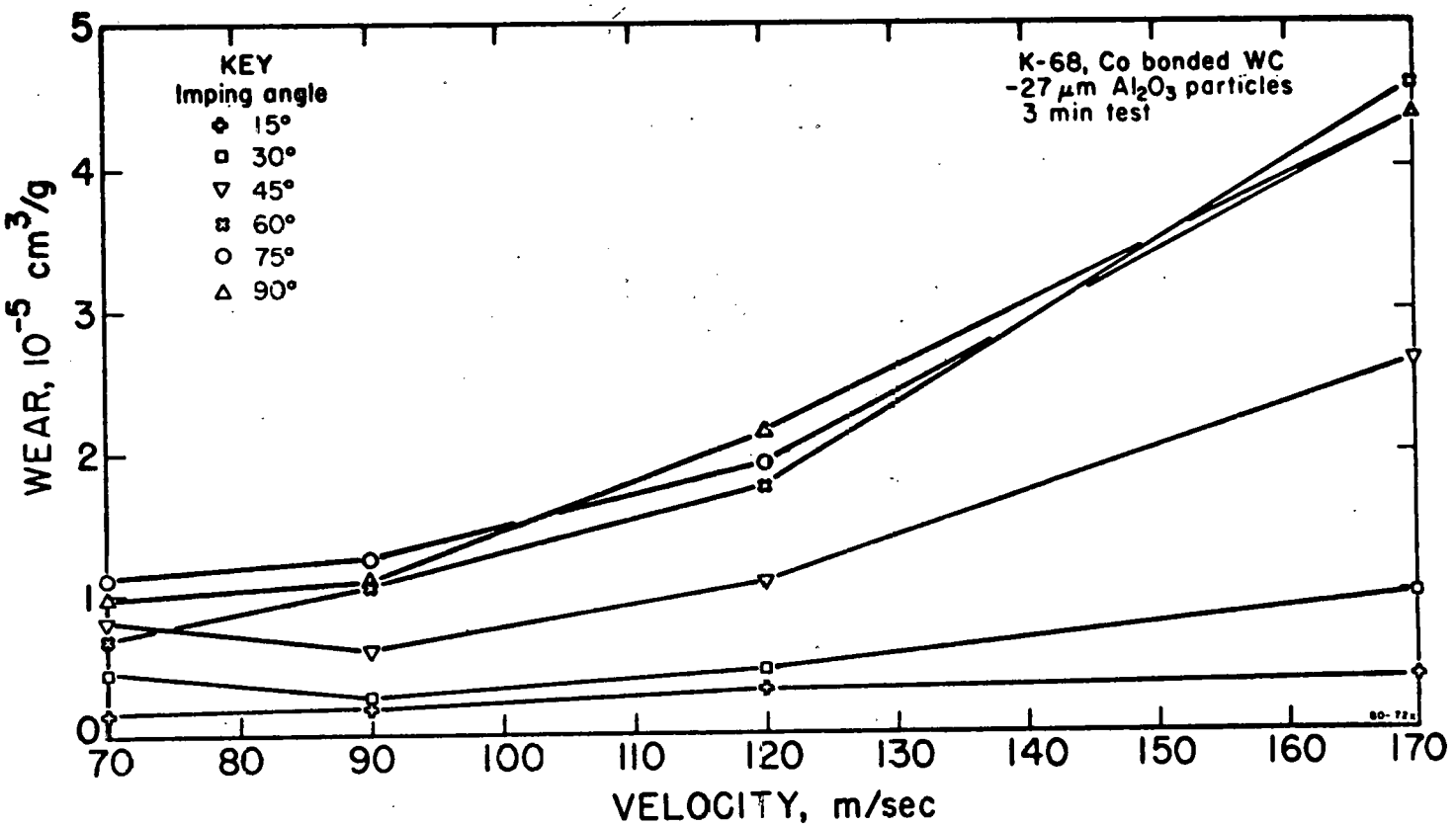


FIGURE 11.-Specific Erosion Wear vs. Particle Velocity for K-68 (5.8 Co/WC).

