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An Axial Sliding Test for machine elements surfaces

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Abstract

Throughout the years, it has become more and more important to find new methods for reducing friction and wear occurrence in machine elements. A possible solution is found in texturing the surfaces under tribological contact, hence the development and spread of plateau-honed surface for cylinder liners. To prove the efficacy of a particular textured surface, it is paramount to perform experimental tests under controlled laboratory conditions. In this paper a new test rig simulating pure sliding conditions is presented, dubbed Axial Sliding Test. It presents four major components: a rod, a sleeve, a housing and a stripwound container. The rod and the sleeve are the two surfaces in relative sliding motion; the stripwound container maintains a constant, but adjustable normal pressure and the housing serves as interface between the sleeve and the container. For carrying out the test, two machineries are necessary: a press to provide the normal pressure and a tensile machine to perform the axial movements. The test is calibrated so that the correspondence between the normal pressure and the container advancement is found. Finally, preliminary tests are carried out involving a multifunctional and a fine turned rod against a mirror-polished sleeve. Qualitatively the multifunctional surfaces improve the friction conditions, but a more structured test campaign is required.

Keywords: machine elements, textured surfaces, axial sliding, experimental tests.

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1. INTRODUCTION

The reduction of friction losses and wear occurrence in machine elements, together with the striving for reducing energy and fuel consumption in the transportation industry are issues whose importance has been growing over the years [1,2]. The world energy consumed to overcome friction lies around 30%, while the economic costs associated with wear is higher than the 5% of the GDP of developed countries [3]. A possible solution has been deemed being surface texturing. Generally, “textured” or “engineered” surfaces are those which have been produced in a specific way in order to give one or more specific functions [4]. In this case the functions to be provided are lubrication capability (by means of lubricant reservoirs) accompanied by load bearing capacity of the surface. A typical instance is represented by plateau-honed surfaces for cylinder liners which have been widely used in the automotive industry in the last three decades. In these surfaces the finishing process removes the peaks which would be worn out during the run-in period but keeps part of the coarser texture from the pre-machining operation [5,6]. The resulting surface has a plateau area capable of bearing loads and deeper valleys able to retain lubricant (**Fig. 1**) [7]. There are several other ways to produce textured surfaces, encompassing adding, removing and moving material techniques [3].

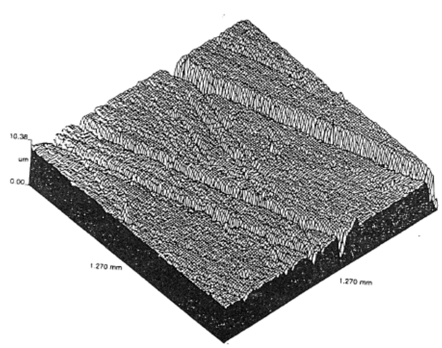

Figure 1: *Isometric plot of a plateau-honed surface [7].*

In order to assess the efficiency of textured surfaces, experimental tests simulating real working conditions have to be performed. A high variety of tests can be performed depending on the tribological situation under examination. Pettersson and Jacobson in [8], for example, used real hydraulic motor components when testing the efficacy of textured surfaces in reciprocating sliding conditions between a piston and a roller. Vrbka et al. in [9] used instead an experimental apparatus consisting of two discs loaded against a roller in order to study the effect of surface texturing on rolling contact fatigue in mixed lubricated conditions.

In this paper is presented a new experimental test apparatus for machine elements, ideated and developed by the authors. It is called Axial Sliding Test (AST). The AST can simulate any machine element presenting an axial movement between two counterparts under pure sliding conditions, such as a piston ring sliding in a cylinder liner. The test is a general one: it has been ideated to evaluate the effectiveness of textured surfaces, but it can be actually used for other purposes as for instance lubricants testing. The selection and pairing of materials, hardness, surface topography, surface coating and lubrication is in fact fully free.

2. AST APPARATUS DESCRIPTION

The test rig consists of four major components: a stripwound Strecon® container, a conical housing, a rod and a sleeve (**Fig. 2**).

