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FRETTING AND TRIBOLOGICAL DAMAGE CHARACTERISTIC OF FLEXIBLE DRIVE SHAFT

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ABSTRACT

Transport is at present one of the most supported industry branches in Europe, it is present form the end of the 18th century – in primitive railways, but some matter concerning especially materials and its applications are still up-to-date and are a goal of scientific works or projects. In this paper have been performed the analyses concerning characterization of used car elements in form of flexible drive shaft. The main goal of the work was the analysis of the material wear resistance after long-term application and natural ageing, reaching over a several years. The analysis was performed based on the results obtained based on research using especially light microscopy as well as Rockwell hardness testing were also carried out in terms of identification of the occurred wear damage characteristic after long-term application. The main reason was to recognize the fretting mechanism on the surface microstructure of the used shaft and to propose eventually prevention for occurrence of these wear mechanism in relation to new produced material.

Keywords: Fretting, Microstructure, Drive shaft, Tribological wear

1. INTRODUCTION

The name of the phenomenon described in this paper is derived from English. "To fret" means to wear, damage or make a pattern on something by constantly rubbing or biting. This phenomenon occurs on the contact surfaces of highly loaded machine elements and is a type of tribological wear. The process consists in the formation of local material losses in machine elements subjected to vibrations or slight slips arising as a result of these elements rotating or reciprocating movement or their movement under the influence of cyclic loads and intense corrosive environmental impact. An example of fretting is ripping the surface of the rivet connecting two cooperating elements. Its surface layer is damaged by the resulting vibrations. The damaged material is then attacked by corrosion, which reduces its strength and leads to increased damage [1-8].

This process appears in the elements of the groups that are nominally resting against each other. They can be: spline, wedge, threaded, pin, bolt, push, rivet, claw and toothed connections. Fretting is a process often confused with friction. In addition to friction, the amplitude of relative displacement, which oscillates around 70 μm, plays a very important role in fretting wear. However, this process was noticed within amplitudes from 0.1 μm to about 300 μm. Due to the very complexity of this phenomenon, its definition has not been strictly defined. In a broad sense, it is the sum of adhesive, fatigue, abrasive, corrosive and plastic deformation wear. There are three groups of factors responsible for fretting wear [9-14]:

- displacement conditions relative to the joined components (load size, oscillation amplitude, oscillation frequency and number of cycles),
- surrounding conditions (temperature, humidity, corrosion intensifying factors),
- properties of the materials used.

Fretting wear is considered mathematically as proportional to the load, however, only if its increase does not reduce the oscillation amplitude. The relationship occurring between the value of motion amplitude and wear is also linear. An increase in amplitude results in an increase in consumption. A growth in the amount of oscillation cycles in the initial phase of the process directly affects the value of wear, but then decreases and reaches a constant value. The material from which the friction pair is made has less fretting wear if it is made of a material with less adhesive capacity, better sliding properties and greater mechanical strength. The influence of the environment is decisive for the intensity of the corrosion process.

In interference joints loaded with bending torque, the fretting wear structure is also influenced by the geometric structure of the contact area and the phenomena occurring during assembly. You can distinguish the type of connection (shrinkage, pressed), the value of the interference force, surface roughness of the associated elements.

The fretting phenomenon causes weight loss and the formation of fretting pits. This can result in the building of a potential notch, which can be the reason for the initiation of fatigue crack. Fretting wear causes loss of interference between components or a change in the conditions of load distribution in the connection. This can lead to further damage to the components and the connection. If fretting is accompanied by fatigue load, fatigue strength is reduced several times [15-19].

Fretting wear prevention is separated into two groups:

- ❖ measures to reduce the amplitude of vibrations:
    - • proper selection of element stiffness,
    - • use of vibration damping devices,
    - • increasing contact load.
- ❖ limiting the effects of fretting:
    - • the use of lubricants on the top of the contact area,
    - • selection of material resistant to fretting,
    - • the use of thermal and thermo-chemical treatment,
    - • applying wear-resistant coatings.

