EVOLUTION OF THE STRUCTURAL CHANGES IN SUPERFICIAL LAYER DURING EARLY FATIGUE PROCESS

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ABSTRACT

In this paper some results concerning the evolution of inner second order tensions and dislocation density in the superficial layer of metallic materials during early fatigue process are presented. Evolution of these sizes shows that the incubation of damage process may be divided in three stages. It is shown that the dislocation density in the first stage of incubation damage process has an important role. The incubation and initiation of fatigue cracks have a cyclic character. Also, the authors have studied the relaxation of crystalline lattice when the fatigue tests are interrupted after 3,1.10^4 cycles and 10^5 cycles respectively.

KEYWORDS

Early fatigue, X-ray analysis, cristalline lattice, damage stages

INTRODUCTION

The complex process of fatigue damage covers several stages. Various mechanisms of damage accumulation which have a more or less known regularity actuate in each stage. Generally, this complex process may be described by a Wöhler curve presented in Fig. 1.

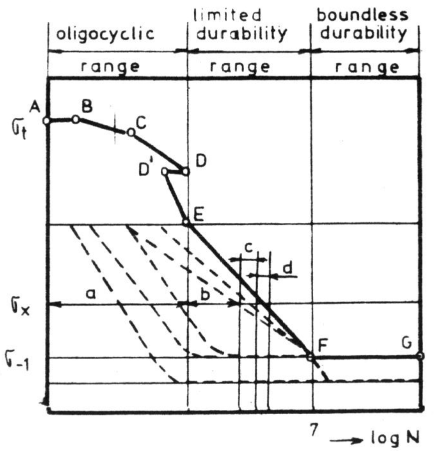

Fig. 1. The Wöhler curve

This curve may be divided into three main ranges: the oligocyclic range(according to point A-D) with tension values between tear strength and limited creep stress; the limited durability range (which is represented by the broken line DEF) and the boundless durability range (according to points F-G).In the limited durability range the accumulation of fatigue damage covers some stages: a) the incubation period of fatigue process when the first centers of submicroscopic cracks appear; b) the microscopic cracks development and extension period; c) the microscopic cracks accumulation period; d) the cracks accumulation period in a masterly crack which leads in final to tearing of the sample.

The latest data in specialised literature(D.Kuhlman-Wilsdorf (1979),O.N.Romaniv et.al.(1988) and V.T.Troshchenko(1985))show that the initiation of fatigue microcracks may occur in the sliding bands in the interphase or in the border of inclusions.In this initiation an important role is played by the dislocation mobility and their accumulation capacity. This mobility is conditioned by their interaction with other dislocations or crystal defects (disolved atoms,grain limit, separation surface between phases etc) and establishes the endurance and the plasticity of metallic materials.In the place of dislocation accumulation there is a tension state. This inner tension state becomes released in the moment when the microcracks appear.

In this paper some results regarding the evolution of dislocation density and inner second order tensions in the superficial layer of metallic materials during early fatigue process are presented.

EXPERIMENTAL

The fatigue tests have been performed on OL52K steel samples using an adequate testing machine. The parameters of fatigue test was: alternate symetric cycle, bending at constant moment and the tension level is 280.106 N/m^2 .

Structural modifications which appear in the superficial layer of tested sample have been evinced by X-ray diffractometry using the DRON-3 equipment diffractometer (so there are presented in the papers of A.N.Guz et al.(1981),and I.Crudu et.al.(1990)). The working parameters of this diffractometer have been:U=40kV,I=20 mA, F_1=1 mm, F_2=0,25 mm, ω_d=0,5°/min., $v_{rec.pap.}$=720 mm/h. The diffraction spectrum of X radiation(MoXK α) was traced within the interval $2\theta \in [15° - 45°]$ and the evolution of the profiles of diffraction lines (110) and (220), corresponding to the ferritic-perlitic stage of steel, were followed depending on the testing time(number of cycles).

