Study on the wet clutch friction interfaces for humid lubrication condition

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Abstract: The friction influencing parameters also influence the wet clutch sliding surface conditions. The tribofilm formations as well as the chemical and mechanical degradation for frictional interfaces can be different for the choice of the lubricant conditions. The present investigations revealed the effects of water contamination in automatic transmission fluid (ATF) not only on the frictional performance, but also on the friction interfaces. The surface profiles of the tested separator plates, the EDS-SEM (Scanning Electron Microscopy-Energy-dispersive X-ray spectroscopy) analysis of the friction interfaces and optical microscopy for the used friction liners showed the difference in surface morphology, adsorption of additive elements, permeability and porosity for a humid clutch environment.

Keywords: Wet Clutch, Friction Characteristics, Paper Friction Material, Water Contaminated ATF.

1. INTRODUCTION

The stability in friction and anti-shudder property are the major concerns for a wet clutch performance. For the required torque generation only a higher friction coefficient cannot fulfill the anti-shudder performance, where the static friction coefficient should be low as well as the dynamic friction coefficient should increase with the sliding speed [2]. These friction characteristics are complex product of the interaction among friction lining, steel counter surface and ATF. Here the friction lining porosity, groove, additive adsorption, steel surface property etc. can significantly affect [3] the ultimate torque transmission and system durability. Under actual service conditions, friction materials can be subjected to a variety of environmental conditions. When a friction material is exposed to the service environment, moisture and other contaminants can have adverse effects on its performance by increasing the friction coefficient for water contaminated ATF, observed in Fatima, et al [1]. This can be due to the change in the friction interfaces or lubricant performance in presence of water. The degradation for the paper based friction surfaces and change in the surface properties upon exposure to humid lubrication were not evaluated in the previous works [1, 4]. In the present work, the same type of paper friction plate has been subjected to a water contaminated lubricant (ATF) in a full scale wet clutch test rig [1, 5] and the post-test friction pairs are characterized to compare and evaluate the change in friction influencing surface parameters like morphology, porosity, permeability, surface adsorption of the additives and degradation.

2. EXPERIMENTAL DETAILS

2.1. Friction test

The friction characteristics were evaluated prior to the post-test analysis in a full scale wet clutch test rig. Almost same test profile (including the test parameters like load, sliding speed, slip time, oil temperature) as mentioned in [1] and [5] were followed for the run in, steady state duty cycles (1000 cycles) and friction-speed measurement cycles (5 cycles after every 200 duty cycles) respectively with the same standard paper based friction plate and the standard steel reaction plate in a commercially available automatic transmission fluid (GM DEXRON®VI). The test was modified just by adding 5 ml distilled water each stage instead of 2 ml regular water and following each stage for 200 cycles. During test the ATF was contaminated with 20 ml of distilled water (conc. 25000 ppm).

2.2. Static ageing of the friction material

To evaluate the interaction among paper based friction liner, ATF and water: a friction plate was immersed in ATF and another friction plate in water contaminated ATF (5ml distilled water in 100 ml ATF, conc. 25000 ppm) for 210 hours at 90°C in an oven [6]. After this ageing process, the residual lubricants were washed away from the friction pairs by rinsing in heptane and dried.

2.3. Surface analysis

Before the surface analysis, the entire post-test cutch plates test were rinsed for few seconds in heptane [ASTM standard E1829 guide] and dried in air. The oil absorption time for the friction plates (new and post-test) were monitored by measuring the time of absorption for adding a drop of 1µL of Group VI base oil [7, 8].
An Environmental Scanning Electron Microscope (SEM) with EDS (JSM 6460, JEOL, Japan) was employed to analyse the static ageing friction liner and the steel plate surface. Since the friction plates are nonconductive in nature. ESEM-EDS are not good to analyse the friction tested friction liner. Morphology of the friction plates are observed in an inverted metallurgical optical microscope (ECLIPSE MA200 Nikon, Tokyo, Japan), where the threshold microscopic images were analysed by the NIS-Elements BR 4.00.008 software for surface porosity measurements. The topography of the new and used separator plate surfaces were investigated using the Wyko NT1100 3D optical surface profiler.

3. RESULTS AND DISCUSSIONS

The comparative assessments of the friction characteristics at steady state (constant load and speed) and the friction-velocity relations at speed ramp for two different conditions (with and without water in ATF) show differences in the outcomes. The increase in mean friction coefficient (COF) in Fig. 1 follows same trend as observed before in [1]. Additionally for speed ramp cycles the friction-speed slopes are becoming further negative with water addition in Fig. 2, which is the indication of a low anti-shudder friction characteristic. The friction and steel surfaces after tests were designated as FP1, RP1 (ATF with water); FP2, RP2 (only ATF), FP3 (static ageing in ATF with water) and FP4 (static ageing in ATF).