2. INVESTIGATION PROCEDURE AND MATERIAL

For investigation a flexible drive shaft was used, presented on Fig. 1. Because of its design as a part made of polymer and iron, a flexible drive coupling reveals lot of advantages because of its properties. First of all, the coupling is designed as maintenance-free, ensuring a long service life. It is also highly resistant to outside factors. Moreover, it compensates also for misalignment caused by high assembly tolerances set by the engineers. For instance, it provides the possibility to avoid sounds and perceptible droning coming from the occurrence of low-frequencies and vibrations caused by mouvement of drive shafts, e.g. by starting up or when a load is changing.

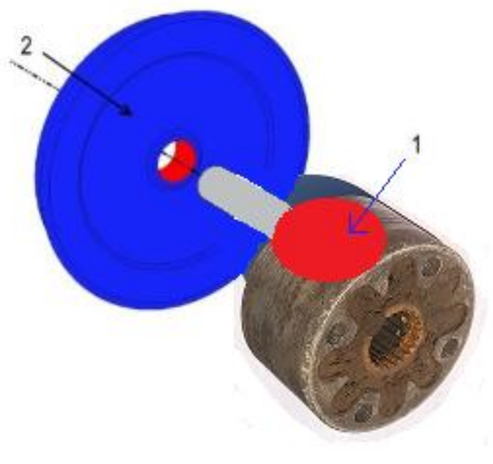

Fig 1: Flexible drive shaft used for investigations

In the connection in cars, fretting wear is very difficult to diagnose due to the lack of ongoing monitoring of the surface structure of the elements. Figure 1 shows the places where the fretting phenomenon (red) occurs at the contact of the wheel hub (2) and the axle sockets (1).

It was found that fretting wear always occurs on both parts of the shoulder. It takes the form of areas of a certain width covering the entire circumference. The reason for this is the limited occurrence of the lubricant and the large surface area of the temporary contact placed between the hub and the shoulder, which is a favorable condition for the formation of adhesive joints and then for the creation of fretting damage. Another condition for the occurrence of fretting wear at this place will be the occurrence of tangential relative displacements between the surfaces of both connected elements. In fatigue tests, the maximum oscillation amplitude will occur at the edge of the shaft connection.

a) b)

Fig. 2 Axis surface wear, a)side view, b) overview

The analysis of changes in the material hardness of the shaft core and shaft surface occurred during long time usage under real conditions was presented in Fig.8. Other investigations involving particularly:

- light microscope - comparison of macrostructure of the material obtained from samples taken from the used and not used fastener, the samples have been cut in the same adequate places in the horizontal and longitudinal direction, polished and then etched in 10% NaOH in room temperature,
- chemical composition investigation using the EDS method - an analysis of possible changes of the chemical composition present in the used material,
- Rockwell hardness measurement - analysis of micro-hardness measurements,
- macro structure comparison and analysis of changes occurring after usage of the axis steal material.

3. INVESTIGATION RESULTS

The microstructure images presented in Figures 2 and 3 show that the dominant damage is the formation of build-up material on the surface of the shaft. The accretions then undergo plastic deformation and tend to dislocate and crack. Also microcracks and local wiping of the roller surface can be observed. The wear area is characterized by brown-black coloration indicating surface oxidation of the material.

The investigated microstructure of the material after long-term usage reveals following feature - slightly dark colored places, which are different types of impurities and reveals a lot of discontinuity places. This could suggest that this material is not a material having the best possible quality. This indicates that this material is a low-grade steel used for the production of flexible drive shafts in the past decades (see Figures 4b, 4d, 4f).

In addition based on the light microscopy analysis of the microstructure of the shaft surface, it can be seen small precipitations see especially in Figure 6b of the size of ca. 5 µm.

