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AN EXPERIMENTAL UNSTANDARDIZED METHOD FOR TESTING THE SLURRY EROSIVE WEAR OF THERMAL SPRAYED COATINGS

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In this study, the authors proposed the set-up and testing a stand for the erosion assessment of the layers deposited by thermal spraying, by a non-standardized experimental method, which would be specific to the operation of the hydraulic power steering pumps used in the automotive industry. The evaluation of the samples was carried out by direct observation and with the help of the stereomicroscope, at magnification powers of 4x and 20x respectively. It was not possible to evaluate the surface morphology by electronic microscopy due to the high fluid contamination of the samples. After 20 hours of operation of the test bench with hydraulic fluid test impregnated with 1% metal span a slight wear trace was observed only on one of the three samples and on the blank sample surface.

Keywords: adhesion, cohesion, TBC, scratch method

1. Introduction

According to ASTM G40-99, from a tribological point of view, erosion is defined as a progressive loss of the original material from a solid surface due to the mechanical interaction between the surface and a fluid, a multicomponent liquid, liquid or solid particle [1]. Of course, this phenomenon is a very expensive one because it generally causes the decommissioning of machines / components that are functioning in potentially erosive environment. For example, in 2000, the UK Department of Commerce estimated losses of about 20 million pounds per year caused by erosion phenomena in various areas, and Finland estimated losses of wear and rubbing of about 2.7 billion euro / a year in 1999. [1] Also, according

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to an estimative report by Mann and Arya, in 1998, India suffered losses of about 120-150 million US dollars just because of abrasive erosion [2].

The erosion mechanism varies according to a variety of parameters: the characteristics of the eroded materials (hardness, density, grain type, thermal conductivity, erosion resistance, etc.), the characteristics of the environments where the erosion occurs (viscosity, temperature, pH, kinetic energy of abrasive particles, angle of impact, etc.). Depending on the environment in which the phenomenon occurs, several types of erosion have been established in the literature [1]:

1. Liquid impingement erosion and cavitation erosion: liquid impingement erosion occurs when small liquid droplets hit the surface of a solid at a very high velocity, causing plastic deformation or even breaking the material at single impact without the liquid to contain particles that can produce solid surface damage. Cavitation erosion is defined as the mechanical destruction of the surface of a solid caused by cavities or bubbles which are destroyed on or near them.

2. Solid particles erosion is defined as the loss of material on a solid surface caused by the repeated impact with small solid particles entrained by a fluid.

3. Erosion / Corrosion: it is produced as a combined phenomenon between the two processes, which influence each other, the corrosion being the one leading to an increased erosion rate based on the preferential dissolution phenomenon, respectively an inhibition of erosion by the creation of passive films on the affected surface.

4. Slurry erosion, which is defined as the wear produced when a solid material is exposed to a stream of slurry (a mixture of solid particles in a liquid) that moves at a very high speed. The difference between solid particle erosion and slurry erosion is due to the fact that in the first case, the particles hit the surface of the solid and are thrown back causing the action of a force on it, while Slurry erosion is characterized by the sliding of particles on the solid surface under the action of an external force.

To study the phenomenon of erosion, several types of tests, both standardized and non-standardized, are described in the literature. Among the standardized tests used for erosion study involving erosion in liquid media we can mention:

- ASTM G32-03: Standardized test method for cavitation erosion using vibration devices. The stand operates on the basis of a high-frequency ultrasonic actuator that produces the vibration of a liquid immersed sample on the surface of which the cavitation phenomenon occurs; [3].

- ASTM G134-95: Method for testing the erosion of solid materials by a liquid jet producing cavitation, similar to the principle of the liquid-jet cutting method without abrasive particles;

- ASTM G73-98: Standard method for liquid impingement erosion testing. It is based on the cumulative erosive effect of individual liquid droplets with repeated impact on the surface;

- ASTM G75-01: Standard test method for slurry abrasion (Miller Number) and slurry abrasion response of materials (SAR Number). The sample is cylindrical and has a circular test surface that slides with oscillation movements in abrasive slurry media under pressure, on a standardized rubberized surface.

