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THE CHALLENGE OF STUDYING TRIBOLOGICAL APPLICATIONS ON THE LABORATORY SCALE

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Abstract: *This work presents briefly an overview of the challenges that the authors face every time they want to study an actual tribo-contact and transfer it to a lab-scale test. In particular, the approach that developed over the years on how to simplify a tribo-contact and accelerate a tribo-test, while maintaining the correlation to the initial application is analyzing. This approach is demonstrated by a series of case-studies where existing industrial tribological problems are analyzed transferred to a relevant test. Moreover, another major issue which is the variability of wear results is addressing. Repeatability and data reliability is recognized as an important major challenge in the field of tribology. The outmost goal is to develop relevant, reliable, and repeatable test procedures which are vital for Research & Development and Quality Control activities.*

Key words: *Friction and wear phenomena; Field conditions; Laboratory scale*

1. INTRODUCTION

Friction and wear phenomena can be frequently met in a variety of industrial and technological fields ranging from the automotive [1] and aeronautical [2] applications up to micro-electronics [3], biomedical [4] and consumer good [5] products.

They are identified as a frequent cause for the failure of engineering components when they operate in contact under loading conditions. From the wide range of application, it is evident that the materials [6], contact geometry and conditions [7], motion [8] and environment [9] vary considerably. This diversity makes each tribological contact unique and thus it should be studied carefully, as a different system. When trying to transfer field conditions to a laboratory test, the most common mistake is that the system is altered to simplify the contact conditions and shorten test duration. However, such an approach can led to the generation of wear mechanisms that do not correlate to the end application. To achieve a good correlation, one must reproduce matching conditions and generate the same wear mechanisms between the complex in-field tribological contacts and the commonly used simplified laboratory tests [10]. To overcome this major obstacle the applied contact geometries, loads, motions, speeds, and environments need to change to match those required in every case study.

Thus, in this work an overview of the challenges that the authors face every time they want to study an actual tribo-contact and transfer it to a lab-scale test is presented. In particular, analyzed is an approach developed over the years on how to simplify a tribo-contact and accelerate a tribo-test, while maintaining the correlation to the initial application.

This will be demonstrated by a series of case-studies where existing industrial tribological problems will be analyzed transferred to a relevant test. In addition, another major issue which is the variability of wear results is discussed. Repeatability and data reliability is recognized as another major challenge in the field of tribology. The outmost goal is to develop relevant, reliable, and repeatable test procedures which are vital for Research & Development and Quality Control activities.

2. EXPERIMENTAL

The major problem is to simplify the field problem to a more controlled problem in a lab test; see Figure 1 and also Ref. [11]. Note that this topic is of major importance from the early stages of tribology discipline; see Ref. [12] since nowadays; see Ref. [13].

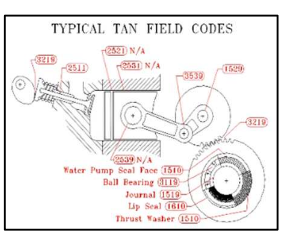
Type of test	Example
Field tests	
Bench tests	
Components tests	
Model tests	
Laboratory tests	

Fig. 1: From field problem to lab test.

Obviously, the best simulation of a field problem, is to perform field tests, but these have two main problems: 1) field tests take too long and are expensive and 2) field tests are a black box: there is lack of control over the test conditions, and there is limited information on component level. The general strategy is to simplify field tests, to reduce their duration and to increase control and repeatability.

To select the most appropriate test method, we applied the Tribological Aspect Number (TAN) approach; see Ref. [14]. This method consists of defining four key criteria, namely type of motion, area of contact, loading type and entry angle of a lubricant; see Figure 2).

In this way, complex tribological contacts can be described by a four-digit number that corresponds to one or more possible tribological tests. After defining the geometry of the contact and test apparatus, samples and counter-materials having the same composition as in field application were prepared, so as to have the same tribo-chemistry.