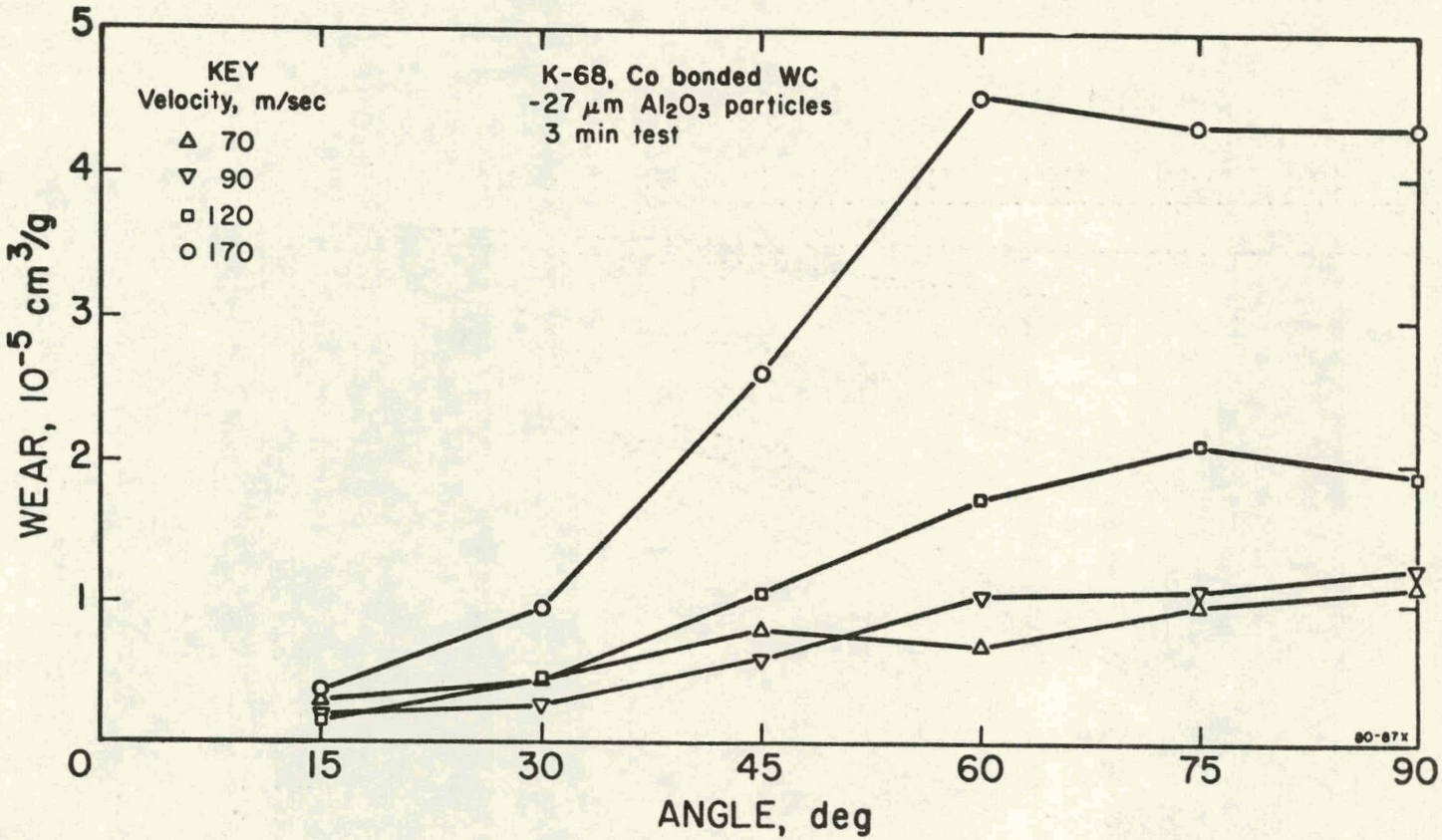


FIGURE 12.-Specific Erosion Wear vs. Particle Impingement for K-68 (5.8 Co/WC).

