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STRAIN HARDENING OF COPPER

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Abstract

Activity of cavitation damage to make the hardness in layers of surfaces, also to microstructures with communicate of materials surface. The hardness will be able to make from mechanical characteristic feature of materials for cavitation damage the decisive element.

The hardness could be to characterize changes of structure of material during plastic deformation.At the very begining of changes of mechanical characteristic feature of materials to make use of their notices are significant in practise before their total degradation.

1. Introduction

The cyclic deformation of copper brought about the dynamic cavitation mechanism affecting on homogeneous structure can help to interpret the fatigue damage of polycrystalline materials.

The strain hardening that precede the surface structure damage can be observed on slip bands with the aid of scanning electron microscope (SEM).

2. Cavitation wear

In the case when a cavitation bubble comes into region of higher pressure than a cavitation pressure is, the rapid steam condensation is occuring and the considerable impacts arise that, together with the other accompanied phenomena, affect on the by-passed body surface and cause its cavitation damage.

The mechanical effects appear by means of increasing the internal stress, arising the dislocations, microcracks and, consequently the fatigue damage of a material. The fatigue process can be characterized with the three stages:

- strain hardening
- breaking the crystalline latice and cracks initiation
- cracks extending

The mentioned fatigue process connected with the cavitation damage is appeared in surface micro-volumes of material.

3. *Cavitation resistance of a material*

The cavitation resistance is a capability of a material to resist the cavitation affects and that is used to be expressed by means of the wear scale. It is posibble to describe the cavitation resistance inderectly expressing:

- the length of latent period
- the time needful to reach the determined volume loss
- the materials loss in the course of determined time
- the average speed of cavitation wear in the course of the evolved stage

For the majority of materials exposed to cavitation effects, the visible materials losses do not occure in the course of latent period. During the stage, the energy of hydraulic micro-impacts on the body surface is consumed predominantly for plastic deformation of a surface layer, appropriately for materials hardening.

4. *Selection of a material*

The pure metals are often used to study the fatigue processes because the investigation of orientation dependences of structure changes during the separate stages of the fatigue damage is easier. The obtained results are important to analyse and interpret the cavitation-fatigue damage of alloys. The most suitable material for the purpose is copper, that is to say to acquire an important knowledge on damage mechanisms and fatigue-fracture rising.

Cavitation impact induced cyclic deformation on the copper surface can be exhibited by means of forming the persistant slip bands comprising the extrusions and intrusions that present the characteristic surface relief, to so-called surface corrugating. The surface reliefs with transition into damaged regions were observed on SEM.

The cast and wrought copper was investigated in scope of the paper. The corrosion resistivity of the material is an important presumption to exclude the corrosion effect from the cavitation course. The difference between the primary copper structure (purity 93%) is perceptible from the metallographic point of view comparing the Fig.1 with Fig.2. For the cast copper is typical the disarranged structure brought about the thermal gradient during its crystallization. The wrought copper is characterized with the regular arrangement of grains with occurence of twins.

5. *Experimental appliance*

The testing appliance consisting of the ultrasonic generator UG 251 linked with the magnetostrictional transducer and gradually changed concentrator was used to simulate the cavitation processes. The applied frequency was 18 kHz and applied amplitude was 7,5 μm. To rise the amplitude of deviation, the gradually changed concentrator was added to the magnetostrictional transducer. At the end of the concentrator, the active sample was put into a vessel with the end of sample 25 mm plunged under the liquid level opposite the jig with a passive sample on the bottom.

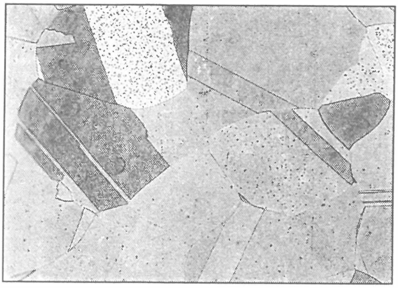

Fig. 1: Microstructure of the wrought copper. Etched in $K_2Cr_2O_7$; magn. 100x.

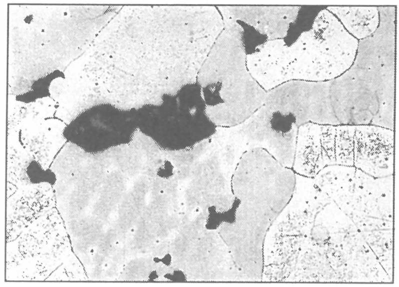

Fig. 2: Microstructure of the cast copper. Etched in $K_2Cr_2O_7$; magn. 100x.