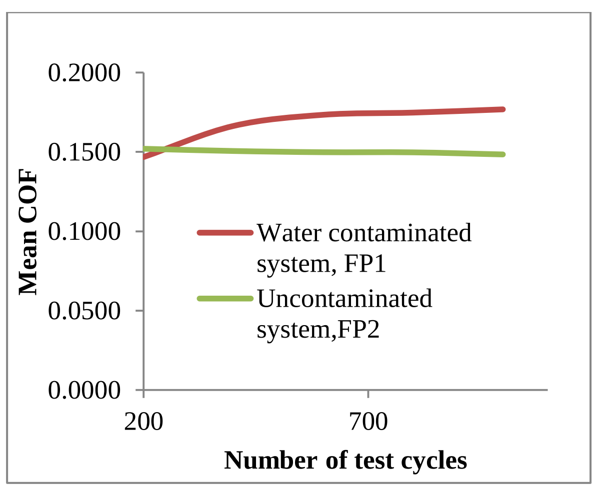

Figure 1. Mean COF vs. number of cycles at steady state during test

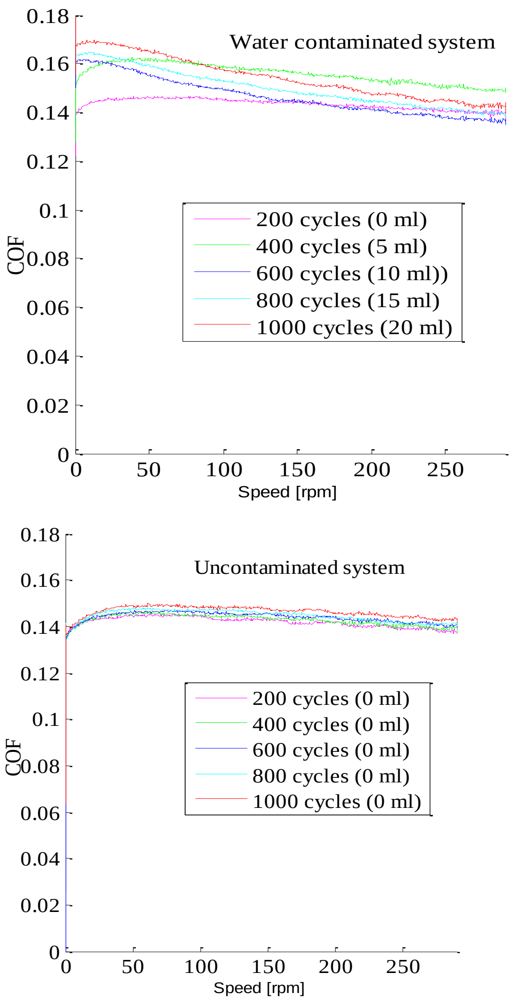

Figure 2. COF vs. rotational speed at speed ramp cycles for both conditions

Table 1 shows the measured surface porosity (%) from the RGB optical microscopic (x20) images along with the oil absorption time for each sample.

Table 1. % Porosity measured for Fig. 3 images and Oil absorption time for the respective surfaces.

Friction liner	**%Porosity**				**Mean Oil absorption time [s]**
	P1	P2	P3	Mean	
New	87.8	81.0	76.88	81.9	11±5
FP1	47.9	44.19	35.72	42.6	130±50
FP2	55.5	55.0	53.27	54.6	90±30
FP3	58.2	53	55.7	55.6	200±45
FP4	51.8	57.1	53.7	54.2	210±10

The above table and the optical microscopy images (x20) in Fig. 3 and of the tested friction plate shows high surface porosity(%) for a new friction plate which seems to be lowest in case of the water contaminated FP1. Uncontaminated FP2 has lower mean porosity and the oil absorption time is also higher for FP1 than FP2. Fig. 3 also shows the difference in the flattening of the surface and the oil absorbed spaces (porous) for FP1 and FP2. FP2 is less flattened compared to FP1 during test. The percentage of porosity for both the static ageing samples, FP3 and FP4 show almost same. However the oil absorption times for FP3 and FP4 are comparatively much higher than the tested FP1 and FP2 according to porosity percentage. It has been found by Zhao, et al. [8] that the oil absorption time can affect the ratio of thin film lubrication and boundary lubrication contributing the total friction. The increased flattening of the frictional surface or decreased porosity can also affect the fluid flow through the friction liner which is related to the additional friction component at high sliding speed [9].

