INTENSIFICATION OF HEAT-TREATMENT PROCESSES

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At the present time the critical point Ac_3 begins to lose its significance as an orienting factor in the technology of heat treatment. This may be borne out, for example, by the fact of the existance of hysteresis in high frequency treatment of steel. The Ac_3 point shifts 200-250° upwards, there is no considerable growth of austenite grains, but the strength of the steel increases due to a sufficiently complete homogenization of the solid solution. Above point Ac_3 there are no phase transformations in the solid solution until the beginning of melting. Consequently, the problem of heating must be solved only in respect to the control of the diffusion processes within the volume of the austenite grain.

As it has been revealed by investigations, it is possible to conduct heating almost to the melting point temperatures and obtain a sufficiently ductile metal after hardening, provided the process of sulfur diffusion is properly controlled.

Sulfur diffuses towards the grain boundaries and in combining with iron forms a low-melting eutectic which envelops the austenite grains at temperatures above 988°.

In this manner there forms a film which disintegrates on impact, and this causes the steel to become brittle.

By introducing cerium, which has a great affinity with sulfur, it is possible to arrest the diffusion of sulfur to the grain boundaries at a high temperature and prevent embrittlement in spite of the developing coarse acicular martensite.

But such a structure is not the direct cause of the brittleness. Fig. 1-a shows a diagram of the mechanical properties of a chrome-nickel-molybdenum steel containing 0.13% C, 1.2% Cr, 4.2% Ni, and 0.4% Mo. This graph was plotted on the basis of the data obtained for samples quenched and tempered subsequent to hardening-heating up to 1200°.

Represented in Fig. 1-b are the mechanical properties registered by us for the samples of steel 12Kh2N4A. The microstructure of steel 12Kh2N4A quenched from 850 and 1200° is shown in Fig. 2.

From an examination of the above data it follows that a rise of the hardening temperature beyond the Ac_3 point of chrome-nickel-molybdenum steel leads to no deterioration of the mechanical properties. Thus the grain size cannot serve as a basis for judging the strength of steel.

An explanation of this fact may be furnished on the basis of the theory of dislocations.

It has been established that a good correlation exists between the density of dislocations and the strength. There also exists a relationship between the unit block sizes and hardness. The microstresses have a relatively small value, and the observable broadening of the lines in the X-ray patterns is essentially attributable to the dispersity of the blocks.

Investigations show that heating to higher hardening temperatures increases the density of dislocations at the grain boundaries up to a certain maximum, whereupon it begins to drop. This corresponds to the variation of the strength values.

Consequently, in spite of the growth of grains, an increase in temperature up to a certain limit does not cause the dislocation density to diminish in the crystal lattice; i. e. there occurs no growth of blocks. The intensification of dislocation density with rising hardening temperature is associated with a more complete homogenization of the solid solution and with the phase hardening resulting from

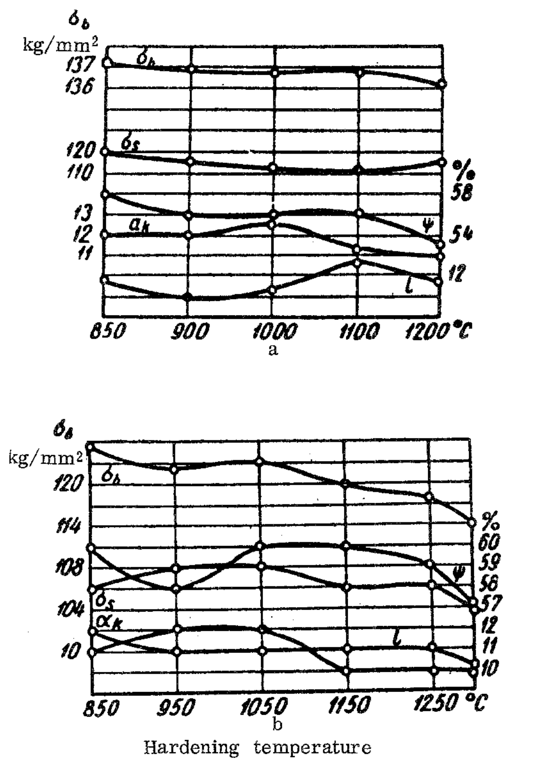

Fig. 1. Mechanical properties vs. hardening temperature. a - Cr-Ni-Mo steel; b - steel 12Kh2N4 A.