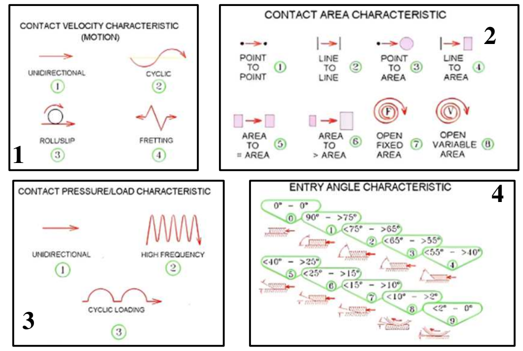


Fig. 2: Schematic showing examples of TAN numbers and the four main criteria for number selection [14].

Subsequently, prescreening tests were performed at variable conditions and the obtained wear mechanisms were analyzed and compared to those of actual components taken from the field. This step is essential in order to achieve a good correlation. Finally, the test procedure was performed multiple times to reflect on the repeatability of results. In this work, two different case studies are presented. One is a test protocol developed for ranking the performance of lubricants for vane pumps; see Ref [15] and the other deals with measuring the friction and wear performance of materials for shock absorbers; see Ref. [16].

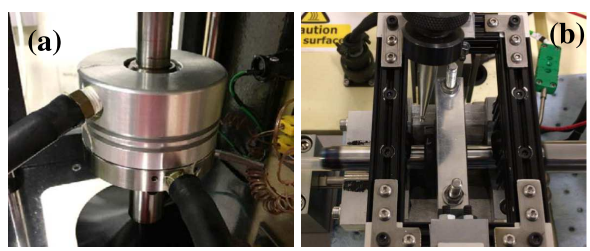


Fig. 3: (a) FMVP and (b) TE-77 shock absorber test configurations.

Vane pump testing: a modified FALEX® MultiSpecimen Vane Pump (FMVP) test machine; see Figure 3a, which used a vane-on-disk test configuration and a hydraulic fluid recirculation test chamber. The complete test protocol is described in the published work [15]. Shock absorber testing: A modified TE-77 Plint® tester was used, to fit the actual components. To mimic the oil film formation in a hydraulic cylinder, a peristaltic pump was used to drip feed oil into the tribo-contact on one side

only; see Figure 3b. The complete test protocol is described in the published work [6].
For the analysis of wear mechanisms optical and SEM microscopy techniques were used, whereas the wear loss was evaluated with 3D confocal measurements.

3. RESULTS AND DISCUSSION

Vane pump testing: The first step to establishing this test protocol was to identify the wear mechanisms that occurred in the field test. By analyzing the wear mechanism of vanes of a Conestoga Vane Pump configuration we observed that the main wear mechanisms were a mild abrasion and localized oxidative wear, as shown in Figure 4a. By fine tuning the conditions of the FMVP configuration, the same mechanisms were generated on the lab-scale; see Figure 4b. However, if we try to accelerate the wear by increasing the applied load, the mechanism changes completely and shifts to severe deformation; see Figure 4c. Thus, the correlation is lost.

(a)

(b)

(c)

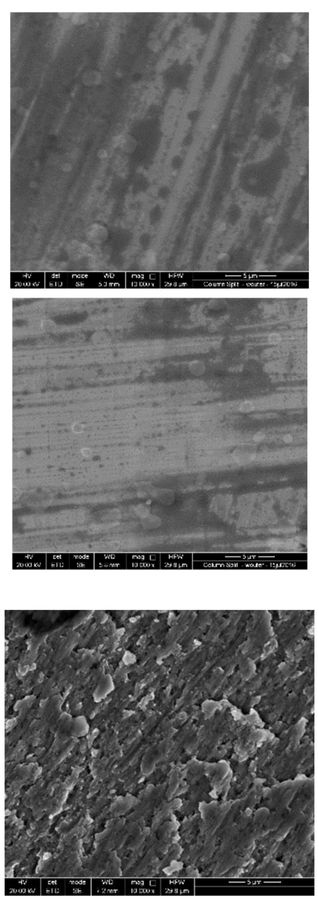


Fig. 4: SEM analysis on vanes obtained after (a) Conestoga Vane Pump test, (b) FMVP lab test with optimized conditions (up to 0.85 GPa) and (c) FMVP lab test at higher loads (1.2 GPa).

After optimization of the test conditions, a ranking of hydraulic oils was performed on both the FMVP and Conestoga Vane Pump apparatus (according to ISO 20763: 2004); see Figure 5.