Non-standardized tests are also used for various experimental applications, of which the following can be mentioned:

- High-velocity water jet equipment in which abrasive particles are introduced, similar to the industrial water jet cutting method with abrasive particles [4];

- Water-jet equipment without abrasive particles acting on a submerged sample in a liquid medium containing abrasive particles that will be accelerated to the tested surface [5];

- Test equipment with slurry jet recirculate under pressure [6];

- A test circuit with slurry recirculation, the abrasive fluid being pumped through an orifice between a rotating disk and a fixed housing in which the test samples are mounted (simulates the conditions in the hydropower plants) [7];

- Test system in which the samples are attached to the ends of the four arms of a rotor, thus having a circular path in the abrasive fluid [8];

- The Coriolis erosion test, in which two flat samples are attached to two arms fixed to a shaft that moves in a cylindrical chamber, the centrifugal force being the one that always pushes the fluid outward. [9];

- Micro Abrasion Test with wheel-on-flat equipment immersed in abrasive media [10].

In this study, the authors proposed setting up and testing a stand for the erosion assessment of the layers deposited by thermal spraying, by a non-standardized experimental method, which would be specific to the operation of the hydraulic power steering pumps used in the automotive industry.

2. Materials and methods

This paper presents experimental data from a larger research regarding the improvement of the wear resistance of hydraulic power steering pumps. The main phenomenon that causes their dismantling is the destruction of the inner surface of the internal pump housing caused by the occurrence of metal swarfs in the hydraulic fluid. Considering how the wear of this surface is produced, the type of fluid, and how abrasive particles act on the surface, it was established that it is wear and tear caused by abrasive erosion. One of the methods for improving the wear resistance of materials, used on a wider scale, is to cover the surfaces by thermal deposition with coatings with specific characteristics.

Even if they are a multitude of testing methods of the erosion phenomenon presented in the literature, neither has been found to express the operating conditions of the hydraulic power steering pump. Consequently, the authors considered it opportune to design and execute a stand simulating a large part of the hydraulic power steering pumps operating parameters.

Fig. 1 shows the overall picture of this stand and its components.

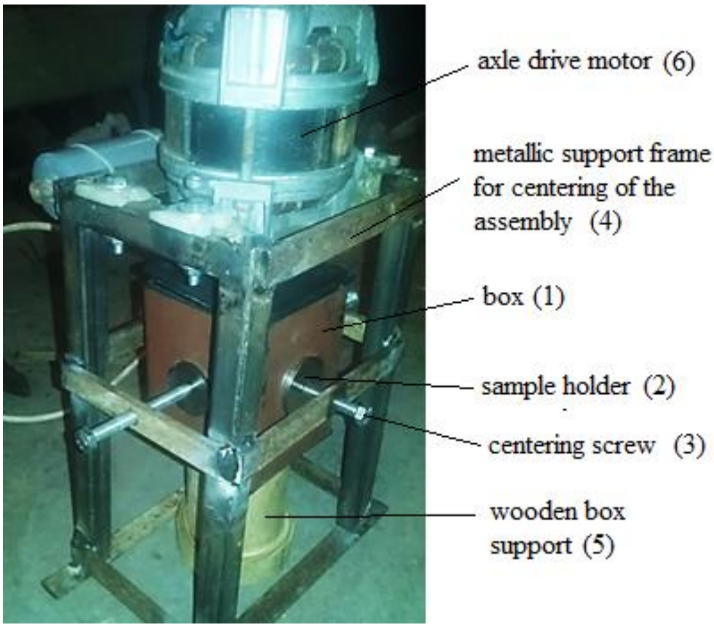


Fig. 1. Overview of the abrasive erosion test bench

For the tests conducted in this study, there were selected three used valve discs, on the surface of which were sprayed, prior to the use in operation, by thermal deposition, three types of coatings, as follows:

- Bonding layer: commercial grade Al_2O_3-30(Ni20Al), produced by Metco Oerlikon;
- Sample 1 (S1): Topcoat of commercial powder Cr_2C_3-Ni20Cr produced by Metco Oerlikon;
- Sample 2 (S2): Topcoat of commercial powder MgZrO - 35NiCr produced by Metco Oerlikon;
- Sample 3 (S3): Topcoat of commercial powder ZrO_2 - 5CaO produced by Metco Oerlikon.

