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DETERMINATION OF THE HEAT-TREATMENT CYCLE FOR 110G13L STEEL FOR INCREASING THE ABRASIVE WEAR RESISTANCE

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The majority of recommendations on increasing the wear resistance of high-manganese steel by heat-treatment methods propose a combination of aging and low-temperature hardening cycles with different temperature—time conditions of conducting them. At the same time the formation of an excess carbide phase without additional alloying of 110G13L steel and the obtaining of a relatively uniform distribution of the dispersed carbides in the volume of the grain providing an increase in wear resistance in abrasive wear are possible.

However, such dispersion hardening is accompanied by embrittlement of the steel. The impact strength may be increased by recrystallization under conditions of low-temperature hardening of the austenite cold hardened in the phase transformation. The recrystallization must be done at a temperature at which significant coagulation or solution of the carbides in the austenite cannot occur.

To determine the optimum aging and low-temperature hardening cycles providing the necessary level of wear resistance and impact strength requires the conduct of many experiments with variation of the austenitizing temperature (t_h) and time (τ_h) and the aging temperature (t_a) and time (τ_a). To reduce the number of tests in this work an orthogonal plan

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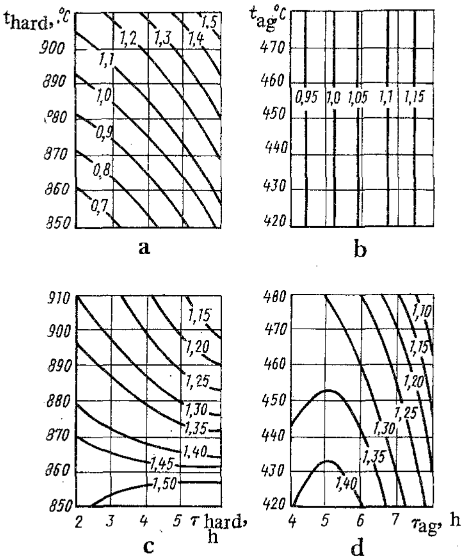

Fig. 1. Impact strength (a, b) in MJ/m^2 and the abrasive wear resistance (c, d) in % of 110G13L steel in relation to the austenitizing temperature and time (aged at 450°C for 6 h) (a, c) and to aging temperature and time (subsequent hardening from 880°C with a hold of 4 h) (b, d).

of a four-factor experiment including, after hardening from 1100°C, aging at 420-480°C for 4-8 h and subsequent hardening from 850-910°C (hold 2-6 h). The experimental data on the influence of heat-treatment cycles on the fracture toughness and abrasive wear resistance was analyzed on the computer by the method of multiple regression analysis with step exclusion of the regressors insignificant at the $\alpha = 0.1$ level.*

An interpolation equation relating the impact strength (MJ/m^2) to the heat-treatment parameters was obtained:

$$a_1 = 0.453 + 0.0656\tau_a + 0.0085\,(t_h - 880) + 0.0130\tau_h^2;$$

R = 0.88; $\sqrt{d_0}$ = 0.16, where R is the multiple correlation coefficient and $\sqrt{d_0}$ is the mean-square deviation.

This model is suitable for the above temperature–time ranges of aging and low-temperature hardening. From the equation it follows that with constant conditions of aging the change in impact strength in relation to austenitizing temperature and time may be described by a curve oriented convexly in the direction of the maximum values of these parameters. An increase in hold at each of the investigated hardening temperatures leads to an increase in fracture toughness. For example, a change in austenitizing time from 2 to 6 h at 850°C is accompanied by an increase in impact strength from 0.5 to 0.9 MJ/m^2 and at 890°C from 0.85 to 1.25 MJ/m^2. An increase in austenitizing temperature with the same hold also promotes an increase in impact strength. In this case the rate of increase in impact strength increases correspondingly to the increase in austenitizing time. The change in the level of impact strength is related to structural changes occurring with an increase in temperature and an increase in the length of heating for hardening since the austenitic grains are refined as the result of the occurrence of the processes of recrystallization and coagulation of carbides. In the case of a long hold at 910°C even some solution of carbides in the austenite is observed. As an example Fig. 1 shows a graphic image of the equation in the center of the plan (Fig. 1a).

