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SCUFFING PERFORMANCE OF LOW-VISCOSITY GEAR OIL CONTAINING ZrO_2 NANOCRYSTALS

4G TRIBOTESTING II

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INTRODUCTION

Improving vehicle fuel efficiency can significantly reduce fuel costs. One way to improve vehicle efficiency for new and legacy vehicles is to reduce frictional loses in the drivetrain through use of lower viscosity lubricants. However, use of lower viscosity lubricants comes with the risk of reducing durability of drivetrain components through increased wear, pitting and scuffing.

Scuffing is defined as a sudden catastrophic failure of a lubricated sliding contact accompanied by a sudden increase in friction, contact temperature, and noise or vibration. Occurrence of scuffing results in loss of surface integrity and functionality of the tribological components. Examples of scuffing include the formation of local welds or localized damage caused by solid-phase welding between sliding surfaces and surface roughening by plastic flow whether or not there is material loss or transfer [1,2].

In this work, we evaluated the scuffing performance of fully formulated gear oil's with and without the addition of ZrO_2 nanocrystals. The presented tests also illustrate a newly developed scuffing protocol utilizing a three ring-on-roller contact. It was documented that two fully formulated gear oils scuffed at approximately the same load, whereas the gear oil containing ZrO_2 nanocrystals formed a tribofilm that prevented scuffing by enabling the contact to enter into a wear mode.

EXPERIMENTAL PROCEDURE

The presented novel scuffing test protocol was developed on the PCS Instruments Micro-Pitting Rig (MPR). The MPR utilizes a splash lubricated three-ring-on-roller contact which can be operated at various levels of loading, sliding, and temperature. The roller is 12 mm in diameter and has a 1 mm-wide test track that comes into contact with three 54 mm-diameter rings. The rollers and rings were made of through-hardened AISI 52100 steel with a hardness of HRC 63 and 60, respectively and both had a Ra roughness of 200 nm. A rings and a roller are shown in the photograph of Figure 1 (a). The three-ring-on-roller contact configuration is shown in Figure 1 (b).

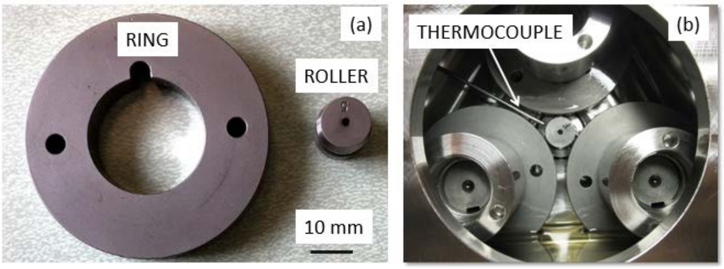

Figure 1. (a) Ring and roller test specimens and (b) three-ring-on-roller test setup

Two fully formulated, commercially available gear oils, a 75W90 and a 75W80 were used in this work. The test chamber of the MPR was filled with lubricant until the roller was submerged. This is relatively uncommon in MPR testing, and was done so that the specimen does not overheat and in turn severely degrade the oil. The results of both standard fully formulated lubricants were compared to a 75W80 that was formulated with 1 wt. % ZrO_2 nanocrystals.

Gear calculations were performed to determine relevant testing conditions. The calculations were based on ASTM D5182 (Evaluating the Scuffing Load Capacity of Oils) [3]. The gear calculations led to the determination of a slide-to-roll ratio, necessary as input to the MPR. The software defines slide-to-roll ratio for gears as specific sliding. A range of SRR values was investigated and the most suitable value that led to scuffing was -190%. The equation for SRR in the MPR is shown in Eq. (1). For the case of the three ring-on-roller contact, SRR is defined as negative when the speed of the roller is higher than that of the rings. Figure 2 shows specific sliding over (or SRR) a range of roll angles. In this plot, B is the lowest point of single tooth contact while D the highest point of single tooth contact. Between B and D there is only one pair in contact taking the load, while outside of B and D two pairs share the load.

