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DISLOCATION SUBSTRUCTURE AND ELECTROIMPULSE SUPPRESSION OF FATIGUE FAILURE IN STAINLESS STEEL

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The change of structure, phase composition and types of fracture of 08Cr18Ni10Ti steel under the conditions of low-cycle fatigue has been studied by the methods of optical, scanning, and transmission electron diffracting microscopy on mesolevel. An increase in safe fatigue life and failure suppression by electroimpulse treatment in the transition to the third critical stage of the dependence of ultrasound velocity on a number of loading cycles have been explained. Attention is given to the process of collecting recrystallization, change in the kinetics of the dislocation substructure self-organization and twinning, and initiation of solid solution decay.

The problem of the fatigue failure of steels and alloys is actual now inspite of its long history of research [1]. It is connected with that, many constructions and products of crucial purpose are used in such modes, but their failure occurs suddenly without marked previous signs. The latest works underlining the complex nature of fatigue phenomenon, connect the development of fatigue failures with self-organization of inner – and interstructural levers of plastic deformation [2-4] and dislocation substructure evolution [5-10]. The deforming solid being unbalanced synergetic system, tends to include the maximum effective dissipation canals of energy.

The failure is the final stage of evolution, appearing after exhaustion by material of its accomodation possibilities.

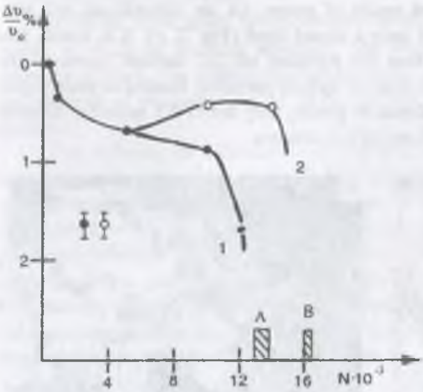

Fig.1. Relative changes of ultrasound velocity from the number of cycles of loading for 08Cr18Ni10Ti steel: usual loading (1); electrostimulation at N = 9000 (2); A is a range of general failure, B is after electrostimulation.

The ultrasound method of diagnose of the critical stages of approaching the fatigue failures has been offered by us earlier when the abrupt fall is noted [11] (Fig.1) on the curve of dependence of the ultrasound velocity υ on a number of the cycles of N loading. The long preparatory stage of process with small gradual collection of microfailures precedes to this. For preventing the fatigue failures it is necessary to suppress the nucleation of mesoscopic substructure and to make weak its spreading through the material on account of lowering the rate of deformation localization and inadmissing the formation of mesoconsentrators of the stresses. It may be reached by treatment of materials with the help of powerful current impulses of optimum parameters according to frequency, amplitude and time of action [12-14]. The important in this scheme is that, the maximum effect of increasing the resource of endurance in different steels up to 20-30% is achieved in electroimpulse treatment at a critical stage $\upsilon(N)$ (Fig.1).

One of the most probable reasons of increasing the resource is the treating of nucleating submicrocracks on account of local heat build-up of the materials in a region of the concentration of current lines at their ends, blunting the latters because of the relaxation of stresses and corresponding lowering of the concentration level of stresses in these zones. And the lowering of general level of the inner stresses [13-14] is – noted.

The preliminary treatment of steel by electric impulses, when the substructure has not been formed yet does not bring to the increase of strength of the specimen [15]. It is quite evident that for purposeful use of this method it is necessary to know the conformity to natural laws of action of the current impulses on evolution of defective dislocation substructure and phase composition of steels being treated.

In this work it is made on 08Cr18Ni10Ti steel. The sizes of samples, scheme of low-cyclic loading, parameters of electrostimulating did not differ from those described earlier in [11-13]. The defective structure, the phase composition, the picture of failure have been studied by methods of modern physical metal science.

In initial state the analysed steel has the anisotropic grains (coefficient of anisotropy is 4,1), the medium size of which is 16 microns. Inside the grains there is a substructure formed as a result thermomechanical pretreatment: the grains having the chaotic and grided dislocation substructure, and also the subgrains. The subgrains, in turn, contain either chaotic distributed dislocations, or the grid are marked.

The interesting peculiarity of dislocation structure of steel being investigated is the presence of a large number of dislocation loops of the vacant type in initial state. As a rule, the loops are in grains with chaotic dislocation substructure.

In material as a result of preliminary treatment in initial state the particles of a complex carbide of the $M_{23}C_6$-$(FeCr)_{23}C_6$ type and titanium carbide of the composition TiC have been formed. The particles of $M_{23}C_6$ carbide have the forms of spheroid (Fig. 2, *a*, *b*); they are located inside and along the boundaries of grains and also form the microliquation lines. The particles of TiC carbide generally are located inside of grains, i.e. on dislocations and subboundaries (the boundaries of subgrains) and have a round form (Fig. 2, *c*). It is stated, that the particles of $M_{23}C_6$ carbide are coarser than the particles of TiC carbide, however the volumetric part of them is lower. The average sizes of carbide particles, located in microliquation lines, are of 1,3 micron, but at the boundaries of grains, they are of 0,5 microns. In some cases there are the particles, the sizes of which are of 6,5 microns.

