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Forming patterns and mechanical properties of austenitic chromium-nickel steel due to strain aging

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Abstract. The work presents the results of studies of forming patterns and mechanical properties of martensite transformation, found in the chromium-nickel steels of 08X18H10T grade, subjected to pre-heat treatment followed by deformation aging. Internal energy state is determined by using acoustic emission. The observed patterns improve the mechanical parameters of steels quenched and plastically deformed at low temperature and then subjected to temper under load in the optimum temperature being associated with obtaining a more stable condition of the structure through the processes of relaxation of internal stresses, high dispersion and uniform distribution of carbides and intermetallic particles, increasing the density of dislocations as well as through other processes occurring during deformation aging martensite. Start your abstract here...

1. Introduction

At present, some traditional ways of increasing the strength of steel and alloys almost have been failed or proved to be uneconomical, in particular, opportunities of doping become limited due to deficit of a number alloying elements. On the other hand, the increasing demands of industry for the quality of alloys and steels with special properties and high strength characteristics makes professionals to look for efficient ways to get simple constructional and corrosion - resisting materials. Promising ways to improve the strength characteristics of alloys are a better use of the structural - phase method for hardening, combined deformation, deformation-thermal, radiation and other technologies. This paper is devoted to studying the regularities of deformation aging of austenitic steel of grade 18 - 10.

2. Materials and equipment

Investigations are fulfilled on austenitic chromium-nickel corrosion - resisting steels of 12X18H10T and 08H18N10T grades. For the mechanical testing, the samples of complex shape with a thickness of a test portion of 1.2 mm, a length of 14.0 mm and a width of 2.1 mm have been prepared. The axis of the samples coincides with a direction the sheet rolling; samples have been pre-annealed in a vertical tube furnace up to 1320 - 1370 K for 15 minutes. Mechanical tests are carried out by stretching the samples at a tensile machine of «soft» type. The rate of deformation during tensile test is 10^{-3} s^{-1} . A sensitive strain gauge is used to test the modulus of elasticity, limit of proportionality and the strength. The test is carried out at elevated temperatures with the use of a tubular resistance furnace with air

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atmosphere. At lower temperature, liquid nitrogen is used as the cooling medium. Fluctuations of temperature do not exceed $\pm 3^{\circ}\text{C}$ in the short-term tests and $\pm 5^{\circ}\text{C}$ in long-term ones.

The metallographic studies are carried out by the optical microscope MIM - 10. X-ray studies of samples subjected to heating after deformation are performed on diffractometer Dron - 1 under chromium radiation with automatic recording the interference line (311) of austenite to chart tape. Calculated under the experimental conditions the relative error of measurement of the crystal lattice period is $\Delta\alpha/\alpha = \pm 0,016\%$. Stress relaxation tests are carried out by the tensile machine with recording time up to 30 minutes. The value of relaxation $\Delta\sigma_{pen}$ is represented by the quantity of voltage drop from the initial value σ_0 to a certain one σ_t reached over a period of time. Measurement of the microhardness H is done with the hardness testing instrument PMT - 3M under load 100 g. In the tests, elastic limit with a tolerance of $\sim 0.001\%$ $\sigma_{0.002}$, conventional yield strength, ultimate strength σ_B and specific elongation $\delta\%$ of the specimen up to rupture are defined. Acoustic emission (AE) is measured by a piezoelectric transducer with gain coefficient of 40 dB. The noise level reduced to the input is 10 mV. The sensitivity of the apparatus is 10^{11} V / m and a working range of 0.1 - 0.8 MHz. AE sensor output signal is input to the main amplifier with gain coefficient controlled up to 60 dB followed by computer registration with a built-analog-digital converter (ADC) allowing to take the readings with a frequency of 3 MHz.

3. Processing technology of steel investigated

After manufacturing, mechanical polishing and annealing the samples are divided into 3 batches. The first batch is subjected to heat treatment according to GOST 5582 - 75 (State Standard). The second batch after the heat treatment (GOST 5582 - 75) is subjected to plastic deformation up to $\leq 20\%$ at a temperature (77 K) of the intensive transformation of austenite in the α phase of the martensite type followed by tempering at 720 K. Samples of the third batch after the heat treatment (GOST 5582 - 75), plastic deformation up to $\leq 20\%$ at the temperature of 77 K followed by tempering at the optimal temperature regime of 675 - 875 K are investigated by both a no-load, and under-voltage (0.1 - 0.75) $\sigma_{0.2}$. Table 1 shows some of the parameters characterizing the state of the steel after the appropriate treatment.

