MICROPLASTICITY PROCESSES UNDER HIGH-FREQUENCY MECHANICAL LOADING OF AUSTENITIC STEEL WITH RESIDUAL MARTENSITE

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The experimental investigation of the character of changes in physical properties (electric resistance, coercive force and damping decrement) of the 06Ch16N15M3B steel deformed by drawing at 77 K depending on the duration of the ultrasonic irradiation has been carried out. The results show that the behavior of relaxation processes being in the structure of the steel with a residual martensite has a non-monotone (two-stage) nature with different relaxation times. A role of dislocation and diffusion processes, activated by the ultrasound irradiation, for equalizing the internal stress field levels in the heterogeneous structures is analyzed.

PACS: 43.35.+d, 61.72.Ff, 61.72.Hh, 62.20.Qp, 62.25.Fg, 81.70.Cv, 83.85.Vb

INTRODUCTION

The presence in austenitic steels of structure elements such as martensite phases promotes the formations of local zones with stress concentrations that deteriorates the mechanical properties and corrosion resistance of material. In the cooling system circuits of steam generators, made of austenitic stainless steels, the fluid motion can be of a turbulent character. In this connection, there mechanical vibration loads arise and increase the local concentrations of internal stresses. It is known, that in some amplitude-time modes of high-frequency loading (ultrasonic irradiation – USI) the internal stress relaxation is realized that is evidenced by the thermal resistance increase, tendency to the irradiation embrittlement decrease [1, 2] etc. Earlier it has been shown that in the process of cyclic high-frequency loading of the austenitic steel containing martensite phases the vibrational energy has a selective character that realizes the relaxation processes at the martensite-austenitic matrix interface [3]. It seems expedient to investigate the mechanisms of microstructure transformations by the high-frequency mechanical loading of the austenitic steel with residual martensite formed as a result of predeformation under cryogenic conditions.

EXPERIMENTAL TECHNIQUE

The 06Kh16N15M3B stainless steel having an austenitic-martensite structure formed by the drawing deformation at 77 K (degree of deformation ε = 17%) in the device described in detail in [4] has been investigated A volume content of the residual martensite was not less than 10% [3]. The deformation was performed after the austenization annealing at 1370 K during 1 hour.

Exposition to USI at 300 K with the use of a magnetostriction transducer (generator UZG-3-4) was varying in the interval τ from 1s to 5h. The intensity of longitudinal ultrasound mechanical vibrations (frequency F = 20.5 kHz) being constant and equal to 6 W/mm^2 (amplitude A ≈ 3μm) has provided the cyclic stress level below the threshold value for the given material [5]. The vibration amplitude was determined optically and controlled with an electrodynamic transducer.

To determine the structure state of the steel after the high-frequency loading with different exposition, the behavior of the electrical resistance, coercive force and internal friction amplitude dependence (IFAD) was analyzed.

The parameter ρ/ρ_o, where ρ_o and ρ is the electrical resistance before and after USI at T = 77K, respectively, was measured with a potentiometric circuit. The magnetization-field characteristics M(H) were taken at 77 K in the closed magnetic circuit by the permeameter principle, the magnetic field was orientated perpendicularly to the sample axis [6]. The hysteresis loops were used to determine the relative change of the magnetic rigidity H_c/H_c^0, where H_c^0 and H_c is the coercive force before and after high-frequency loading, respectively. The initial value of the coercive force was H_c^0 = 22.5 kA/m.

The internal friction amplitude dependences (IFAD) were measured with a reverse torsional pendulum at room temperature (frequency f = 0.3 Hz) before and after high-frequency loading with exposition τ=10 m (τ is chosen from the stages of relaxation processes activated by USI [7].

RESULTS AND DISCUSSION

The 06Ch16N15M3B steel deformed by drawing in the liquid nitrogen medium was a highly-dispersed heterophase structure containing nanoinclusions of martensite phases and a wide spectrum of crystalline defects with a nonequilibrium concentration [3]. For the initial (deformed) steel (Fig. 1) the absence of a distinct internal friction amplitude dependence and low values of IFAD damping decrement is characteristic that evidences on the presence in the structure of excess vacancies [8].

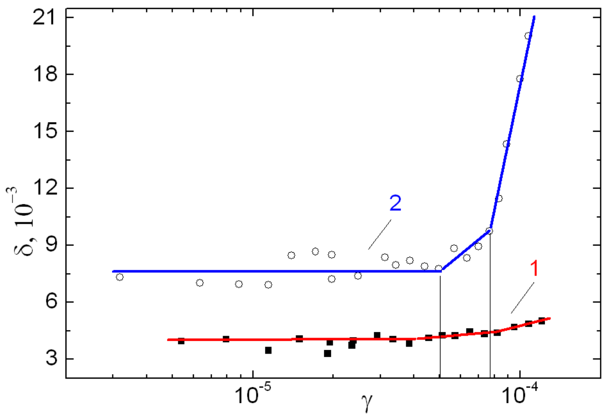

Fig. 1. Internal friction amplitude dependence of the 06Kh16N15M3B steel preliminary deformed by drawing at 77K (1) and subjected to the subsequent high-frequency loading (2)

The formation of such a structure after deformation provides in the material a sharply nonuniform relief of residual internal frictions. One can see that the material predeformed by drawing to 17% at 300 K has not a martensite phase, and the parameter ρ^{77}/ρ_o^{77} changes slightly during the subsequent USI. Also, note, that according to the results of M(H) measurement after different duration of high-frequency loading of samples deformed at 77K, the volume content of the residual martensite (not less than 10%) [3], is unchangeable.

