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Preliminary Tuft Testing of Metallic Bristles Versus PS212, PS300, and HVOF300

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Abstract

Turbine engine brush seals are designed with sacrificial brushes and hard shaft coatings to minimize shaft wear and reduce the cost of engine overhauls. Replacing a worn seal is more cost and time effective than refinishing an engine shaft. However, this tribological design causes excessive brush wear and reduces long term seal efficiency.

An alternative approach is to coat the shaft with a solid lubricant and allow the bristles to wear into the shaft coating similar to traditional abradable labyrinth seals. This approach can result in reduced seal leakage by forcing the leakage to flow through the seal bristle pack or through a more tortuous shaft wear track. Key to this approach is limiting the shaft wear to an acceptable level were surface refinishing would not be required during every engine overhaul.

Included in this paper are brush seal tuft test results for four metallic bristles (nickel-chrome or cobalt-chrome based superalloys) tested against three solid lubricant coatings (NASA's PS212, PS300, and HVOF300). These test results are also compared to previous baseline tests conducted with plasma sprayed chrome carbide. Compared to the baseline results, no tribological benefit was achieved with the metallic bristle/solid lubricant tribopairs tested. To improve the performance of the solid lubricant coatings, issues regarding lubricant phase sizes (homogeneity), and composition need to be addressed.

Introduction

A typical brush seal is made with fine wires densely packed between two plates (Figure 1). To allow the bristles to deflect and follow shaft excursions the bristles are set at a forty–five degree angle from the shaft. This ability to respond to shaft eccentricities without losing sealing performance gives the brush seal an advantage over traditional labyrinth seals. Brush seals, even when worn line-to-line with the shaft, have lower leakage rates than typical labyrinth seals. However, the minimum seal leakage of a brush seal occurs before the designed interference fit between the seal and shaft wears away. Low bristle-to-rotor friction is also important to minimize heat generation in rotor components already operating close to their temperature-stress limit. Therefore, to maximize overall turbomachinery efficiency, brush seal interfacial wear and friction should be minimized (ref. 1).

Traditionally, brush seals are designed with a hard shaft coating and a sacrificial brush. This is done to reduce surface wear and the costly expense of surface refinishing during engine overhauls. The trade-off of using hard shaft coatings is excessive brush wear and reduced long term seal performance. Solid lubricants provide an opportunity to improve the long term seal performance by wearing in much like an abradable labyrinth seal. In other words, the seal would wear line-to-line below the shafts unworn outer diameter forcing leakage flow to pass through the wear track or directly through the brush bristle pack creating a labyrinth type flow restriction. Minimizing shaft wear to an acceptable level without refinishing at every overhaul interval is crucial to the success of using solid lubricants.

To investigate the possibility of using solid lubricants for brush seal applications, two NASA developed coatings were tested against four metallic bristle materials. Characterization of each tribopair included measuring the friction coefficient along with the brush and journal wear factors.

The results of these tests are also compared to previously tested metallic bristles versus (75–25 wt%) plasma sprayed chrome carbide (ref. 2). Included in this comparison is data for H25, a cobalt chrome superalloy, against plasma sprayed chrome carbide which represents the industry standard and the baseline for this study.

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Specimen Materials and Preparation

The three coatings tested were PS212, PS300, and HVOF300. PS212 is a plasma sprayed chrome carbide based solid lubricant. Two versions of the chrome oxide based 300 series coating were tested (plasma sprayed and high velocity oxygen flame sprayed). Both the 200 and 300 series coatings have added silver for low temperature lubrication and barium fluoride/calcium fluoride eutectic for high temperature lubrication (refs. 3, 4, and 5). Coating compositions are presented in Table 1.

Before testing each journal is diamond ground to 38.1 mm (1.5 in.) diameter with a surface roughness less than 0.4 μm (16 μin.). Typical coating thickness is 0.25 mm (0.010 in.). Figure 2 shows the final journal configuration.

The four wire materials tested were H25, I718, H230, and H242 (see Table 2 for compositions). These materials were all selected because of their high temperature capabilities and their availability in wire form.

Each tuft is made with 920 bristles welded into a superalloy collar. The wire diameter for each material was 0.071 mm (0.0028 in). After welding, the tufts are diamond ground to a 45° angle simulating an actual brush seal interface (Figure 3). For additional information regarding test specimens or facility used see reference 6.

