Effects of Thermally-Sprayed Molybdenum Coating Characteristics on Wear Resistance

PURDUE MATERIALS ENGINEERING

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The objective of this project was to evaluate the relationship between microstructure and wear properties for developing a new specification for molybdenum coatings on transmission shifter forks. Characteristics examined for their effects on wear performance include porosity, hardness, and composition. While increased hardness had significant effects on the abrasive and dry sliding wear resistance, under lubricated conditions, little to no effect of coating characteristics on wear resistance were observed.

This work is sponsored by John Deere Technical Center in Moline, IL.

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Project Background

A shifter fork is what allows gears to be changed in a tractor transmission. In order to improve their wear resistance, a thermally-sprayed molybdenum coating is applied to the areas were the shifter fork comes into contact with the synchronizer. The molybdenum coating provides wear resistance to the part to allow for a longer part life. In most transmissions, the shifter fork is passively lubricated and experiences sliding wear against a hardened steel synchronizer. Improving the wear resistance of the coating will help increase the life of the transmission and drive down repair costs.

Figure 1: Shifter fork (top left) with synchronizer and gear. Arrows indicate wear surfaces that receive the spray coating.

Experimental Procedure

The coatings tested were provided by one of John Deere's coating suppliers. The specifics of the various coating parameters and compositions are shown in Table 1. Alloy composition was used to vary hardness. Porosity level was varied through process parameters. Previous research suggests that increasing the primary gas pressure should decrease porosity and increasing thermal spray amperage should increase hardness values.

Table 1: Composition and target characteristics for coatings A-H

Composition	Alloy 1 (0.8% C)		Alloy 2 (1.4% C)	
Hardness (HV)	300	500	500	700
Low Porosity (≈ 2-3%)	A	C	E	G
High Porosity (≈ 7%)	B	D	F	H

Abrasive wear tests were run on molybdenum coated ductile iron substrates using ASTM G65 standards as well as pin-on-disc wear tests as shown Figure 2. Further characterization of the different coatings was performed using SEM imaging, ImageJ porosity analysis, and micro-hardness testing.

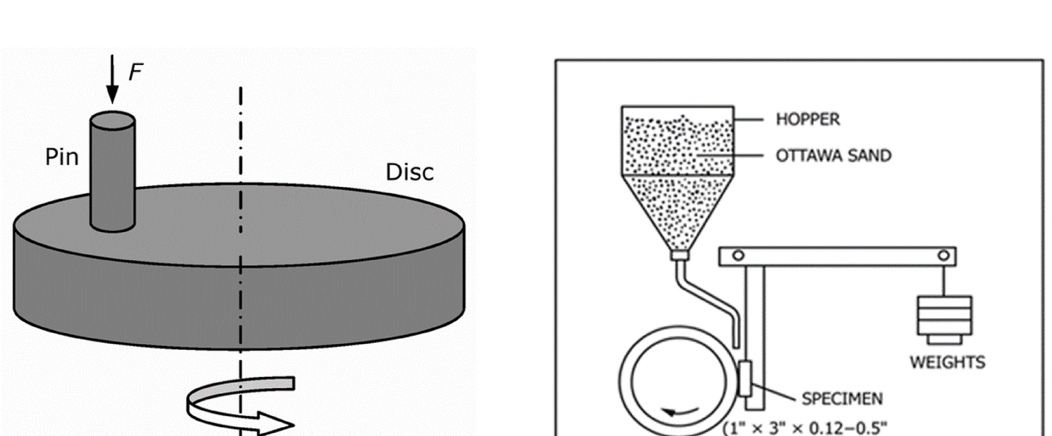

Figure 2: Pin-on-disc wear test shown on left and ASTM G65 shown on right

Hardness

The results from micro-hardness testing shown in Figure 3 suggests that Alloy 2 in general is significantly harder than Alloy 1. However, this rule does not hold true for coating H. Coating H appears to have about the same hardness values as coatings A-D all of which have Alloy 1. This may be connected to level of porosity compared to the coating with Alloy 2. Coating G was found to have the highest Vickers hardness with an average of 617 ± 96 HV. In general, the spraying parameters did not seem to have the expected effects on the hardness.