FIGURE 13

Laser remelted METCO 16C flame sprayed coating on type 316 stainless steel; 200 X mag.

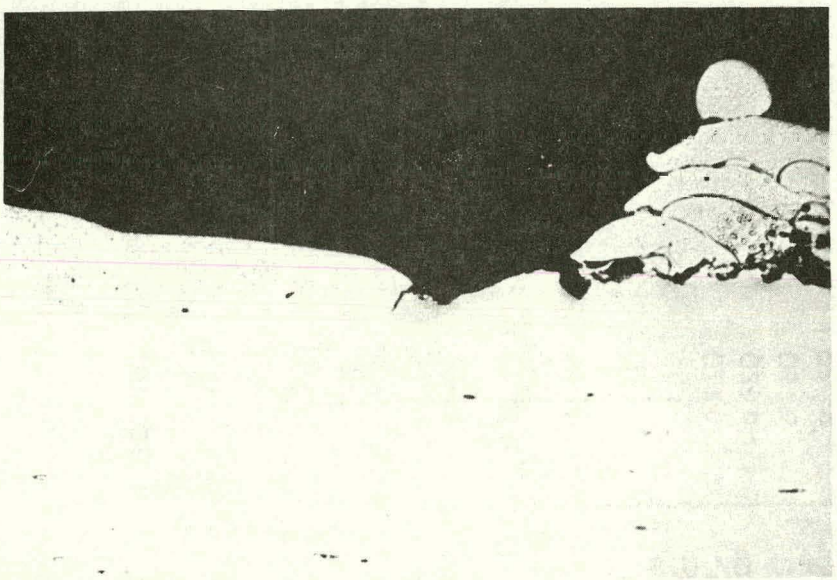


FIGURE 14

Laser remelted METCO 19E flame sprayed coating on type 316 stainless steel; 200 X mag.

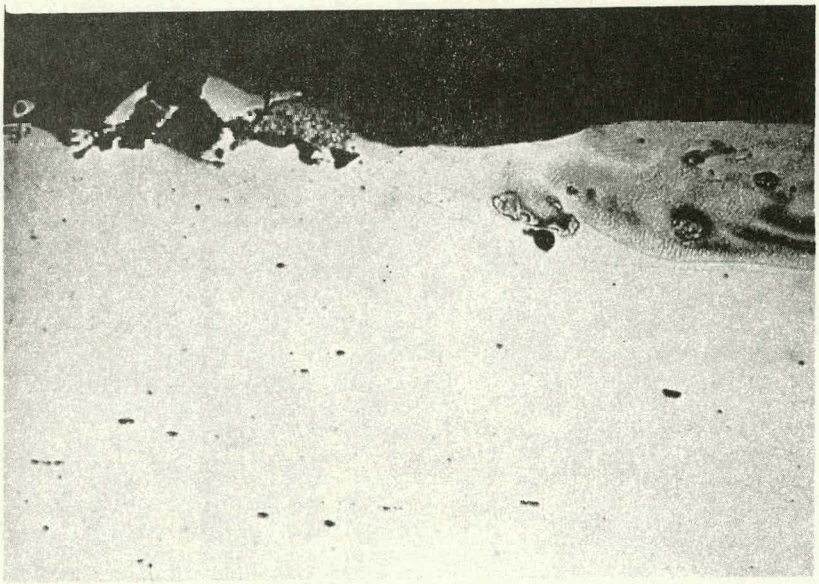


FIGURE 15

Laser remelted METCO 32C flame sprayed coating on type 316 stainless steel; 200 X mag.