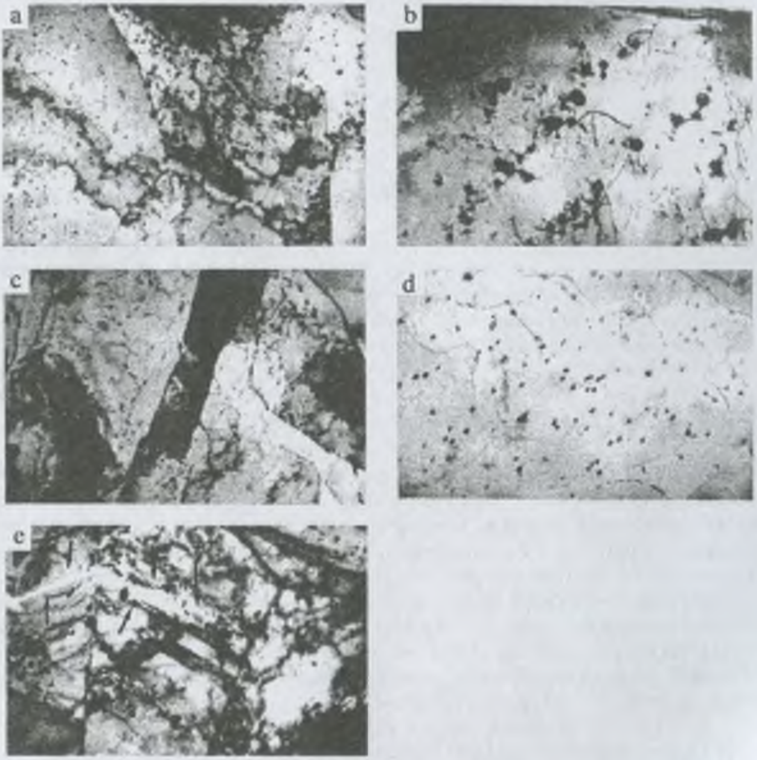

Fig.2. Second phases in 08Cr18Ni10Ti steel: *a*, *b* – $M_{23}C_6$ carbide particles located at the grain boundaries (*a*) and inside grain boundaries (*b*); *c*–*e* – TiC carbide particles at dislocations, subboundaries (*c*), and dislocation loops (*d*); *e* – ε-martensite (the microcrack is market by arrows); *a*–*c* – the initial state, *d* – after electrostimulation of the initial material; *e* – zone of the fracture of initial sample; x8600 (*a*); x17000 (*b*–*e*).

The electrostimulation of initial sample, as the metallographic researches have shown, practically not changing the form of grains, increases their average size on surface layer of steel bringing it to the value of 26,0 mcm. The growth of grains is accompanied by change of their distribution according to sizes: practically the grains disappear fully, the sizes of which are less than 10 mcm. The change of function of distribution the grains according to sizes testify that during the process of electrostimulation in a medium being analized probably the collecting recrystallization runs.

In initial state many grains contain twins of annealing. The volume fraction of such grains is ~0,28 of material structure. The electrostimulation is accompanied by intensive twinning of steel. The volume fraction of grains with twins is increased up to ~0,7. Here, both the increase of medium sizes of twins and the amounts of grains containing the twins are marked.

The ordering of dislocation substructure during electrostimulation is accompanied by some changes of the value of dislocation density (Table 1). Namely: the density of dislocations in grid-substructure located in grains, is lowered, but in grid-substructure, located in subgrains it is increased; the density of dislocations in a structure of dislocation chaos is not practically changed. Here, the value of scalar density of dislocations in average by material in current action is increased slightly from $2{,}3\text{x}10^9$ cm^{-2} in initial state to $3{,}3\text{x}10^9$ cm^{-2}. The electrostimulation brings to a lowering of average sizes of loops and their quantity in a unit of material volume. In this case, if the average sizes of loops decrease less than two times, but the density of loops decreases ~ 46 times (Table 1).