$$SRR(\%) = \left(\frac{2 \cdot \left(U_{Ring} - U_{Roller} \right)}{U_{Ring} + U_{Roller}} \right) \cdot 100 \qquad (1)$$

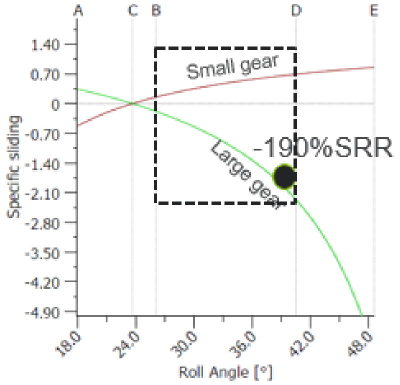

Figure 2. Specific sliding over a range of roll angles for the gear used in ASTM D5182

The scuffing protocol consisted of a load ramp that increased in a stepwise manner starting at 75 N. The computer software was programmed to run to the maximum load of the machine increasing the load by 25 N every five minutes with a period of 2 minutes between steps until scuffing occurred.

RESULTS AND DISCUSSION

Typically, scuffing is associated with a sudden increase in traction coefficient, contact temperature, and noise or vibration. The MPR records all of these parameters which can be used to detect scuffing. The scuffing load limit for 75W80 was approximately 550 N. A test performed using 75W90 let to similar results. As it can be seen from Figure 3 (a), the traction coefficient starts at approximately 0.12 and after a break-in period decreases until the point of scuffing which is demarked by a sudden increase in the traction coefficient value. The scuffing event is also associated with an increase in the vibration signal as shown in Figure 3 (b). Additionally, the temperature, which increases gradually over the course of the scuffing test showed a dramatic increase at the moment of scuffing as it is evident from the change in slope of the temperature measurement shown in Figure 3 (c). Finally, a linear variable differential transformer (LVDT) measuring linear vertical displacement (wear) captured the scuffing event as shown in Figure 3 (d). The stepwise increase in load is shown in all of the plots of Figure 3.

Figure 4 shows the measurements used to detect scuffing for the oil containing ZrO_2. As it can be seen from the traction coefficient in Figure 4 (a), a series of microscuffing events occur, however, unlike the result shown in Figure 3 (a), the contact quickly recovered after each of these events. Additionally, the vibration remained low during the entire test as shown in Figure 4 (b), while the temperaure measurement exhibited a gradual increase as shown in Figure 4 (c). Finally, from the wear measurement of Figure 4 (d), it can be seen that the increase in wear is gradual compared to the case of Figure 3 (d).

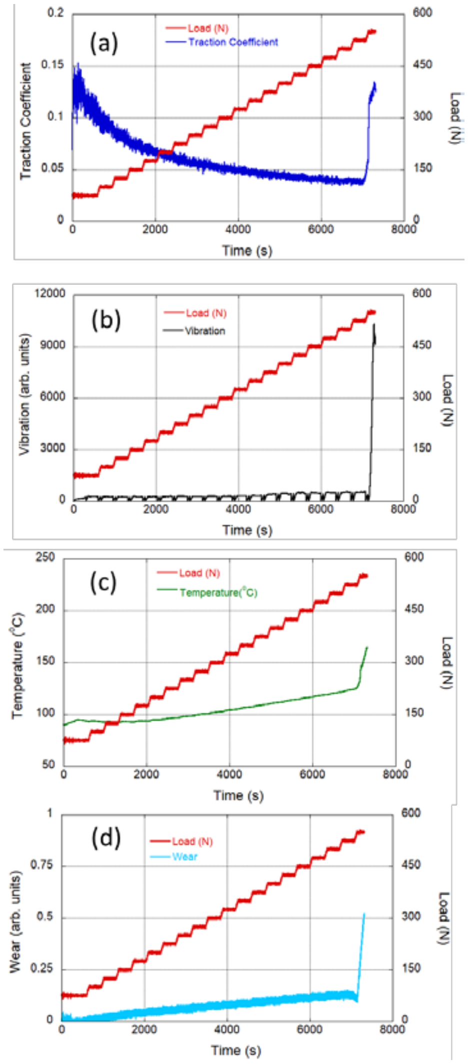

Figure 3. Measurements used to detect scuffing for 75W80: (a) Traction coefficient, (b) Vibration, (c) Temperature, and (d) Wear

