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CHROMIUM ION PLATING STUDIES FOR ENHANCEMENT OF BEARING LIFETIME

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Abstract

Last summer six 440-C hardened (∿ R.C. 60) stainless steel roller bearing test rods were ion plated with various chromium films of thicknesses from .2μ to 7μ. During the past six months Dr. B. N. Bhat (Weekly Notes EH23, February 2, 1982) reported that the thinner (∿ .2μ) coating sample had 3X the fatigue life of the unplated (standard) specimens. Contrastingly the samples having thicker coatings (several microns) had short fatigue lives (about 3% of the unplated standard).

This year initially only one specimen has been chromium ion plated (∿ 10μ thick) as the VTA system has required almost continuous refurbishment. However the VTA system was gradually returned to as good as new condition and during the final week six more specimen rods were ion plated. Thus, the summer objective was met, but little time was available for film characterization or report writing during the final week.

Acknowledgements

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Introduction

Last year's report[1] provided introductory background material on Ion Plating.

Objective

This year's objective is to ion plate about six roller bearing rods with about 0.3μ of chromium.

Equipment

The ion plating apparatus VTA Model 7375 was custom built by Vacuum Technology Associates and consisted of three main components: (1) a Varian (NRC) vacuum system Model 3117; (2) an electron beam gun system, a Sloan Multihearth 270° gun powered by a Sloan Model Five/Ten power supply; (3) the high voltage power supply for bias voltage (10 KV, .5a), also made by VTA.

General Comments

Testing separate parts of the VTA system is difficult due to vacuum interlocks which shut off the electronics, e.g., without a vacuum the e-beam voltage will not activate. The VTA bias supply is extremely powerful 10KV at 500 ma giving a 5 KW power output which is equal to that of the electron beam itself. Thus insulation and metal may be easily vaporized or melted if the system arcs, producing plating shorts on electrical insulators.

Samples

Eight smooth (∿ 8μ") hardened (R.C. 60) 440-C stainless steel roller bearing test rods, 3-1/4" long by 3/8" diameter, supplied by Dr. B. N. Bhat were similar to those used last year[1] except for some carbon black (from hardening) on the end disks and in the centering cavities.

Experimental Methods

Patience seems to be a chief ingredient in successful electron beam ion plating, e.g., allowing the vacuum system to stabilize at steady state. The bias voltage Vc was slowly increased during discharge cleaning so as not to: (1) damage the feedthrough insulation, (2) evaporate Teflon hydrocarbons into the system, nor (3) cause pressure current runaway. A very low rate of increase of e-beam power minimized the outgassing partial pressure.

Samples 10, 11, 12, 13, 14 and 15 were bead blasted on the ends with a large orifice (∿ 1/8") while the holes were blasted with a pen type small orifice (∿ 1/2mm) jet. The excess grit was removed by air blown jets and by an acetone rinse. Surface oxygen was removed by a 2 to 2.7 KV d.c. glow discharge at ∿ 8 ma for about one hour. Since the substrate is hot water cooled, overheating and arcing to the ground shield occurred at 3 KV after about 30 minutes.

The specimen rod axis was mounted coaxially with the jar axis to produce a symmetric uniform coating. For further uniformity NASA personnel had replaced during the past six months the top center stationary high voltage feedthrough with an NRC rotary feedthrough so the sample could rotate about its own axis. This should provide less destructive vibrations during subsequent bearing testing of samples 9, 12, and 13, but it was unused on #'s 8, 10, 12, and 14. The rotator was switched on only a few seconds at a time because of an increase in arcing with continuous rotation.

Results

The Cr plating thickness in sample #3 varies from +10% to -10% (11μ to 9μ) from the front to the back of the rod although the system had circular symmetry about the rod axis. The 150 mg mass gain predicts an 8.2 average film thickness using the bulk density of Cr of 7.19 gm/cm3.