The same ranking was obtained with both methods, indicating that this technique can be effectively used for the comparison and ranking of hydraulic fluids.

However, the test results do not yet match quantitatively with those of the ISO Vane pump test but are extremely useful to pre-screen and complement the pump test.

Thus, lubricant manufacturers can evaluate variations of a product and develop new formulations on smaller volumes and in shorter test times. By saving on time and cost, they can also perform more tests to also reflect on the repeatability of both the process and product.

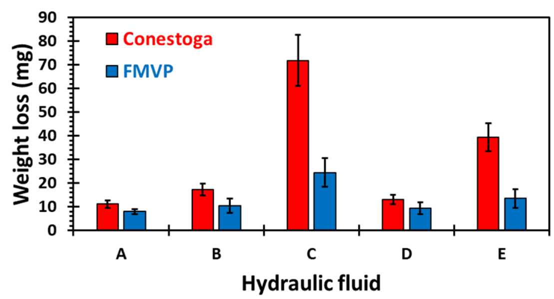


Fig. 5: Ranking of five different hydraulic fluids, obtained from Conestoga Vickers (ISO 20763: 2004) and FMVP tests (20 hrs, 150 lbf).

Shock absorber testing: Similarly, in this case study the first step was to identify the wear mechanism on shock absorbers after actual in-field conditions; see Figure 6.

The main wear mechanism was initially “two body abrasion” and subsequently “three body abrasion” which took place due to the generation of debris particles in the tribo-contact.

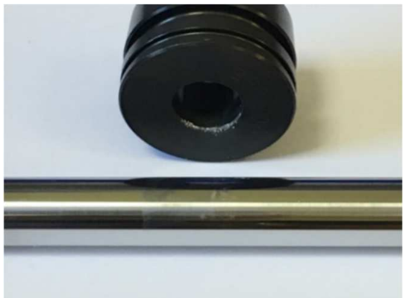


Fig. 6: Worn shock absorbers.

To bring this method closer to reality, the TE-77 Plint® tester was modified to hold the actual parts and a peristaltic pump was used to drip feed oil into the tribo-contact.

By fine tuning the test conditions, the same mechanism (mild abrasion) was obtained with the lab test; see Figure 7a. However, if the conditions are not correct there is again a risk of altering the wear mechanism.

In this case, by increasing the load to accelerate wear, the wear mechanisms changes from abrasion to a mixture of adhesive wear (indicated by the formation of a tribolayer) and to abrasion; see Figure 7b.

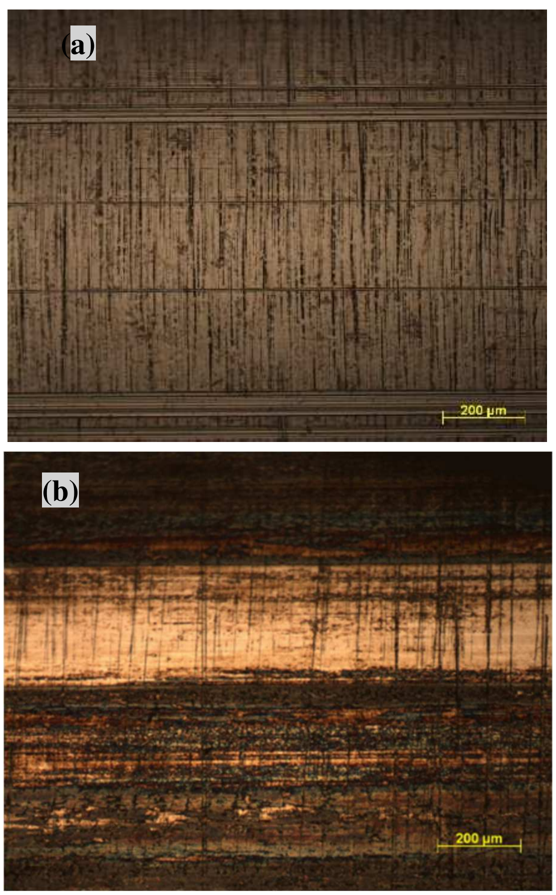


Fig. 7: Wear analysis of shock absorbers under (a) optimized and (b) high load accelerated conditions.