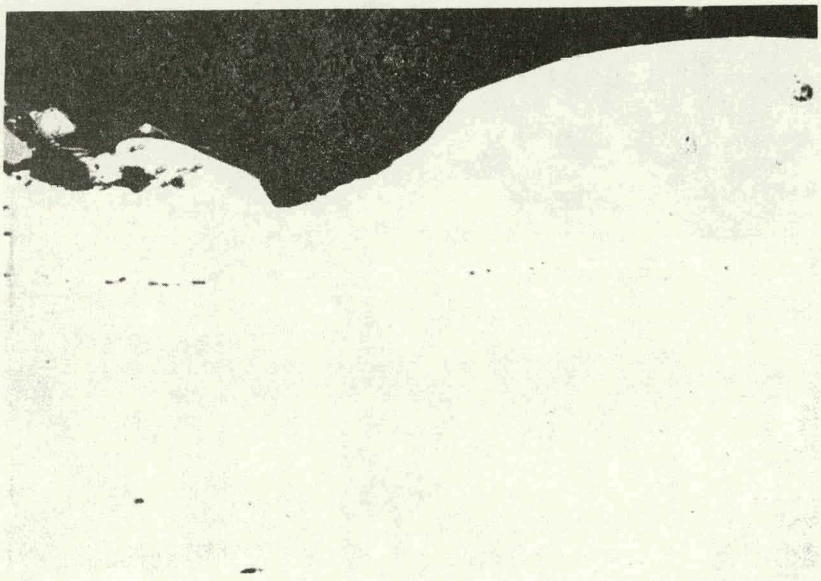
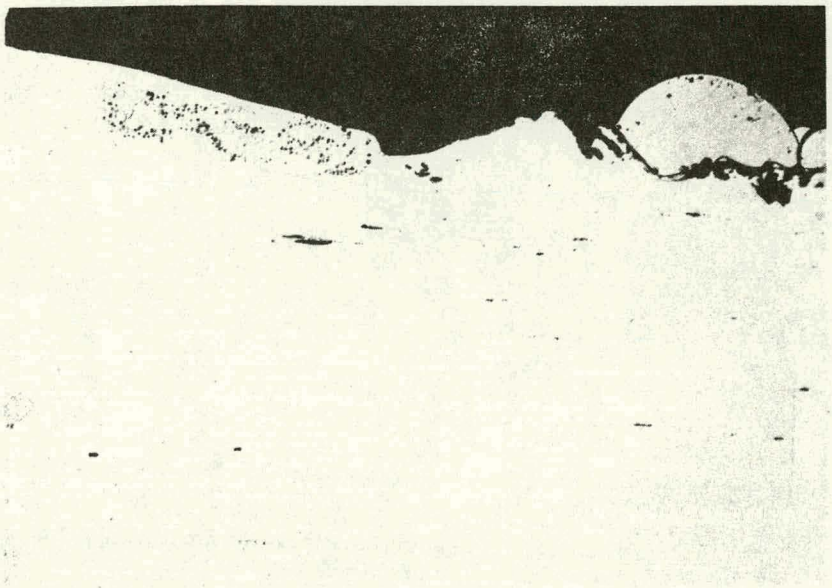


FIGURE 16

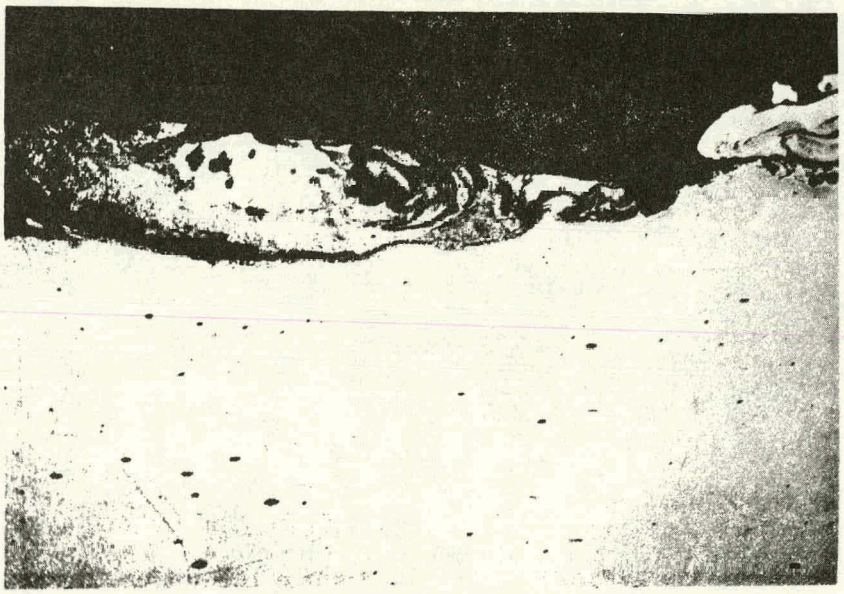
Laser remelted METCO 34F flame sprayed coating on type 316 stainless steel; 200 X mag.

