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Analysis of lubricating oils in shear friction tests using infrared thermography

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HIGHLIGHTS

- A verification of the Thermography use in boundary lubricated friction tests is made.
- Mineral oils SAE 20 W50 API SJ and ISO VG 10 are used.
- The scuffing is recorded by means of thermography for SAE 1045 steel specimens.
- It is concluded that Thermography can be used in friction tests for the lubricant film rupture detection.
- It is concluded that Thermography can be used to compare different or similar lubricant oils in the cooling role.

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ABSTRACT

The aim of this work is to analyze the ability of Thermography to monitor the behavior of SAE 20 W50 API SJ and ISO VG 10 lubricating oils from the thermal point of view until the moment of the lubricant film rupture, characterized by the sudden increase in friction, noise, vibration and Temperature in a shear friction test. The methodology used is based on the analysis of thermograms that indicate temperature profiles during the friction tests and at the moment of mechanical failure, comparing these results with those obtained by a thermocouple. The specimens, consisting of SAE 1045 steel cylindrical pins, are rubbed against a wear ring consisting of a weld-locked bearing under the condition of a boundary lubrication regime. Tests were performed by increasing load conditions up to 180 N at 10, 15 and 20 Hz rotations (600, 900 and 1200 rpm). The results show the qualitative and quantitative capacity of the Thermography in the detection of scuffing considering the emissivity of the lubricating oil film equal to 0,82. It is concluded that the Thermography can be used for the detection of the breaking of the lubricating film in pin-on-ring friction tests.

1. Introduction

In Tribology, temperature appears as an important parameter indicative of the severe wear occurrence, also called scuffing. The first studies involving this form of wear were based on the principle of a critical temperature existence in the contact of surfaces, above which the scuffing phenomenon would begin.

Despite the difficulty in determining temperature values that represent a typical behavior of the scuffing beginning, many authors presented some of these values for different tribosystems [2,4–6].

The increase in temperature of a body can be detected by means of Thermography, a technique well consolidated within the predictive maintenance and applied in many fields, including military and medicine, which allows the visualization of thermal images, based on the emitted infrared radiation by a surface.

For tests on lubricated or non-lubricated surfaces, laboratory evaluations are performed on equipments called tribometers, which can both find a tribological pair that is more resistant to friction failures and evaluate the performance of certain lubricating oils.

In this context, the question that guides this work is: Can the Thermography identify the moment of a lubricating film failure in a friction test? If so, what would be the variables to be manipulated for the correct execution and interpretation of a thermogram? In addition, what would be the temperature curve

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characteristic that could report the occurrence of a lubricating film rupture?

The aim of this work is to meet these information needs by using shear friction tests in a test bench with different commercially used lubricating oils, varying parameters such as applied load, oil type and rotation of the wear element from the point of view of Thermography (analysis of the lubricating oils temperature profiles during the experiments).

2. The study of scuffing

The science that specifically studies the problems caused by sliding friction between pieces is the Tribology, defined as the "science and technology of interactive surfaces in relative movement and related subjects and practices" [7].

One of the main focuses of Tribology is wear and tear.

Progressive wear leads machines and equipment used in industries to disablement, as long as maintenance procedures are not performed. To do so, it should be kept in mind that precautionary procedures such as lubrication must be correctly carried out, observing the quantity, type and frequency of exchange of the lubricants. Lubricants have the function of avoiding direct contact between metal faces, in order to facilitate movement between them, reducing the friction.

According to DIN 50 320 cited in [8], wear is the progressive removal of material from a surface in sliding or rolling contact against a surface.

Scuffing is one of the most dangerous forms of wear which is characterized by a marked increase in resistance to movement and irreversible macroscopic damage to the machine components. There is no exact definition for scuffing, but according to ASTM G40-12 cited in [4], this phenomenon can be determined as a form of wear occurring in an improperly lubricated tribosystem characterized by observable macroscopic changes in texture associated with the sliding direction. Its occurrence is associated with the lubricating film rupture in a boundary lubrication condition, besides plastic deformation of surface roughness, contact temperatures higher than 150 °C, high contact pressure, lubricant chemistry, the presence of a protective film on the surface, surface roughness, texture and properties of materials [1]. Scuffing is associated with the presence of high loads or speeds, generating excessive heat that can rupture the lubricating film [9].