The samples were tested in operation of an internal combustion engine from Dacia 1400, model 102/13 for 36 hours, the results being presented in a previous paper [11], which resulted in the appearance of a tribofilm composed from combustion residues on the burned surfaces. A fourth sample was also used, made of low alloy steel, as a blank sample (M).

The stand was designed to function as follows: in the wall of the box (1) are mounted the supports with the samples to be tested (2), their centering being made with the help of some screws (3) on the metallic support frame (4). Fixing the samples on the walls of the box and sealing the mounting holes is done with a silicone cord, these aspects being shown in Fig. 2 a, b.

Fig. 3 shows the way of holding the specimens on the support disk (Fig. 3a). The machining dimensions of these elements were designed and executed so that the alignment of the sample surface with the inner face of the box could be obtained (Fig. 3c). It has been chosen to implement such a support to diversify the geometry of samples that can be tested with this stand.

The box is placed on the support (5), the samples and the support disks are tightly mounted, and the box is filled up to a capacity of ¾ of its volume with a hydraulic fluid contaminated with 1% iron fallings. At the time of placing the container on the support, inside it comes the rod with the four pallets that will ensure the movement of the abrasive fluid during the tests. The rod is driven by a 1.2 kW (6) engine mounted at the top of the test bench with a speed of 1250 rpm.

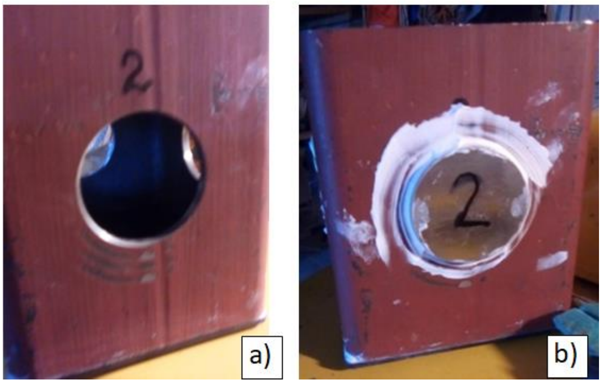


Fig. 2. Construction and assembly aspects of the test stand box:
a) wall mounting hole;
b) sealing the sample holder to the box wall.

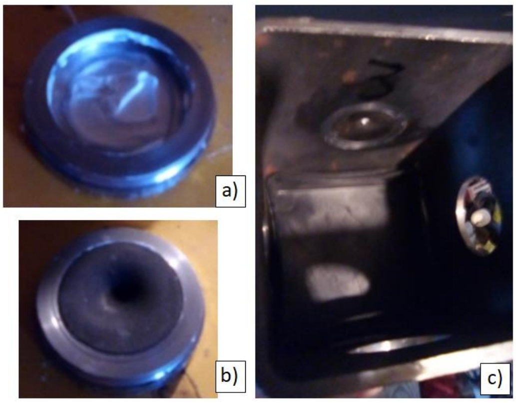


Fig.3. The mounting method of the samples in the test box wall:
a) support for samples;
b) aspect of the sample assembly in the support;
c) the layout of the support in the box wall, with the alignment of the surfaces.

The test duration in this study was of 20 hours, after which the samples were extracted and cleaned in an ultrasound bath with alcohol for 30 minutes. For an easier evaluation, it was chosen the following encoding method: samples in pre-erosion test condition were coded P1.0, P2.0, P3.0 and M.0 respectively, and the samples after exposure to abrasion erosion were coded P1.1, P2.1, P3.1 and M.1, respectively.