Figs. 2 and 3 represent the dependences of the parameters ρ/ρ_o and H_c/H_c^0 of the 06Ch16N15M3B steel after different duration of high-frequency loading. It is shown that the change of the characteristics being studied has a non-monotone behavior. After USI with exposition $\tau \approx 1$ s the parameters ρ/ρ_o and H_c/H_c^0 behave similarly: they sharply decrease and further increase under USI exposure increasing to $\tau \approx 30$ m. In the case of longer USI expositions (to $\tau \approx 150$ m) the attainment of saturation for H_c/H_c^0 and monotonic drop for ρ^{77}/ρ_o^{77} is observed.

The IFAD curves (see Fig. 1) shows that after USI the critical amplitudes are practically unchangeable, i.e. the changes are not observed in the characteristic distribution of lengths of dislocation segments formed in the process of low-temperature plastic deformation. So, the amplitude mode of USI corresponds to the before-threshold values when the mass multiplication of dislocations is not realized. Moreover, after high-frequency loading the IFAD enhancement is observed: there the apparent critical amplitudes arise due to the increase of pendulum oscillation energy dissipation as a result of easier displacements of dislocation segments and IFAD background increase.

To interpret the structure transformations, providing a two-stage character of the relaxation process flow in both the magnetic phase (martensite) and the nonmagnetic phase (austenitic matrix), let us analyze the obtained experimental data. The first response to the external periodic perturbation (USI) of the nonuniform nonequilibrium structure, formed by the preliminary low-temperature deformation by drawing, is an activation of the structure transformation processes in the zones of high stress concentrations. Earlier, in the case of USI with before-threshold amplitude values under conditions of the grain boundaries "sharpening", reached by the temperature conditions of loading (in the liquid helium medium of 4.2 K), the generation of single dislocations in the local volumes adjacent to the grain boundaries was observed [9]. It can be assumed that such development of microplasticity in the 06Ch16N15M3B steel takes place near the martensite phase-matrix interface and reveals in the change of phase conjugation conditions. The last can be also caused by the vacancy sink in the ultrasound field onto the interfaces. As a consequence of changes in the degree of coherence (phase conjugation conditions) with the matrix the level of internal stress fields decreases that is evidenced by the sharp decrease of ρ^{77}/ρ_o^{77} and H_c/H_c^0 at short-time expositions (Figs. 2, 3).

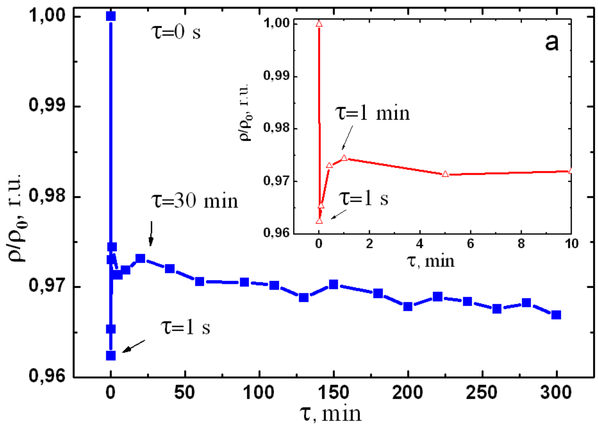

Fig. 2. Electrical resistance of the 06Ch16N15M3B steel deformed by drawing at 77K as a function of the subsequent ultrasonic irradiation time; a – c in the expanded time scale

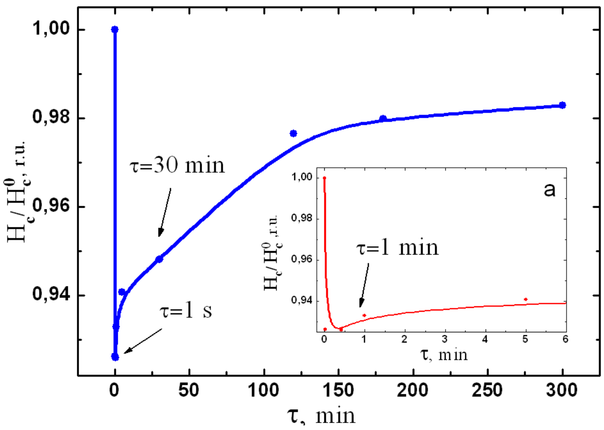

Fig. 3. Coercive force of the 06Ch16N15M3B steel deformed by drawing at 77K as a function of the subsequent ultrasonic irradiation; a – c in the expanded time scale