A large number of reviews, monographs, and original papers (see, for instance, [1]) have been published on studying patterns of martensite transformation of austenitic steels. It is relevant for these steels to decrease viscosity and plasticity, fatigue spalling carbides, loss of gas density etc. Uniform distribution of carbide phase has a decisive influence on the formation of a high-complex of mechanical, corrosion and other properties. Resolving the problem of obtaining alloys with good mechanical properties is largely dependent on the technique of mastering the use of domestic reserves. One of the characteristics of this class of steels after heat treatment is a small stability of austenite which becomes α - phase of the martensite type under the influence of plastic deformation. It is known that at low temperatures with a increasing the deformation of steels of austenite class, the α -martensite content increases simultaneously. In the process of austenitic-martensitic transformation occurs a substantial change in the state of the residual austenite by volume and phase cold working [2]. In samples of 2 batch, it is manifested the dependence of strength on the degree of deformation with a clear indication of saturation (figure 1).

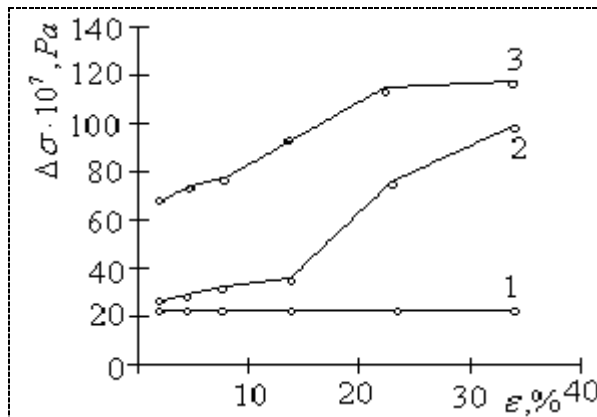


Figure 1. The increment $\Delta \sigma_{0.2}$ (curve 2) and $\Delta \sigma_t$ (curve 3) dependences of quenched steel on a degree of deformation (ε) at 77K and following heating-up to 770K with a heat rate of 0.175 K/s. A rupture is at 300K. Curve 1 is the value σ_t of heat treated steel (GOST 5582 – 75) deformed at 300 K.

Formation of martensite phase in steel at low temperature deformation is accompanied by elastic microstress initiation and dislocation structure [3]. Metallographic studies show that the austenitic steel structure in the quenched state is saturated by carbide inclusions. Intense precipitating carbides in austenite occur at stabilizing temper, which leads to a reduction in percentage of not only carbon but also the alloying elements in austenite and, consequently, it is accompanied with small changes in specific volume. Based on the above said, it is possible to suggest a slight decrease of quenching stresses. Further straining at 77 K up to $\varepsilon \leq 20\%$ after the heat treatment leads to an increase of strength parameters, the reason for which it is necessary to look at formation of both the martensite phase of austenite and greatly influence of the residual austenite and carbide inclusions (Table 1).

Table 1

Batch №	Processing technology	σ_t , $\times 10^7 \text{N/m}^2$	$\sigma_{0.2}$, $\times 10^7 \text{N/m}^2$	Rockwell hardness	Structure
1	Heat processing (GOST 5582 - 75)	63.8	22.5	54 – 56	Austenite, carbide
2	Heat processing, plactical deformation at 77K up to $\varepsilon \leq 20\%$ with next temper at 720K.	102	64	60 – 32	Martensite (80%), austenite, carbide
3	Heat processing, plactical deformation at 77K up to $\varepsilon \leq 20\%$ with next temper at 720K under stress $\sigma_L = 0,5\sigma_{0.2}$	175	106	64 – 66	Martensite (90%), austenite, carbide

Next temper at elevated temperatures appreciably effects on the strength characteristics, the magnitude and nature of which depends on temperature and heating rate (figure 2, figure 3).

