# CHANGE IN TEMPERATURE FIELD DISTRIBUTION DURING ELECTRIC-ARC HARDENING

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*The distribution of temperature fields during electric-arc hardening is investigated. A model of the temperature distribution with respect to a hardened zone depth is developed for different carbon-content steels subjected to electric arc hardening. The calculated results are compared with experimental data to show good agreement.*

An electric arc is an effective tool for modifying metal surfaces. A detailed study of the processes in hardened layers treated by an electric arc is stimulated by practical needs of technologies employing the energy of an electric arc. Specific features of electric-arc hardening have been discussed earlier. They have necessitated modeling of the temperature field distribution for a more comprehensive study of the mechanism of forming a complex of mechanical and service properties of hardened surfaces.

**Materials and Methods.** The present work is aimed at investigation, using mathematical modeling, of the temperature field distribution at any point in a hardened zone bulk in the case of a moving electric arc. This allows the hardened zone properties to be predicted with a high degree of probability for the investigated production cycles. As test materials, steels 45KhNM and 150KhNM have been chosen, the initial structure of which consists of a carbide ferrite mixture formed to the 1st-stage type with different ratios and morphology of excess phases. Thus, if the steel 45KhNM contains about 10% of excess ferrite, then steel 150KhNM has 15% of excess cementite.

The strength of the arc current was 200 and 300 A at an energy source displacement velocity of 110 and 150 m/h, which allowed creation of a different level of energy contribution to hardened layers. Thus, the possibility appeared of forming both a fusion zone and an electric-arc hardening zone on a surface. The microstructure was studied with microscopes Neophot-2 and Jeols. The depth and width of the hardened zone was measured on metallographic specimens in the cross section of an electric arc trace. The microstructure was brought to light in a 4% nitric acid solution in ethyl alcohol. Microhardness of the hardened zone was measured with a PMT-3 hardness microgauge using the standard procedure. Microhardness distribution with respect to the hardened zone depth was evaluated on the metallographic specimens of the trace cross section in the place of maximum depth. Mathematical modeling of the temperature field distribution was accomplished on IBM PC/AT personal computers in PASCAL language.

**Results and Discussion.** On developing electric-arc hardening technologies, one of the most important problems is the creation of the optimal level of temperature fields in the region subjected to heat action. Here, account should be taken of the chemical composition of treated steels differing in thermophysical properties. Because of the short duration of the process, we could not obtain experimentally the information of interest to us. Therefore we have constructed a new analytical solution of the nonstationary differential heat conduction equation for electric-arc treatment of a work-piece surface. The problem mentioned above is considered in [1, 2]. At the Ural Polytechnic Institute, a program has been developed to study the temperature field distribution with respect to the depth of the hardened zone.

Analysis of the calculated results has shown that for bulky bodies subjected to electric-arc hardening the influence of the heat liberated in phase changes (martensite transformation) may be neglected. As seen from the table, the difference in the temperature field values, with and without taking account of the heat of phase changes, is insignificant. Thus, on developing the programs, one may avoid additional time expenditures connected with the input of data on the phase composition of tested steels subjected to electric-arc treatment. In what follows, the main focus will be on a change in the process parameters of electric-arc hardening.

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TABLE 1. Temperature Field Distribution with Respect to the Hardened Zone Depth for the Point Y = 0.00; Steel 45KhNM; Regime I = 200 A, V = 150 m/h

| Z, mm | X, mm | | | | | |
|---|---|---|---|---|---|---|
| | 0,00 | 0,20 | 0,40 | 0,60 | 0,80 | 1,00 |
| 0,00 | 1750,0 / 1782,3 | 1310,0 / 1340,0 | 832,0 / 851,0 | 460,0 / 470,2 | 220,0 / 230,4 | 65,0 / 63,0 |
| 0,10 | 1540,0 / 1562,0 | 1180,7 / 1203,0 | 640,0 / 657,0 | 290,7 / 306,0 | 130,0 / 142,0 | 40,0 / 44,0 |
| 0,20 | 1350,0 / 1376,0 | 960,0 / 975,0 | 510,0 / 524,0 | 160,8 / 182,0 | 85,0 / 97,0 | 30,0 / 33,0 |
| 0,30 | 1187,0 / 1188,0 | 745,0 / 762,0 | 390,0 / 407,0 | 87,0 / 96,7 | 52,0 / 61,0 | 20,0 / 24,0 |

**Note.** The numerator gives the values without taking into account the heat of phase changes, the denominator, with account.

