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EXPERIMENTAL RESEARCH REGARDING THE EVOLUTION OF SOME PARAMETERS OF THE SUPERFICIAL LAYER IN LOW CYCLE FATIGUE PROCESS

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ABSTRACT

The development of some mechanic engineering systems in, feasible to pressure vessels, aeronautics, ship building technology, requires a full investigation of the material features that are to be examined under a low cycles fatigue to strains close to the limit of the material elasticity. In this paper we present a testing machine at variable stresses in oligocyclic range. An own testing stand was patented by Romanian Standard Office, some results concerning the evolution of inner second order tensions, microhardness in superficial layer during low cycles fatigue process and the microscopic images of cracks, some results concerning the evolution of the crystalline lattice parameter, level of the texture were realised in steps of each two thousand cycles until a limit of 10^4 cycles. Two types of steel are tested.

KEYWORDS: low, cyclic fatigue, structure, superficial, layer, dislocation, density, texture

1. General considerations

The low cyclic fatigue of materials is a damage process that appears in various domain of engineering. This process can be finding during exploitation of some machines or aggregates subjected to a periodical or no just periodical action [2], [2], [13].

The boats during their going on sea or ocean are subjected to low cyclic fatigue. Similar process occurs during get off or landing of plane. Some vessels from chemical industry due to modification of pressure during charging or discharging are subjected to low cyclic process. During of this process the superficial layer of material suffers certain structural changes and their monitoring allow to establish the mechanism that leads at damage process. The structural changes in superficial layer are usefully in order to establish the history of material, as well as the next behavior of material. A systematic study of the structural changes is performed in frame of testing program of materials used in engineering where appear and develop the low cyclic fatigue process. Using an original testing machine some materials have been subjected to low cyclic fatigue process and by X-ray diffraction method the superficial layer of tested sampled was investigated. It was obtained information on fine structure of the superficial layer, namely: stress state, dislocation density, texture onto superficial layer as well as other mechanic characteristics as micro-hardness [4], [15].

2. Experimental methodology

In order to perform a complete study of the behaviour of the superficial layer during fatigue test and to evince the main factors, which determine the damage process, the structural cybernetic model was introduced. In Figure1 this model is presented and it allows to a systematic study of the input parameter changes under action of the commanding ones (Crudu & Macuţă 1991) [3].

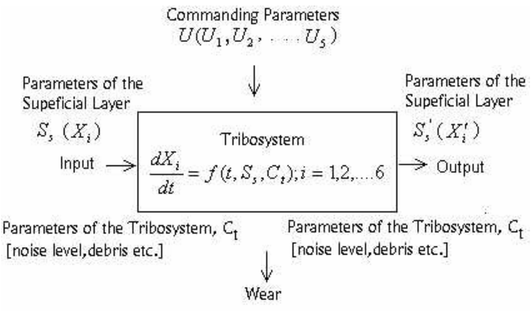


***Fig.1.** A cybernetic model used in study of friction process adapted in study of the low cycle fatigue process [15].*

The input/out parameters are: superficial layer parameters (s_s-s'_s) [x_1- macro and micro-geometry, x_2 - microhardness and hardness, x_3 – tension state, x_4 – chemical composition, x_5 – structure, x_6 – purity] and tribosystem parameters (c_s) [noise, debris]. Some of the mentioned parameters, as x_2, x_3, x_5, can be changed from exterior such the durability of the material to be in a certain interval.

The commanding parameters (u) [u_1 – nature of material, u_2 – shape of the sample, u_3 – dimension of the sample, u_4 – working medium, u_5 – kinematics, u_6 – energetics] called external factors, by their action can change some superficial layer parameters x_i, i=1 – 6. In our experimental program the evolution of the x_2, x_3 and x_5 was showed by changing u_1 (type of steel: ol 52) and u_5 (testing frequency: ν_1=20 cycles/min, ν_2=40 cycles/min., testing deformation: ε_1=2000 μm/m, ε_2=2500 μm/m, ε_3=3500 μm/). In order to estimate the dislocation density the x-ray diffraction method was used.

