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INFLUENCE OF THE HEATING TEMPERATURE ON THE PROPERTIES OF STEEL

D.M. Berdiev*; A.A. Yusupov*; A.Kh. Abdullaev*; B.K. Abdullaev*

*The Tahkent State Technical University,
Tashkent, UZBEKISTAN

ABSTACT

The article analyzes the methods of heat treatment of iron-carbon alloys.,In particular, the modes of heat treatment of steel grade 45 and 40X were studied. The essence of unconventional modes is that by means of preliminary high-temperature HT, a high level of defectiveness of the crystal structure of steel is achieved. Thus, it has been shown that with significant heating of steel, extreme temperatures are observed at which, after cooling, structures with an increased (after normalization) dislocation density or with a high level (after quenching) are formed.

KEYWORDS: *Austenitic Steel, Iron, Steel 40X, Melting, Low-Carbon Martensitic Steels*

INTRODUCTION

An important problem of modern mechanical engineering and repair enterprises is to reduce the cost of metal and energy resources. Since the main parts of machines are made of carbon and low-alloy steels, the service life of which is mainly determined by mechanical properties, they are hardened by heat treatment (TO) - quenching and tempering. The accepted standard modes of maintenance of metal products, as a rule, provide high mechanical properties, but in some cases this turns out to be insufficient. In particular, this concerns the toughness of metals [1], which ensures high product reliability.

In recent years, in order to exclude large grains in blanks, considerable attention has been paid to structural heredity [2]. Dependence of the mechanical properties of low-carbon martensitic steels on the structural heredity during HT [3]. In articles [4] heredity is considered during phase transformations.

MATERIALS AND METHODS

Based on the studies carried out, it was established that all unconventional modes of steel HT are based on the fundamental laws of phase transformations [5]. The essence of unconventional modes is that by means of preliminary high-temperature HT, a high level of defectiveness of the crystal structure of steel is achieved. This allows, upon repeated heating, depending on the completeness of repeated structural transformations, to significantly refine the steel grain [4]. However, in the studies carried out, there were unresolved theoretical and practical issues related to phase transformations of steels:

- the effect of the heating time on the temperature and the value of the extremum of the dislocation density after γ - α - transformation upon cooling in air and after annealing of steel upon cooling together with the furnace.

In this work, not only the mechanism of α - γ - α - transformations is considered, but also it is noted that with high heating there is an extreme temperature at which atoms of refractory impurity phases pass into a solid solution (austenite). In this case, upon cooling (γ - α transformation), the dislocation density in the α - phase increases. During repeated phase recrystallization, some of these dislocations are retained, which significantly increases the performance of steel products.

Investigated samples of steels 45 and 40X industrial smelting. Armco iron samples were used as a reference material. Steel grades are regulated by STSD 3541-79. The chemical composition of the investigated heats is shown in Table 1.

TABLE 1 CHEMICAL COMPOSITION OF STEEL SAMPLES FOR RESEARCH

№	Steel grades	Element content,% wt.						
		C	*Mn*	*Si*	*S*	*P*	*Cr*	*Ti*
1.	Армко-Fe	0,04	0,04	0,03	0,02	0,015	-	-
2.	45	0,42	0,65	0,26	0,02	0,02	-	-
3.	40X	0,41	0,74	0,35	0,025	0,022	0,92	-

The samples were thermally treated at different temperatures: the initial temperature for each steel was chosen from the calculation above the critical point of heating temperatures Ac_3 + 30 ÷ 50 °C, and then at temperatures of about 900, 1000, 1100, 1150, and 1200 °C. The holding time at each of the above temperatures was different: 5 minutes, 20 minutes, 2 hours, and 5 hours. Depending on the holding time, heating was carried out in a salt bath or in an oven. The samples were cooled in air, in water or oil, as well as while cooling together with the oven. Thus, the thermal prehistory of steel was created. The repeated phase recrystallization was always carried out with heating to Ac_3 + 30÷50 °C for each steel.

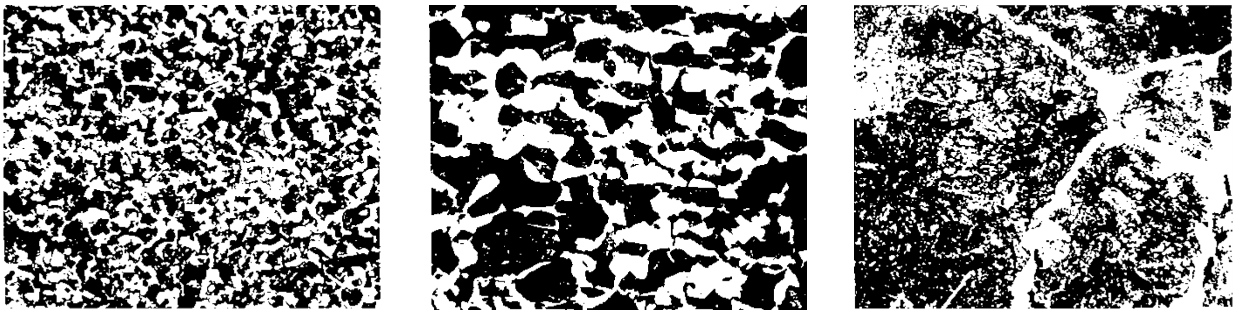
Analyzes were carried out: metallographic - on microscopes MIM-8M [6]; X-ray diffraction - on the DRON-2.0 installation. The state of the fine structure of steel (dislocation density), the amount of retained austenite, the period of the crystal lattice, and the amount of carbon in the phases of hardened steel were determined [7].