A change in the aging temperature in the investigated temperature range does not influence the impact strength of the steel. In the interpolation equation obtained this regressor is significant and the change in impact strength as the result of aging is caused only by its length. In connection with this the relationship of impact strength to aging conditions (Fig. 1b) is represented by straight lines parallel to the Y axis. The level of

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*The calculations were made by O. G. Kasatkinyi.

the impact strength increases with an increase in aging time regardless of the subsequent hardening cycle. The increase in impact strength with an increase in aging time from 4 to 8 h with any of the investigated austenitizing cycles is constant, 0.2 MJ/m², and only the absolute value of impact strength changes. With an increase in austenitizing time from 2 to 6 h the impact strength after aging for 8 h and hardening from 850°C increases from 0.75 to 1.15 MJ/m² and after hardening from 880°C from 1.0 to 1.4 MJ/m². The maximum impact strength (1.7 MJ/m²) may be reached after aging in the 420-480°C range for 8 h and water hardening from 910°C (6 h). It has been experimentally established that the maximum impact strength after aging and low-temperature hardening is approximately equal to the impact strength obtained after normal water hardening from 1100°C.

Since any developments in 110G13L steel heat-treatment cycles are directed primarily toward increasing its wear resistance, the aging and subsequent hardening cycles must be selected so as to provide not only a high impact strength but also an increase in wear resistance.

The abrasive wear of the steel was determined in friction of the specimen on emery paper in forward movement along the generatrix of a rotating cylinder, that is, on fresh abrasive for a length of 200 m with a load of 0.2 MPa. The degree of wear was determined from the decrease in specimen weight, and the relative wear resistance from the ratio to the wear resistance of a specimen of 110G13L steel water hardened from 1100°C.

The complex relationship of the abrasive wear resistance (g/cm²) to the aging and hardening conditions may be represented graphically in the form of a function of hardening temperature and time (Fig. 1c) and in the form of a function of aging temperature and time (Fig. 1d) and also may be described by the regression equation

$$\alpha = (9{,}64 - 2{,}35\tau_a - 5{,}87\tau_h + 0{,}0021 t_a\tau_a + 0.00685 t_h\tau_h + 0{,}143\tau_a)\cdot 10^{-2};$$
$$R = 0{,}86;\ \sqrt{d_0} = 1{,}0.$$

An analysis of this relationship shows that with an increase in aging temperature the wear resistance drops. The parabolic character of this relationship is an indication of the possibility of obtaining the same level of wear resistance with two aging times (within limits of 4-6 h). A further increase in aging time with a constant temperature leads to a reduction in wear resistance. With any constant temperature the influence of aging time on wear resistance is strengthened with approach to the maximum hold, 8 h. The maximum wear resistance observed under certain aging temperature and time conditions is shifted in the direction of a shorter aging time with an increase in temperature.

After water hardening from 850°C (2 h) (preceding aging for 5 h at a temperature below 440°C) the abrasive wear resistance is 55% higher than for the standard. With an increase in austenitizing time to 6 h at 850°C the relative wear resistance increases to the maximum value 1.65 (aging at 420°C for 5 h).

The reduction in wear resistance with an increase in hardening temperature for all of the variations of aging is most significant in the 880-910°C range, especially with an increase in austenitizing time. While, after aging at a low temperature for a short time, relatively short austenitizing makes it possible to still maintain a high level of wear resistance (40-45% higher than the wear resistance of the standard), with the maximum aging temperature and time subsequent hardening leads to a reduction in abrasive wear resistance to approximately the level of the standard.