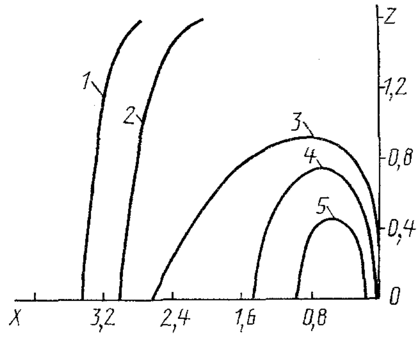


Fig. 1. Temperature fields in the plane XZ for the point Y = 0.00 and moment of time $\bar{t}$ = 0.5 sec [treatment conditions: I = 300 A, V = 150 m/sec and I = 200 A, V = 110 m/sec (curves coincide); steel 150KhNM]: 1) 600°C; 2) 800; 3) 1200; 4) 1800; 5) 2000.

The basic variants of changing the arc current strength and the energy source displacement velocity, with processing in a scanning mode, as well as the levels of temperature fields formed have been considered. Analysis of the calculated data reveals that the running energy, widely used in literature as a determining characteristic of welding processes [3, 4], is not so characteristic in the case of electric-arc hardening. Distribution of temperature fields for two regimes having the same running energy but different process parameters (Fig. 1) convincingly demonstrates this fact.

Figure 2 shows microstructures of steel 45KhNM treated in different regimes but having the same running energy. Foremost attention will be paid to the influence of the variation of arc current strength and energy source displacement velocity under hardening conditions. In electric-arc hardening investigations, of importance are heating cycle parameters, i.e., heating rate and residence time at a maximum temperature. Figure 3 shows the temperature distribution as a function of time for the current strength of 300 and 200 A. An increase in the current strength is seen to result in a 1.5-fold increase in the heating rate. Heating rate variation is shown in Fig. 4. The extremely short duration of heating is noteworthy 0.01-0.03 sec at temperatures of about 2000°C, which is manifested only in surface microfusion.

Analysis of the influence of an energy source displacement velocity (Fig. 5) shows that the velocity is a characteristic responsible for the residence time of a metal within the region of maximum attainable temperatures that is highly consistent with the results of microstructural analysis. Also, the structural analysis of steel 150KhNM in the case of treatment in different regimes has shown that when the energy source displaces at 110 m/h, the structure has needle-shaped martensite with some

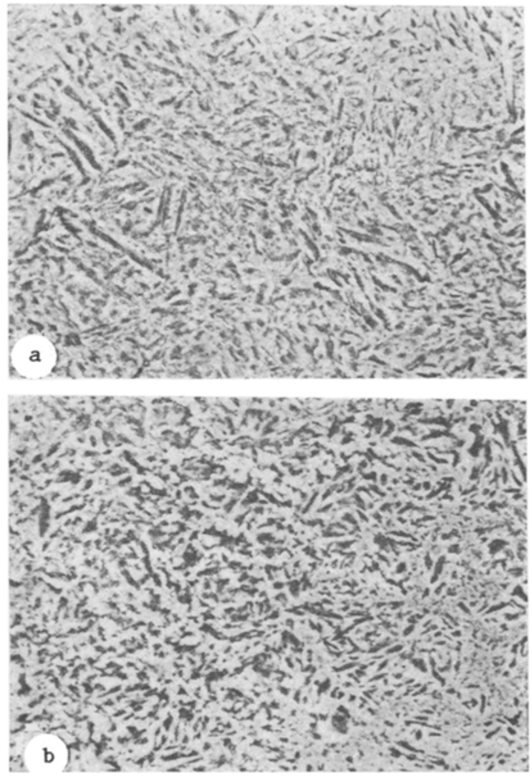


Fig. 2. Microstructure of steel 45KhNM: a) I = 200 A, V = 110 m/sec;
b) I = 300 A, V = 150 m/sec × 1000.