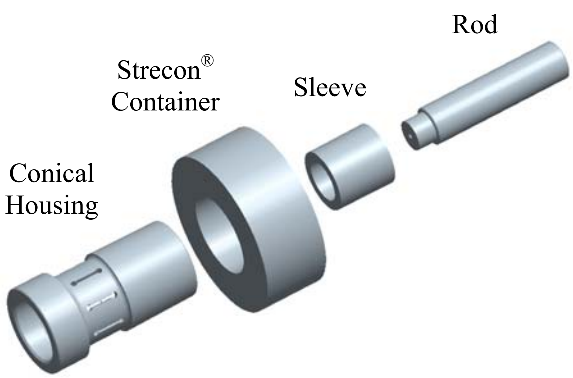

Figure 2: *Axial Sliding Test major components.*

During the experiments the only parts in relative motion with respect to each other are the rod and the sleeve, to which the tested surfaces are applied. The rod is in the actual case a cylinder made of a chromium-molybdenum-vanadium alloyed steel (Vanadis 6) with a hardness of 62HRC, diameter Ø38mm and length equal to 135mm. The sleeve is a 58mm long hollow cylinder made of the same material, but slightly harder (64HRC). Its inner diameter is nominally 50 µm larger than the rod diameter, while the outer diameter is Ø58mm. The sleeve is placed inside the housing (**Fig. 3**), which is cylindrical on the inside and slightly conical on the outside, the outer surface being 1° slanted.

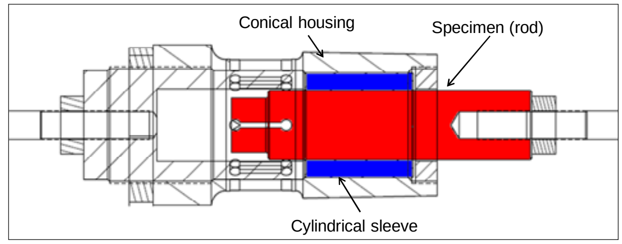

Figure 3: *Axial section of the assembled AST rig (Strecon® container not shown).*

The fourth major component, the Strecon® container, envelops the conical housing and has the crucial function of keeping the normal pressure on the housing-sleeve system uniform.

2.1. Stripwound container

In order to guarantee the maintaining of a constant pressure, a special production process has been used to realize the Strecon® container: the stripwinding technique. Developed over the last thirty years [10,11], the stripwinding process consists in a 0.1mm thick high-strength strip wound around a hardened core of high-alloyed tool steel (**Fig. 4**) [12,13].

Figure 4: *Stripwound Strecon® container section [13]. The AST container presents the inner surface with the same degree of conicity as the housing.*

During the winding process the strip material is loaded with a controlled back tension: varying it from layer to layer provides an optimal stress distribution (**Fig. 5**) [12,13]. The equivalent stress is distributed over hundreds of layers, thus avoiding stress concentrations [13]. As a result, the peak stresses in the stripwound containers lie within the elastic limits: no plastic deformation and pressure losses are observed [12,13].

The inner surface of the container used for the Axial Sliding Test has been ground to the same angle (1°) as the housing. The low cone angle keeps the container self-locking on the housing and thus the maintaining of a constant pressure is achieved.

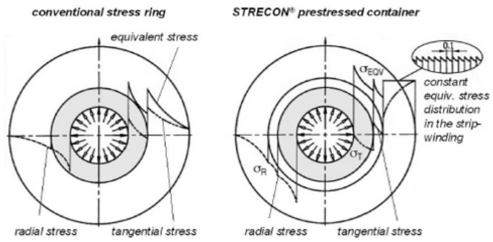

Figure 5: *Stress distribution in a conventional stress ring (left) and in a stripwound Strecon® container (right) [13].*

3. AST SET-UP

In order to be performed, the axial sliding test needs two pieces of machinery: a hydraulic press and a tensile test machine.

3.1. Pressing operation

The first operation to be performed is to load the AST apparatus. The assembled test rig is placed in the hydraulic press and the container is pressed down the housing increasing the normal pressure at a constant rate with its advancing. The incremental advancement of the container at every press stroke is known thanks to a series of pressure rings with calibrated heights arrayed beforehand around the housing. A mathematical model based on the theory of multiple shrink fitted rings [14] has been used in order to correlate the advancement, the sleeve inner diameter shrinkage and the normal pressure. In order to verify and calibrate the model, the sleeve shrinkage as a function of the container progress is experimentally determined (**Fig. 6**).