3. Results and discussions

The evaluation of the samples was carried out by direct observation and with the help of the stereomicroscope, at magnification of 4x and 20x respectively. It was not possible to evaluate the surface morphology by electronic microscopy due to the high hydraulic fluid contamination of the samples.

Figs. 4, 5, 6 show comparative images of the initial sample surfaces (after being tested in the internal combustion engine) and those of the samples after exposure to the abrasive erosion tests at different magnification.

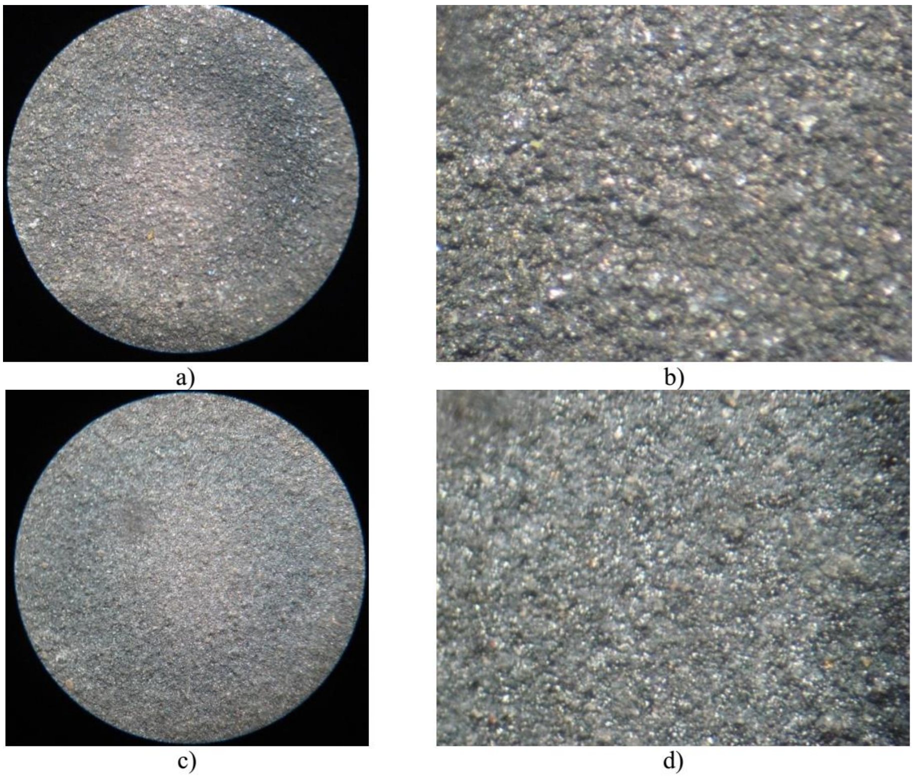


Fig. 4. Surface morphology before the tests: a) Sample 1.0 (4x); b) Sample 1.0 (20x); and after the tests: c) Sample 1.1 (4x); d) Sample 1.1 (20x)