Note that the three thinnest films had the least visibility as expected. Also note that the darkest sample had the highest plating pressure (35μ) in keeping with last year's trend. Optical rechecks of the above estimated film thicknesses should be made by others before any destructive testing.

Refurbishment of VTA 7375 Ion Plating System

Initially the VTA Model 7375 system ion plating system was in only fair condition with a rather high ultimate jar pressure in the 10^{-6} torr range. During the first two weeks a lightning damaged fore pump motor was replaced, a magnetic stress free, quick mounting sample holder was machined, shorts and misadjustments in the e-beam gun were corrected and 440C roller specimen #8 was successfully ion plated with a 10μ chromium film.

Specimen #9 was mounted in the jar but not coated because the ultimate bell jar pressure was too high ($\sim 5 \times 10^{-5}$ torr). Based on the time rate of increase of pressure in the closed system jar, the apparent air leak rate was judged to be a large 5% of the Ar leak rate so that considerable oxygen contamination could be expected. During the third week no leak could be detected with acetone, thermal protection on the diffusion pump failed, thus requiring the system disassembly and methodical decontamination.

During the fourth week the jar pressure level was still poor so a helium leak detector (Veeco MS-9) was acquired on loan from UAH. A large leak was pinpointed in the foreline valve which was eventually corrected by tightening the valve's bellows slot nut.

The blanked-off, i.e., high vacuum valve shut, diffusion pump pressure was then checked at 3×10^{-8} torr (without the cold trap) - a good indication that all was now well at least below the bell jar high vacuum valve. This NRC valve should be watched as the manual shows an O-ring seal but the present seal apparently is formed by a soft elastic flat washer.

Grounded insulator shields were made and installed over the high voltage feedthrough. Filament shields were enlarged and longer e-beam current #10 leads were installed to zig-zag around the above new shields.

During the fifth week the NRC foreline valve leak reappeared so an "extension spreader wrench tool" was fashioned from 5/8" copper pipe which helped to correct the problem. Hand polishing of the top Al plate was begun around the seal areas. Etch marks near the jar seals were found in the stainless steel base plate on the Al top plate which could have contributed to the high pressure. Thus a decision was made to send the top Al plate, the Varian ring and the bottom plate to Building 4705 for resurfacing by lapping. The glass cylinder which had a chipped sealing surface, but not all the way through, was also sent for lapping.

During the sixth week helium leak testing of the e-beam water cooling section was begun; two leaks of greater than 10^{-8} std. cc/sec were found. About eight welds, rewelds and rechecks with the helium detector were required to produce the leak proof welds which are now undetectable on the Veeco MS-9 Leak Detector of sensitivity 10^{-8} std. cc/sec.

During the eighth week helium leak checking indicated a torque of about 50 ft.lbs. is required to stop the leak in the metal to metal Swagelock flange. The carousel hearth showed a slight He leak during rotation but the leak stopped when the rotation stopped. The 18.75" Al top plate was received, the lap ($\sim$800 grit) looked basically good but several heavy scratch marks had to be hand polished in the O-ring contact area. A set screw induced bulge in the O-ring groove of the center rotary feedthrough was found and resurfaced. This tap hole had been recently added as a terminal for the high bias voltage wire. The center (3/8" shaft) rotary NRC feedthrough was helium tested and found leak free ($<10^{-8}$ std. cc/sec).

The base plate acid pits were lapped but presumably some foreign grit has introduced severe ($\sim$.2 mil. deep) scratches into the base plate and into the Varian ring.

An 18" x 3/4" Al "proof" disk (too big for the Bldg. 4711 lathes) has been machined at UAH to blank off either the top of the Varian ring or the top of the glass jar to isolate troublesome leaky parts of the VTA system without a He leak detector.

Several 58 X Leitz photomicrographs of specimen #8 show that the Cr film peeled away with a knife blade rather easily from the interface with the 440C stainless steel.