In the first experiment the rod is not assembled in the test rig. The loading operation is repeated several times and before each stroke the sleeve inner diameter was measured with a three-point internal micrometer at different axial positions. When the sleeve and the housing come to a full contact the sleeve diameter reduces proportionally with the container advancement (**Fig. 6**). The reduction is estimated being 13µm every mm of progress of the Strecon® container. The experiment is then repeated with a hollow rod (Ø26 mm inner diameter) assembled with the sleeve. The reduction is now estimated being 9µm every mm of progress of the container.

The model has thus been calibrated and the normal pressure increase is deemed being 34MPa every mm the stripwound container slides down the housing. This is based on the interference generated between the sleeve and the rod, like in shrink-fitting operations [14].

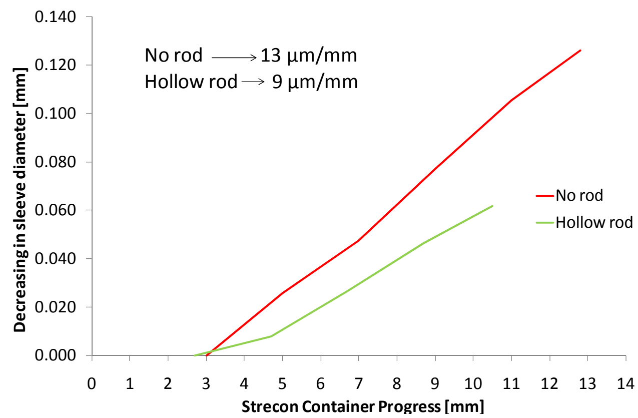

Figure 6: *Sleeve inner diameter reduction as a function of the container progress: the "no rod" and "hollow rod" configurations.*

Once the pressing operation is completed, the whole apparatus is transferred to the second station, the tensile test machine.

3.2. Tensile machine

The loaded apparatus is mounted in an Instron 8516 fatigue test machine with a load capability of 100kN both in tension and in compression (**Fig. 7**).

Figure 7: *Axial Sliding Test mounted on a tensile machine.*

The test is at last carried out making the rod sliding back and forth inside the sleeve according to a predefined program. As an example, the rod can

follow a sinusoidal movement with constant frequency or a square-wave movement with constant speed. Throughout the test, the force necessary to keep the frequency (or the speed) constant is measured by a calibrated load cell.
In Fig. 8 is shown an example of load and position results of an Axial Sliding Test performed following a sinusoidal movement: 10 cycles with a frequency of 0.2Hz and a sampling frequency of 10 points/s. The rod is slid 15mm back and forth and the load varies between 1.5 and -1.5kN.

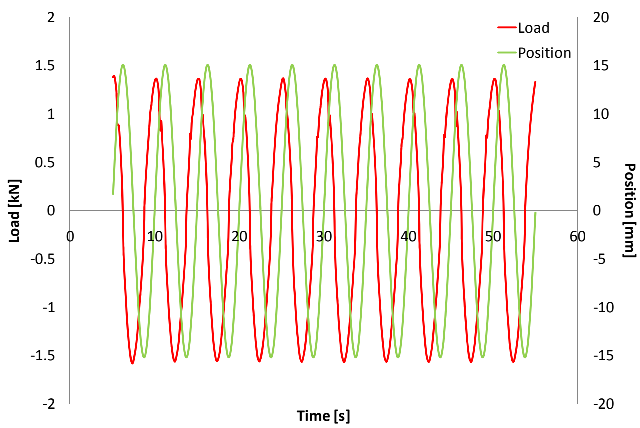

Figure 8: Load and position results of an Axial Sliding Test following a sinusoidal movement.

4. PRELIMINARY TESTS

As stated above, despite it offers numerous testing possibilities, the Axial Sliding Test has been ideated for assessing the efficacy of engineered surfaces. Of a particular interest is the testing of a new typology of textured surfaces, the so-called multifunctional (MUFU) surfaces [15,16]. They are produced through a two-step manufacturing process, namely a primary hard-turning operation which provides a periodic texture pattern, followed by a robot assisted polishing (RAP) operation to create the plateau regions able to bear loads [15-17]. An example of multifunctional surface applied to an AST rod is shown in Fig. 9, right-hand side. Thanks to the high control of the RAP process, it is ideally possible to obtain multifunctional surfaces assuming any value of the plateau bearing area [15-17].