Table 1. Parameters of defective substructure of 08Cr18Ni10Ti steel

State of steel	P_v / $\langle\rho\rangle$x10^9, см$^{-2}$				$\langle\rho\rangle$, x10^9, см$^{-2}$	D_l, nm	ρ_l, x10^9 см$^{-3}$
	1	2	3	4			
Initial	0,8/1,5	0,05/1,1	0,1/8,4	0,05/3,2	1,8	52	7,4
Electrostimulated	0,6/1,4	0,05/4,0	0,2/4,2	0,15/9,2	3,1	29	0,16

Notes: 1 and 2 are the grains and subgrains (respectively) with a structure of dislocation chaos, 3 and 4 are the grains and subgrains (respectively) with a grid-substruction. P_v is volume fraction of dislocation substructure, $\langle\rho\rangle$ is a scalar density of dislocations, ρ_l is a volume density of dislocation loops, D_l is a average size of loops

The electrostimulating of steel is accompanied by further decay of γ -hard solution on the basis of iron. It brings to increasing the average sizes of the particles of carbide phases and their volume fraction (Table 2). Besides, the peculiarity of current action is found: the formation of carbide TiC particles on dislocation loops (Fig. 2, *d*). Only by means of dark-pole analysis it manages to find out these particles. On light-pole image the particles are surrounded by characteristic ring (arc-shaped) extinctional contours that indicates the coherence tie of crystalline lattices of matrix and carbide. The essential lowering of the density of loops in the process of electrostimulating (see Table 1) is therefore caused by separating the particles of titanium carbide on them.

So, the electrostimulation by composite sample influences on the plastic properties of steel: the recrystallization plasticizies the material; the reconstruction of dislocation substructure and the formation of microtwins increase to some extent the strength of steel; the decay of hard solution and possible leave of hydrogen atoms from atmospheres of Cottrell plasticizies the steel; but the extraction of dispersed particles of the second phase strengthens it. Therefore, the effect of electrostimulation action on mechanical properties of steel will be determined by combination of mechanisms mentioned above.

Table 2. Parameters of carbide phase of 08Cr18Ni10Ti steel

State of steel	$M_{23}C_6$ carbide		TiC carbide					
			subboundaries		dislocations		Loops	
	l/d, nm	δ, %	*d*, nm	δ, %	*d*, nm	δ, %	*d*, nm	δ, %
Initial	$\frac{120}{110}$	1,2	23	1,9	26	1,4	-	-
Electrostimulated	$\frac{135}{86}$	1,9	33	2,9	40	1,4	15	1,4

In the process of low-cyclic loading the completion of formation and evolution of mesoscopic substructure being a criterion of fatigue failure occurs. With selected scheme of loading, type of samples and level of applied load (80 MPa) the samples withstood at average 13500 cycles of loading (Fig.1). The fractographical analysis of failure surface has given off three zones: a zone of stable growth of crack, a zone of speedy growth of crack and a zone of scrap. The whole surface of zone of stable growth is covered by fatigue microstrips oriented mainly normally to spreading of crack growth. The average distance between grooves characterizing the path of crack by cycle of test is 2,6 mcm in initial sample. There is a large number of secondary microcracks on the surface of failure. Their origination takes place on innerphased (boundaries of grains) and interphased (boundaries of carbide – matrix division) boundaries. The distance between these microcracks in initial sample is 17 mcm.

The zone of speedy crack growth is characterized by mixed microrelief. On the surface of a failure there are the fan-shaped microstrips, the areas with pseudostrips and pits, the latters form the transcrystallite facets of chipping.

The stimulation of initial material by current impulses at the beginning of the third stage of dependence $\upsilon(N)$ increases the number of cycles up to failure by ~20%. It is enough noticeable effect. As in usual loading on the surface of failure there are the same three zones. However, the quantitative data testify about increase of steel viscosity. It is confirmed by lesser distance between fatigue grooves (1,9 mcm) and secondary microcracks (7 mcm) in electrostimulated sample in comparison with initial one. Therefore, the scale of local inhomoginuity of plastic deformation decrease during electrostimulation that prevents the formation of concentrators of stresses.

The analysis by methods of diffraction electron-microscopy of the zone of fracture of initial sample and the sample electrostimulated at the beginning of the third stage of dependence $\upsilon(N)$ revealed the following. Firstly, the electrostimulation brings to slowing-down the process of self-organization of dislocation substructure, i.e. in zone of fracture in initial sample there is a cell substructure, but in electrostimulated one there is a transition of grid substructure to cell remained unfinished. Secondly, the electrostimulation suppresses the process of martensitic $\gamma \to \varepsilon$ transformation occurring in zone of fracture of research material (Fig.2e). Since in electrostimulated sample ε martensite is in smaller quantities and in the background of cell-grid dislocation substructure, the stability to nucleation of microcracks in the latter is higher than in initial material. Thirdly, the electrostimulated sample is failed in higher values of scalar density of dislocations and density of curved extinctional contours, in smaller quantity of microcracks and smaller value of torsion curvature of the crystalline lattice in comparison with initial sample.

So, the effect of increasing the resource of steel 08Cr18Ni10Ti in small-cycled fatigue has a multifactorial character on mesolevel and linked (except reasons mentioned in [11-

14,16]) with running the processes of collecting recrestallization, the change of self-organization kinetics of the dislocation substructure and initiating the decay of hard solution with separating the particles of titanium carbide and, at last, with addition of martensitic γ → ε transformation.

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