After optimization of the test conditions, the repeatability of the process was checked, by performing tests with well controlled reference oils and materials. An example of a triplicate test is shown in Figure 8.

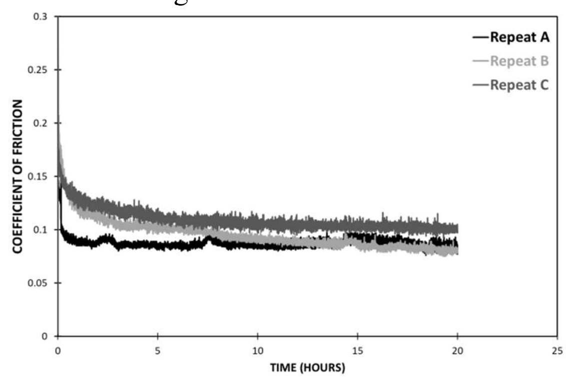


Fig. 8: Triplicate test on reference oil and shock absorbers with optimized test conditions.

From Figure 8, it can be seen that the friction at steady state conditions is very similar. However, if the test was cut short (less than 2 hrs in this case), then a significant difference between the samples would have been found. This variation was attributed to differences in the initial surface topography. This shows clearly the risk of shortening a test in order to save time and obtaining data during the run-in period. On the other hand, it is positive to see this method is sensitive enough to distinguish frictional differences caused by topographical features.

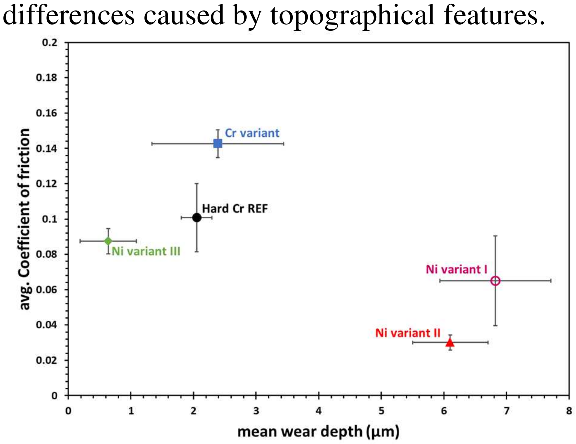


Fig. 9: Ranking the friction and wear of different rods versus reference rod guide and oil.

Once the method was set up and optimized, it can be successfully used to successfully rank the tribological performance of oils and material combinations under relevant to the applications conditions; see Figure 9. Also, it allows to perform multiple tests in a much shorter time, and therefore the repeatability can be easily assessed; see also Ref. [17].

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4. CONCLUSION

From this work the following conclusions can be drawn:

- Developing a lab-test is a rigorous procedure that requires multiple steps namely, identification of tribo-contact and failure mechanism, development and optimization of test procedure and repeatability and correlation check.
- This procedure was demonstrated in two different case studies, which were the simulation of vane pumps and shock absorber applications. Both procedures correlate well to the actual application.

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Provocarea studierii aplicațiilor tribologice la scară de laborator

Această lucrare prezintă pe scurt o imagine de ansamblu a provocărilor cu care se confruntă autorii de fiecare dată când doresc să studieze un tribo-contact real şi să-l transfere într-un test la scară de laborator. În special, abordarea care s-a dezvoltat de-a lungul anilor cu privire la modul de simplificare a unui tribo-contact şi de accelerare a unui tribo-test, menţinând în acelaşi timp corelaţia cu aplicaţia iniţială, este analitică. Această abordare este demonstrată printr-o serie de studii de caz în care problemele tribologice industriale existente sunt analizate transferate la un test relevant. În plus, se abordează o altă problemă majoră, care este variabilitatea rezultatelor uzurii. Repetabilitatea şi fiabilitatea datelor sunt recunoscute ca o provocare majoră importantă în domeniul tribologiei. Scopul principal este de a dezvolta proceduri de testare relevante, fiabile şi repetabile, care sunt vitale pentru activităţile de cercetare şi dezvoltare şi de control al calităţii.

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