The major purpose of the Axial Sliding Test is therefore to prove the effectiveness of such surfaces compared to others produced through conventional manufacturing processes (turning, grinding, etc.). For the preliminary tests three specimens have been realized, whose roughnesses were measured before and after testing with a skidless inductive profilometer. They are namely a mirror-polished sleeve with extremely low roughness (Ra < 0.02µm), a rod turned with a feed rate of 0.1mm (finely turned) and a multifunctional rod with a bearing area of the plateaus equal to 40% (**Fig. 9**). The specimens were then lubricated with high-viscosity synthetic grease based on perfluorinated polyether oil (BARRIERTA® L55/3) [18].

The tests were carried out as previously described, since Fig. 8 is taken from a test performed with the multifunctional rod. 30mm constant-speed ramps (not

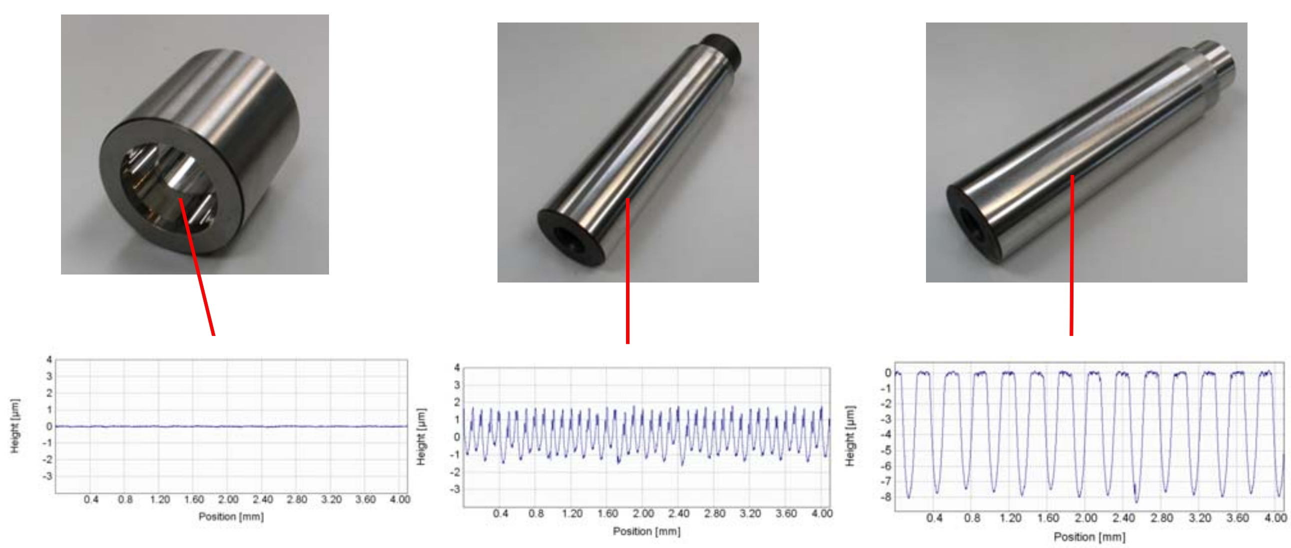

Figure 9: Specimens used for the preliminary tests and their roughness profiles: a mirror polished sleeve (left), a fine turned rod (center) and a rod with a multifunctional surface (right).

shown in the figure) preceded and followed the sinusoidal movement in order to utilize the central zone of the rod. A number of tests were performed at different normal pressures, i.e. at different advancements of the stripwound container. Precisely, the friction forces were recorded each 0.2mm advancement of the container. For starting the experiments, a reference point (a reference pressure ring combination) is needed. Initially, the ring combination which would not allow a manual movement of the rod after the pressing operation was chosen as the reference point. It is a subjective method and therefore not an ideal one, but it allows to screen loose combinations out. For each test the positive friction forces when the rod is at its maximum speed (rod position equal to 0 according to Fig. 8) were taken and averaged.