The metal - metal contact can be determined by the observation of a characteristic metal rubbing noise [10] as well as the formation of smoke in the contact for extreme wear cases or still determined by electric contact, through capacitive or resistives techniques [11,12].

Infrared systems were build for scuffing studies, both for the analysis of the surface roughness and texture roughness influence on the contact temperature and on the scuffing beginnig [3] and for the evaluation of the additives presence in lubricating oils influence on contact surface temperatures before and during the scuffing [2].

The friction force variation, the coefficient of friction and the temperature in the contact are indicators of the scuffing beginning [6,5]. The combinations of materials with higher scuffing loads have better resistance to this type of wear, but they do not necessarily provide higher scuffing temperatures (temperature at the beginning of wear due to the lubricating film breaking) [5].

Therefore, in view of the temperature importance in friction studies, Thermography can be a very important tool for the Tribology science.

In order to obtain precise quantitative thermographic evaluations, however, it is necessary to observe certain environmental and surface parameters of the object to be studied. Emissivity is the most common source of errors in thermal measurements by means of monoband (which operate only in a spectral range) passive systems (which do not need an additional source of heat to the surface of interest), accompanied by reflected radiation, limited atmospheric transmittance, variations of radiation emitted by optical components, detector noise and other internal electronic sources [13]. Therefore the knowledge of variables such as emissivity, reflected temperature, ambient temperature, relative air humidity, air velocity and distance of the object of study are important for Thermography.

Although the emissivity is a spectral, directional and temperature function, the knowledge of this function is little reported in the literature given its complexity. Thus, total hemispheric emissivity values are more common to be encountered, although their application is restricted to diffuse gray surfaces [13]. The directional emissivity for dielectric or conductor materials is approximately constant for up to 60° measured from the normal of interesting surface [14].

Estimates of hemispheric emissivity for certain spectral bands can be determined by methods such as blackbody simulation (by painting the surface of interest with a known emissivity paint), calorimetric (energy balance) or radiometric methods (thermal radiation sensors) [15].

To simplify and reduce costs, wear studies are usually made in simulators, which may have different geometries, but always use one specimen against another for testing.

3. Materials and methods

To perform scuffing verification by means of Thermography, a friction test bench was designed and is shown in Fig. 1. The bench was adapted to a tensile and compression test machine of the Multi-disciplinary Laboratory of Materials and Active Structures of the Federal University of Campina Grande (LAMMEA/UAEM/CCT/UFCG). However, any machine which has the same working principle could be used to perform these kind of experiments what makes this work easily reproducible.

The numbering of the components in Fig. 1 corresponds to the following items:

1. Filizola BME 10 kN Traction and Compression Testing Machine;
2. Support of the specimens;
3. HBM load cell (200 N) and Filizola load cell (10 kN);
4. ½ CV electric motor;
5. Base for the engine;
6. Wear ring;
7. Oil tank (Crankcase);
8. Self-aligning bearings and bearings housings;
9. Shaft;
10. Adapter base for machine.

The base for fitting, support and crankcase were made of SAE 1020 steel, since this material is more accessible. In order to improve the resistance to the mechanical stresses used in the tests, the shaft was made of SAE 1045 steel. The wear ring is composed of a ball bearing of 52 mm external diameter, 25 mm internal diameter and 15 mm thick, fastened by welding. The chemical composition of the ball bearing is shown in Table 1.

It was decided to use two types of oil with different applications (the Petronas VS + Max 20 W50 API SJ, used in car engines and Ingrax Unix Pneumax S ISO VG 10, applied in pneumatic systems) to verify differences in thermographic readings, once they have different physical properties. The oils were purchased in a local store