To determine the cavitation resistance, the mass-loss-method was chosen as the one of the possible methods comparing the ability of a material to resist to the cavitation damage. The standard conditions of cavitation damage were used and the found-out values of mass losses were plotted in graphs with time dependence. The samples were exposed to cavitation up to 500 minutes with maximum total mass loss value 70 mg, see Fig.3. The speed of separating of the material from the beginning is rising exponentially but after 30 minutes of loading the mass-loss vs. time dependence is constant. The latent period is practically zero.

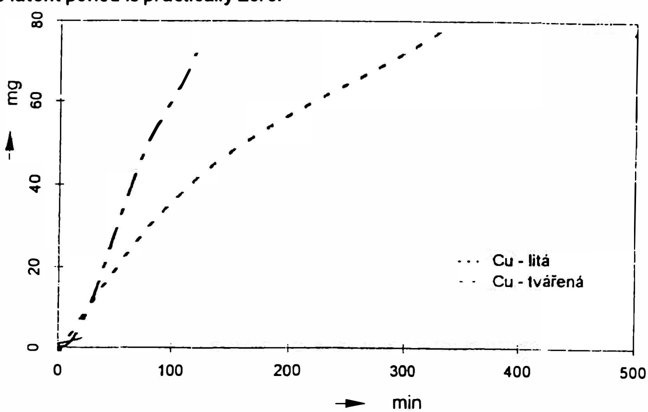

Figure 3: Graphic dependences of mass losses in copper.

It is possible to prove the rise of plastic deformation in surface layers of pure cast copper in this way that a cavitation damage is applied on an annealed material (cooling in water) accompanied with the polyedric grains forming and partial implications of arising the slip lines. During the initial stage of cavitation deformation with the deformed crystallic grains forming, the slip planes are getting into positions containing only very small angles with the direction of deformation; the lattice orientation in the crystalline planes is deformation-controled. The effect is accompanied with the twinning and other, more complicated slip processes.

The lattice along the dislocation line is greatly deformed and the slip processes can start as early as the external stress is relativelly low. The cleaner and more perfect crystals are better deformable with respect for better motion of dislocations (a number of dislocations is less), see Fig.4. A dislocation reaching the own grain boundary in a polycrystalline material can not continue its slip motion to a neighbouring grain. The other dislocations moving on the mutually intersecting slip planes are the main obstacles for the dislocation motion in strain-hardened metals. During the next cavitation producing, the slip lines are proceeding in structure accompanied with the typical twinning - see Fig.5. At the beginning of the hardening process, there is a state for which the internal stresses affecting the dislocations are not canceled and the particles are put so closely side by side, that a dislocation line can not pass and the material seems to be outwardly hard. There is possible to study the hardness of grains brought about the structure defects that prevent the dislocations moving.

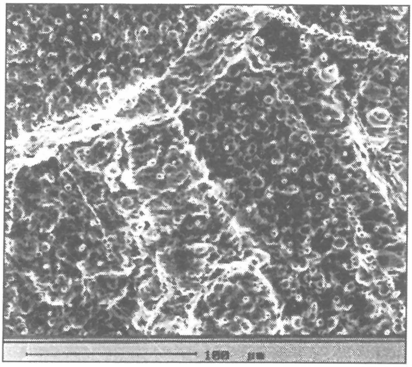

Fig. 4: The slip lines in cast copper at the beginning of cavitation damage

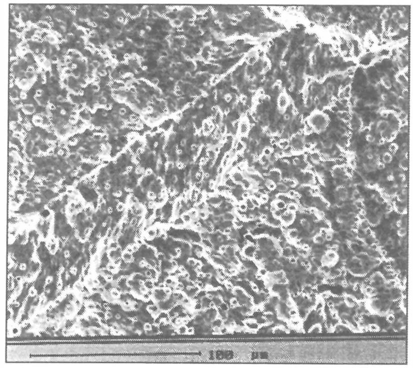

Fig. 5: Detail of twinning in cast copper after 10 minutes of cavitation damage.

6. Experiment

The strain hardening before the starting metarials degradation can be consequently expressed on the basis of microhardness changes in the frontal section crossing the centre of primary cavitation region. Like this formed profile of the cavitation-loaded wrought copper with the characteristic sharp tips and hollowed formations is shown on Fig.6. There is a visible breaking out of relatively great parts of grains from the micrograph.

Although the mechanism of wrenching-up of the material is influenced by means of the intermetallic phases, the profile of cast copper is different and the surface relief shows shorter projections in comparison with the wrought copper - see Fig.7.

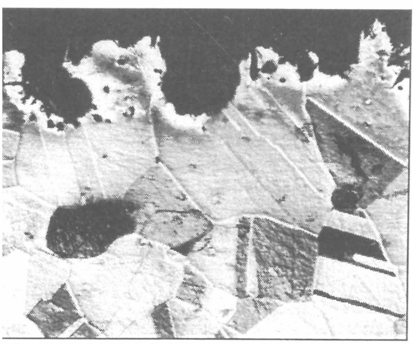

Fig. 6: Profile features of the wrought copper after cavitation affecting; magn. 50x.