Test Apparatus and Procedures

These tests were completed on the Brush Seal Tuft Test Rig at the NASA Lewis Research Center (Figure 4). One advantage of this facility is it allows tufts to be tested with a constant contact pressure. This constant load allows accurate tribological measurements of both the tuft and journal without the confounding effects of unsteady loads and pressure differentials. The maximum test spindle speed and test temperature are 17,000 RPM and 800 °C (1292 °F) respectively. When mounting the test journals, the total indicated runout was limited to less than 0.009 mm (0.00035 in.). This facility has been shown to characterize candidate brush seal materials accurately at about 1/10th the cost of full scale seal testing (ref. 2).

Two tufts were made for each of the material combinations tested. Each tuft was tested in two, twenty-five hour segments. The standardized test temperature, surface speed, and contact pressure were 650 °C (1200 °F), 24 m/s (78.5 ft/s), and 75.8 kPa (11 psi) respectively. During each test the friction force, temperature, and speed were measured with a ±250 gram linear

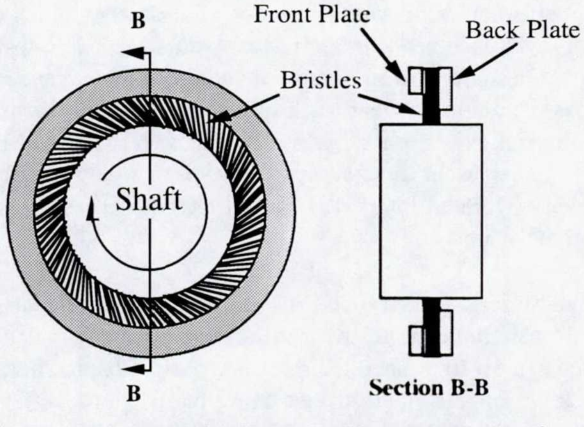

Figure 1.—Schematic of a typical brush seal showing front and cross section views.

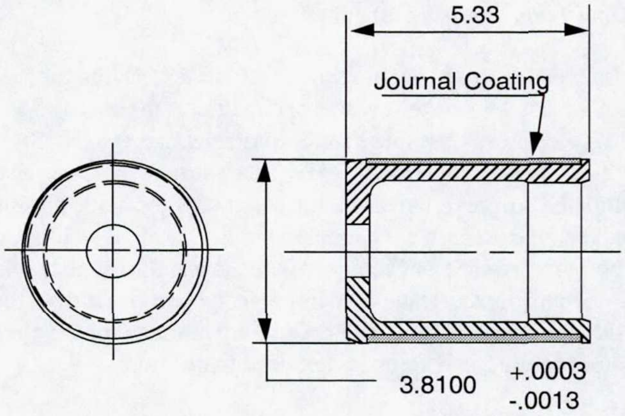

Figure 2.—Journal specimen configuration showing dimensions and geometry (dimensions in cm).

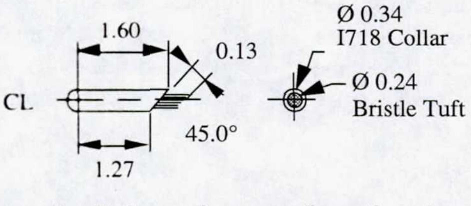

Figure 3.—Tuft specimen configuration showing dimensions and geometry (dimensions in cm).

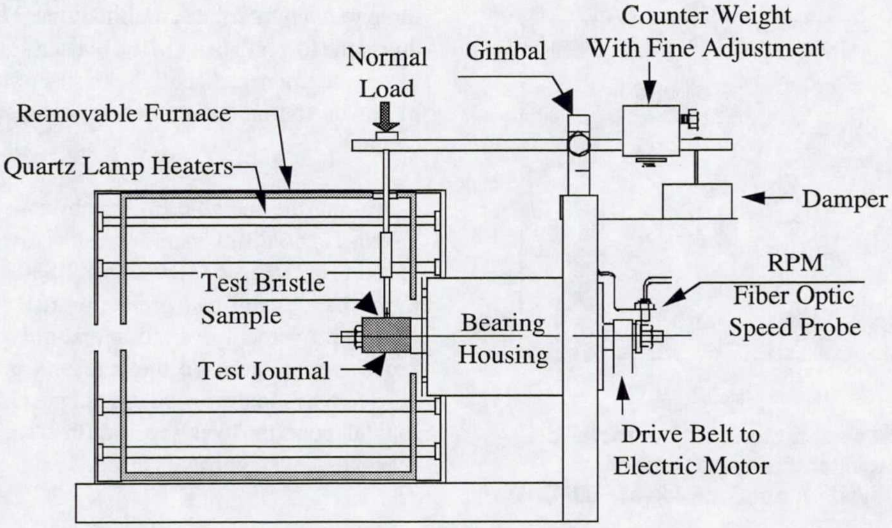

Figure 4.—Cross section side view of brush seal tuft test rig.