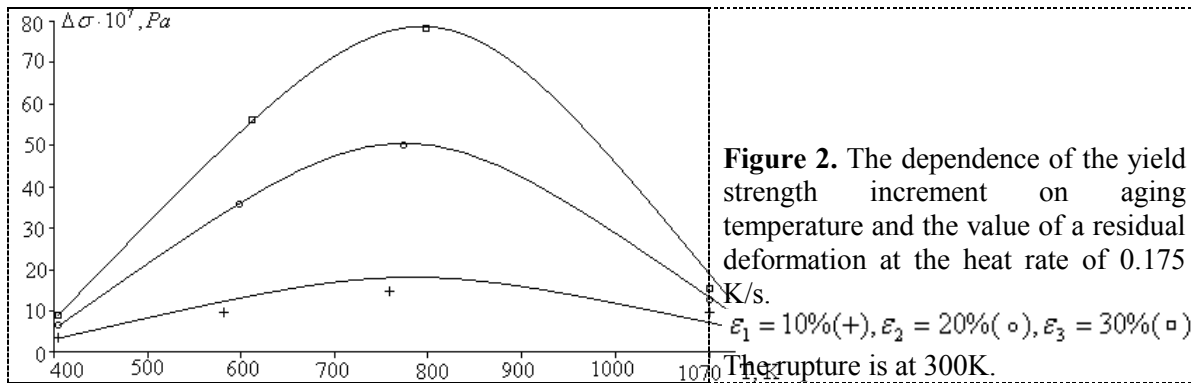


Figure 2. The dependence of the yield strength increment on aging temperature and the value of a residual deformation at the heat rate of 0.175 K/s. $\varepsilon_1 = 10\%$ (+), $\varepsilon_2 = 20\%$ (○), $\varepsilon_3 = 30\%$ (□). The rupture is at 300K.

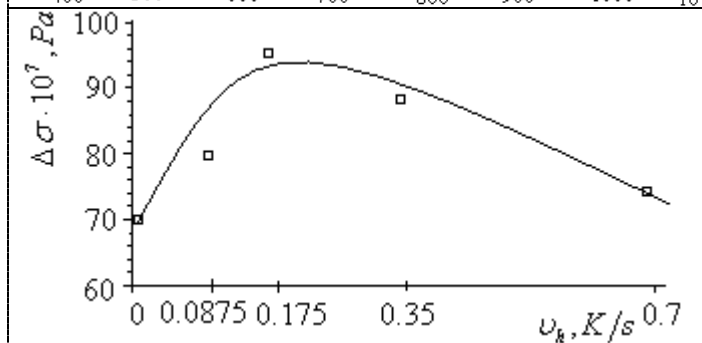


Figure 3. The dependence of the yield strength increment on the heat rate ν_h at the optimal annealing temperature 770K and the residual deformation $\varepsilon = 20\%$. The rupture is at 300K.

4. Determination of the internal state of the investigated steel using acoustic emission.

As the content of the martensite phase in the investigated steel is around 80 - 90% due to mechanical-thermal treatment, then the most likely source of acoustic emission (AE) in the field of elastic deformation is dislocation processes and processes related to the cracking of carbides formed as a result of strain aging martensite. Average energy of single pulse recorded with the deformation $\Delta\varepsilon$ of the sample is determined by the formula

$$W_u = \frac{W(\varepsilon)}{\dot{N}(\varepsilon)} \tag{1}$$

and is $\sim 10^{-16}$ J. This value of a single pulse is at the range of 10^{-10} - 10^{-19} J, which corresponds to dislocation processes and processes of microcrack formation. In figure 4, the example of the dependence of the average single pulse energy W_u on a deformation quantity calculated by equation (1) is represented. Typically, bursts in the histogram correspond to the AE activity bursts that are associated with the unsteadiness of distribution of internal crystal lattice imperfections.

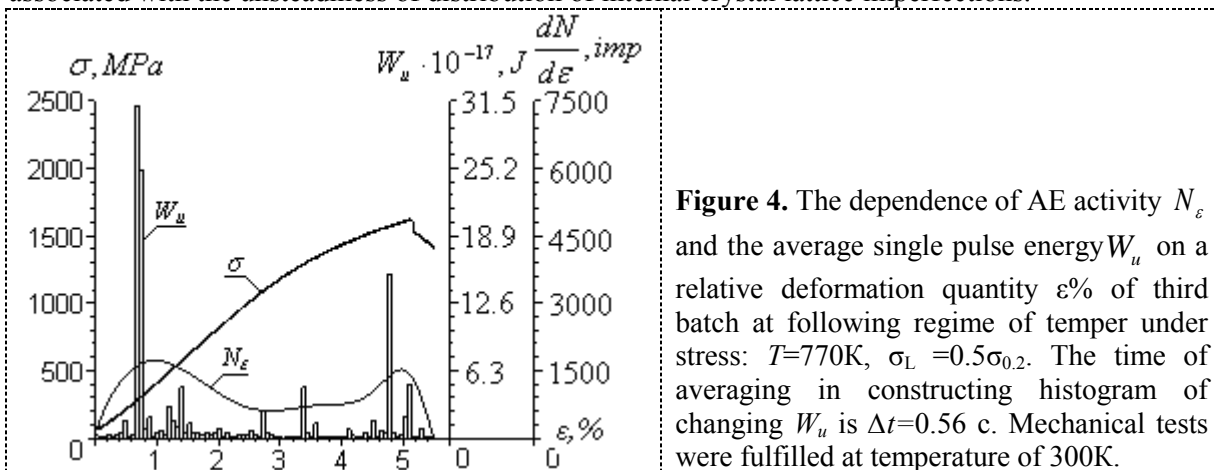


Figure 4. The dependence of AE activity N_ε and the average single pulse energy W_u on a relative deformation quantity $\varepsilon\%$ of third batch at following regime of temper under stress: $T=770K$, $\sigma_L = 0.5\sigma_{0.2}$. The time of averaging in constructing histogram of changing W_u is $\Delta t=0.56$ c. Mechanical tests were fulfilled at temperature of 300K.

