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ON THE MICROSTRUCTURE OF THE FATIGUE FRACTURE SURFACES IN TITANIUM

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INTRODUCTION

The contribution of twin boundaries to the fatigue fracture of titanium seems to be well established [1], the same can be said about slip bands. Grain boundary cracks, including cracks at the twin boundaries were found also by Owens et al [2].

More recently so called slipless fatigue was established as being the characteristic feature of the fatigue fracture of titanium. It was proposed and elaborated by MacDonald and Wood in a series of papers [3-5]. They found that at low frequency of loading /28 Hz/ fracture begins by shear without observable slip. However, at high frequency /16 kHz/ fatigue cracks initiate in separate grains at slip bands in the maximum shear direction. The crack formed in this manner grows consecutively by linking up with other similarly cracked grains and thus formed macrocrack follows the direction of maximum tension. According to MacDonald and Wood, slipless cracks have their origin and come to the end at the grain boundaries, they promote formation of many secondary cracks at the slip bands and at the grain boundaries and they often cause displacement of fragments of the cracked grains. MacDonald and Wood considered both elastic fatigue at alternating torsion and two stages of plastic fatigue starting from formation of coarse pits up to their elongation and coalescence.

Benson et al [6] reported nucleation of cracks in Ti6Al4V alloy in the slip bands at room temperature as well as at 590 K. He did not find the evidence for crack initiation at the boundaries of deformation twins in α-phase. Munz [7] in the systematic study of fatigue dependence on frequency of loading found at low frequency crack initiation at grain boundaries, in slip bands or transcrystalline, without any visible connection with slip bands. At higher frequencies only slipless cracks occured.

These inconsistences in the interpretation of fatigue mechanism in titanium tend us to undertake the study of micro structure of fatigue fracture surfaces in this metal with the special attention focused on the effects of slipless cracking proposed by MacDonald and Wood.

EXPERIMENTAL RESULTS

The material under study was polycrystalline titanium of the nominal purity 5N. Specimens were subjected to alternate plane bending with the frequency of 25 Hz. Results reported in this paper were obtained from electron microscopic study of the specimen broken after 5.5. 10^5 cycles at the stress amplitude 200 MN/m^2.

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As can be seen in Figure 1 the formation of the fatigue crack is associated with strong plastic deformation which changes the geometry of the sample surface in the region of the main crack. Plastic deformation demonstrates itslef in formation of slip bands and twins. Characteristic feature of fatigue fracture of titanium seems to be the existence of numerous secondary cracks of different lengths. They develop in slip bands and cleavage planes, and at grain boundaries including most probably twin boundaries also. The distribution and dimensions of these secondary cracks are clearly visible in Figure 2 which shows the edge of the main crack.

Most typical fragments of the fatigue fracture surface as observed in SEM at higher magnifications are shown in Figures 3 and 4. These photographs show intercrystalline fracture along cleavage planes and fracture along grain boundaries. Fatigue striations are scarcely visible. The net of secondary cracks covers the substantial amount of the fracture surface. In Contrary to this, clearly ductile fracture was observed in the region of residual cracks (Figure 5).

Much more detailed images of the fracture surface were obtained with the use of replicas and TEM /Philips EM 300/ equipped with the high angle goniometer.

Figures 6 and 7 show segments of the fracture surface covered with regular arrays of striations, these segments are separated by the regions with the structure typical for cleavage fracture without any trace of fatigue striations. Large steps visible on the fracture surface are probably connected with the secondary cracks. It is interesting that fracture velocity as registrated in the striations is rather low and varies in the observed region between 3.10^{-4} cm/s and 1.10^{-3} cm/s. Large contribution of the fracture along grain boundaries and twin boundaries to the formation of the main crack is probably responsible for the fact that regions exhibiting fatigue striations are often confined to the areas of single grains - situation rather different from the one found in other metals and alloys [8]. The same mechanism can be responsible for the formation of small secondary cracks marked in Figures 7 and 8. The situation we meet here seems to be analogous to some extent to the formation of so called tongues observed on the fracture surfaces of some b.c.c. metals. Such tongues are interpreted there as the evidence for the purely brittle mode of fracture, however, one must have in mind the differences in crystalline structure of titanium and cubic metals. Fragment of the fracture surface shown in Figure 9 exhibits a totally different microstructure from that shown in Figures 6 - 8. Here fracture occured predominately at the cleavage planes and grain boundaries. One can observe local shears and less pronounced striations at the upper left and lower right corners of Figure 9.