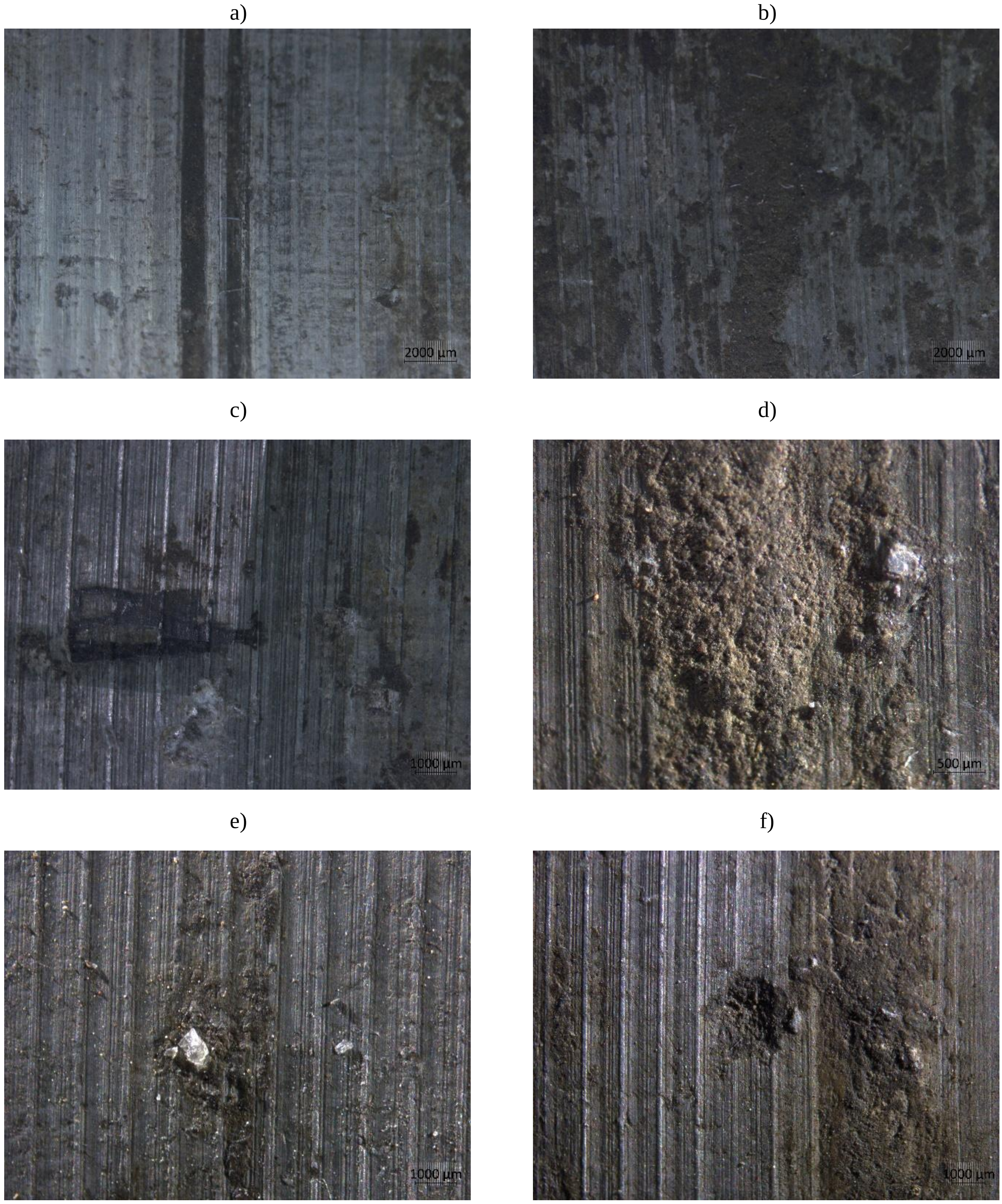

Fig. 3 Fretting wear on flexible drive shaft surface: a) machining rings after metal late treatment, b)fretting along the machining trenches, c) separate fretting places, d) corrosion areas, e) inclusion in the surface, f) wholes after falling out inclusions

The nature and location of the fretting wear are similar on the entire area of the shaft surface. The machining rings, covering the entire circumference on the outer sides of the shaft are probably the reason for initiation of fretting, by creating discontinuities of the surface, and creating the possibility for nucleation of surface damage e.g. by the sedimentation of dust and impurities coming from outside..