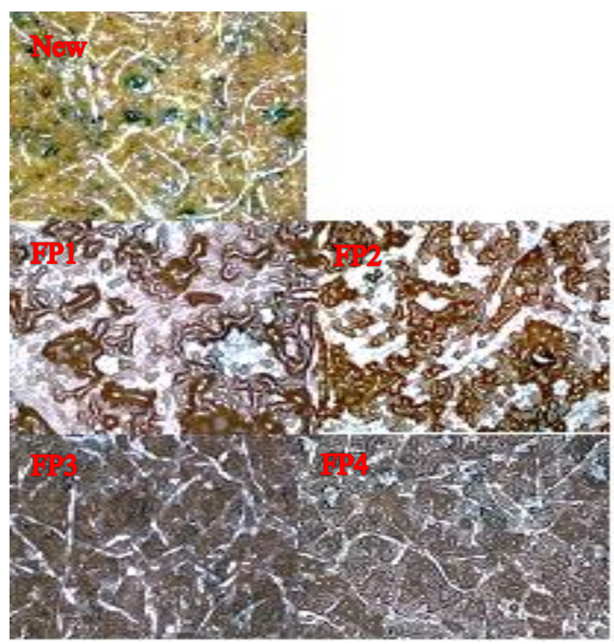

Figure 3. The RGB optical microscopic images (x20) of the friction surfaces

The SEM-EDS analysis in Table 2 for the selected area in Fig. 4 shows for FP4 there is present Mg, Ca and P, while Ca and Mg are almost absent and P is low in the water treated FP3. The atomic % of oxygen is high for FP3. 3D surface profiles in

Table 3 for the tested steel surface show large change in the roughness parameters (R_a, R_k, R_{pk}). Both RP1 and RP2 after sliding for 1000 duty cycles, provide relatively smoother surface than a rough new steel plate. This change is higher for RP1 which was tested in water contaminated ATF. This matches well with the findings in [1] and it is also clear that load bearing area or core roughness parameters (R_k, Rpk) are relatively low for water contaminated test surface.

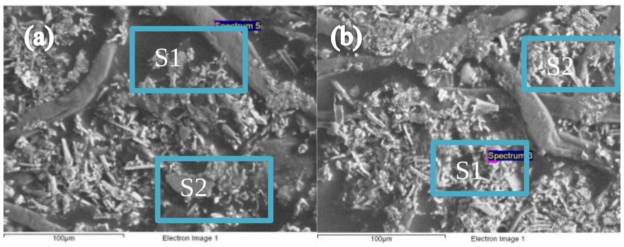

Figure 4. ESEM-EDS images for the static ageing friction surfaces(a)FP3, (b) FP4

Table 2. ESEM-EDS analysis for the static ageing friction surfaces (Figure 4).

FP3 -S1		**FP3-S2**	
Element	**Atomic%**	**Element**	**Atomic%**
C K	63.9	C K	64.2
O K	30.0	O K	34.5
Na K	0.1	Na K	0.6
Si K	6.0	Si K	0.3
		P K	0.3
Totals	100.0	S K	0.1
		Totals	100.0
FP4-S1		**FP4-S2**	
Element	**Atomic%**	**Element**	**Atomic%**
C K	66.7	C K	76.8
O K	26.6	O K	14.5
Na K	0.3	Na K	1.1
Al K	0.4	Mg K	0.2
Si K	5.6	Al K	0.7
P K	0.1	Si K	6.2
S K	0.2	S K	0.1
Ca K	0.1	K K	0.1
Totals	100.0	Ca K	0.2
		Fe K	0.1
		Totals	100

Table 3. 3D surface profiles for new and used (RP1 and RP2) steel plates

Roughness Parameter	New surface			RP1			RP2		
	0°	90°	**Mean**	0°	9o°	**Mean**	0°	90°	**Mean**
R_a, nm	358	369	**363**	53	80	66	120	116	**118**
R_k, nm	1220	1242	**1231**	140	196	168	360	339	**349**
R_{pk}, nm	325	213	**219**	584	41	49	110	71	**90**

The ESEM-EDS analyses for these post-test steel surfaces in Table 4 show the atomic concentration for two different morphological areas in the SEM images (Fig. 5). The concentrations of P is 0.4 to 0.1 atomic% and Ca is around 0.2 to 0.1 atomic% for RP2; these elements are absent in the RP1 steel surface. Other elements are closely analogous. Both the EDS analysis of the static ageing frictional surface and the post-test steel surface show the differences in the adsorption of the lubricant additives to form the tribofilm. In fact tribofilm is a thin layer of organic materials formed on the friction liner and counter surfaces during sliding and is important to determine the frictional property. Though the ESEM-EDS evidences do not reveal any friction modifying nitrogen containing groups or any organic compound or chemical bonds of C for the tested surfaces and [8], the presence of Ca in the friction surface and steel surface can be from metallic detergents in the ATF. This Ca can influence the tribofilm formation by controlling the friction modifiers adsorption on sliding surfaces, thus effect the anti-shudder property by reducing friction for decreasing sliding speed. The P could come from the antiwear additives (Pyrophosphate, Dialkyl hydrogen phosphite) and friction stabiliser like phosphoric acid. Zhao et al. [7, 8] suggested the formation of tribofilm on frictional surface at the very early stage before sliding. That is why the friction plates were statically aged to identify this ATF (with or without water) interaction with the friction liner. Since the concentration of Ca or P are low or absent for the water treated samples, this can be liable for the less adsorption of friction modifying tribofilm for clutch surfaces in presence of water, which ultimately increases the mean friction and negative friction-speed relation.