FIGURE 17



Laser remelted METCO 36C flame sprayed coating on type 316 stainless steel; 200 X mag.

FIGURE 18



Laser remelted METCO 70C-NS flame sprayed coating on type 316 stainless steel; 200 X mag.

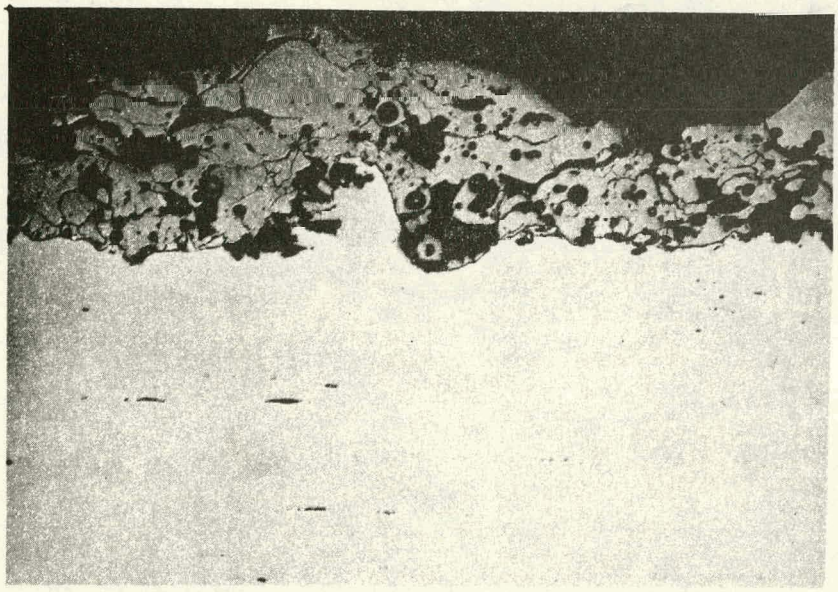


FIGURE 19

Laser remelted METCO 70C-NS plasma sprayed coating on type 316 stainless steel; 200 X mag.

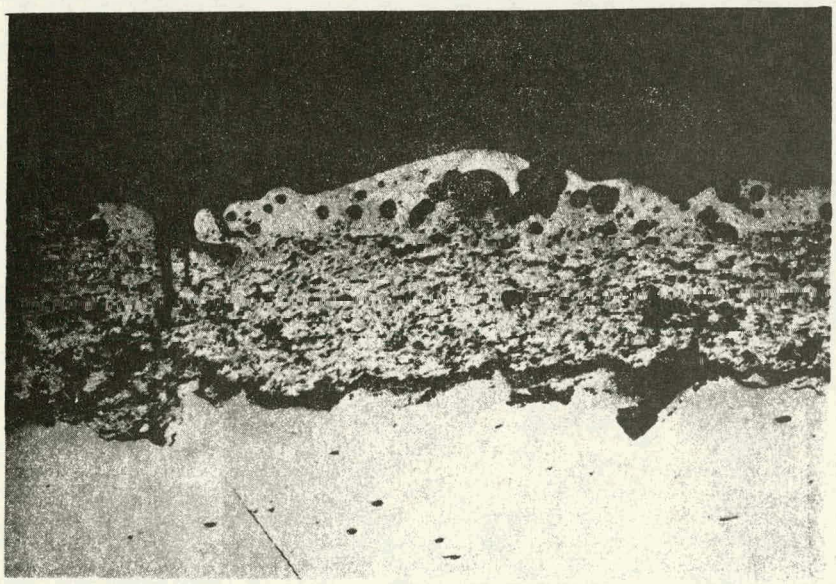


FIGURE 20

Laser remelted METCO 74SF plasma sprayed coating on type 316 stainless steel; 200 X mag.

