A COMPLEX STUDY OF SURFACE FATIGUE IN CARBON STEELS CAUSED BY ROLLING CONTACT AND SLIDING FRICTION

A.Szabó[1], K. Bán[1], G· Juhász[2], L. Novák[3] and A Lovas[1]

[1] *Department of Vehicle Manufacturing and Repairing, Budapest University of Technology and Economics, Bertalan L. u. 2., H-1111 Budapest, Hungary*
[2] *Department of Vehicle Parts and Drives, Budapest University of Technology and Economics, Bertalan L. u. 2., H-1111 Budapest, Hungary*
[3] *Department of Physics, Faculty of Electrical Engineering and Informatics, Technical University of Kosice, Park Komenského 2, 042 00 Košice, Slovakia*
E-mail: szabo@kgtt.bme.hu

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Introduction

The formation of macroscopic defects (cracks) near the surface of structural elements where either rolling or sliding processes take place, is significant not only from economic but also safety points of view. Therefore, detection (localization) of these defects - which mostly appear as microscopic cracks(Fig 1.)- is of great practical importance.

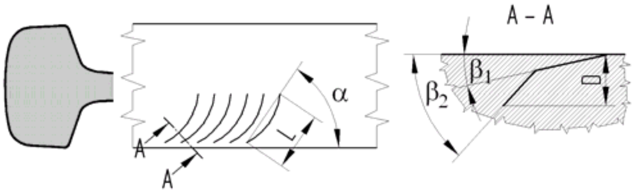


Fig.1. *Typical arrangements of crack formation, induced by rolling contact deformation (A-A section: the crack propagation in the material)*

Most of crack-detection methods are based on direct, optical observation. Only a very few experiments are based on indirect measurements, which can detect principally the embryonic state of crack formation or even the pre-existing stress accumulation, which would be helpful in avoiding catastrophic breaking phenomena. The paper presents a complex study which includes thermopower, static coercivity as well as micro hardness measurements and comparison of the results obtained which makes possible to recognize very early state of damage evolution.

Experimental

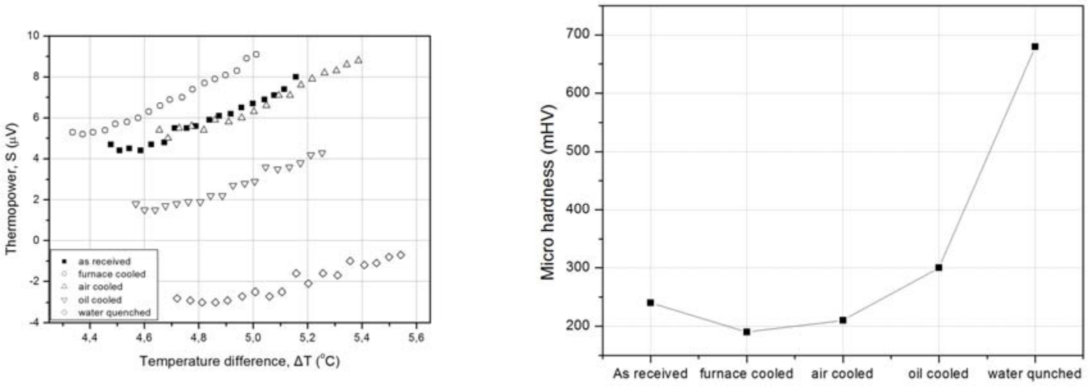
Commercial C45 steel and Mn 0,9% carbon steels were used for experiments. The details of thermopower, static coercivity, as well as microhardness measurements are reported in Refs [1,2].

Results and discussion

The change of hardness and thermopower due to the accumulation of the bulk, or surface stresses

It is well known, that the hardness of Fe and the low-alloyed carbon steels (Fe-C alloys mainly with pearlitic structure) increases either by cold working (work hardening) or via rapid quenching (quench-hardening). Although, both types of hardening are bulk effects, their mechanisms are different. The origin of work hardening is essentially a dislocation pile up mechanism. In contrast, the quench hardening is inducted via phase transformations (the tendency of increasing martensite phase formation is supported by the literature) where the generated internal stress is responsible for the hardness increase.

The thermopower (TEP, S(ΔT)) shift clearly demonstrates the contribution of phase transformation and the stress level increase in the hardening process. (see Fig.2/a) The same increasing bulk stress state is clearly reflected in the trend of micro hardness values, measured on the same sample. (see Fig.2/b.) In this case, the resulting S change (gradual shift to negative direction), is a result of two effects: phase transformation and induced stresses.

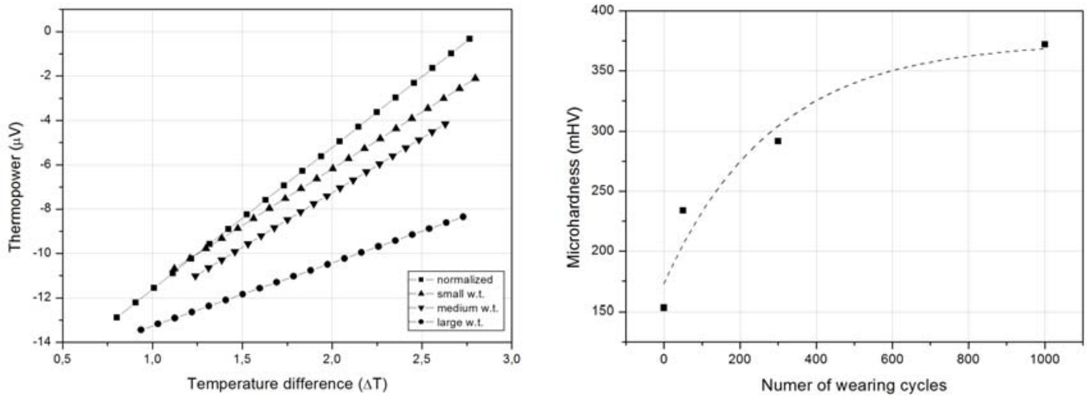


(a) *(b)*

Fig 2. *The influence of thermal treatment of studied samples on thermopower (a) and micro hardness (b)*