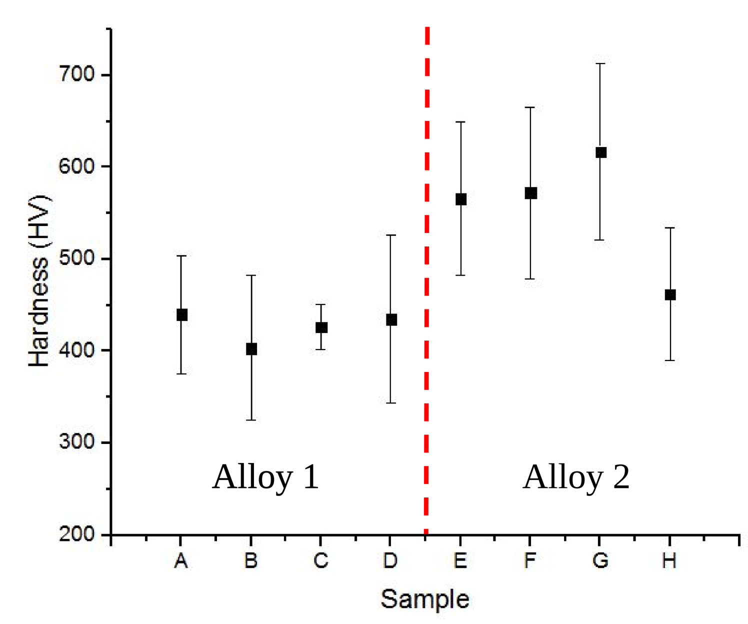

Figure 3: Plot showing the average hardness values and standard deviations from samples A-H.

Porosity Analysis

Figure 4 shows the amount of porosity for sample A-H. Sample B has the lowest porosity at 2.5% and sample E had the highest with a porosity of 11%. Some of these porosity values are much higher than expected. Possible explanations for this include pull-out during sample preparation or a difference in results from spraying parameters than shown by previous work.

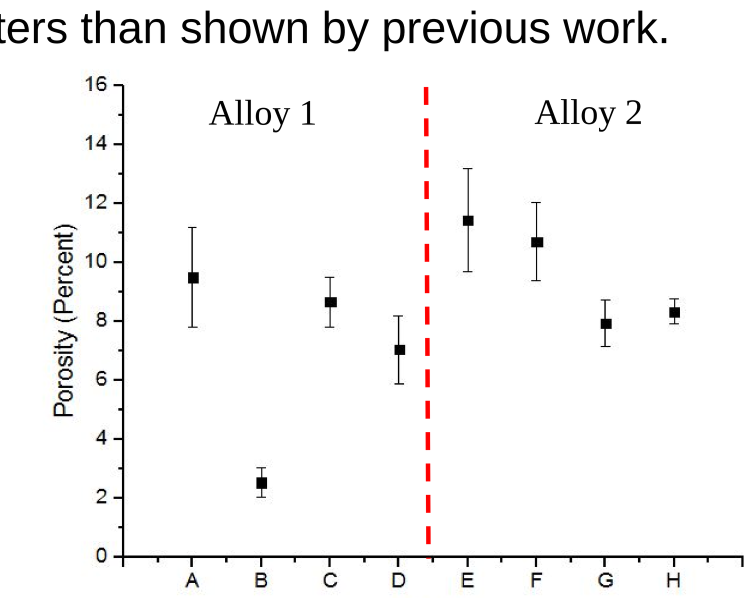

Figure 4: Plot showing percent porosity for samples A-H.

Microstructure

Figure 5 shows a backscattered image of coating type G, with the gap between splats clearly visible. Compositional analysis did not suggest heterogeneous carbon distribution, which may have indicated presence of molybdenum carbide phases.

