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FEATURES OF CHANGE OF MECHANICAL PROPERTIES OF PRECIPITATION HARDENING ALLOY 47XHM AT HARDENING AND AGEING

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Mechanical properties of nickel-chromic austenitic alloy 47XHM have been studied. It was shown that at increase of heating time for hardening the deforming pressures fall, plasticity grows that is connected with dissolution of excess α-phase. In order to obtain high strength properties with minimum level of elastic imperfections the thermal processing of alloy should be carried out in temperature range 650...750 °C, and time of ageing should be from 8 to 20 h depending on temperature of ageing.

Nickel-chromic alloy 47XHM possesses high corrosion resistance, low temperature coefficient of modulus of elasticity, nonmagnetic property, low elastic hysteresis and elastic aftereffect, high fatigue strength and used in industry not only as spring material [1] but also as an element of construction of nuclear and thermonuclear reactors [2].

Earlier in [3] influence of hardening temperature, curing time for hardening and cooling rate for phase-structural state of alloy 47XHM was carefully examined.

The aim stated in this work consisted not only in studying structural-phase transformations and properties of alloy 47XHM but also in the fact that to show concrete ways of implementing the obtained results for increasing technological plasticity and strength properties of this material.

Experiment

The object of investigation is alloy 47XHM of industrial production and standard chemical composition (47 % – Cr, 5 % – Mo, res. – Ni).

Mechanical tests of samples at room temperature on uniaxial tension were carried out at the device of the type «POLYANI» by standard technique in accordance with SS 1497-84. By stress-strain diagrams yield points and ultimate strength were calculated and sample specific elongation after breaking was determined as well. Sample structural-phase state was studied at optical (NEOPHOT-21) and electron (EM-125K) microscopes. Sections for metallographic investigations were polished and etched by electrolytic method in 10 % acetic-chloric electrolyte. Samples for electron microscopy in the form of discs were prepared by the method of spray electro-polishing as well as by the method of foil thinning.

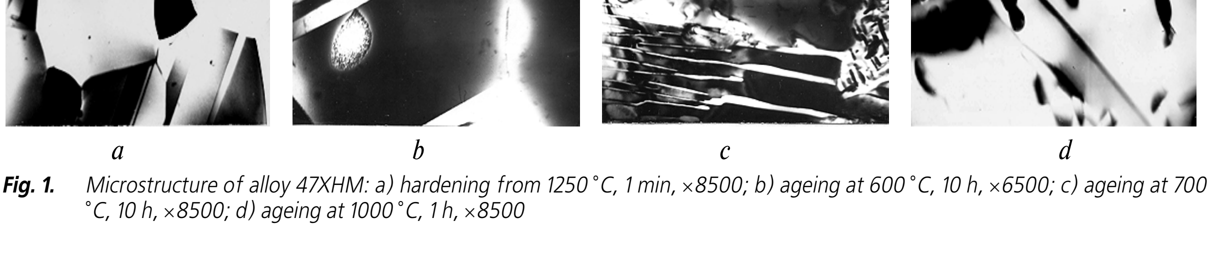
Results and their discussion

After hardening in temperature range 900...1300 °C structure of alloy 47XHM is two-phase consisting of grains of γ-matrix and particles of α-phase on the basis of Cr, having bcc lattice (Fig. 1, *a*). Increasing curing time for hardening the dissolution of strengthening α-phase, growth of matrix grains, increase of alloy anisomerousness and change of grain boundary character were stated. Growth of grain in alloy 47XHM is inhibited very much due to the presence of excess α-phase which decelerates boundary migration at collective recrystallization.

Dependence of plasticity and resistance to deformation of alloy 47XHM on hardening temperature is given in Fig. 2. It is seen that at hardening temperature growth the alloy plasticity increases and deforming stresses ($\sigma_{0,1}$ is the yield point, σ_1 is the stress at residual deformation in 1 %, σ_B is the ultimate strength) steadily decreases. Increase of plasticity at hardening temperature increase is conditioned not only by dissolution but also by the processes of coalescence and spheroidezation of the excess α-phase.

Analysis of dependence of mechanical properties on curing time at 1300 and 1225 °C shows that at increase of heating duration deforming stresses decrease and plasticity grows. Decrease of resistance to deformation as well as increase of alloy plasticity is conditioned by dissolution of excess α-phase. The process of dissolution begins with disperse particles and at curing time increase larger particles are dissolved enriching matrix solid solution with alloying component. Plasticity grows at increasing homogenization time at 1300 °C up to 30 min inclusive and after that the curve comes to saturation.