The analysis of the distribution of X radiation intensity diffracted within the interference fringe shows that in the first stage of fatigue test it is subjected to a law distribution of the type:

$$I_{(110)}=I_0 \exp[-\pi(\Delta\theta/\beta)^2] \qquad (1)$$

but in the following stage of fatigue test it is subjected to a law distribution of the type:

$$I_{(110)}=I_0[\sin^2(2\pi\Delta\theta/\beta)/(2\pi\Delta\theta/\beta)^2] \qquad (2)$$

From the relation (1)and (2) it follows that the coherent scattering of X-radiation is influenced by the presence of dislocations, namely,of separation of mosaic locks into subblocks. In these relations are noted: $I_{(110)}$ is the diffraction line intensity in the point placed at the distance $\Delta\theta$ from the line gravity center; β is physical width of line (110) and I_0 is the diffraction line intensity in gravity center abscisa point.

The analysis of the line(220) shape gives data concerning the level of inner second order microdeformations. The width of the diffraction line (220) is directly proportional to the lack of homogeneousness of the interplane distances, η, which can be determined by the relation:

$$\eta=(\Delta d/d)_{220} = (\beta/4tg\theta)_{220} \qquad (3)$$

The level of the dislocation density in the crystalline lattice, ρ, was estimated by the ratio $(I_{fon}/I_{max})_{220}$, where: I_{fon} is minimum intensity of diffraction line (220) and I_{max} is maximum intensity of the same line.

In fig.2 and 3 are presented the evolution of width β_{220} of line (220) and of ratio $(I_{fon}/I_{max})_{220}$ respectively versus number of testing cycles N.