SUMMARY

Fatigue fracture of polycrystalline titanium occured at the stress amplitude 200 MN/m has definitely mixed character marked down in the microstructure of the fracture surface. This surface is covered by the arrangements of clearly defined striations but not in the continuous manner, regions of fracture surface exhibiting striations are separated by large steps and the regions showing the evidence of brittle fracture - cleavage and cracks going along grain boundaries. In general there is evidence for large plastic deformation in the vicinity of the main crack. Many secondary cracks of different lengths and directions are observed together with the main fatigue crack. Fatigue striations although change their separation and direction locally, can serve in general as the indicator of the mean velocity of the fatigue fracture in titanium.

Presented photographs do not indicate on the substantial contribution of afroementioned slipless fatigue to the fracture of the material under study. Maybe it is limited to the single slip plane which in case of titanium can be identified with the cleavage plane. In this case it would not be any especially new feature of fatigue fracture. Slipless cracking is difficult to agree with clearly defined fatigue striations connected with consecutively activated slip systems and interpreted as the evidence for the plastic mode of fracture [9].

Mixed character of the fatigue fracture is probably one of the main reasons for the difficulties with the application of commonly used formulas for calculation of the velocity of fracture in titanium.

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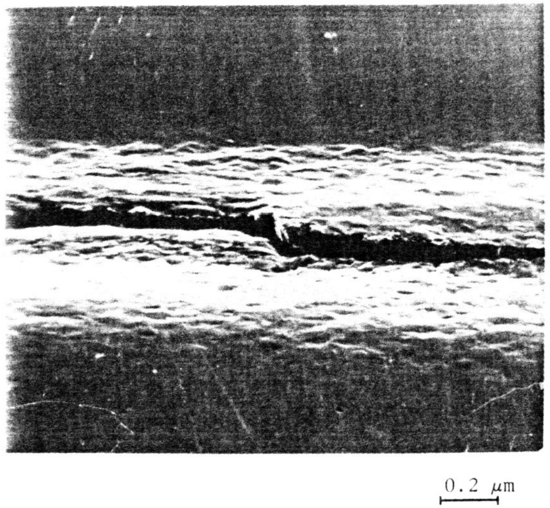

Figure 1 SEM image of the sample surface with the fatigue crack

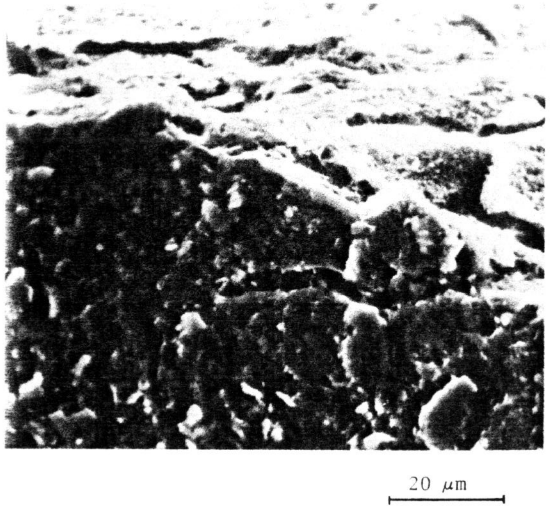

Figure 2 SEM image of the edge of the fatigue crack, secondary cracks well visible.

