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ADHESIVE WEAR OF ROLLERS IN VACUUM

TRACK OR CATEGORY: WEAR
CONTROL ID: 1258388

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ABSTRACT

This work was done to support NASA's James Webb Space Telescope that is equipped with a Near Infrared Camera and Spectrograph and Micro Shutter Assembly (MSA). A MSA mechanism's qualification test in cryogenic vacuum at 30°K for 96K cycles resulted in roller wear and formation of some debris. Lab tests in vacuum were conducted at NASA Glenn Research Center (GRC) to understand the wear of Ti6Al4V mated with 440F steel rollers. Misalignment angle was found to have the most significant effect on debris formation. At misalignment angle of 1.4°, significant amount of wear debris were formed within 50,000 cycles. Very few wear particles were found for a zero misalignment angle, and the total wear was small even after 367,000 cycles. The mode of wear in all the tests was attributed to adhesion, which was clearly evident from video records as well as the plate-like amalgamated debris material from both rollers. The adhesive wear rate was found to be approximately proportional to the misalignment angle. The wear is a two-way phenomenon, and the mixing of both roller materials in wear debris was confirmed by x-ray fluorescence (XRF) and EDX spectra. While there was a net loss of mass from the steel rollers, XRF and energy dispersive x-ray (EDX) spectra showed peaks of Ti on steel rollers, and peaks of Fe on Ti rollers. These results are useful for designers in terms of maintaining appropriate tolerances to avoid misalignment of rolling elements and the resulting severe wear.

INTRODUCTION

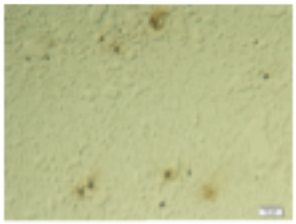
The James Webb Space Telescope (JWST) is an orbiting lab capable of observing infrared light from faint and very distant objects. A mechanism on the JWST will manipulate a micro-shutter assembly (MSA). The mechanism uses rollers to allow translation of a certain subassembly. A qualification test of the mechanism in cryogenic vacuum environment at 30°K was completed for 2x cycles (96,000) of the design life. The test unit was then inspected. Loose debris was found near the roller wear tracks thereby prompting this assessment. The rollers and surfaces of the mating anodized base and cover plates showed varying degrees of wear along contact paths.

The NASA Engineering Safety Center (NESC) set out to better understand the wear phenomena utilizing a vacuum roller rig at NASA GRC. This article documents the first four of a series of tests with special focus on the effect of misalignment angle.

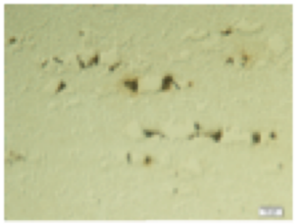
EXPERIMENTAL TECHNIQUES

Materials: The test roller pairs tested were a 440F steel roller vs. a Ti6Al4V roller matching the MSA mechanisms' configuration. However, the first test made use of a 440C roller that was available while making the 440F rollers. The materials chemistry and the corresponding microstructure photos together with the hardness (HRA) values are given in Figure 1.

Matl	440C	440F	Ti6Al4V
C	1.03	1.00	0.02
Co	0.02		
Cr	13.7	17.7	
Cu	0.20		
Fe	Bal	Bal	0.11
Mn	0.52	1.03	0.006
Mo	3.69	0.5	0.015
N	0.034		0.0062
Ni	0.25	0.1	0.002
O	0.013		0.172
Ca	0.004		
Mg	0.001		
Na	0.006		
Si	0.25	~0.5	0.05
S	0.01		<0.001
Ti	0		Bal
V	0.02		4.15
W	0.01		
Se		0.2	
Al			6.31



440C Micro HRA=58.0



440F Micro HRA=62.2

Ti6Al4V Micro HRA=68.1

Figure 1. Composition and Micros of Materials

Equipment: A Vacuum Roller Rig (VRR) shown in Figure 2 is used in this investigation. Its hardware consists of a vacuum system capable of producing <$3x10^{-7}$ Torr, a driving motor, a brake, and a turntable to provide roller misalignment angles ranging from -1.4° to +1.4°. It has the capacity of measuring the roller loads in all three orthogonal directions and the roller torque. During the test the surface conditions of the rollers are continuously recorded using a digital video record, and still photos were recorded using a high-resolution camera at intervals of 15 to 30 minutes depending on the need.