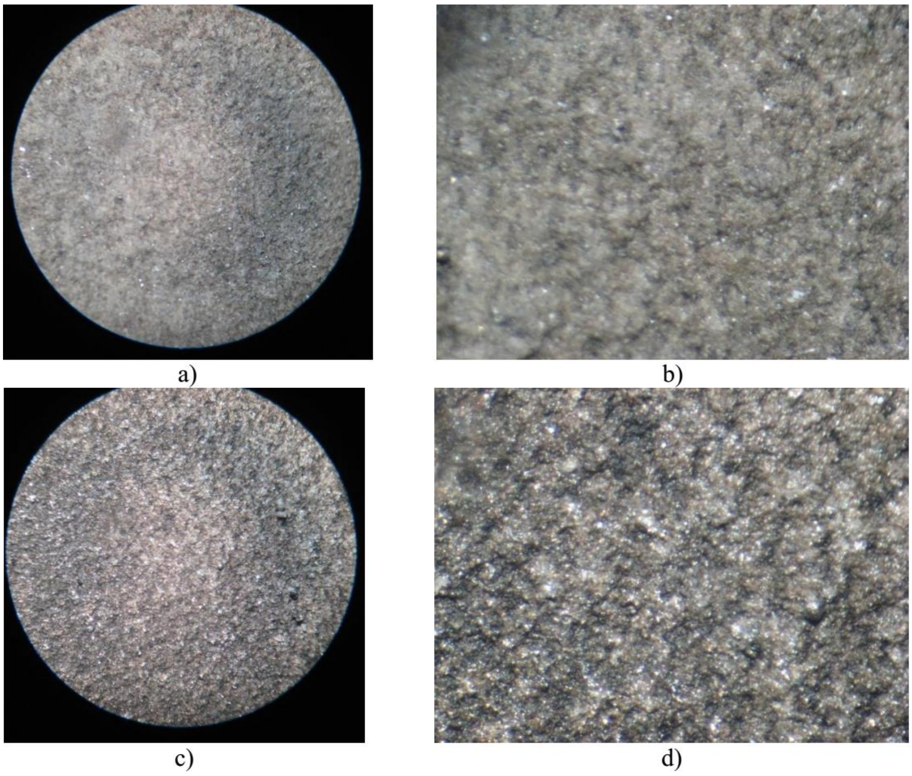
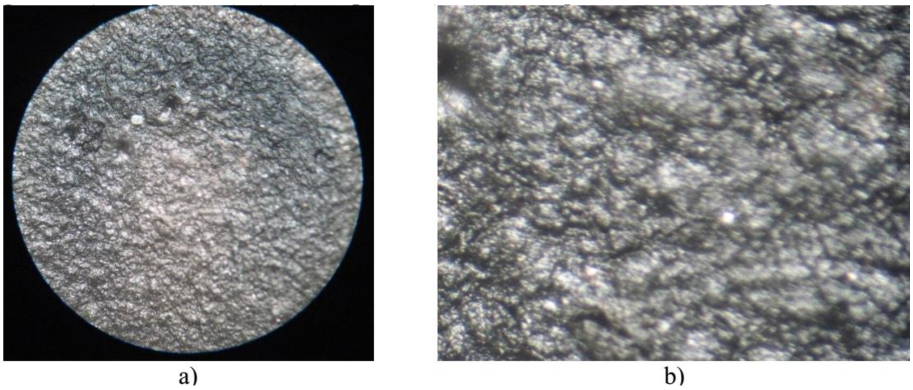
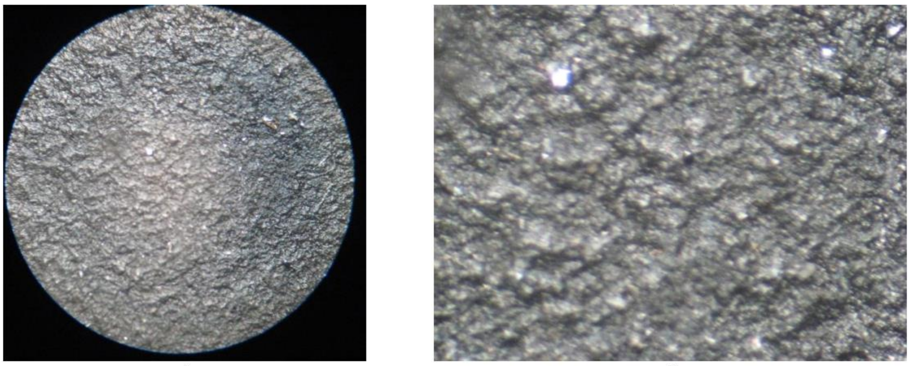


Fig. 5. Surface morphology before the tests: a) Sample 2.0 (4x); b) Sample 2.0 (20x) and after the tests: c) Sample 2.1 (4x); d) Sample 2.1 (20x)





c) d)

Fig. 6. Surface morphology before the tests: a) Sample 3.0 (4x); b) Sample 3.0 (20x) and after the tests: c) Sample 3.1 (4x); d) Sample 3.1 (20x)

Analyzing the comparative images of the sample surfaces before and after applying the abrasive erosion tests, it can be observed that, for Sample 1, the irregular appearance of the surface of the layer deposited by thermal spraying is kept unaltered (see Figs. 4a, b), only a slight color change caused mainly by immersion in the hydraulic test fluid (Fig. c, d) being visible.