3. Experimental

We have conducted the examination of material features in fatigue process for two steels used in pressure vessel engineering: OL 52 and 10TiNiCr180. Using laminate samples, the investigations have been realized at variable solicitations of pure bending on a patented machine (Buzdugan & Blumenfeld 1979). The tests have developed in a symmetrical alternative regime at two frequencies: f_1=20 Hz, f_2=40 Hz.

The deformation domain was established in an experimental program of tests using the resistive tensometry. The deformations of samples were imposed at the superior limit of elastic domain, evaluated from characteristic curves. The deformations imposed in case of OL52 were: ε_1=2000 μm/m, ε_2=2500 μm/m, ε_3=3500 μm/m and in case of 10TiNiCr180: ε_1=1500 μm/m, ε_2=2000 μm/m, ε_3=2500 μm/m, respectively.

In the present paper we presented the experimental results only for OL52 steel. The experiments were performed in steps of two thousand cycles until a limit of 10^4 cycles. In every step, we investigated the lattice parameter and texture level (Bogatet & Budaci 1980, Crudu & Macuta 1991). For this investigation we used an X rays diffractometer, DRON-3.

3.1. Results and discussions

In Figures 2 and 3 the evolution of the lattice parameter for OL 52 steel tested to fatigue process for three imposed strains, ε_1, ε_2 and ε_3 at two frequencies are respectively presented.

Analyzing those two figures, a general tendency of decreasing of the ferrite phase lattice parameter, is evinced, when the number of the testing fatigue cycles increases. This occurs for the all imposed strains. A strong decreasing is revealed for small strains and frequencies, respectively for high strains and frequencies. The change of the lattice parameter can be explained by supposing of a migration process of some alloyed elements during fatigue tests. This fact presents validity by a soft increasing of the lattice parameter during the fatigue test for an established testing cycle number.

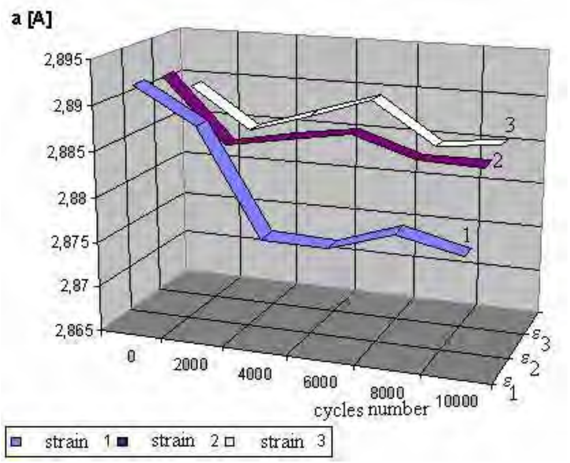


Fig. 2. *Evolution of lattice parameter for f = 20 cycles/min [15].*

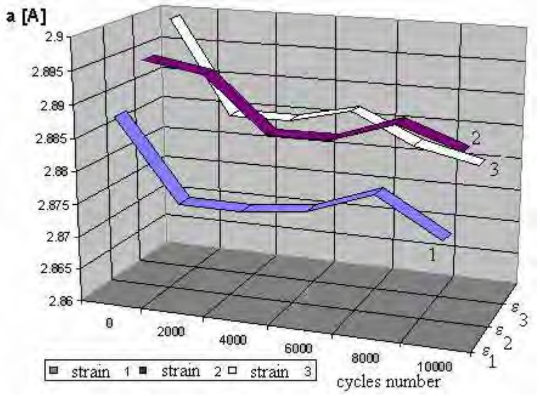


Fig. 3. *Evolution of the lattice parameter for f = 40 cycles/min [15].*

This increase appears more early when the strain is bigger. The migration process of atoms in and from elementary cell of the ferrite phase shows the existence of a high kinetic of atoms in the superficial layer during fatigue tests.

This kinetic can have negative effects if the material is tested in corroding media.

