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TECHNOLOGY OF CONTROLLED HARDENING OF DIES

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Problems of using microcomputer-controlled cooling of workpieces by a water-air flow in heat-exchange devices are considered as applied to different regimes of cooling of metals. This will make it possible to replace expensive and environmentally harmful traditional hardening media by a water-air mixture, improve the quality and durability of hardened metal products, and decrease the resource and energy expenditures on the technological process of thermohardening.

The processes of heat treatment of workpieces of iron-based alloys are widely used in many fields of the national economy. The processes of cooling of high-temperature metals make up a large proportion of all technological procedures carried out in industry. Liquids, melts of salts, solutions of liquids with polymeric additions, gas-liquid flows, etc. are used as hardening media. However, at the present time, traditional methods of cooling of metals and the facilities for their realization can no longer comply with increasing requirements on the quality of workpieces subjected to heat treatment and on their physical and mechanical properties. The chief shortcoming of these methods is the impossibility of controlling the rate of cooling of workpieces in the process of their heat treatment and, as a result, the difference of the obtained properties from the prescribed ones [1-4].

A plant for controlled water-air hardening of dies with dimensions of up to 1200 × 1000 × 1000 mm and a weight of up to 8 tons has been installed at the Minsk Automobile Plant. The hardening chamber of this plant designed for thermal hardening of the working surface of dies using controlled water-air cooling is shown in Fig. 1. Heat is removed from the working surface of a workpiece using a water-air mixture formed by a set of injectors that can be controlled in the same or independent fashions in accordance with the strength characteristics required for this workpiece.

The number of control channels corresponds to the number of atomizing injectors and, consequently, to the number of possible characteristic zones separated on workpieces with a complex and developed surface. As a rule, to prevent thermal stresses, it is necessary to set the same rate of cooling for the working surface of the hardened workpiece. Injectors that belong to different zones are controlled in different fashions, and injectors that belong to the same zone are controlled in the same fashion.

Figure 2 shows the working surface (impression) of a die with separated characteristic zones. It should be noted that the edges of the impression (zone 1) can have lower strength characteristics than the basic working part of the die. However, in practice, when hardening is performed with traditional media (oils, aqueous solutions, melts of salts and alkalis, polymeric solutions, and others), the hardness of the metal at the edges is higher since both sides of the edges are cooled (edge effect), and this cannot be prevented.

In controlled cooling, the corresponding injectors are attached to each zone of the workpiece, and all the remaining injectors located beyond the boundaries of the workpiece do not participate in the process of thermal treatment and cannot be accidentally brought into operation by attendants.

To decrease the temperature gradient across the surface of the workpiece, it is necessary to select the same rates of cooling for all the zones from thermal-kinetic diagrams of the corresponding steel quality in accordance with the required strength characteristics (Fig. 3). However, the actuating mechanisms for feeding

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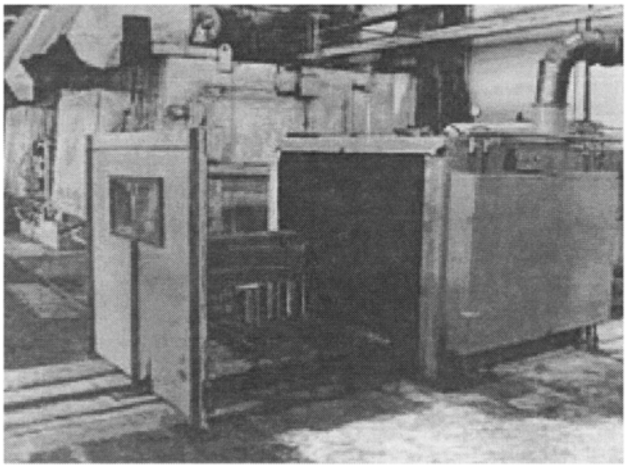


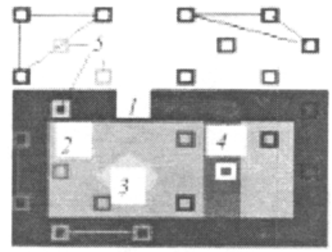
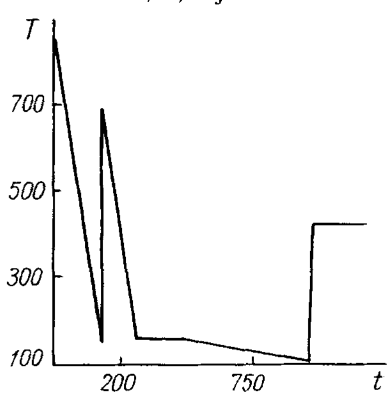


Fig. 1. Hardening chamber of the production plant of the Minsk Automobile Plant for controlled hardening of hammer dies with dimensions of up to 1200 × 1000 × 1000 mm and a weight of up to 8 tons.