According to the EDS investigation results it can be state what changes have occurred within the material compared between the sample material obtained from the used shaft. A very important issue is the relative stability of the chemical composition measured on the cross-section surface of the material and it phases present as impurities as well as intermetallic phases or precipitates. Figures 6a and 6d shows the elements detected in the sample from the used shaft. The samples made from the used material (Fig. 6c, marked place) shows numerous precipitates, consisting from the following elements such as silicon e.g. silicon.

a) b)

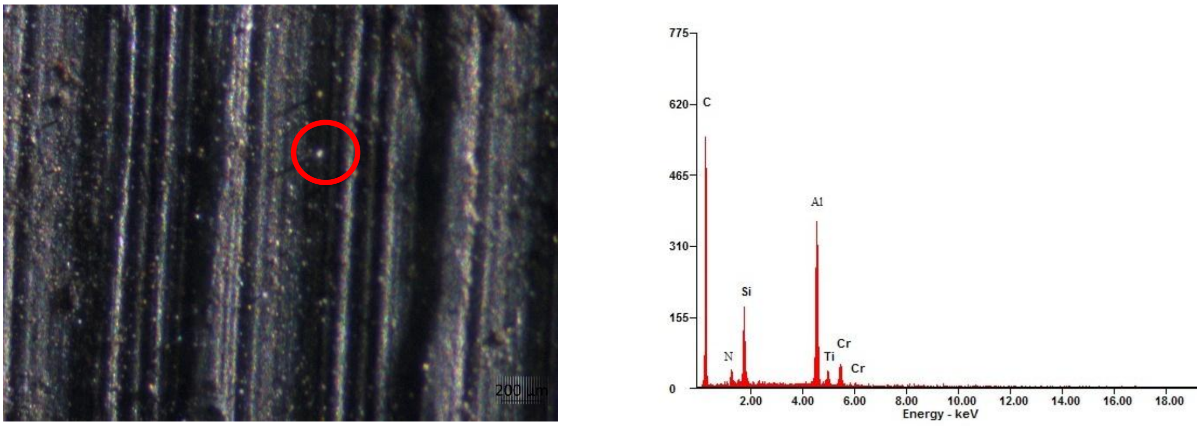

Fig. 4 Microstructure and the corresponding EDS area microanalysis: a) high mag image with visible small wear particles, b) EDS

Based on Rockwell hardness measurement, the hardness value of the material should be in the range 45-48 HRC. The measured average hardness of the used elastic shaft is equal 48 HRC. The analysis of the results reveals that the mean hardness value of the used fastener is very coherent with the theoretical value, and does not exceed 3%, however with different distribution along the entire element.

Summarized it can be state that the revealed changes can be observed in terms of the structure of the surface, where the amount of the fretting mesh at the surface of the material used for a decade due to the wear process of the surface as well as the production process parameters is very high. Themselves the research hypothesis was confirmed, that the material of the elastic shaft will reveal significant damaged and that there will appear in the microstructure different changes, for example: the occurrence of areas with fretting as well as of impurities and the occurrence of not desired intermetallic phases and/or precipitates. In addition, it determined that the sample material, which was produced few decades ago, was of low quality. Fretting wear is a phenomenon not fully studied. The complexity of mechanisms occurring during the formation and progress of wear does not allow for unambiguous determination of ways to prevent wear. Damage resulting from fretting, i.e. micro-cracks and pitting, can be a source of notches for fatigue cracks. The results of many studies indicate that the fatigue strength of a material treated with fretting decreases even by about 30%. From the industry's point of view, the wheelset is a critical element when it comes to ensuring safety. During production processes, particular attention should be paid to the material from which the set is made and the raceways of bearings, lubricants used in axle boxes and the quality of the connection. The surface condition of the joined elements is also very important, i.e. the type of treatment used and the level of roughness.

4. CONCLUSIONS

Summarized the following issues were found:

- The study of mechanical properties suggest a lack of change in hardness between the material of the used elements. the determined hardness is between 45-48 HRC, what is generally in the range of the allowed measurement error. So the analysis of the presented hardness measurement results allows to conclude that the long-term usage of the elastic shaft does not affect the material in a significant way, ensuring originally obtained values.
- It was confirmed the presence of additional elements, occurring in form of impurities measured by mind of macrostructure on the surface in only minimal. The impact of discontinuities on the microstructure can be of huge importance for long-term applications. Special care should be devoted to the quality of pure material used for production of the flexible drive shafts.
- The results of the tests carried out by mind of optical microscopy show that the particle size of the used elastic shaft reaches from 8 to 10 mm. It is possible that o of the factor which helps to build the fretting areas on the surface is the mashing process, which leads to the formation of trenches, which forces and accelerate the occurrence of fretting.

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