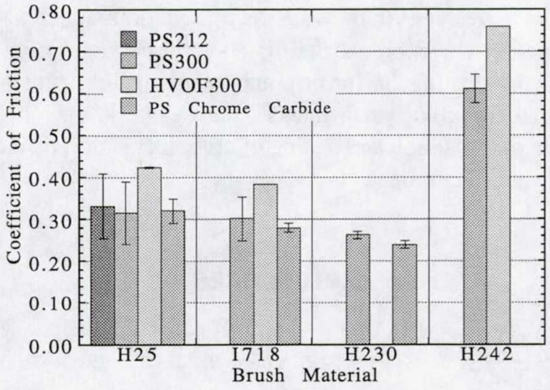

Figure 5.—Average friction coefficients for four metallic bristles tested against three solid lubricants and plasma sprayed chrome carbide at 650 °C (1200 °F).

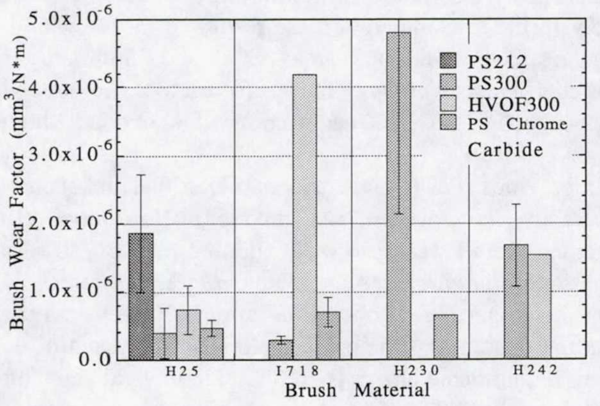

Figure 6.—Brush wear factors for four metallic bristles tested against three solid lubricants and plasma sprayed chrome carbide at 650 °C (1200 °F).

voltage displacement transformer (LVDT load cell), a Type K thermocouple and an optical speed pick-up respectively. The brush wear was calculated from the difference in bristle lengths from inscribed witness marks. To facilitate these measurements, low magnification photomicrographs (25x) were taken before and after each test segment. Post test analysis of the journals is completed by measuring the circumferential wear track cross sectional area with a stylus type surface profilometer at 90° intervals around the journal. Finally, wear factors for both the brush and journal are calculated based on the measured wear, test load, and sliding distance.

Results and Discussion

As seen in Figure 5 the friction coefficients ranged from 0.25 to 0.45 except for the tests conducted with the H242. In both tests completed with H242 the friction coefficient was above 0.60. Brush wear factors ranged from $2.9\text{x}10^{-7}$ $\text{mm}^3/\text{N}\cdot\text{m}$ (low wear) for I718 against PS300 to $4.8\text{x}10^{-6}$ $\text{mm}^3/\text{N}\cdot\text{m}$ (moderate wear) for H230 against PS300 (Table 3 and Figure 6). Journal wear factors ranged from $2.7\text{x}10^{-8}$ $\text{mm}^3/\text{N}\cdot\text{m}$ (low wear) for I718 against plasma sprayed chrome carbide to $6.6\text{x}10^{-6}$ $\text{mm}^3/\text{N}\cdot\text{m}$ (moderate wear) for H25 against PS212 (Table 3 and Figure 7).

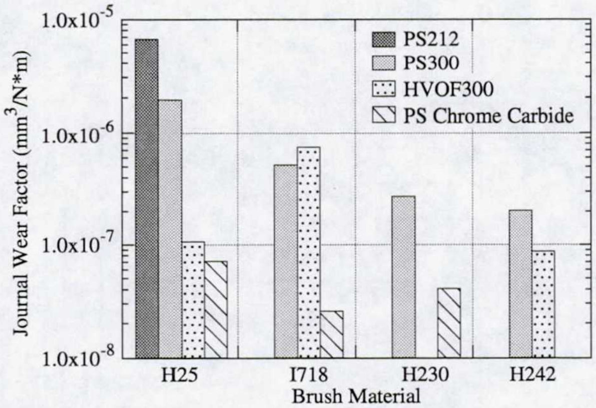

Figure 7.—Journal wear factors for four metallic bristles tested against three solid lubricants and plasma sprayed chrome carbide at 650 °C (1200 °F).