In the case of Sample 2 it is observed that the surface of the sample has a different morphology, the aspect observed in Fig. 5c, d after the erosion test being much rougher and more irregular than the appearance of the initial surface, as can be seen in Fig. 5a, b.

The appearance of Sample 3, which is obtained from a ZrO-CaO system powder, can be seen in Fig. 6a, b in the initial state respectively in Fig. 6c, d after subjected to the abrasive erosion test. On a comparative basis, we note that this layer, similar to Sample 1, was not affected by the erosion phenomenon.

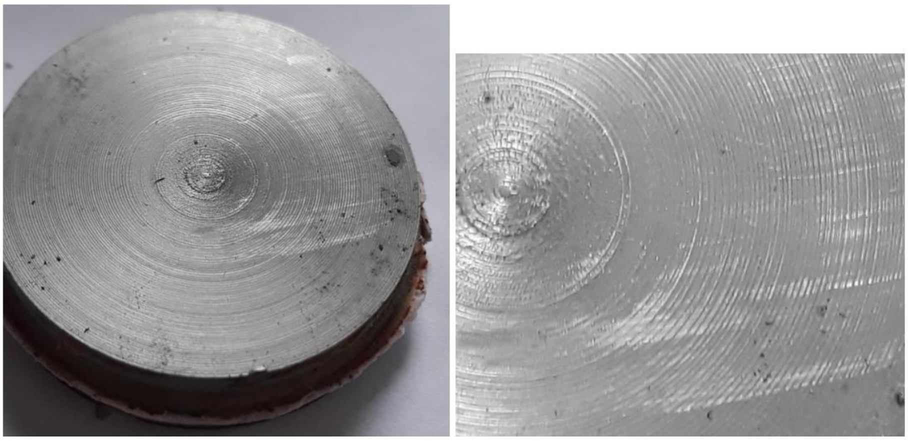


Fig. 7. a) Wear appearance on the control sample surface M.1; b) detail of the trace produced by the surface abrasion erosion test M.1.

Fig. 7 shows the appearance of the blank sample after testing, highlighting the erosion traces that the abrasive fluid respective the metallic particles with which it has been contaminated have produced during the test.

4. Conclusions

Erosion is a very expensive phenomenon, representing a progressive loss of the original material from a solid surface due to the mechanical interaction between the surface and a fluid, multi-component liquid, liquid or solid particles.

Depending on the environment in which the erosion phenomenon occurs, several types are mentioned in the literature: Liquid impingement erosion and cavitation erosion, Solid particle erosion, Erosion / corrosion and Slurry erosion. Slurry erosion is the wear produced when a solid material is exposed to a stream of slurry (a mixture of solid particles in a liquid) that travels at a very high speed. The erosion phenomenon is studied both on the basis of standardized tests (ASTM G32-03, ASTM G134-95, ASTM G73-98, ASTM G75-01), but also non-standardized tests designed for specific applications.

The abrasive erosion test stand proposed in this study is designed to be specific to existing stresses in the operation of hydraulic power steering pumps used in the automotive industry.

The tested samples were from the thermal deposition coatings category, the powders used being from the systems: CrC-NiCr, MgZrO-NiCr and ZrO-CaO.

Following the erosion test applied to these coatings, it was observed that one of these was visibly affected (MgZrO-NiCr) along with the blank sample made of low alloy steel.

Therefore, we can state that the designed stand is functional and can be used successfully in evaluating the abrasive erosion of the layers deposited by thermal spraying.

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