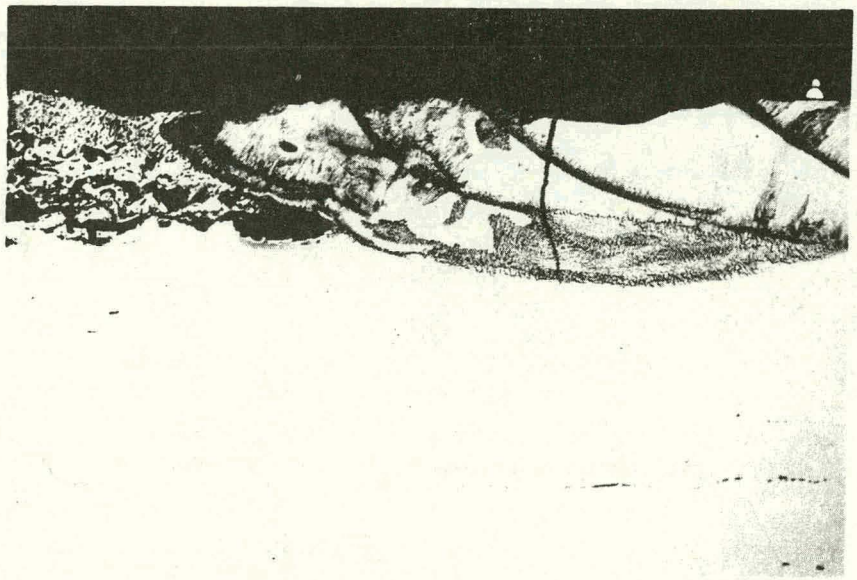


FIGURE 21

Laser remelted METCO 81 VF-NS plasma sprayed coating on type 316 stainless steel; 200 X mag.

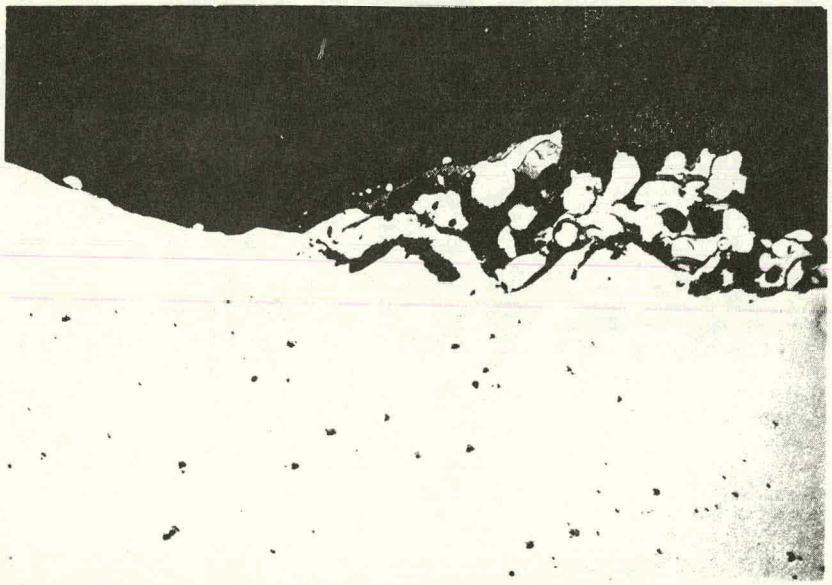


FIGURE 22

Laser remelted METCO 81 VF-NS flame sprayed coating on type 316 stainless steel; 200 X mag.

