ON THE ROLE OF PHYSICOCHEMICAL PROCESSES IN THE SURFACE LAYERS OF STEEL DURING CYCLIC DEFORMATION IN MELTS OF LOW-MELTING METALS

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ON THE ROLE OF PHYSICOCHEMICAL PROCESSES IN THE SURFACE LAYERS OF STEEL DURING CYCLIC DEFORMATION IN MELTS OF LOW-MELTING METALS

(Presented by Academician P. A. Rebinder on 25 V 1960)

It is known that, under the action of surface-active media, the fatigue strength of steel may decrease significantly ([1,2]). These conclusions confirm Academician P. A. Rebinder' s theory of the adsorption-induced facilitation of deformation and reduction in the strength of solids ([3]).

If, however, a surface-active medium has no influence on the strength of solids, or even increases it ([4–6]), then the reason for this must be sought in those additional or secondary surface phenomena that mask the manifestation of adsorption effects but may be connected with them. In particular, the creation in the surface layers of a metal, by roller burnishing ([7,8]), of compressive stresses leads to prevention of the harmful influence of a surface-active medium during cyclic deformation of the metal. This is explained by the fact that, during burnishing, surface defects are closed, and the surface-active medium cannot penetrate into the interior of the metal.

A considerable increase in the fatigue strength of steel specimens with stress concentrators under the action of molten tin or the Pb–Sn eutectic was found ([4–6]). It was assumed ([6]) that this phenomenon was caused by plastification of the bottom of the concentrator by the liquid-metal melt, as a result of which the stress concentration decreased.

In connection with the positive effect found for the action of molten Sn or Pb–Sn on cyclically deformed steels, it is also of interest to investigate whether other melts lead to an analogous effect. The experiments carried out give a negative answer. As can be seen from Fig. 1, under the action of the Pb–Bi eutectic melt* there is a sharp drop in the fatigue strength of specimens with stress concentrators**. Similar results are also obtained when testing specimens of steels of the 1Kh18N9T type. Consequently, the effect of increasing fatigue strength under the action of molten tin or the Pb–Sn eutectic is the result not only of plastification, but also of those diffusion and chemical processes that take place when the deformed steel is in contact with tin.

To confirm this assumption, fatigue-strength tests in the Pb–Sn eutectic melt

Fig. 1. Fatigue-strength curves of specimens with stress concentrators, made of normalized steel 50. Frequency of stress variation 50 cycles/sec. 1 —specimens tinned with Pb—Sn eutectic in air at 400°. Unshaded squares denote control points obtained in tests of tinned specimens in a beaker with a Pb—Sn eutectic melt; 2 —specimens in air at 400°; 3 —specimens in air at 20°; 4 —tinned specimens in a Pb—Bi eutectic melt at 400°.

Figure 1: Fig. 1. Fatigue-strength curves of specimens with stress concentrators, made of normalized steel 50. Frequency of stress variation 50 cycles/sec. 1 —specimens tinned with Pb—Sn eutectic in air at 400°. Unshaded squares denote control points obtained in tests of tinned specimens in a beaker with a Pb—Sn eutectic melt; 2 —specimens in air at 400°; 3 —specimens in air at 20°; 4 —tinned specimens in a Pb—Bi eutectic melt at 400°.

were arranged in a somewhat different manner than had been done previously (4–6).

Specimens tinned with the Pb—Sn eutectic were tested in air at the same temperature at which they had previously been tested for fatigue—

* To ensure reliable wetting of steel specimens by the Pb—Bi eutectic melt, the specimens were first tinned with the Pb—Sn eutectic melt and then immersed in a bath with the Pb—Bi eutectic melt. During fatigue-strength testing, the specimens were in a bath with the Pb—Bi eutectic melt.

** The specimens had the same stress concentrators as in work (6), but with an angle at the tip of 45°.

···strength in a bath with a Pb—Sn eutectic melt. As can be seen from Fig. 1, the life of the specimens in this case remained increased. What is essential in these experiments is that during testing the surface film of the melt is oxidized and, consequently, the plasticizing effect disappears. Nevertheless, the specimen continues to withstand an increased cyclic load.

On this basis one might suppose that plasticization of steel by the melt has no influence on the effect of increasing fatigue strength, and that the whole matter lies in the physicochemical processes that arise during tinning of the steel. The experiments do not confirm such a conclusion, since tinned specimens tested at room temperature have a fatigue-strength limit 30-35% lower than that of untinned specimens.