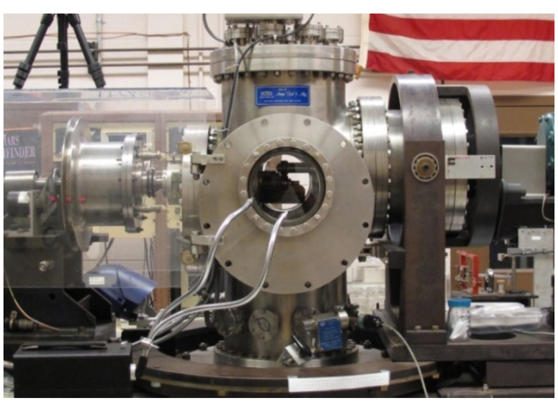


Figure 2. Photo of the GRC Vacuum Roller Rig

Test Procedure: Before the test each roller is subjected to careful cleaning and weighed to resolution of 0.1 milligram. Then the rollers are weighed again after the test to measure the change. Before each test the rollers are subjected to surface roughness measurements that consist of scanning the roller at four locations angularly displaced by 90° and the trace direction being parallel to the axis of the roller. The test is run with the top roller made of steel having a diameter of 35.6 mm, width 12.7 mm, and a turned crown of 200 mm radius. The bottom roller is made of Ti-6Al-4V having a diameter of 35.6 mm, width 12.7 mm, and is turned straight cylindrical with no crown. The tests are run at an approximate maximum contact pressure of 770 MPa, shaft speed of ~15 rpm and misalignment angles ranging from -1.4° to 0.0°, depending on the test. In this paper results of the first four tests are described in the table on the next page. Tests were done at room temperature and at vacuum <$3\ x10^{-7}$ Torr.

RESULTS

Table 1 shows the results of each experiment and the corresponding roller materials, roller surface geometry, surface treatment, initial surface roughness parameters (Ra Rq Rz), roller misalignment angle, the test duration in terms of shaft revolutions, the roller mass changes and measured debris mass. From this table, it is clear that the steel roller lost mass while titanium roller gained mass when the misalignment angle was non-zero. Surface examination of the rollers and debris using XRF and EDS clearly indicate material transfer between the rollers and debris being an amalgam of both roller materials. Figure 3 shows roller pairs after the conclusion of tests 1 through 4. The state of rollers after test 3 and the resulting debris are shown in Figure 4. SEM photos of test 3 debris is shown in Figure 5 together with EDS spectra indicating presence of both Fe and Ti peaks at location "A", while presence of only Ti peak at location "B" on the very same debris particle indicating mixing of roller materials in the debris collected.

Table 1: Configuration of the Experiments and Results.

	Roller Position	Roller Material	Roller Geometry	Final Machining	Surface Treatment	Initial Surface Parameters Ra (μm)	Rq (μm)	Rz (μm)	Shaft Angle (deg)	Test Duration (revs)	Change in Mass (mg)	Roller Pair Change of Mass (mg)	Loose Debris Mass (mg)
Test1	Top	440C	Crowned	Turned	None	0.627	0.750	3.176	-1.4	26,080	-5.4	0.5	*
	Bottom	Ti6Al4V	Flat	Turned	None	0.537	0.628	2.768			4.9		
Test2	Top	440F	Crowned	Turned	None	0.572	0.638	2.208	-1.4	60,228	-125.8	4.9	22.8
	Bottom	Ti6Al4V	Flat	Ground	None	0.212	0.313	2.778			98.1		
Test3	To	440F	Crowned	Turned	None	0.581	0.651	2.312	-1.4	77,326	-207.2	6.5	65.7
	Bottom	Ti6Al4V	Flat	Turned	Anodized	0.405	0.507	2.870			135.0		
Test4	Top	440F	Crowned	Turned	None	0.327	0.420	1.863	0	347,925	-5.2	5.8	*
	Bottom	Ti6Al4V	Flat	Turned	Anodized	0.484	0.606	3.349			-0.6		