Metallographic and X-ray studies showed an intensive growth of austenite grain with an increase in the heating temperature, and the dislocation density was very low, although an extreme temperature is clearly observed for steels 45 and 40X, when the dislocation density is increased (Table 2), and the austenite grain grows (Fig. 1)

TABLE 2 THE AMOUNT OF AUSTENITIC STEEL GRAIN DEPENDS ON THE HEATING TEMPERATURE

Heating temperature, °C	Steel grades					
	45			40X		
	d_{av}, mm	*N* ball	$\rho, 10^8 cm^{-2}$	d_{av}, mm	*N* ball	$\rho, 10^8 cm^{-2}$
850	0,017	9	эталон	-	-	-
870-880	-	-	-	0,0193	8	etalon
1000	0,106	3	1,7	0,021	8	1,73
1100	0,168	2	3,5	0,032	7	5,57
1200	0,214	1	1,5	0,102	3	1,75
1260	-	-	1,5	0,107	3	4,37

Note: d_{av} – average grain diameter; *N* – ball number according to STSD 8639-92



870 °C 1100 °C 1260 °C

Fig. 1. Microstructure of steel 40X after annealing at heating temperatures: 870, 1100, 1260 °C(× 100).

The difference in the density of dislocations between the maximum and minimum in percentage terms is significant, but in absolute terms it is very small: $\Delta\rho \approx 1,64$ or $3,84 \cdot 10^8$ cm^{-2}. Naturally after the repeated phase of crystallization and crimping, when the density of dislocations grows by three orders of magnitude up to 10^{11} cm^{-2} under the influence of the low density.

With an increase in the heating temperature, a certain growth of austenite grain is observed. However, in all cases, there is an extreme heating temperature of 1100 °C with an austenitization time of 20 min, when, after cooling, the maximum level of dislocation density can be recorded (Table 3). From the tabular data, a relatively large increase in ρ is seen, but the absolute difference is not large.

When normalizing large-sized parts, the holding time in the austenitic region during the heating process can be calculated in hours. In this case, the effect of the influence of extreme temperature on the state of the fine structure of steel has not been determined [8].

Studies have shown that with an increase in the holding time during heating of the steel after the γ - α transformation, the density of dislocations of the α - phase decreases, and the peak of the maximum shifts to lower heating temperatures (Fig. 2).

TABLE 3 DISLOCATION DENSITY OF STEELS AFTER NORMALIZATION AT DIFFERENT HEATING TEMPERATURES (AUSTENITIZATION 20 MIN)

Normalization temperature T, °C	Armco-iron		Steel 45		Steel 40X	
	$\rho, 10^9 cm^{-2}$	ρ/ρ_{900}	$\rho, 10^9 cm^{-2}$	ρ/ρ_{850}	$\rho, 10^{10} cm^{-2}$	ρ/ρ_{870}
Ac_3 +30÷50	–	–	1,0	–	1,13	–
900	0,37	–	–	–	1,13	1,0
1000	0,88	2,38	1,73	1,73	2,31	2,0
1100	1,40	3,78	4,5	4,5	4,54	4,0
1200	0,73	1,97	2,99	2,99	1,26	1,08