Fig. 2. Characteristic zones for a large-size die: 1) edge zone of width 120 mm; 2) basic impression; 3) cylindrical hollow of depth 200 mm; 4) lock zone; 5) injectors.



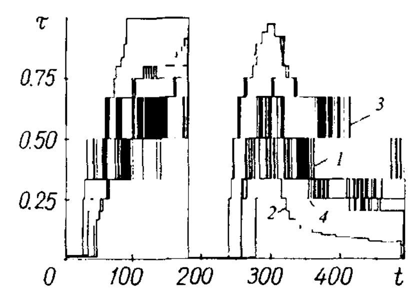
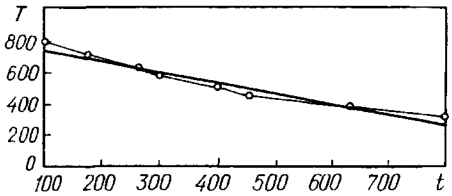


Fig. 3. Graph of the temperature change for all zones.

Fig. 4. Fashions of control for each zone in hardening: 1) edge zone of width 120 mm; 2) basic impression; 3) cylindrical hollow of depth 200 mm; 4) lock zone.

the water-air mixture to the die impression are controlled in different fashions depending on the disposition of the zones (Fig. 4).

In the case of controlled cooling of only the working surface, it becomes possible to realize the self-tempering regime due to the intrinsic heat of the workpiece [5]. For its realization, we modeled the process of hardening cooling at different self-tempering temperatures (Fig. 5). We can state that the duration of the process of hardening cooling is linearly dependent on the self-tempering temperature. Because of this, the duration of the process of thermal hardening can be determined, when needed, from the graph constructed for this type of workpiece (dies). However, a change in the hardening time as a function of the characteristic dimension is of greater interest to the user. Since only the working surface is cooled in controlled heat exchange, the characteristic dimension is the distance from the surface to the fastening part, and this distance decreases multiply in restoring the die impression when its working period ends. In the case of repeated hardening of the restored workpiece, the duration of the process of thermal hardening should accordingly be decreased.



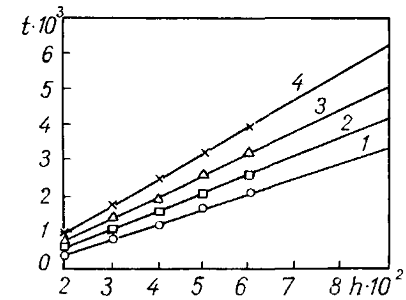


Fig. 5. Duration of the process of controlled cooling vs. self-tempering temperature.

Fig. 6. Duration of the process of heat treatment vs. characteristic dimension at a tempering temperature of: 1) 550°C, 2) 500, 3) 450, 4) 400

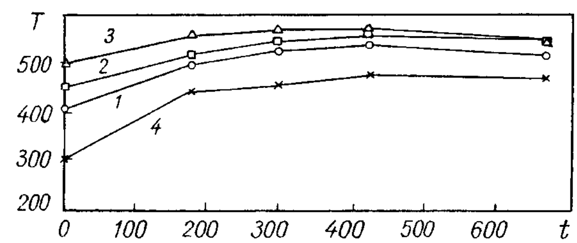


Fig. 7. Change in the temperature of the shank of a die in the self-tempering regime (experiment): 1, 2, 3) for a temperature of 540°C; 4) 500 (curves 1-3 were obtained in different experiments).

Figure 6 shows the time dependence of the duration of the process of heat treatment on the thickness of the die as the self-tempering temperatures change in the range of 400 to 550°C. Since controlled removal of heat is performed from the surface of only one face (the impression) of the die and it is approximately twice the coefficient of heat transfer from the side surfaces of the die at a given isothermal hold, a linear change in the characteristic dimension (the thickness of the die) causes a corresponding increase in the duration of the process of thermal hardening.