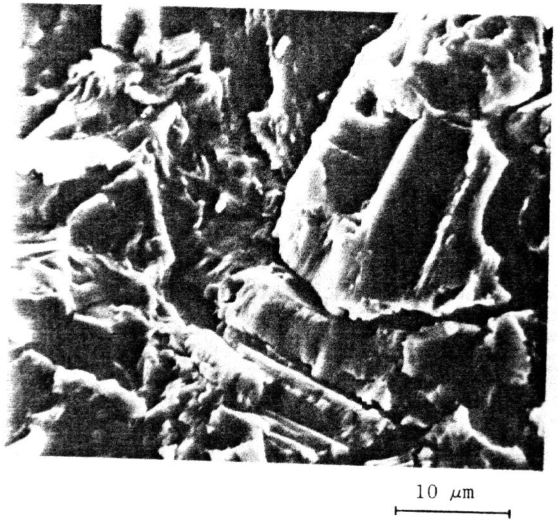

Figure 3 SEM image of the fatigue fracture surface

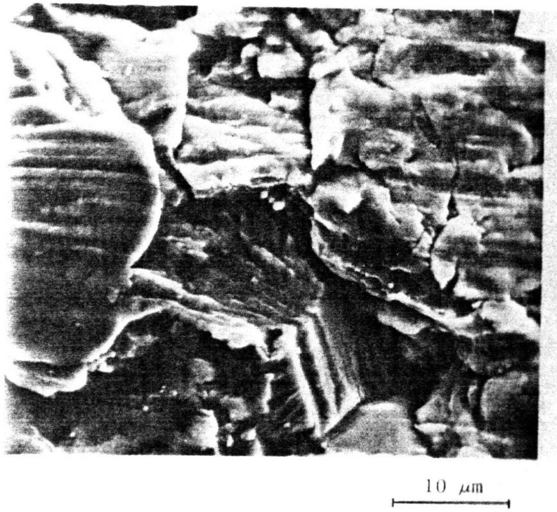

Figure 4 SEM image of the fatigue fracture surface.

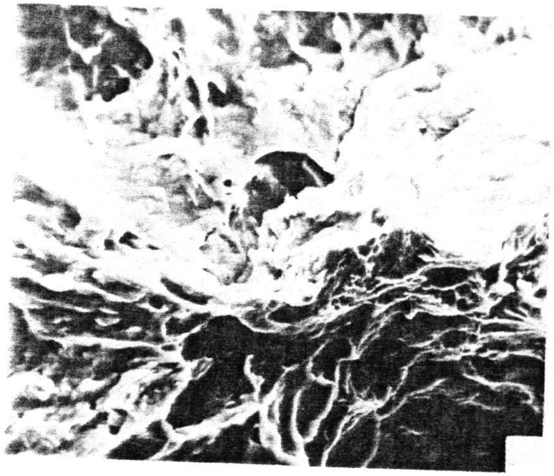

Figure 5 SEM image of the surface of the residual (ductile) fracture.

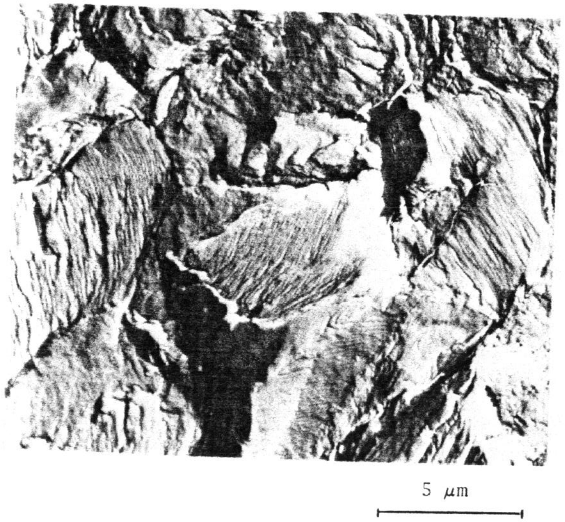

Figure 6 Plastic-carbon replica of the fatigue fracture surface. Mixed mode of fracture.