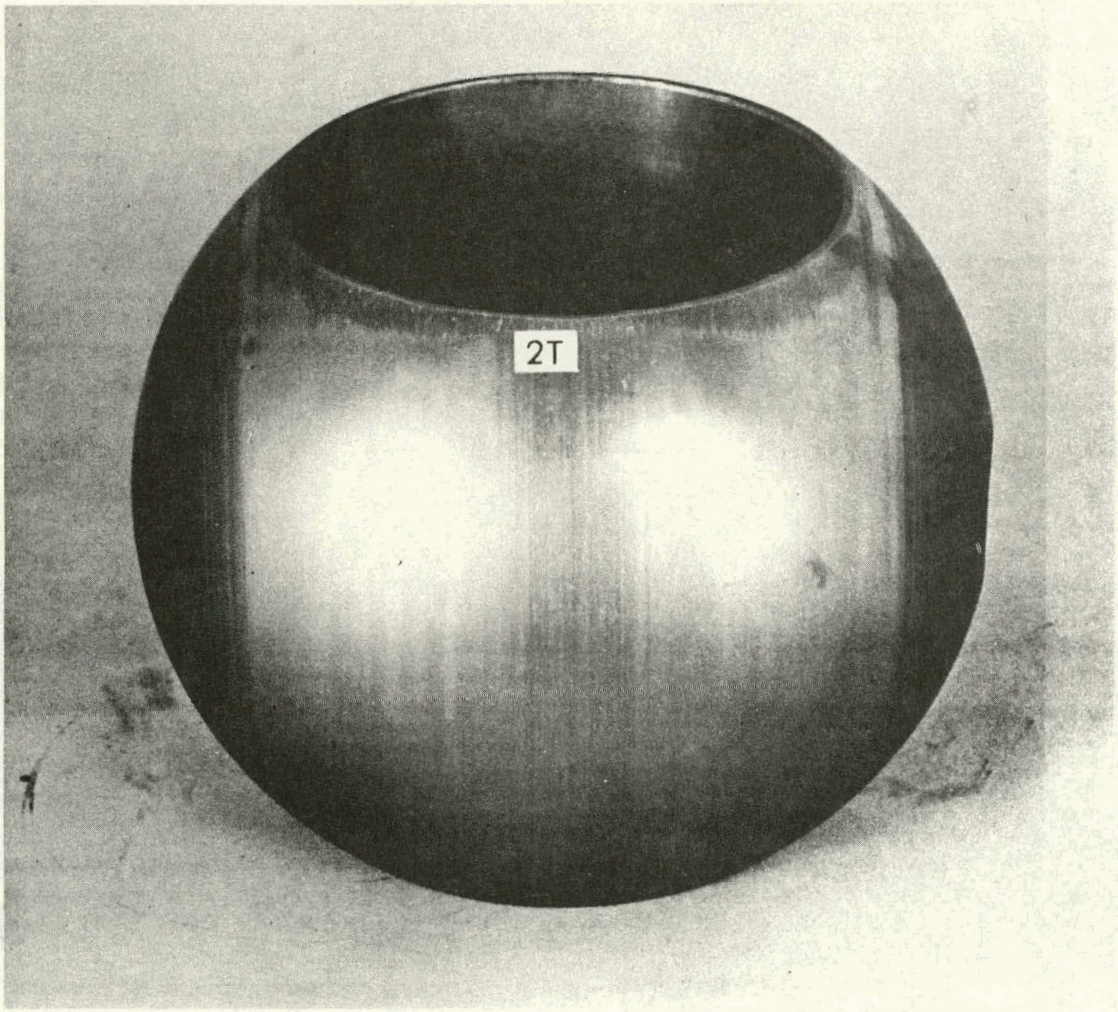


FIGURE 23. - Ball valve ball after 3,500 open-close cycles in ball-valve tester. Ball coating is METCO 19F.