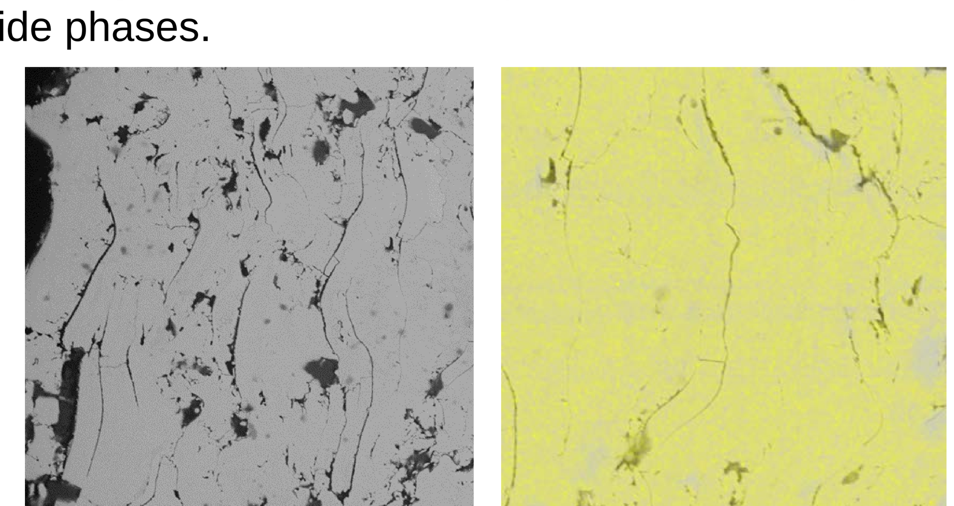

Figure 5: Back-scattered image (left) of coating G, showing gaps between lamellar splats. Elemental mapping (right) does not indicate MoC presence

Wear Testing

The results from ASTM G65 abrasive testing, presented in Figure 6, show that sample G performed the best with the least amount of mass loss. Samples E-H (0.8% C) have a significantly lower mass loss than samples A-D (1.4% C). Varying the thermal spray amperage to increase and decrease hardness had no effect on the abrasive wear performance. Statistically, with 95% confidence, sample pairs of A and C, B and D, and E and G, have no difference in wear performance. The primary gas pressure differences did have a significant impact on the wear loss. Every sample that was sprayed with a higher primary gas pressure had much less wear loss than samples sprayed with a lower gas pressure.

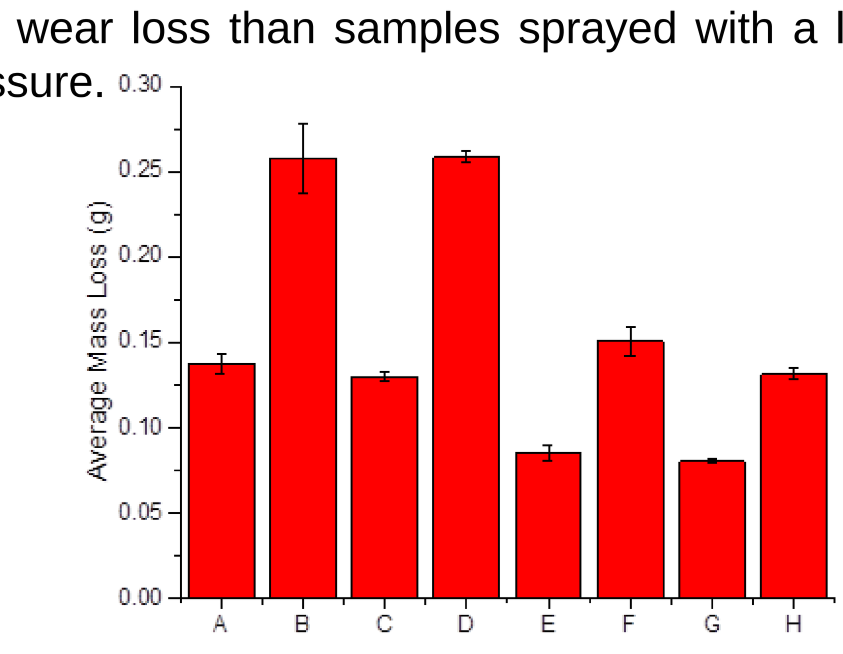

Figure 6: Mass losses for abrasive ASTM G65 wear tests.

Lubricated pin-on-disk wear tests revealed that the lubrication dominates the wear performance of the coatings. This is similar to results John Deere found in lubricated linear reciprocating tribometer tests. The wide range of coatings perform similarly. As is shown in Figure 7, the two lubricated tests show very little wear compared to the non-lubricated test. These minute mass losses for the lubricated cases are shown in Table 2.

Figure 7: Wear scars (from right to left) of pins run under the following conditions: lubricated 30 min. test for P1, lubricated 30 min. test for P6, and non-lubricated 20 min. test for P6.

Table 2: Mass loss data after a 30 minute lubricated pin-on-disk wear test.

Sample	Mass Loss (g)
P1	<.0001
P2	.0001
P6	.0001

Conclusions

Abrasive and dry sliding wear tests suggest that a 1.4% carbon-molybdenum alloy and increased primary gas pressure would increase wear resistance in thermally-sprayed coatings compared to a 0.8% carbon alloy. Lubricated sliding wear tests indicated that while the increased carbon content and gas pressure increased abrasive and dry sliding performance, the drastic change in the coefficient of friction overwhelmed the differences in hardness and porosity. Given our findings, there is not enough data to support that any changes in the current coating specification would significantly increase performance in sliding wear.