The migration process is more slowly in case of the small strain and more intensive at high frequencies and big strains; at small strain the process is more intensive at small frequencies. The presented data show that there is the possibility to command from exterior the durability of tested material by changes of the imposed strain and testing frequencies in a certain range. In Figure 4 and 5, for 20 cycles/min and 40 cycles/min, the evolution of the texture parameter, measured by ratio I_{max}/I_0, where I_{max} and I_0 are, respectively, the maximum intensities of the X-ray diffraction line (220) of the ferritic phase, for tested and non-tested samples, are presented.

From figures, an inverse texture (IT) process of material is evinced. The higher degree of the IT occurs in the case of the bigger strain, ε_3 [4]. This IT can be associated to some mechanical micro-processes that lead to a preferential orientation of the crystalline planes in [220] direction in relation to laminated state of material, when $I_{max}/I_0 = 1$.

From the view of presented histograms, can be analyzed the distribution of the texture degree of steel during fatigue tests and a relationship with plasticity properties can be established. At small frequencies the material presents a normal hysteresis, but at high value the inertial properties of material are smaller.

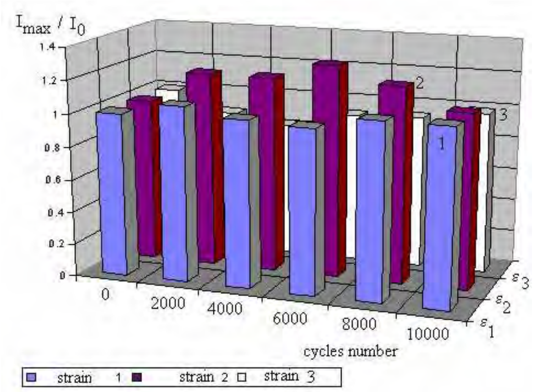


Fig. 4. *Evolution of texture level for f = 20 cycles/min [15].*

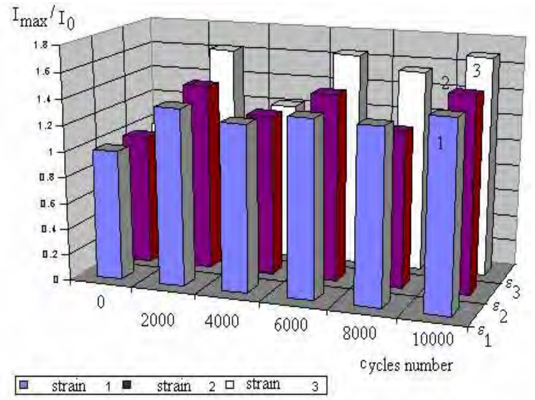


Fig. 5. *Evolution of texture level for f = 40 cycles/min[15].*

3.2. Conclusions

During fatigue tests, the lattice parameter presents a general tendency of decreasing when the number of the cycles increases, for those three strains and those two frequencies. The decreasing occurs in jumps and can be associated to a migration of alloying elements from steel. The migration process is strongly influenced by number of fatigue cycles and level of strain [4].

During fatigue tests, a texture process of ferrite phase occurs and it is influenced by level of strain and frequencies. The texture process, evinced by X-ray diffraction method, shows data about inertial properties of fatigue tested material. The steel looses the elastic properties when it is tested at high frequencies, the influence of strain being not very important.

3.3. Dislocation density

In our experimental is presented the evolutions of the $\left(I_f / I_{\max}\right)_{220}$ ratio (Buzdugan & Blumenfeld 1979) against of the testing cycles number for two frequencies are presented (20 and 40 cycles). For example this evolution is done for: OL52 steel, three imposed deformations, ε1, ε2, ε3, and a frequency of ν1=20 cycles /min (fig.6).

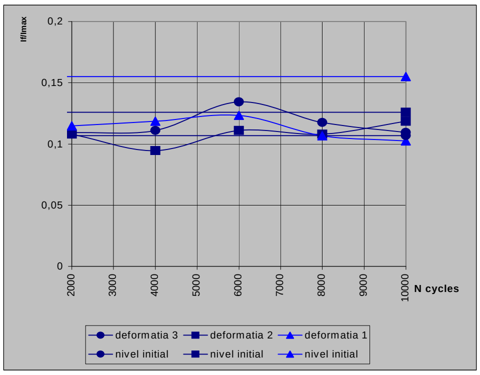


Fig. 6. *Variation of the 220 on number of testing cycles for frequency ν1=20 cycles/min[15].*

3.4. Analyses of the superficial layer microhardness

In Figure 7 and 8 the variation of the, HV, microhardness (Bogatet & Budaci 1980) on number of testing cycles, for ε_3=3500 μm/m and the two testing frequencies are presented.