Examination of the surface of the roller for the case of 75W80 and 75W80+1 wt. %ZrO_2 shown in Figure 5 (a) and (b), respectively, it is evident that the test track of the latter test has increased in width significantly due to the microscuffing events, which allowed wear to compete with scuffing and prevent it. A brown tribochemical film formed on the surface of the roller tested using 75W80 can be seen in Figure 5 (a) with scuffing marks present, whereas, a thicker blue/gray tribofilm containing Zr (confirmed with energy-dispersive X-ray spectroscopy analysis-not shown) formed on the surface of the roller tested using 75W80+1 wt.%ZrO_2 as shown in Figure 5 (b).

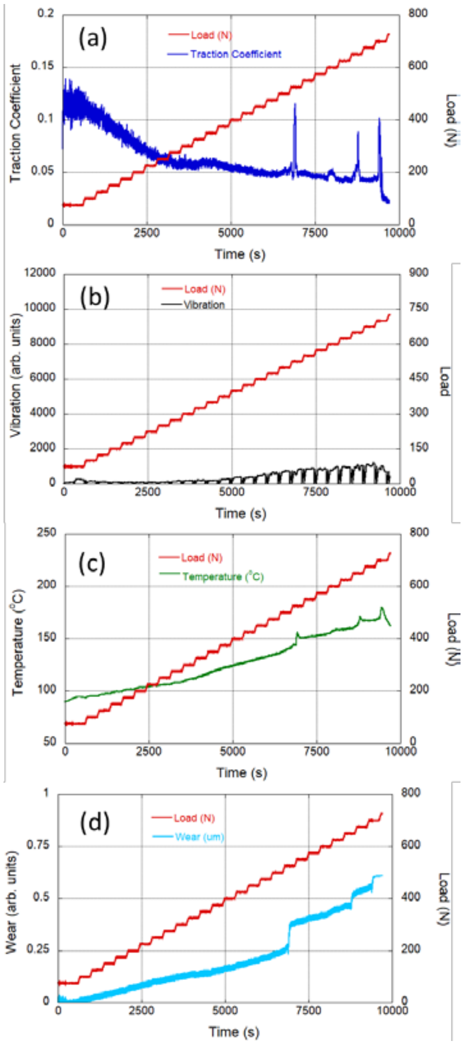

Figure 4. Measurements used to detect scuffing for 75W80+1 wt. % ZrO_2: (a) Traction coefficient, (b) Vibration, (c) Temperature, and (d) Wear

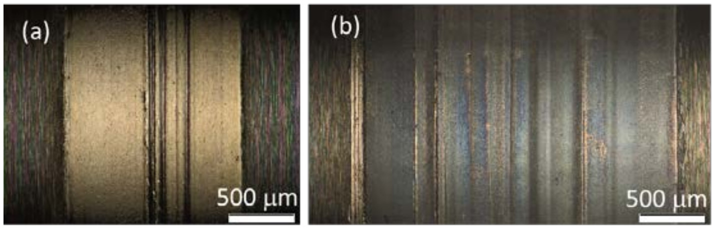

Figure 5. Micrographs of the roller test track for (a) 75W80 and (b) 75W80+1 wt.% ZrO_2

CONCLUSIONS

A scuffing test protocol was developed using a three-ring-on-roller contact, and was subsequently used to evaluate gear oils. Two fully formulated gear oils, a 75W90 and a 75W80, were tested and had a similar load carrying capacity. However, when 1 w.t. % ZrO_2 was added to the 75W80 formulation, it prevented scuffing by enabling the contact to enter into a wear mode. It is possible that such formulation can provide the necessary protection to allow for the use of lower viscosity gear oils due to the formation of thick and durable tribofilms on the surface of components.

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KEYWORDS

Low viscosity, Gear Oil, Scuffing, ZrO_2