During the ninth week the lapping problems were overcome by Mr. Richard Long who ground out the scratches in both surfaces of the Varian ring and both surfaces of the base plate to an estimated 10 microinch finish.

The e-beam gun was left out (the two waterline Con Flat Flanges being blanked off) during initial leak testing of the ring, the new replacement (recleaned in building 4706) glass cylinder jar and the lapped top plate. The suspected combination high voltage (modified for rotation) feedthrough proved leak free. However a makeshift leaky weld of a stainless ($\sim$1/4") tube to a Swagelock fitting at the argon leak inlet was found and rewelded (but not leak tested). An NRC 1/8" pipe thread fitting which did not require a weld was used as a replacement. The stainless steel flexible Ar leak line was sprayed with helium with no response on the leak detector which in the above system test had less sensitivity since it was connected by a 6' x .5" I.D. hose to the small fore line ($\sim$1/8" I.D.) tap-in valve of the NRC-3117 Vacuum System.

During the tenth week a second ion plating attempt on sample #9 was made. However, the e-beam voltage would not initially come on due to high voltage arcs in the -10 KV feedthrough. Disassembly and subsequent bead blasting of the inside of the feedthrough cleared the short. However the e-beam high voltage still tripped each time it was activated. The 2.5 minute delay timer for the high voltage take was found to be closing but not holding. Mr. C. A. Torstenson found a close substitute timer and wired it into the Sloan Five/Ten power supply.

During the tenth week Mr. Torstenson procured a hot water heater thermostat and wired it into the diffusion pump current line for protection against the previous overheating. This provided an overnight pumping capability which (with LN cold trap) yielded an estimated jar pressure of 6×10^{-7} torr before the first plating with the refurbished system.

During the last week samples 9, 10, 11, 12, 13, and 14 were each ion plated with roughly less than 1μ of Cr. The film thicknesses are not known since most effort was toward coating all samples.

Conclusions

The VTA Ion Plating System operated rather well (once refurbished) plating 0.3μ films compared to a few years ago when 40μ films were attempted. This is not surprising since most of the VTA downtime has been related to film and powder buildup.

REFERENCES

1. Davis, J. H., "Al to Cr Ion Plating Studies for Surface Enhancement," NASA Contract Report, Jan. 1982, NASA CR-161855, p. XXVIII

2. Davis, J. H., "Ion Plating for High Temperature Applications," NASA Contractor Report CR-161511, p. V, Oct. 1980

TABLE I

Sample #	Date Plated	ΔM (cp) Sample	ΔM (μm) Source	Color Film	Film Thickness Est T (μ) From ΔM	Used Step Substr Rotator	T (μ) Dec Tac	Electrode Gap (in.)	CLEANING T (hrs)	CLEANING Vc (KV)	CLEANING Ic (ma)	CLEANING T (°C)	PLATING P (μ)	PLATING Vc (KV)	PLATING Ic (ma)	PLATING Ie (ma)	PLATING T (min)	PLATING P (μ)	Comments
8		/50	6	Grey	8	No	10	5.5	1.1	2.2	6	200	23	2	5	400	2	25	2-discharge cleanings
9	8-12-82	-10	1 ± .5	Blackish	~1	Yes		6.5	1	2.4	5	~300	25	2.4	4	60	5	5	cut depth mark around center
10	8-13-82	+1	2.2	Bluish	3	No		6.5	2	2.4	6	250	25	2.4	6	80	5	31	
11	8-13-82	-4	.06	Invisible	.08	No		6.5	1.1	2.4	9		25	2.4		40	5	30	Burned out Ic meter
12	8-16-82	-10	1.6	Bluish	2	Yes		6.5	1	2.7		~250	22	2.2		90	5	30	
13	8-11-82	-15	.67	Invisible	.9	Yes		6.5	1	2.7		~300	20	2.5		80	5	25	Some hair
14	8-18-82	-7	.32	Invisible	.4	No		6.5	1	3(2)		200	20	2		58	5	26	Some arc
15	Standard			None															