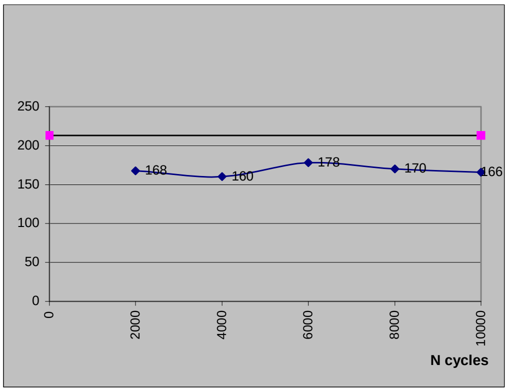


Fig. 8. *Variation of microhardness vs testing cycles for v = 40 cycles/min[15].*

There is a jumps decreasing of the HV by hardening and softening processes.

At low frequency this decreasing is lesser like in case of high frequency for the **SAME** imposed deformation. This shows that the hardening and softening process occur with different speeds.

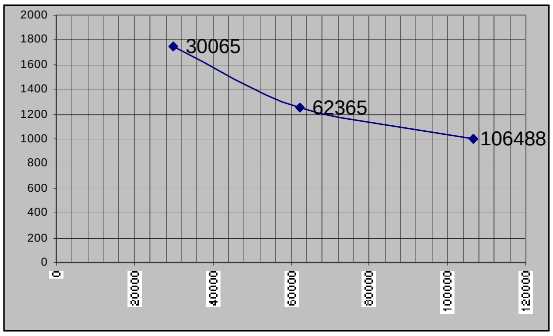


Fig. 9. *Experimental Wöhler curve[15].*

4. Aspect of wöhler curve

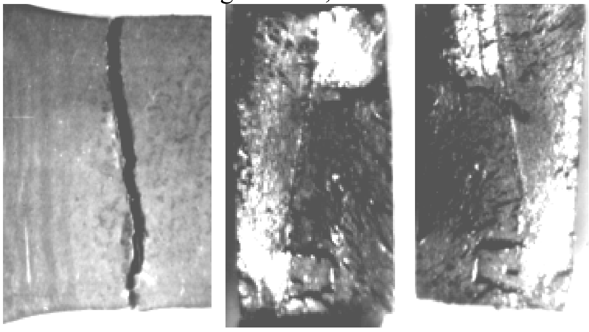
The tests have developed in a symmetrical alternative at two frequencies. The testing frequency of the samples was of 20 and 40 cycles/ min. In paper the results refer to testing frequency of 40 cycles/min. During fatigue test the temperature measurements showed a variation small 2^{o}C, the temperature effects being without importance. In Figure 9 the experimental Wöhler curve is presented.

4.1.Macroscopic aspects of the cracks

Like general aspect, in each case, Figures 10, 11 and 12 the damage process by fatigue test is initiated at sample surface in places where the microscopic flows are presented.

The tested samples present in damaged surface a smooth aspect and an area characteristic to damage.

In Figure 6a, the aspect of tested sample is presented. It can see the presence of sliding bands near crack. This appears due to relative big propagation speed of deformations into crystalline grains having favorable orientation and small relative intensity of total deformation. In deformation process in elastic-plastic range the weigh of plastic deformation is relatively big in a small time testing (N_r = 30065 cycles until damage) at deformation ε_3 = 3500 μm/m (ε_3 real = ε_3/2). The weigh of damage surface by fatigue process is small and located in vicinity damaging initiator. This is showed in Figures 10b, 10c.