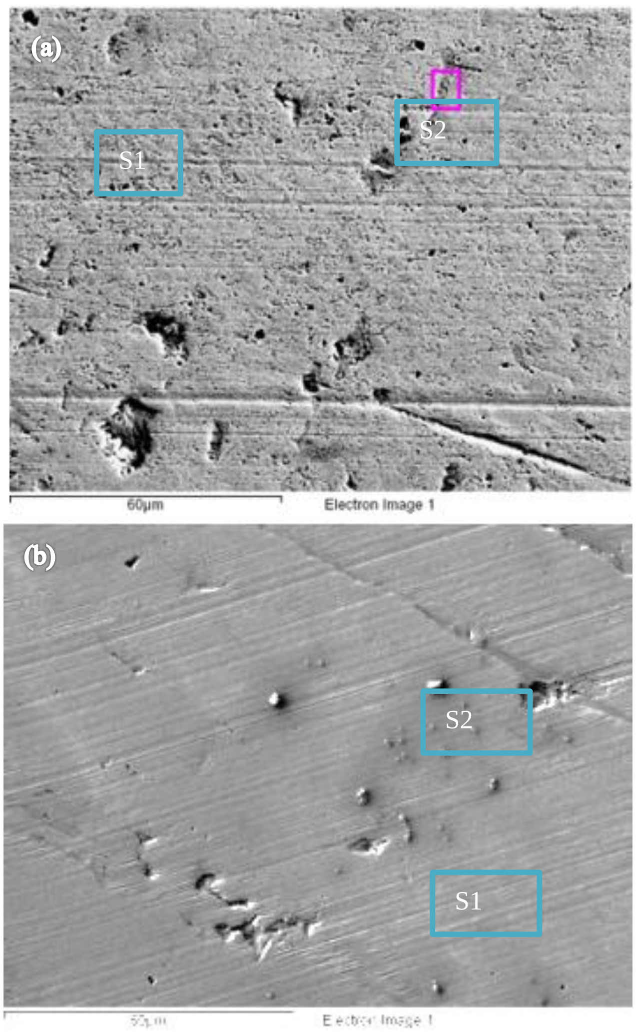

Figure 5. ESEM-EDS images for the static ageing friction surfaces (a) RP1, (b) RP2

Table 4. ESEM-EDS analysis for the Steel sliding surface

RP1			
S1		**S2**	
Element	Atomic %	Element	Atomic%
C K	23.3	C K	52.1
Al K	0.7	O K	24.4
S K	0.8	Mg K	3
Mn K	0.5	Si K	2.7
Fe K	75.1	Mn K	0.2
Totals	100.0	Fe K	17.6
		Totals	100.0
RP2			
S1		**S2**	
Element	Atomic %	Element	Atomic%
C K	47.4	C K	59.1
P K	0.4	O K	17
S K	0.7	Mg K	4.4
Ca K	0.2	Si K	2.5
Mn K	0.3	P K	0.1
Fe K	51.0	Ca K	0.2
		Mn K	0.1
		Fe K	16
		Co K	0.1
Totals	100.0	Totals	100

4. CONCLUSIONS

It is significant from the present study that the change in friction liner porosity, permeability, counter surface topography, tribofilm formations are distinctive for a water contaminated cutch system. Though the differences in tribofilm formation for the interaction of water contaminated ATF with the paper friction liner are not clearly revealed for these findings. So what is mainly contributing the specific frictional behaviour for water addition is not yet well-defined. To confirm the relationship between the friction trend and the friction pair degradation (change in porosity, permeability, surface flattening, adsorption of friction modifying elements or organic compounds), more surface active techniques like X-ray photoelectron spectroscopy (XPS). Since the amount of Ca and P in post-test steel surfaces after SEM-EDS are relatively lower than the regular uncontaminated cases [8]. That might require longer ageing in the rig to get a resilient tribofilm. It is also essential to analyse the change in the physical and chemical nature ATF with water, since the effect of ATF viscosity, additives action can largely contribute to the higher friction at low sliding seed.

5. REFERENCES

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