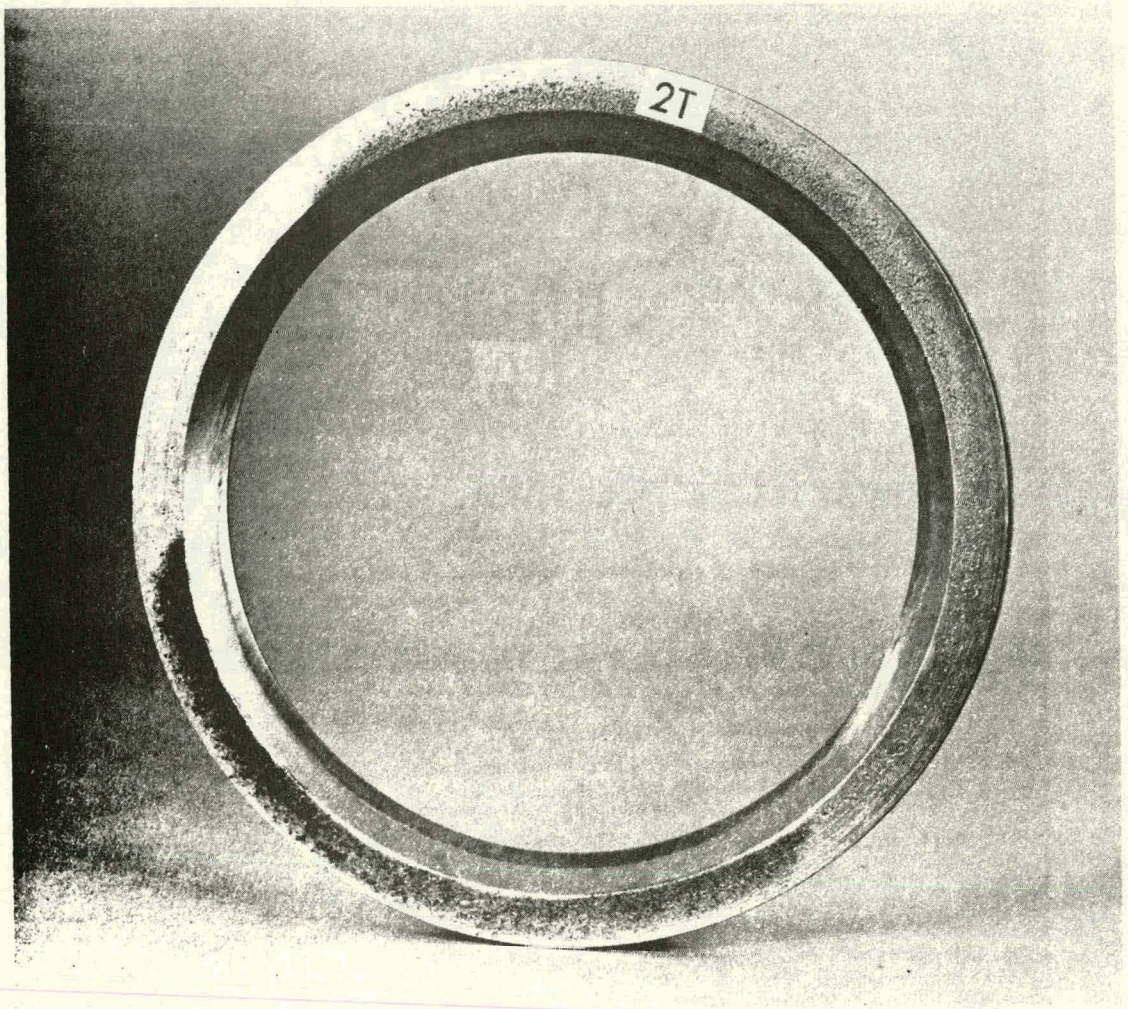


FIGURE 24. - Ball valve seat after 3,500 open-close cycles in ball-valve tester. Seat coating is Stellite 6B.

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