In order to separate the mentioned effects, surface sliding were performed on the same, normalized steel samples. Results are illustrated in the Fig.3.

Both the thermopower measurements and micro hardness tests were carried out along a wear track. The degree of wear was gradually increased and quantified by the scratch number (50-small; 150-medium; 1000-large wear track).



(a) *(b)*

Fig.3. (a) Thermopower *characteristics of samples with different wear degrees ; (b) micro hardness versus number of wearing cycles.*

As the wear track increases, the S(ΔT) shifts also in negative direction (Fig 3/a). Besides, the change of the slope for the individual curves is more pronounced, and strong divergence is observed for all S(ΔT) curves. The evaluation of micro hardness in the wear track is illustrated in Fig 3/b.

The possible role of increasing surface roughness was also examined during these experiments, using an etalon with a calibrated rank of surface roughness specimens.

It was found that the roughness increase itself has no influence on the thermopower value (see the Fig.4.), consequently the increasing deformation inducted stress in the surface layer is responsible for the thermopower change.

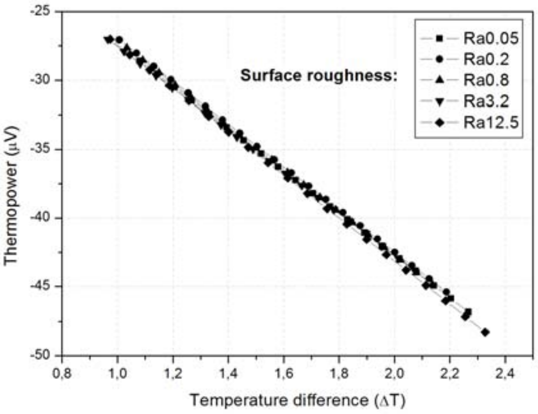
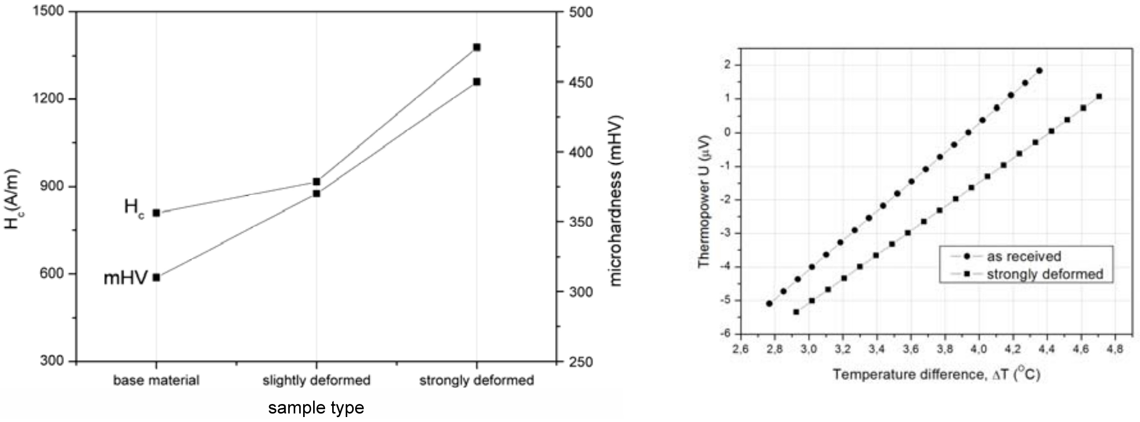


Fig. 4. *The test of influence of surface roughness on thermopower*

The coercivity increase in the surface layer prior to the initial period of crack formation

Fig.1 shows, that cracks are developed in the surface layer due to work hardening. Simultaneous H_c increase can be detected across the sample, depending on the rate of degradation. It is visible that right before crack formation, the H_c value suddenly increases (Fig 5/a). The work hardening can also be supported by hardness measurements, which was performed on the cross-sectional area of the sample (Fig.5/a.). According to the metallographic micrograph, visible structural change can also be detected in the vicinity of surface along the rolling track.

Fig 5/b shows, that simultaneously with increasing H_c and microhardness values, there is a negative S(ΔT) shift in the thermopower.



(a) *(b)*

Fig.5. *Static coercivity (Hc) and microhardness (mHV) versus deformation state (a) thermopower measured on samples with different deformation states (b)*

Summary

1. Simultaneous changes in microhardness, thermopower, as well as in coercivity were observed in the surface layer of carbon steel samples being previously subjected to rolling or sliding.
2. The observed changes are the consequence of increasing work and quench hardening, which was already developed in the period of plastic flow.
3. In this level of “work hardening” crack formation cannot be detected in the samples.

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