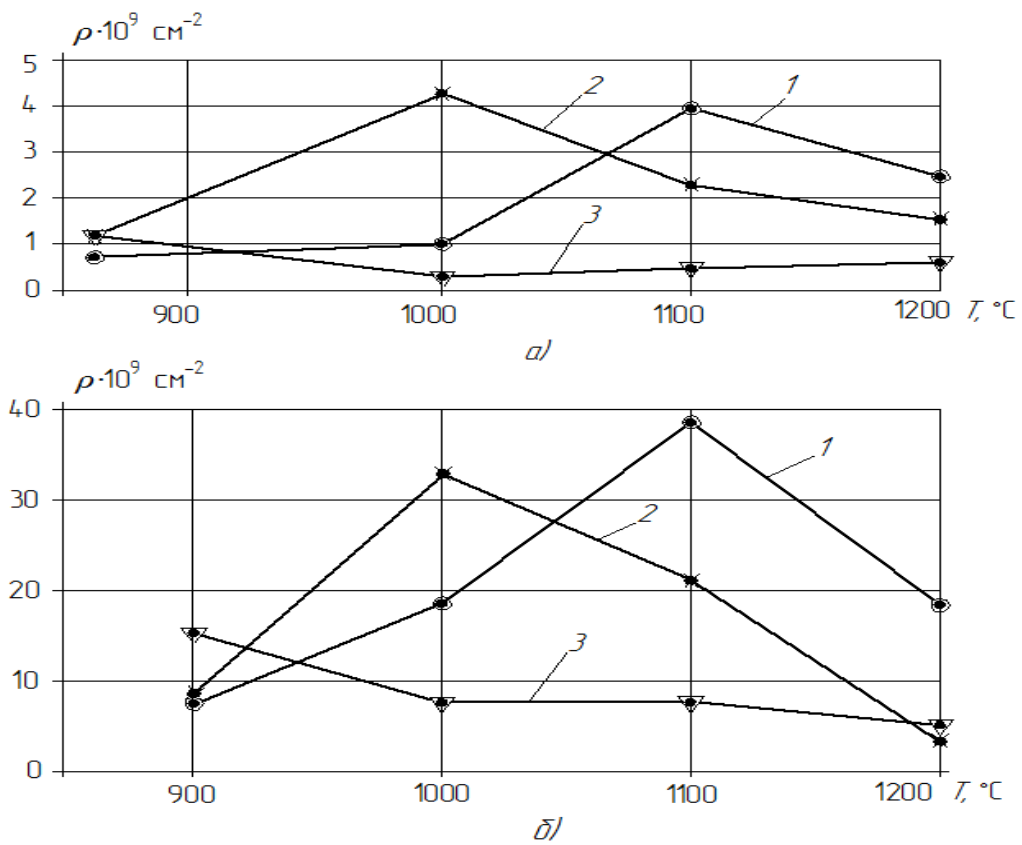


Fig. 2. Influence of temperature T of heating and holding time 20 min (1), 2 h (2), 5 h (3) on the density ρ of dislocations of normalized steels 40 *(a)* and 40X *(b)*

Quenched steel samples are the most convenient for studying the structure parameters, since their main structure is martensite and a certain amount of retained austenite. Of particular importance is the density of dislocations in steels quenched from a temperature (1100 °C) of heating in comparison with quenching in an environment from the usually accepted temperatures (above the heating temperatures of Ac_3 + 30 ÷ 50 °C). This difference is large at low carbon content, for example, 288% for armco iron. For samples made of steels 45 and 40X, it is 37 and 69%, respectively. It is possible to assume that the effect of the growth of the density of dislocations in the hardened and low-tempered steel in the case of the hardening with an extreme temperature

(1100 °C) at the speed of In this case, in the process of quenching cooling and at low tempering, a redistribution of carbon atoms between phases was observed: carbon atoms pass into dislocations and into residual austenite.

The influence of the holding time on the dislocation density at different heating temperatures after quenching cooling is shown in Fig. 3. The nature of the change in the density of dislocations with an increase in the holding time is similar to the change in density during normalization. The same results were obtained in the study of steel 40X.

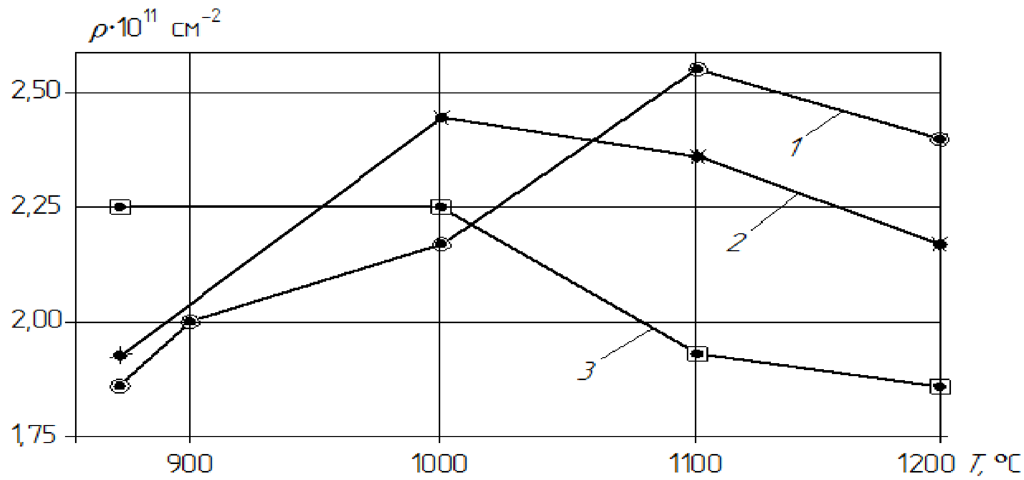


Fig. 3. Influence of temperature *T* and holding time 20 min (1), 2 h (2), 5 h (3) on the density ρ of dislocations in hardened steel 45: tempering at heating 200 °C

CONCLUSION

Thus, it has been shown that with significant heating of steel, extreme temperatures are observed at which, after cooling, structures with an increased (after normalization) dislocation density or with a high level (after quenching) are formed. The extrema of the dislocation density occur at temperatures of 1100, 1000, and 900 ° C with holding times of 20÷30 min, 2 h, and 5 h, respectively. The increase in the dislocation density depends on the content of carbon and alloying elements in steels.

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