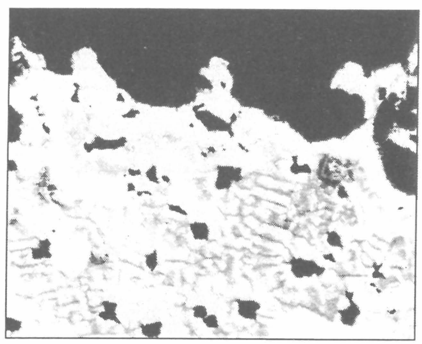

Fig. 7: Profile features of the cast copper after cavitation affecting; magn. 50x.

The difference is apparent as early as from the dealt-out microhardness of the two materials in dependence on radial distance. The graphic dependences - see Fig.8 and Fig.9 - show the considerable change of hardness in case of directly attacked grains for the wrought as well as for the cast copper. The dealt-out values of hardness give evidence about the total difference of the two materials. The wrought copper after work hardening and cavitation hardening presents the values of hardness from 85 HV to 68 HV, while the cast copper presents values of hardness from 75 HV to 54 HV. Hence it follows, that there is less dislocations in the cast copper after cavitation hardening than in the wrought copper. The cavitation resistivity of the wrought copper is less in comparison with the cast copper. That fact confirms the mentioned theory of cavitation damage.

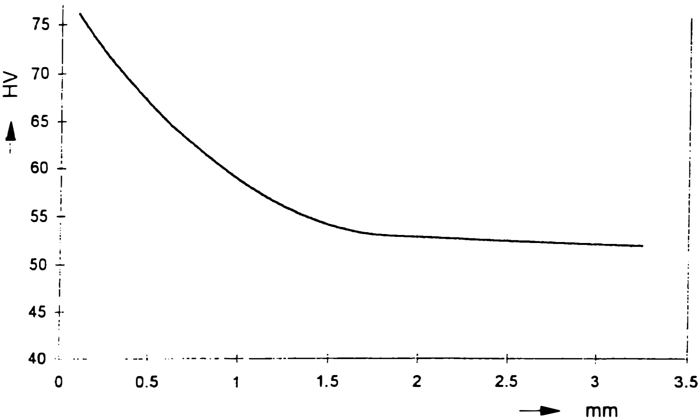

Figure 8: Dependence of microhardness on radial distance from the surface; the cast copper.

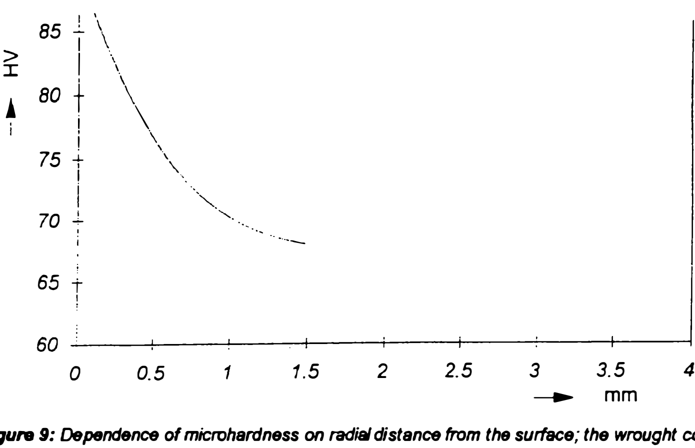

Figure 9: Dependence of microhardness on radial distance from the surface; the wrought copper.

7. Conclusions

The initial mechanism comes in case of studied materials always at the weakest structure regions, f.e. at grain boundaries. The next course of materials damage is dependent on its mechanical properties, on its ability to be plastically deformed as well as on its heat treatment. During the continuing cavitation, the perceptible difference between the grains and the grain boundaries successively disappears and cavitation proceeds into depth. The stage is characterized with the separation of macroscopic parts of material and its total degradation.

Oxide layers were not proved in the case of copper, which is brought about the dominant influence of cavitation damage that does not make it possible. Cavitation process can be classified as one of the possibilities of rising the limiting state of a material. The attaining of limiting state depends on the dynamics of a damage accumulation, that is a function of substructure and structure state of material, technologic and constructional characteristics of a product and conditions of its utilizing.

The mechanical loading, the operating temperature as well as the energetic fields influence the cavitation process. Cavitation brings about the local surface damage that can conduce to limiting state. Understanding the causes, sorts and forms of limiting state of a material enable us to choose the procedures precluding f.e. a collapse of a construction or its components and thus prevent arising the accidents with materials character - crashes, people endangering or ecological catastrophes.

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