a b c

Fig. 10. *Macroscopic aspects of crack for ε_3 = 3500 μm/m[15].*

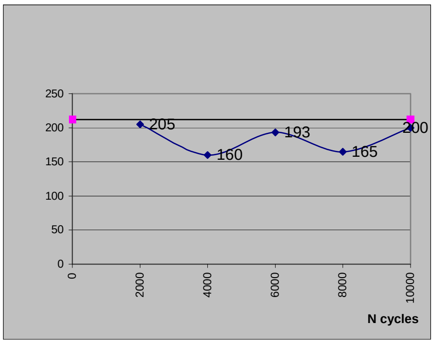
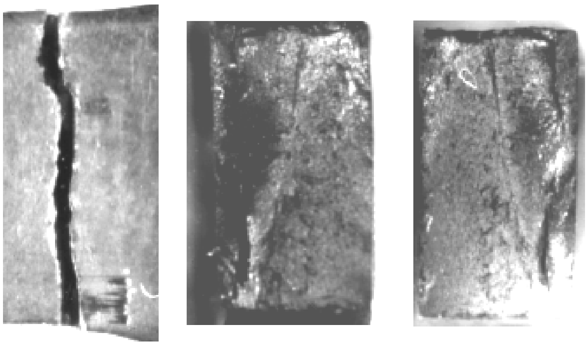


Fig. 7*. Variation of microhardness vs. testing cycles for v = 20 cycles/min[15].*



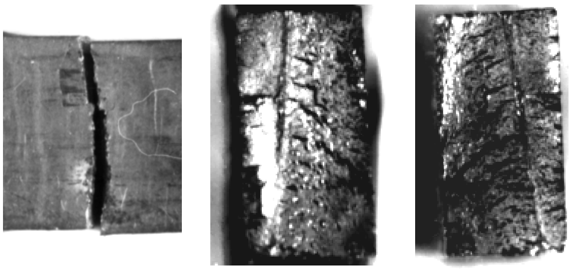
a b b

Fig. 11. *Macroscopic aspects of crack for ε_2 =2500 μm/m[15].*

In Figure 11a it is presented, for a deformation of ε_2 = 2500 µm/m, the shape of the sliding bands in vicinity of the damage area. The sliding bands have a high fines degree due to extension of elastic- plastic range into more time interval and a big number of cycles (N_r = 62635 cycles until damage). It is considered that the weigh of the plastic deformation in the whole elastic-plastic range is smaller comparatively with previous case. In Figures 11b, 11c the damage surface presents a large smooth area in vicinity of the damage initiator and it is developed on the whole of width of sample. The damage surface appeared in a located area well established.

In Figure 12a on the smooth surface, sliding bands appears for a very big number of fatigue cycles (N_r = 106488 cycles until damage) at a big distance of damage zone. The explanation consists in the fact that the deformation speed is relatively reduced and the plastic deformations will be taken at next fatigue cycles in neighbor zones with smaller deformation resistance. The extension of the plastic deformations in vicinity of damage zone is explained by propagation of the plastic deformations to grains situated in deformed zones [8].

In Figures 12b, 12c a large damaged zone is evinced that is developed on the whole of width of sample, having a bilateral aspect. This can be explained by fact that the propagation speed of the failure surface is small and allowed the initiation of the failure by fatigue from a zone located in opposed side.



a b c

***Fig. 12.** Macroscopic aspects of crack for ε_2 =2000 µm/m[15].*

5. Conclusions

By extension of the tribolayer and tribosystem concepts to the study low cycle fatigue process of the steel, the structural changes in the superficial layer are shown. It was evinced a microfatigue process that is strongly influenced of frequency testing, deformation level, and number of the fatigue tests.

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The general releasing process occurs by microproceses of tensioning and releasing of the crystalline lattice. Their amplitude and periods depend of frequencies and imposed deformations [1].

Evolution of the second order tensions can be correlated with evolution of the microhardness in ferrite grains as well as with the density sliding bands (Fouquet 1979). Our results can be used in order to explain the damage mechanism of the tested samples subjected to low frequency fatigue test and high tensions.

The researches concerning micro and macro aspects of the fatigue failures at big tensions and low fatigue cycles will be continued in order to establish the relationships with structural changes occurring at lattice level.

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