The test results are plotted in Fig. 10. The ordinate axis displays the friction stresses obtained dividing the measured forces by the nominal area of contact. The abscissas, instead, represent the normal pressure increase relatively to a zero point. This zero point is not the manually determined reference; rather it is the first combination which requires loads higher than 0.5kN. This artificial reference, which corresponds to still low friction stresses, has the advantage of being based on a specific number rather than a subjective feeling. Moreover, by discarding the results at extremely low loads, it helps to pair otherwise offset curves. The error bars shown in Fig. 10 represent the standard deviation calculated from the 10 results each test provides.

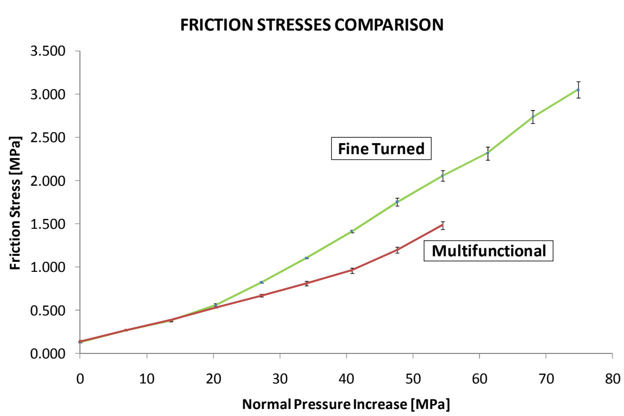

Figure 10: *Friction stresses comparison between a fine turned and a multifunctional rod loaded with a polished sleeve.*

4.1. Discussion

With reference to Fig. 10, the artificial reference couples very well the two curves, being the friction stress 0.142MPa and 0.133MPa for the multifunctional and the fine turned rod respectively. The two curves show to increase coherently for the first 15MPa of normal pressure increase from the zero point, to eventually diverge after that limit. Due to the high lubricant viscosity it is possible that a thin film separating the two surfaces is still maintained until the pressure is 15MPa, hence the similar behavior. After the limit, the system enters surely in a mixed lubrication regime. The friction force appears to increase more rapidly for the combination fine turned rod - polished sleeve than the multifunctional rod – polished sleeve one. By fitting a line through the observed data, the friction coefficient can be estimated. For the combination involving the fine turned rod μ=0.046, while for the one involving the multifunctional rod μ=0.027. The multifunctional surface seems to assure a better friction reduction than the fine turned one.

Nevertheless, it must be remarked that the results obtained are just the outcomes of preliminary tests, performed mainly with the purpose of improving the understanding of the AST apparatus and the machineries involved. The high viscosity lubricant, for example, was chosen to protect the surfaces for future usage (no wear marks were indeed detected in the post-test examination). The results, though, could have been partly biased by the high lubricant performances. Only a qualitative assessment of the multifunctional surfaces effectiveness can be provided after these tests, but not a definitive answer. Therefore a more structured series of tests performed with a less effective lubricant and involving different kinds of machined and multifunctional surfaces is required.

5. CONCLUSIONS

In this paper a newly developed test rig simulating pure sliding conditions between two machine elements is presented. It has been referred to as Axial Sliding Test and, though it opens to a wide range of applications, it has been ideated for testing textured surfaces, in particular multifunctional surfaces. The test apparatus consists of four main components, of which two perform the relative sliding: the rod and the sleeve. The Strecon® container manufactured using the stripwinding technique allows the maintenance of a constant normal pressure throughout the whole experiment. Two machines are needed for performing the test: a press to load the system and a tensile test machine for ensuring the rod-sleeve relative movement. The test is calibrated so that the normal pressure increase per mm advancement of the stripwound container is known. Preliminary tests are carried out comparing the friction forces associated to a multifunctional and a fine turned rod when they both are loaded by a mirror-polished sleeve. These initial tests prove qualitatively that a multifunctional surface can be a valid candidate for reducing friction forces in machine elements subjected to pure sliding, but a more structured test campaign is needed. A new series of tests involving a number of machined surfaces, both by traditional methods (grinding, polishing, etc.) and multifunctional, is thus forthcoming.

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