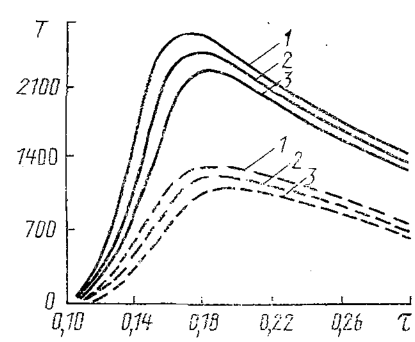


Fig. 3

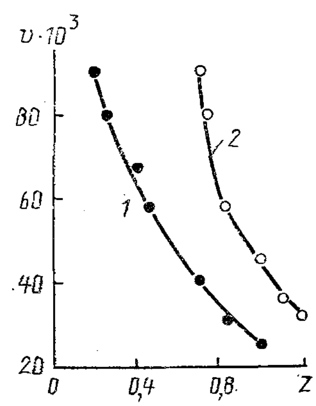


Fig. 4

Fig. 3. Temperature cycles for steel 150KhNM at V = 110 m/h: Z = 0.7 mm (1), 0.8 (2), 0.9 (3); dashed curves, I = 200 A; solid curves 300 A. T, °C; $\tau$, sec.

Fig. 4. Heating rate variation at electric-arc hardening with respect to the hardened zone depth: 1) differentiation interval 360-700°C at I = 200 A, V = 110 m/h; 2) the same at I = 300 A, V = 110 m/h. v, °C/sec.

amount of residual austenite. An increase of the displacement velocity by 50 m/h leads to a size reduction of the needles and a decrease of the residual austenite. Using the calculated results and experimental data, we have developed nomograms (Fig. 6) relating the temperature variation at a concrete point in the hardened layer bulk with the technological parameters of the process. The nomograms enable us to determine the temperature at a point and, therefore, a hardened layer structure. At the

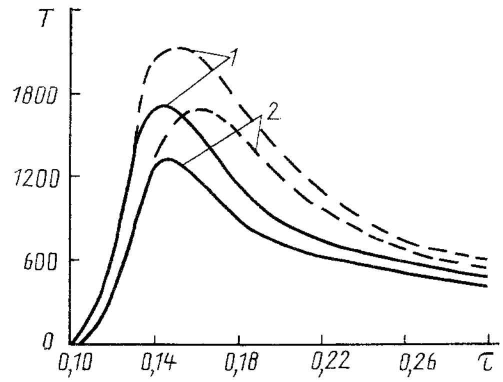


Fig. 5. Temperature cycles for steel 150KhNM at I = 200 A (solid curves, V = 150 m/h, dashed curves, 110 m/h): Z = 0.6 mm (1) , 0.7 (2).

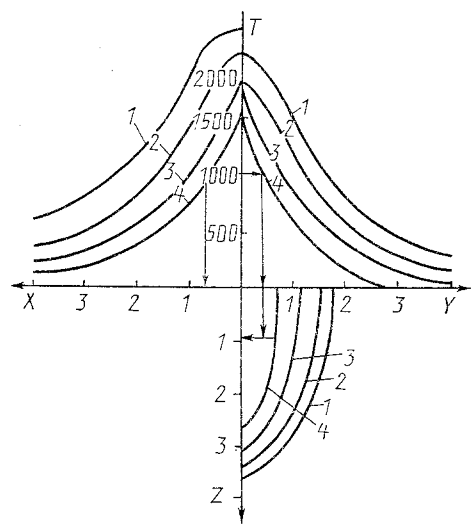


Fig. 6. Nomogram for determining temperatures with respect to the hardened zone depth at electric-arc hardening in the regime I = 200 A, V = 150 m/h: $\tau$ = 0.1 sec (1), 0.2 (2), 0.3 (3), 0.4 (4); $\tau$, moment of time from the beginning of treatment.

same time, an inverse problem may be solved. Having given concrete electric-arc hardening parameters, we may forecast a region where a certain temperature field will be formed. Taking account of the calculated data, one may determine, with a sufficient degree of probability, the level of mechanical and service properties of surfaces subjected to electric-air hardening.

## CONCLUSIONS

1. Modeling of the temperature fields in an electric-arc process has shown that the running energy cannot be considered as the main characteristic determining the parameters of a temperature field.

2. During electric-arc hardening of bulky bodies it is necessary in calculation to take into account the heat of phase changes.

3. It is established that arc current strength variation is responsible for a change in the heating rate.

4. The time of metal residence in the region above critical point A depends on the change of an energy source displacement velocity.

5. The nomograms developed together with thermokinetic diagrams, allow a choice of operational electric-arc hardening parameters and forecasting of the level of mechanical properties and the structure of a hardened layer.

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