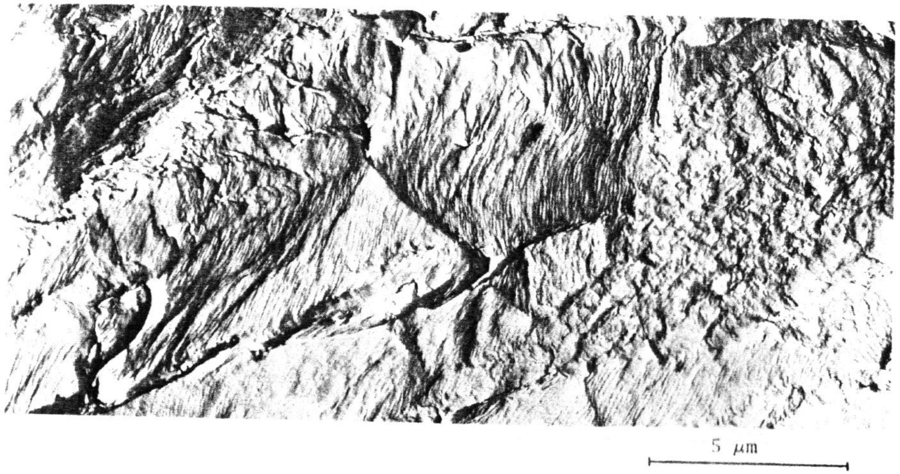

Figure 7 Plastic-carbon replica of the fatigue fracture surface. Mixed mode of fracture.

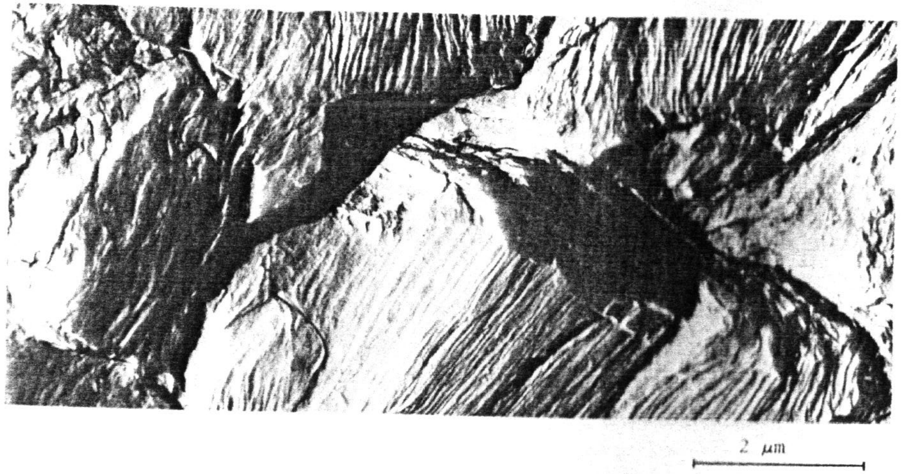

Figure 8 Plastic-carbon replica of the fatigue fracture surface. Plastic fatigue striations at higher magnification.

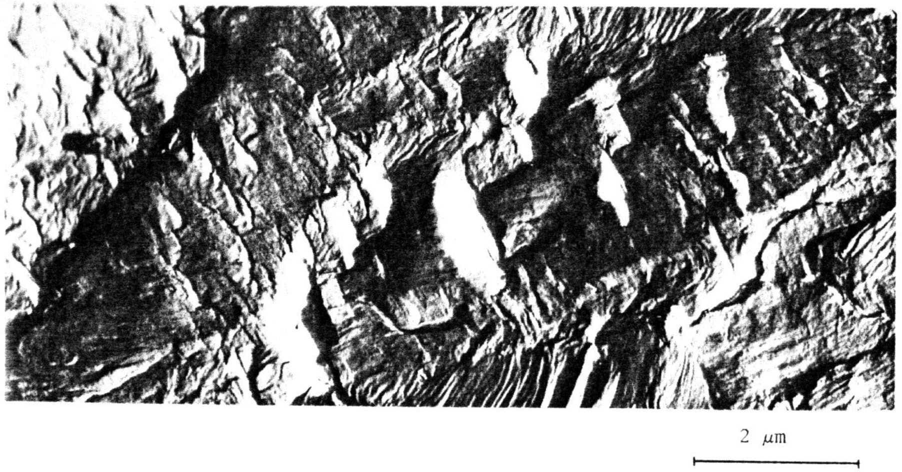

Figure 9 Plastic-carbon replica of the fatigue fracture surface. Mainly brittle mode of fracture.