The character of changing mechanical properties depending on curing time at 1250 and 1225 °C obeys to the same law that at 1300 °C but occurs at lower intensity.



a *b* *c* *d*

Fig. 1. *Microstructure of alloy 47XHM: a) hardening from 1250 °C, 1 min, ×8500; b) ageing at 600 °C, 10 h, ×6500; c) ageing at 700 °C, 10 h, ×8500; d) ageing at 1000 °C, 1 h, ×8500*

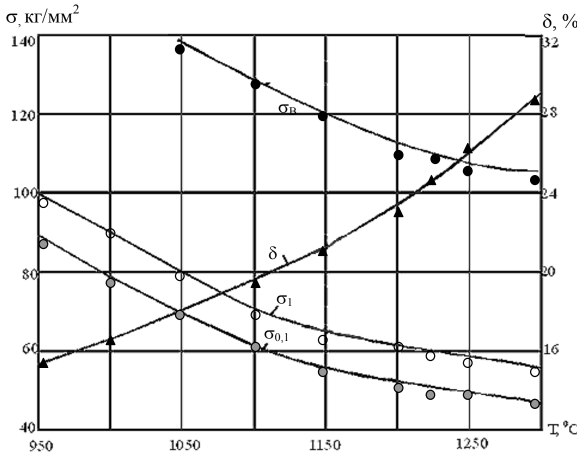


Fig. 2. *Dependence of plasticity and resistance to deformation of alloy 47ХНМ on hardening temperature*

After hardening from 1200 °C the value of yield point and ultimate strength of samples are higher more than 10 kg/mm² in comparison with temperature range 1300...1250 °C. Character of changing plasticity at hardening temperature 1200 °C changes sharply instead of expected growth of plasticity at heating time increase its fall is observed. The reason of such phenomenon is not determined although structural investigations of sample fracture mode in cross-section show the presence of so-called structure «fish-scale» fracture. It is appropriate to consider that «fish-scale» structure is not the feature of heat treatment flaw however, it may well be so that it may be one of the reasons of decreasing plasticity and viscosity of alloy.

Rather wide spread of values of plasticity and strength values at testing sample hardened from 1200 °C should be indicated. Obviously, spread of values is influenced not only by structure inhomogeneity but also partial flashing of a particle of α-phase being on grain boundary as well as the presence of undissolving particles which are stress concentrators. All these reasons result in microcrack formation decreasing alloy plasticity and viscosity.

As precipitation hardening alloys are mainly used after treatment including hardening and ageing then the investigations of ageing influence on structure and mechanical properties of alloy 47ХНМ were of interest.

At ageing at 600 °C of hardened alloy 47ХНМ at ageing time increase the strength properties insignificantly grow (Fig. 3). Comparing the data of structural investigations (Fig. 1, *b*) at change of strength properties (Fig. 3) some conclusions may be made and namely: contribution into alloy hardening is, obviously, conditioned only by decay inside the excess phase but as the volume fraction of this phase is low (5...10 %) and size of extractions inside these particles amounts from 15 to 40 A then increase of strengthening is low. There is no structural change inside the matrix in comparison with the hardened material (up to 10 h of ageing (Fig. 1, *b*) and therefore, its contribution into alloy hardening may be neglected. Certain decrease of plasticity occurs, probably, owing to formation of segregation of alloying components on grain boundaries.

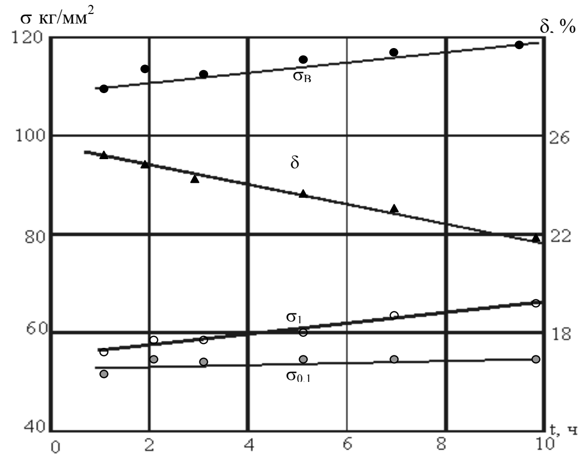


Fig. 3. *Mechanical properties of alloy depending on ageing time at 600 °C hardened preliminary from 1250 °C, 2 min*

The data on kinetics of alloy hardening at 700 °C hardened preliminary at 1250 °C are given in Fig. 4. At the initial stages of ageing the increase of resistance to small plastic deformation is already noted. Its value grows sharply at further increase of ageing time. The noted increase of hardening responds to decay stage as a result of which the intermittent decay with the extraction of noncoherent α-phase is intensively developed (Fig. 1, *c*).