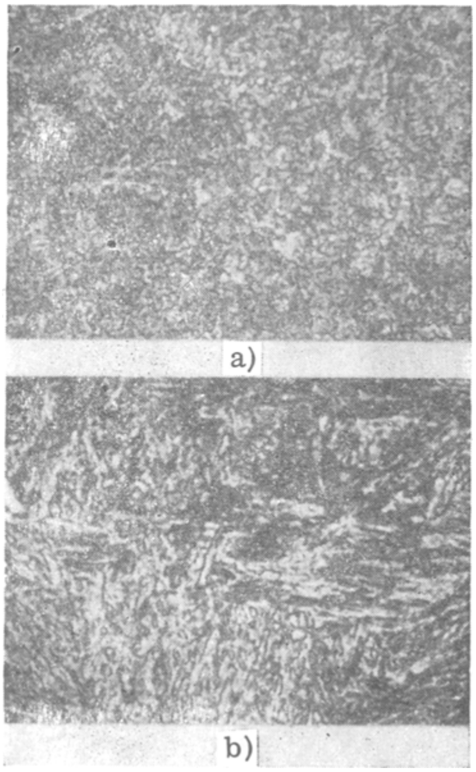

Fig. 2. Microstructure of hardened steel 12Kh2N4A. x 400.
a-quenched from 850°, b-quenched from 1200°,

quenching. The decrease in the density of dislocations after a definite degree of heating is, therefore, connected with the recrystallization of austenite. The dispersion of dislocations as a result of inadmissible overheating occurs with great intensity. The alloyed steels possess a higher lattice dislocation stability than carbon steels.

The critical point corresponding to the maximum concentration of dislocations at the grain boundaries for most steels is above 1200°, and in steels containing the elements which form thermally stable carbides and manifest a chemical affinity with sulfur this point may be located around the 1300° level.

The temperatures at which no decrease in strength is to be registered in steel after hardening may be called "extreme". The lower boundary of the "extreme temperature range" corresponds to the formation of grains not larger than size No. 5. The strength values resulting from room temperature tests of notched and skewed samples are convincing (Fig. 3). It may be seen from the figure that, in spite of the considerable growth of austenite grains, the steel preserves sufficient strength even in conditions conducive to fracture.

It follows, therefore, that the evaluation of the strength of steel on the basis of the grain size is not in keeping with modern ideas about strength based on the theory of dislocations.

By varying the temperature and the duration of tempering it is possible to produce high plasticity characteristics, regardless of the coarse-grained structure of overheated steel.

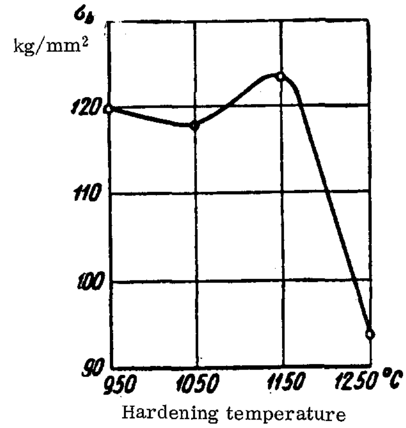

Fig. 3. Strength of steel 45 as a function of the hardening temperature; tempered at 550°.

An increase of the tempering time causes a more complete precipitation of the carbides from martensite and induces their coagulation. This gives the steel enhanced toughness and higher resistance to impact loads.

An X-ray diffraction study of the fine structure of steel heated to elevated temperatures permitted us to establish a relation between the width of lines (110) and the hardening temperature.

For hardened and untempered samples the broadening of line (110) depends on the mosaic block size and the stresses, the splitting of the line is due to the tetragonality of the martensite crystals. In steel 45 the maximum line (110) widening was registered for specimens quenched from 1050°. (The X-ray diffraction studies of the steels was carried out by a group of students of the Moscow Steel Institute under the direction of S.S. Gorelik, Associate in Technical Sciences)

The greatest widening of lines (110) is observable in boron-steel-45 samples quenched from 1150°; in steel-12Kh2N4A samples the widening is constant up to 1300°, in steel 30KhGT broadening begins after 1150° and continues at temperatures exceeding 1300°. This may be attributable to the fact that dispersed carbides precipitate during cooling, and this leads to structural refinement. It was noted that when the hardening temperature reaches the upper limit of the "extreme range" there occurs no deterioration of the mechanical properties in the hardened samples of this steel. Apparently, owing to the impoverishment of the carbide phase in the readily soluble carbides during the alloying of austenite, the quantity of dislocations increases at the grain boundaries, and this prevents the deterioration of mechanical properties.