On the other hand, nonmonotonic behavior of AE activity is driven by changes in the mechanisms of deformation in the mechanical tests (figure 4, smooth curve) [4, 5]. It is found that the value of AE activity in the area of elastic deformation is most pronounced in the case of temper under stress at $\sigma_L = 0.1\sigma_{0.2}$ and $\sigma_L = 0.15\sigma_{0.2}$. The quantity of AE activity monotonically decreases with increasing stress of temper in the elastic-plastic region. This pattern of behavior of AE activity in the elastic area, depending on the temper stress in the strength state, is associated with the ratio of processes of strain aging martensite: the formation of carbides, the increase in the density of mobile dislocations and pinning it by impurity atoms, as well as the relaxation of internal stresses. The behavior of the mechanical characteristics correlates with the behavior of some parameters of AE (figure 5).

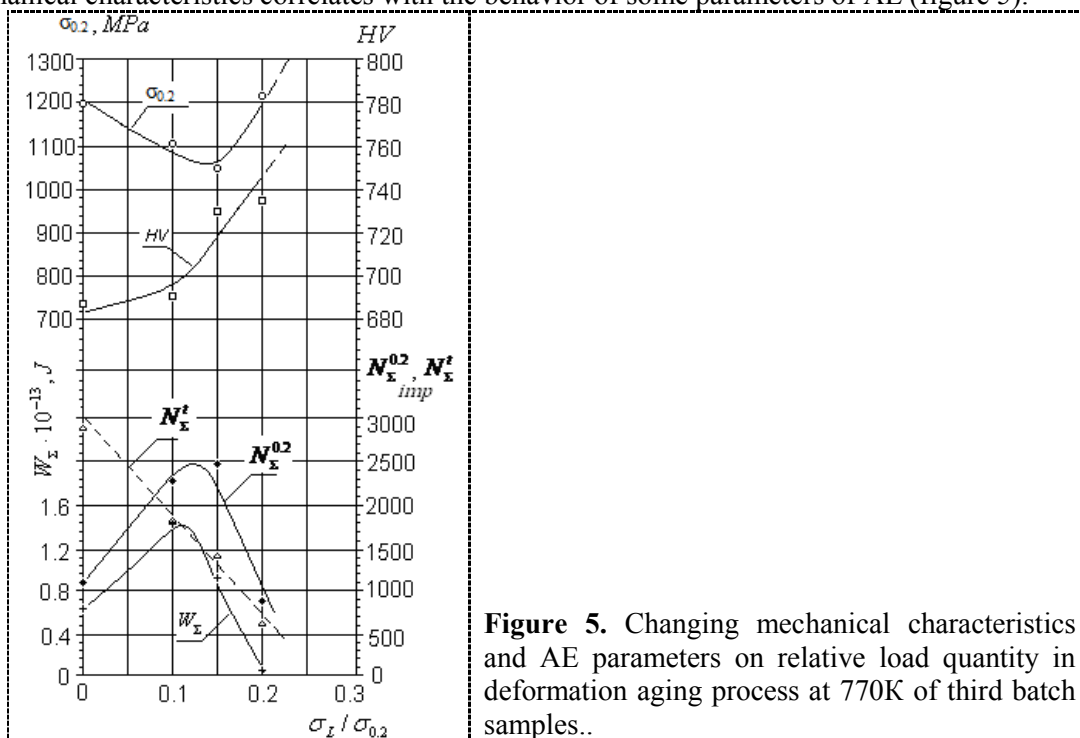


Figure 5. Changing mechanical characteristics and AE parameters on relative load quantity in deformation aging process at 770K of third batch samples..

Thus, improving the mechanical characteristics of austenitic steel plastically deformed at low temperature promotes lowering the relaxation and acoustic parameters as a result of temper under load in the optimum temperature regime. The observed patterns are due to the achievement of a more stable state of the processed steel structure through the processes of relaxation of internal stress, high dispersion and uniform distribution of carbides and intermetallic particles, increasing the density of dislocations and through other processes occurring during strain aging martensite. The dependence of the value of activity level \dot{N} and the total AE N_{Σ}^t on a value of the applied stress and the tempering temperature is manifested, which gives an indication of the existence and magnitude of internal stresses in the investigated steel.

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