Electron-microscopic and metallographic investigations of structure showed that the intermittent decay begins from grain boundary and finishes in 5...10 hours after beginning of ageing (Fig. 1, *c*), and decay volume fraction amounts to 75...85 % that responds to maximal hardening. The nature of hardening at this ageing temperature is conditioned by retardation of dislocation, intermittently extracted particles of α-phase.

At increase of ageing duration alloy plasticity falls steadily and decreases to 5 % for 10 h of ageing while it amounted to 25 % for hardened alloy. Such fall is well explained if sharp increase of strength is taken into account. Besides, it should be noted that sensitive elements work in elastic domain with very small residual deformation and therefore, such reserve of plasticity is enough for safe performance of devices.

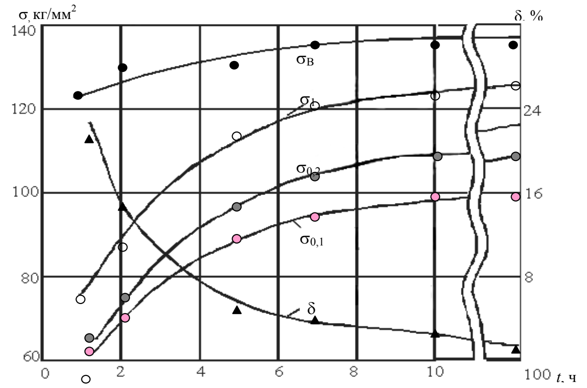


Fig. 4. *Mechanical properties of alloy 47ХНМ depending on ageing time 700 °C hardened preliminary from 1250 °C, 2 min*

At further increase of ageing temperature the change in the character of dependence of alloy strength properties on ageing duration is observed. The data on the influence of ageing time at 800 °C on microflow resistance, deforming stresses and plasticity of alloy 47XHM are given in Fig. 4. First of all it should be noted that at initial stages of ageing the deforming stresses and especially yield point have the value not worse than properties of alloy aged at 700 °C. Therefore, such mode may be recommended at manufacturing resilient sensitive elements as in this case time of thermal treatment decreases considerably.

Increasing ageing time the yield point and other deforming stresses including ultimate strength decreases that is conditioned by the beginning of coagulation process in cells of intermittent decay and at 100 h ageing of spheroidezation of lamels of α-phase. At the same time plasticity grows that is dislocation occurring at deformation overcome easier obstacles in the form of large coagulated particles of α-phase. Thus, decrease of strength properties and increase of plasticity at alloy overageing is caused by growth of distances between earlier formed extractions due to their coagulation, decrease of particle number in matrix volume unit and decrease of stress required for bypass of particles by dislocations.

Intensity of coagulation processes increases at further growth of ageing temperature, for example, at 900 or 1000 °C; also the fall of strength properties is observed. Therefore, it is not appropriate to carry out thermal postprocessing – ageing in specified temperature range.

Conclusion

Increasing heating time for hardening the deforming stresses fall and in this case plasticity grows that is connected with dissolving of excess α-phase. The character of changing plasticity of samples hardened from 1200 °C changes sharply, instead of expected growth of plasticity at heating time increase its fall is observed. It is supposed that it is caused by the presence of «fish-scale» fracture in structure.

It is not appropriate to carry out hardening of alloy 47XHM lower than 1225 °C as it results in microcracks formation at deformation decreasing plasticity and viscosity of alloy.

Temperature increase more than 1300 °C results in sharp decrease of plasticity that is conditioned by flashing of particles of α-phase on the basis of Cr and liquid phase spread on grain boundaries.

At ageing at 600 °C of hardened alloy 47XHM at ageing time increase the strength properties grow insignificantly that is conditioned by decay inside α-phase.

At growth of alloy ageing temperature to 700 °C at initial stages of ageing the increase of resistance to small plastic deformations is noted. Its value increases sharply at further rise of ageing time. Strengthening is caused by discontinuous precipitation of α-phase in γ-matrix.

At ageing temperature 800 °C strength properties decrease at increase of ageing time that is conditioned by the beginning of coagulation process in cells of intermittent decay and at 100 h of ageing by spheroidezation of lamels of α-phase.

Thus, in order to obtain high strength properties with minimal level of elastic defects the thermal treatment of alloy should be carried out in temperature range 650...750 °C and ageing time should amount from 8 to 20 h depending on ageing temperature.

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