Investigations show that during the $\alpha \rightarrow \gamma$ -state transition phase hardening takes place and the austenite grains become finer.

In this manner the fact that the fine structure influences the mechanical properties of steel was established.

A comparison of the X-ray patterns and the structures of the same samples, as observed through electron microscope, confirm the above postulates.

Thus, an increase of the hardening temperature from 900 to 1200° for steel 45 tempered at 500° leads to a reduction in the amount of the carbide phase, finer carbide-phase inclusions (550-850° A), and the formation of zones with a finer structure of acicular troostite. The high strength of steels 45 and 12Kh2N2A is attributable to the increased number of mosaic blocks.

A decrease in strength is observable in steel 12Kh2N2A after heating to temperatures above 1300°. This may be explained by the enlargement of the blocks and dispersion of dislocations.

Fig. 4 shows the structure of steel 45 subjected to quenching in oil from 1300° and 850°, and tempered at 500°. A comparison of the photomicrographs points to a considerable refinement of the pearlite structure in the case of high-temperature treatment. The structure of steel heated to normal hardening temperature contains large carbide inclusions. This indicates that during high-temperature heating homogenizing takes place in the microvolumes (in the adjacent zones a coarser structure may still be preserved, in spite of the prolonged heating).

As a result of this investigation it was established that the hardening temperature produces a strong influence on the broadening of the lines in the X-ray patterns of the tested steels. This indicates the hardening temperature affects the block structure of the matrix to a considerable extent.

No lines could be detected in the X-ray patterns for the carbide phases present in steel 12Kh2N2A. This betrays the fact of their exceedingly high dispersity.

In steels 45 and 40 (with boron) a rise in temperature is accompanied by a greater broadening of lines due to the formation of high internal stresses.

High-temperature heating may be utilized to accelarate cementation in the process of high-frequency-current heating; it may be used for hardening parts right after stamping, for copper soldering, for austempering of carbon-steel tools, for annealing maleable cast iron.

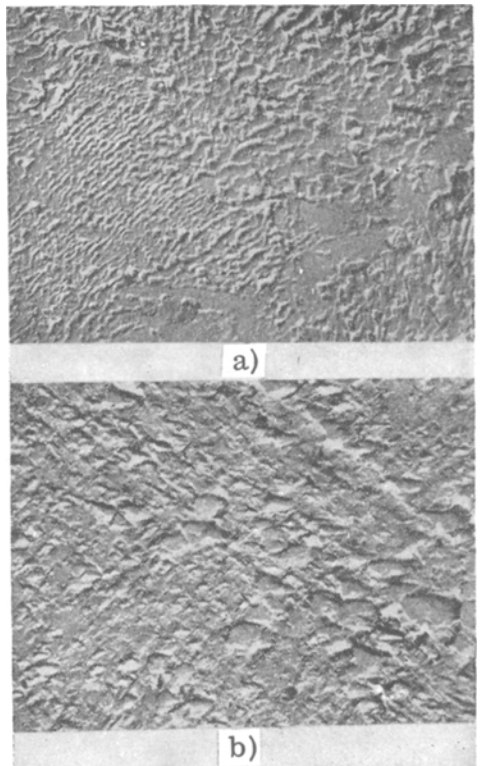

Fig. 4. Steel 45 structure after hardening and tempering at 550°. The temperatures of quenching a - 1300°, b - 850°.

CONCLUSIONS

1. The mechanical properties do not depend on overheating characterized by the appearance of coarse-grain structure.

2. For various grades of steel the static strength is stable after quenching in oil from temperatures of the "extreme range". The plasticity characteristics of steel quenched from the extreme range temperatures may be controlled by proper tempering conditions.

3. The stability of the high static strength indices for all steels quenched from the "extreme-range" temperatures is attributable to the homogenization of the solid solution, increased density of dislocations at the austenite grain boundaries, the refinement of the mosaic blocks, and the formation of an optimal fine structure due to phase hardening resulting from $\alpha \to \gamma$ transformation in the process of heating.

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