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Also noteworthy are experiments that directly show the important role of plas-

Fig. 2. Schematic of an apparatus for investigating stresses arising in the surface layers of steel as a result of diffusion of the melt

Figure 2: Fig. 2. Schematic of an apparatus for investigating stresses arising in the surface layers of steel as a result of diffusion of the melt

ticization of steel by the melt at the initial moment of cyclic deformation. As is known (9), carrying out fatigue-strength tests in a Pb—Sn melt on specimens that have not been tinned beforehand can lead to a considerable decrease in fatigue strength. Consequently, only the combined influence of the plasticization effect and of other physicochemical processes at the initial moment of cyclic deformation can lead to an increase in the fatigue strength of steel.

It is known that the plasticization effect is the most general, universal effect of the action of a surface-active medium, always arising during deformation of a metal in any surface-active medium (10). The plasticization effect is associated with facilitating the emergence of dislocations onto the surface of the metal being deformed (11). In addition, in the plasticization effect a significant role may belong to subsurface dislocation sources (having one pinning point), whose start-up stresses are considerably lower than those of sources with two pinned points. A reduction in surface energy should lead to increased activity of subsurface sources and to a decrease in the yield strength of the metal (10).

Thus, the essence of the positive influence of plasticization of the surface layers of a metal at the initial moment of cyclic deformation consists in the removal of local internal normal stresses arising at the head of a pile-up of dislocations near the surface layer of the metal, which in the ordinary state may be a considerable obstacle to moving dislocations (12).

However, it should be borne in mind that the plasticizing effect can lead to an increase in fatigue strength only in the case when, for some reason, the surface-active melt cannot penetrate into the metal along the developing defects. Such reasons are absent when the Pb—Bi eutectic is used, and therefore a considerable decrease in fatigue strength is observed. In this case there is only the effect of an adsorption-induced reduction in cyclic strength, since neither lead nor bismuth, at the accepted test temperatures, reacts chemically with steel (13).

The process proceeds differently during cyclic deformation of steel in a tin melt or in the Pb—Sn eutectic.

A tin melt, diffusing into the depth of the metal along developing defects, enters into a chemical reaction with the steel, forming an intermetallic compound of the type $FeSn_2$. Since the lattice cell size of $FeSn_2$ is larger than that of the Fe atomic lattice (13), compressive stresses arise in the surface layer of the metal, hindering the penetration of the tin melt into the depth of the metal.

Fig. 2. Schematic of an apparatus for investigating stresses arising in the surface layers of steel as a result of diffusion of the melt

Of course, tin from the melt will diffuse through the intermetallic layer into the depth of the metal. However, upon encountering Fe, chemical interaction will again occur with the formation of new compressed volumes of metal.

Therefore, the dissolution of the surface layers of steel that takes place during tests in a bath with a tin melt or the Pb—Sn eutectic does not lead to the removal of compressive stresses.

As was shown (14), the compressive stresses that form are stable over a fairly wide temperature interval.

The formation of compressive stresses in the surface layer of steel as a result of tin diffusion and the formation of an intermetallic compound of the type $FeSn_2$ can be observed qualitatively using the following simple device (Fig. 2). A flat specimen 1 is clamped at one end in a collet 2. An extension 3 with a mirror 4 is placed on the cantilevered end of the specimen; a beam from illuminator 5 is directed onto the mirror. The specimen is tinned on one side. With the aid of electric furnace 6, the temperature of the specimen is brought to a specified value (400°). After this, from the deflection of the beam on scale 7 one can—

but one can observe how the specimen gradually bends in the direction indicated by the arrow. Such bending can occur only under the action of compressive stresses in the surface layer.

Thus, during prolonged fatigue tests, in the incipient microcracks of fracture there is time for a phase film of the intermetallic compound $FeSn_2$ to form; it causes the appearance of compressive stresses in the surface layer of the specimen and thereby impedes the further development of the microcrack. As a result, the fatigue strength of the steel increases. In those cases where side effects of this kind are absent (for example, fatigue tests of steel in a Pb—Bi melt), the effect of a sharp reduction in fatigue strength is fully manifested, as indeed should be the case in very strongly surface-active media. The Rebinder effect is a universal effect, always present during the deformation of metals in surface-active media, but in some cases it may be masked by side effects associated with the formation of new phases.

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