The induced magnetic anisotropy formation by the ultrasonic irradiation is responsible for the magnetic rigidity behavior. In the case under consideration (dynamic mode) forced deflections of magnetization orientations can occur in the volume of the single-domain ferromagnetic phase [3] due to the magnetoelastic interaction with a free energy

$\Phi \sim Mf_{ijk}\alpha_i e_{fk}$, where M is the magnetic moment; f_{ijk} – tensor of piesomagnetic modules; α_i – directional cosines of M; e_{fk} – deformation tensor components [10]. Induced coupled magnetoelastic oscillations [11] provoke the effects similar to the magnetic aftereffects. For the induced magnetic anisotropy behavior, evidently, responsible is the redistribution of point defects (mostly, ultrasound generated vacancies) in accordance with the magnetization direction in the interior of martensite subgrains. And, because of the vacancy generation under USI the diffusion coefficient can vary [5, 12]. In addition, the diffusion acceleration in the martensite phase under given USI conditions occurs due to the interaction of the impurity atoms with mobile edge dislocations and helical dislocation kinks [13]. As a result, because of the vacancy generation under high-frequency loading, the induced anisotropy relaxation time will change.

As is noted above, for the material predeformed by drawing at 300K, the changes in the parameter ρ^{77}/ρ_o^{77} after USI are insignificant. This means that during USI the preferred activation of structure transformations take place at the interfaces which, in our case, are the martensite phase boundaries. Note, that in the process of structure change an additional factor is the directed diffusion of ultrasound-generated excess vacancies. The IFAD measurement results show that the internal friction background increase after USI (see Fig. 1) is in accordance with the observed stage of slow decrease of the electric resistance (see Fig. 2,a). This indicates on the fact that additional factors, which influence on such electrical resistance change, can be the processes of dislocation cluster unblocking in the γ-matrix, dislocation redistribution and the nonequilibrium vacancy migration to the sinks. Note, that such a structure transformation under USI in the 15Ch2MFA steel (hull plate) was observed earlier [2] using the electron microscopy method. From the experimental data obtained it follows that in the cryogenically predeformed austenitic steel the behavior of dislocations and excess vacancies in the field of mechanical alternating stresses is determined by the effects of interaction and self-coordination.

CONCLUSIONS

Character of changes in physical properties (electric resistance, coercive force and damping decrement) of the 06Ch16N15M3B steel deformed by drawing at 77 K depending on the duration of the ultrasonic irradiation with before-threshold amplitudes is studied.

1. The investigations results shows that the behavior of relaxation processes in the structure of the steel containing residual martensite, activated by the ultrasonic irradiation, has a two-stage nature with different relaxation times.

2. It has been established that the high-frequency mechanical loading of the steel containing residual martensite changes the degree of martensite phases-matrix conjugation.

3. A role of dislocation and diffusion processes activated by the ultrasound irradiation for equalizing the internal stress field levels in the austenitic steel with deformation martensite is determined.

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Article received 22.10.2014

ПРОЦЕССЫ МИКРОПЛАСТИЧНОСТИ ПРИ ВЫСОКОЧАСТОТНОМ МЕХАНИЧЕСКОМ НАГРУЖЕНИИ АУСТЕНИТНОЙ СТАЛИ С ОСТАТОЧНЫМ МАРТЕНСИТОМ

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Проведено экспериментальное исследование характера изменения физических свойств (электросопротивления, коэрцитивной силы, декремента затухания) деформированной волочением при 77 К аустенитной стали 06Х16Н15М3Б от продолжительности последующего ультразвукового воздействия. Установлено, что протекание при этом релаксационных процессов в структуре с остаточным мартенситом имеет немонотонный (двухстадийный) характер с отличающимися временами релаксации. Показано, что высокочастотное механическое нагружение изменяет степень сопряжения мартенситных фаз с матрицей. Анализируется роль дислокационных и диффузионных процессов при ультразвуковом воздействии в выравнивании уровней полей внутренних напряжений в гетерогенных структурах.

ПРОЦЕСИ МІКРОПЛАСТИЧНОСТІ ПРИ ВИСОКОЧАСТОТНОМУ МЕХАНІЧНОМУ НАВАНТАЖУВАННІ АУСТЕНІТНОЇ СТАЛІ З ЗАЛИШКОВИМ МАРТЕНСИТОМ

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Проведено експериментальне дослідження характеру зміни фізичних властивостей (електроопіру, коерцитивної сили, декремента загасання) деформованої волочінням при 77 К аустенітної сталі 06Х16Н15М3Б від тривалості подальшого ультразвукового впливу. Встановлено, що протікання при цьому релаксаційних процесів у структурі із залишковим мартенситом має немонотонний (двостадійний) характер з відмінним часом релаксації. Показано, що високочастотне механічне нагруження змінює ступінь сполучення мартенситних фаз з матрицею. Аналізується роль дислокаційних і дифузійних процесів при ультразвуковому впливі у вирівнюванні рівнів полів внутрішніх напружень у гетерогенних структурах