The time dependences of the duration of the process of cooling were measured for dies of different thickness at different self-tempering temperatures: from 550°C (curve 1) to 400°C (curve 4). They show the ways of a possible change in the duration of the process of hardening with increase in the thickness of the workpiece. The points on the curves correspond to calculated data, while the predicted sections of the curves are free of points.

All the advantages of controlled cooling can be demonstrated with dies used in blacksmith fabrication of steel forgings. The working part of the die (the impression) is heated in the process of work and is subjected to impact loads. Because of this, the higher the hardness of the die, the greater its durability. However, the higher the hardness of hammer dies, the higher the risk of their brittle failure, which, among other things, can be responsible for grave traumata to workers. Because of this fact and the fact that traditional methods of hardening provide the same hardness of the metal on all surfaces of a workpiece, there is a rule: the more severe the operating conditions of a die, the lower its hardness should be. This problem can be partially solved as follows. After hardening by immersion in petroleum oil and tempering at 450–550°C, the fastening part (shank) of the die is subjected to additional annealing for several hours in a slot-type gas furnace. However, one is unable to obtain a large temperature gradient across the die width because of the high thermal conductivity of steel, and therefore the difference between the hardness of the impression and the hardness of the shank of dies is usually small. Consequently, a decrease in the hardness of the die impression causes the service life of the die to decrease.

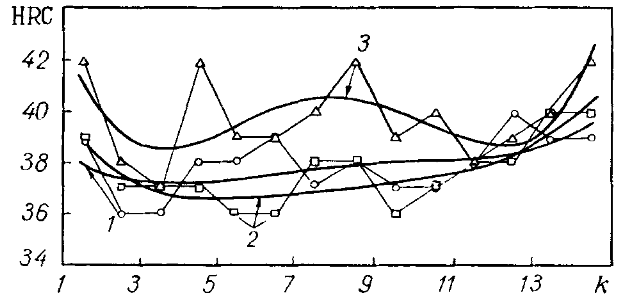


Fig. 8. Graphs of the hardness distribution over the cross section of a die at different distances from the surface [1) 60 mm; 2) 40; 3) 20] and the averaged curves.

As a result of controlled hardening by a water-air mixture a hardness of 39–41 HRC units was obtained on the impression of the treated die. This corresponds to the technical requirements on the hardness (36–42 HRC units) of these dies in the case of their traditional oil hardening and the corresponding tempering in a furnace at 540°C.

We measured the temperature of the metal on the working surface of a die with the aim of determining the correspondence between its theoretical and actual values in the process of self-tempering (Fig. 7). It was found that the difference between these values is no more than 10% with account for the measurement error (curves 1, 2, and 3). The graph of the temperature change (curve 4) corresponds to a self-tempering temperature of 500°C. The hardness of the shank of a die hardened by the method developed is 24–28 HRC units, which corresponds to the optimum value for the fastening part of the die (24–29 HRC units in the case of its furnace treatment). Thus, the new technology of hardening of dies made it possible to obtain a better compromise on hardness between the working and fastening parts of dies as compared with that provided by traditional technologies of hardening. The technology proposed does away with the need for furnace tempering and additional annealing of the shank in a slot-type gas furnace.

Figure 8 shows the distributions of hardness over the cross section of a die at different distances from the surface. A T-shaped hollow of width 160 mm and depth 60 mm was milled in the working part (the impression) of the die. Therefore the hardness of the metal at the extending edges of the workpiece turns out to be somewhat higher than that in the hollow and follows the shape of the surface. Furthermore, in tempering, due to the heat transfer from the developed surface, the temperature of the metal in these zones is lower than in the hollow located closer to the region of high temperatures. It should be noted that at a depth of 40 mm from the surface the hardness of the metal is lower than that at a depth of 60 mm. This is explained by the fact that the zone of increased hardness of the metal is located at the interface between the martensite structure formed as a result of tempering and the martensite structure formed as a result of hardening. These measurements were performed with the aim of determining the depth of calcination in controlled water-air cooling, since doubts were expressed on the impossibility of attaining the calcination obtained in traditional oil hardening.

Production tests have shown that the service life of hammer dies hardened by the method proposed is longer than that of dies hardened by the traditional technology by a factor of 1.5–2.

NOTATION

T, temperature, °C; t, time, sec; τ, the duration of the pulse of action of the water-air mixture, sec; HRC, units of Rockwell surface hardness; k, number of measurements; h, thickness, mm.

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