* Very small amount of debris not easily visible, mass could not be measured

Test#1 26,111 Test#2 59,117 Test#3 50,939 Test#4 347,396

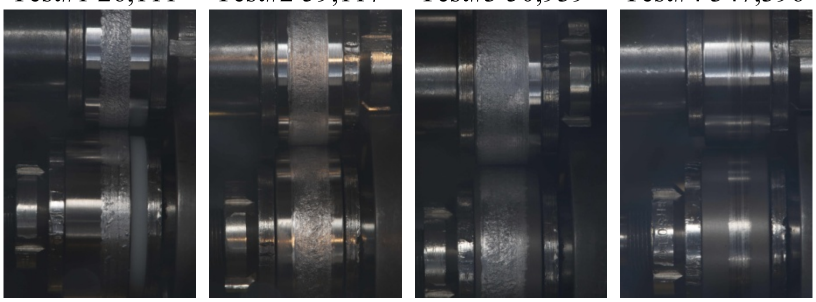


Figure 3. Roller pairs after completion of tests 1 to 4.

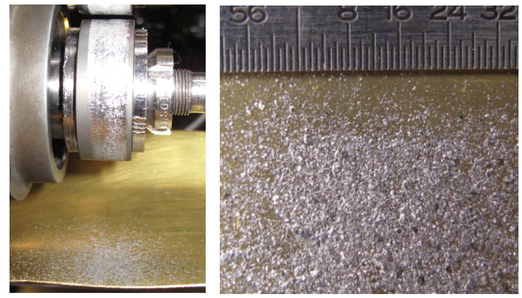


Figure 4. Wear Debris from Test#3.

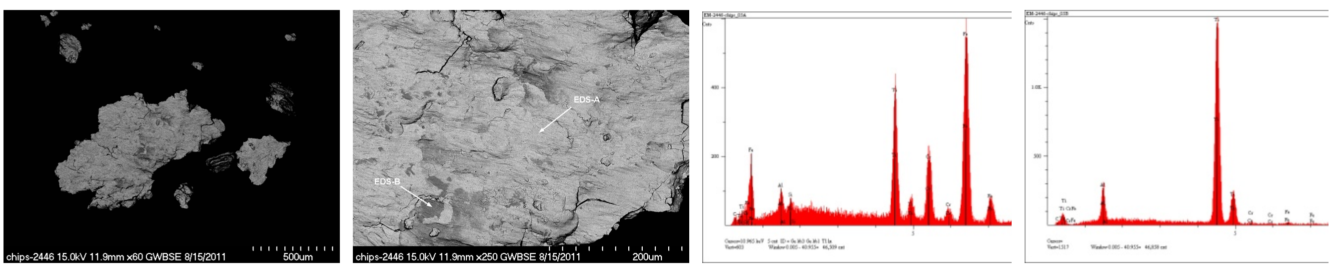


Figure 5. SEM photos of test 3 chip showing presence of Ti, and Fe at two locations EDS-A and EDS-B.

CONCLUSIONS

1. The mode of wear in these tests was adhesion between the rolling surfaces as was evident from the slow speed video, the plate-like amalgamated debris from both rollers, and analysis of the debris.
2. For 440F and Ti-6Al-4V pair of rollers with misalignment angle of -1.4°, large amounts of debris were found within 50,000 cycles, for both anodized and untreated surfaces.
3. With a zero misalignment angle, there was minimal debris even beyond 367,000 cycles. A swipe of the debris collection pan with a clean glove showed presence of debris later examined under SEM.
4. Examination of rollers and debris using XRF and EDS analysis showed conclusively that material transfer was a two-direction phenomena; with iron peaks found on titanium and titanium peaks on steel rollers.
5. Although material transfer was a two-direction phenomena, for non-zero misalignment angle the consistent trend was a net mass gained by titanium alloy rollers and net mass loss from the steel rollers.
6. From this work it is clear that misalignment angle has significant effect on for the rate of adhesive wear, material transfer, and debris formation.

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KEYWORDS

Wear Mechanisms, Adhesive Wear, Wear Particles, Debris, Wear in Vacuum