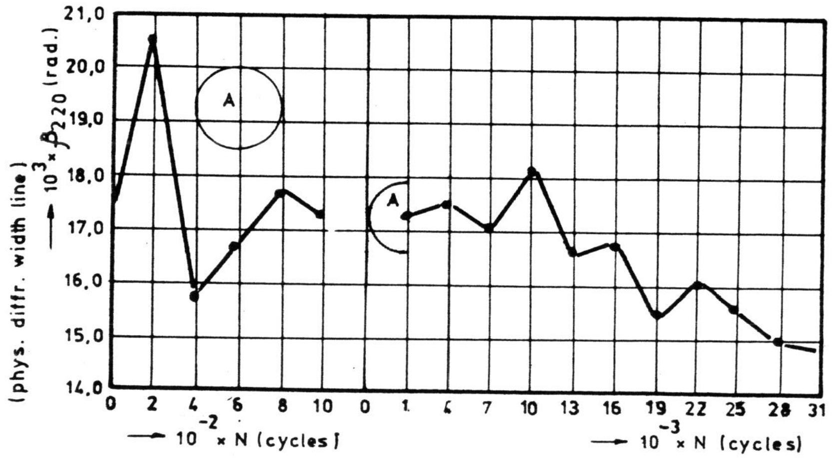

Fig.2. Evolution of β_{220} versus N

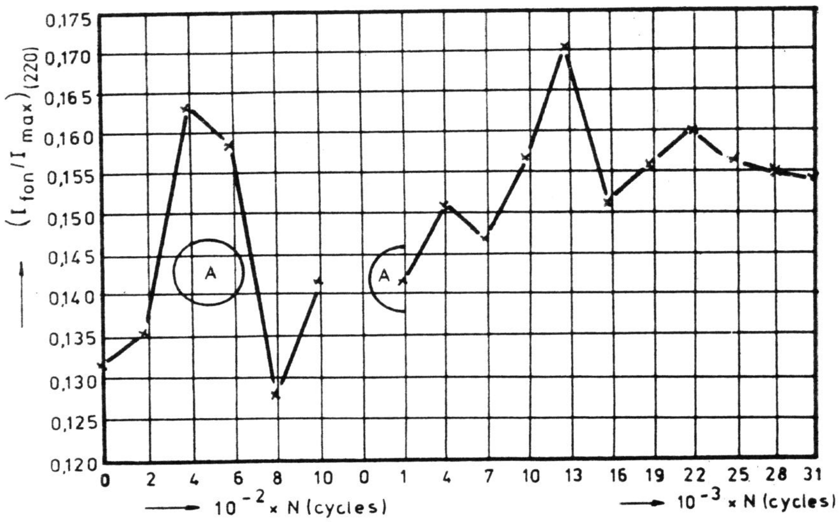

Fig.3. Evolution of (I_{fon}/I_{max}) versus N

In details A the evolution of sizes β_{220} and (I_{fon}/I_{max}) are presented versus size N in the first thousand testing cycles. This aspect evinces once again the role of dislocations in the first stage of damage by fatigue process. Thus, in the first stage, the accumulation of dislocations leads to the strain hardness of crystalline lattice. The further growth of dislocation density over a certain limit arouses appereance of the first submicroscopic cracks and a release of the tension state occurs.

Between 8.10^2 and 7.10^3 cycles there is a stability state in both the inner second order tension and dislocation density (the variations of structural sizes far smaller). We consider that in this stage an equilibrium between the generation and the annihilation of dislocations is established. Also, the processes of plastic microdeformations have a high degree of reversibility.

Between 7.10^3 and $1,9.10^4$ cycles release in tensions of crystaline lattice occur which are characteristic of fatigue process; but there is a tendency of the general level of tension to decrease. In this range the Frank-Read sourses are activated, the dislocation density grows very much and their accumulation occurs. This leads to the appearance of the first microcracks and therefore the diminuation of general level of tension.

Over $1,9.10^4$ cycles the level of inner second order tension becomes small but the diffraction line (110) has a "si" shape (relation (2)). This evinces the existence of a lot of microscopic cracks which leads to division of mosaic blocks in subblocks.

Also, in this paper we studied the relaxation in time of crystalline lattice subjected to the fatigue process. Thus, after $3,1.10^4$ and 10^5 cycles the fatigue test has been interrupted and we followed the evolution in time of inner second order tension levels within the 216 hours. The results are presented in fig.4.

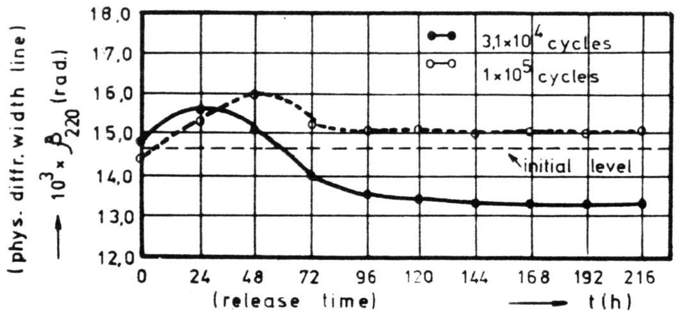

Fig.4. Evolution in time of size β_{220}

In both situations in the first 24 h and 48 h a growth of microtension levels occurs, then they follow a decrease until 98 h and 72 h respectively. After these periods the tension states remain constant. Data show that in case when the test is interrupted in the incubation period of damage ($N<3,1.10^4$ cycles) a release of tension state occurs under initial level tension but when the test is interrupted over incubation period ($N>1,9.10^4$ cycles) the release of tension state over initial level state occurs.

CONCLUSIONS

Structural changes which occur in the superficial layer of metallic material during fatigue process have been evinced by X-ray diffractometry using a DRON-3 equipment.

Evolutions of sizes β_{220}, (I_{fon}/I_{max}) as well as of shape of diffraction line (110) show that the incubation of damage by fatigue process may be divided into three stages.

An important role in the first stage of incubation process of damage is given by the level of dislocations.

The processes of incubation and initiation of fatigue cracks have a cyclic character and they consist in plastic microdeformations and a local strain hardnesses.

The interruption of testing ,in incubation stage of damage by fatigue process, leads to release of inner second order tensions state at an inferior level of initial tension state.

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