Average friction coefficients for H25, I718, and H230 against plasma sprayed chrome carbide are 0.32, 0.28, and 0.24 respectively (ref. 2). Comparing these results to those of the two plasma sprayed solid lubricants (PS212 and PS300), the friction coefficients were within 10% for each of the three wire materials. The HVOF300 had friction values over 30% higher.

In previous tests with the tribopair IX750, a nickel chrome superalloy, sliding against PS212 reported by Hawthorne (ref. 7), a higher overall wear rate was exhibited than IX750 sliding against chrome carbide. As pointed out by Hawthorne, PS212 has a heterogeneous surface with lubricant phase sizes larger than the diameter of the brush materials. The result of these oversized lubricant phases is preferential removal of the lubricants from the PS212. After the lubricating phases are removed from the surface, what remains is a very rough, low density nickel-chrome bonded chrome carbide that causes excessive brush and journal wear. This same phenomena was observed in the H25 versus PS212 test. Out of the four tests completed with H25, the test against PS212 had the highest journal and brush wear. After this was observed no additional tests were conducted with the PS212.

As previously reported, the H230 bristles began to flair after 50 hours of testing against the plasma sprayed chrome carbide (ref. 2). This same phenomena was observed with the H230 against the PS300. Due to the severity of the flaring the brush wear factor was estimated to be 2.8x10^{-7} mm^3/N·m. Based on the bristle flaring observed in these tests no additional H230 tests were completed.

Compared to HVOF300, the PS300 consistently had a lower friction coefficient and a lower brush wear factor for two of the three wire/counterface combinations. This result was expected due to the lower density of the plasma sprayed version. Furthermore, the improved coating density of the HVOF300 resulted in lower journal wear factors against the H242 and H25 (Figure 7).

Among the metallic brush/lubricant coating combinations tested, I718/PS300 was the best. However, compared to the baseline H25/PSCr$_2$C$_3$, the I718/PS300 wear couple exhibited more than seven times greater journal wear without a significant improvement in friction and only a modest reduction in brush wear. Based on these results the metallic brush/solid lubricant tribopairs tested did not provide any additional tribological benefits over the industry standard of H25 against plasma sprayed chrome carbide.

Concluding Remarks

The results, especially for I718/PS300, show that tuft wear can be reduced by incorporating solid lubricants in the shaft coating. However, shaft wear increased dramatically. This observation corroborates that of Hawthorne suggesting that improving coating uniformity and reducing lubricant phase size may improve performance. Future work may include coating optimization and testing of other tuft materials including advanced ceramics.

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Table 1: Coating Compositions by Weight and Percent Volume of PS212, PS300, HVOF300

Coating	Constituent, wt.% (vol. %)			
Designation	Ni-Co-Cr_2C_3*	NiCr-Cr_2O_3**	Ag	BaF_2/CaF_2
PS212	70 (67)	—	15 (9)	15 (24)
PS300 and HVOF300	—	80 (80)	10 (6)	10 (14)

* By wt.% contains 54 Cr_2C_3, 28 Ni, 12 Co, 2 Mo, 2 Al, 1 B, and 1 Si

**By wt.% contains 80 Cr_2O_3, 16 Ni, and 4 Cr

refs. 4, 5, and 6

Table 2: Chemical Composition of Wire Samples (wt.%)

	Co	Ni	Cr	Fe	W	Mo	OTHERS (< 6 wt.%)
H25	51	10	20	3	15	—	Mn, Si, C
I718	—	52.5	19	18.5	—	3	Nb, Ti, Al, C, Cu
H230	5	52.7	22	3	14	2	Si, Mn, C, Al, B, La
H242	2.5	60	8	2	—	25	Mn, Cu, Al, Si, C, B

Table 3: Wear Factor Interpretation

Wear Factor ($mm^3/N\cdot m$)	Interpretation
>10-4	High Wear
10-5 to 10-6	Moderate to Low Wear
<10-7	Low Wear

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