A reduction in the temperature of subsequent austenitizing and an increase in its time promotes an increase in wear resistance with any aging cycles. A short hold with an increase in austenitizing temperature leads to less reduction in wear resistance than a long one. The maximum wear resistance (60% higher than the wear resistance of 110G13L steel heat-treated using the normal cycle) is obtained after aging at 420°C for 6 h, austenitizing at 850°C for not less than 4 h, and water quenching. With an increase in aging temperature and time the relative wear resistance drops. Aging at 460-480°C for 4-6 h and subsequent hardening from 850°C (3-6 h) make it possible to obtain a quite high level of wear resistance, 1.4-1.45 times higher than for the standard.

The change in abrasive wear resistance of the steel correlates with the changes in its structure. Refinement of the grain as the result of recrystallization leads to an increase in wear resistance with any aging cycles. Aging using cycles providing precipitation of the dispersed carbides in the volume of the grain leads to a significant wear resistance of the steel. An increase in austenitizing temperature and time causes coagulation of the carbides. The embrittlement of the steel as the result of carbide formation is compensated by austenitic grain refinement. This agrees with the results of investigation of the change in impact strength and the character of failure of the steel after aging and austenitizing using similar cycles.

Therefore, the complex heat-treatment cycle for 110G13L steel developed by us (harden from 1100°C + age at 460-480°C for 4-6 h + harden from 850°C with a hold of 3-6 h) makes it possible to effectively increase its wear resistance with maintenance of a sufficiently high level of impact strength without additional alloying. Combined solution of the interpolation equations obtained opens possibilities for optimization of the wear resistance and resistance of the steel to brittle fracture in relation to its specific service conditions.

IMPROVING THE HEAT RESISTANCE OF AUSTENITIC STEELS BY THE THERMOCHEMICAL TREATMENT METHOD

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The heat resistance of austenitic steels containing volatile components becomes an important factor when parts made of such steels are used in various systems and devices where these parts are subjected to heat, either during service or under vacuum. Some undesirable processes (such as the austenite–ferrite phase transformations [1]) affecting physicochemical properties of the steel might occur due to heating. The heat resistance of austenitic steels can also be impaired due to blistering which occurs when such steels are used under radiation conditions [2]. This makes the improvement of austenitic steels' heat resistance especially important. The authors consider that one way to achieve this improvement is to use thermochemical treatment (TCT) for fabrication of protective coatings consisting of chemical elements with a low atomic number, such as Al and Ti (on the basis of minimum sz^2 value, where s is the material erosion coefficient and z is the atomic number).

The present work* studies the following Cr–Mn and Cr–Ni austenitic steels: ÉP838 (12% Cr, 14% Mn, 4% Ni, 1.4% Al, <1% Mo; <0.03% C) and 316 (16-18% Cr, 10-14% Ni, 2% Mn; 2% Mo; <1% Si; <0.03% C; <0.03% S; <0.045% P).

A microbalance was used for studying the material evaporation process under high, oil-free vacuum conditions (about 5 μPa). Evaporation rates from an open surface to vacuum were measured by the weight loss of 8 × 16 × (0.1-0.2) mm polished plate specimens suspended from a quartz microbalance with $4 \cdot 10^{-7}$ g/μm sensitivity.

The protective coatings were deposited on the steel surfaces by TCT methods. Two methods were used: 1) saturation in a powder medium; and 2) electrolytic aluminizing in molten salts (see Table 1).

As was established previously [3] on the basis of kinematic curves obtained for vacuum evaporation of ÉP838 and 316 steels at different temperatures, the evaporation rate of their volatile components is of parobolic form. Phase analysis of the condensate carried out by the electrographic transillumination method showed that the main component of the vapor phase formed above the ÉP838 steel is Mn, while above 316 it is Cr. Evaporation of the above elements is controlled by their diffusion to the surface, which explains the parabolic form of their evaporation rate curves. Evaporation rates of the Cr–Ni steels are considerably lower than those of the Cr–Mn steels in similar temperature ranges.

ALUMINIZING

It is necessary to prevent or slow down the evaporation of volatile elements from the steel surface during aluminizing. The efficiency of that protective coating is proven by

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