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FEATURES OF TIN-BATH HARDENING FOR SMALL PARTS

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The method of quenching in tin melt was tested for low-weight parts with a large specific surface, made of a number of steels with a high temperature of the onset of martensitic transformation. The advantages of this method in comparison with traditional hardening technologies are established, as well as regularities in the change of cooling curves for various mass ratios of the part and the quencher are revealed. The practical possibility of adjusting the cooling rates in the process of hardening in various temperature ranges in order to optimize the phase ratio in steel while maintaining the possibility of preventing the occurrence of microcracks is shown.

Keywords: martensite, sorbitol, trostite, bainite, heat exchange, hardness, cooling rate, microcracks, hardening, hardening check, quencher, steam jacket, low-melting alloys.

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1. Introduction

In modern economic conditions, a very important role continues to be given to effective methods of hardening the surface of engineering products with using various quenchers. For the first time, the method of quenching materials in low-temperature metal melts was proposed as early as 1885 by D.K. Chernov. Currently, there are a large number of different quenchers for hardening the metal parts [1], however, further improvements of technologies for thermochemical treatments [2] and dynamics of temperature fields in production [3] require new approaches to manage and control technological parameters during hardening of products, and, if necessary, also for subsequent behavior modeling of the corresponding products [4]. One of the important requirements for quenching media is the variable cooling rate of a part. Quencher creators try to provide accelerated cooling of the product when passing the temperatures of the onset of austenite decomposition and to provide optimal cooling in the temperature ranges that ensure the formation of hardening phases (in particular, martensite) in steel, the increase in the content of which ensures the required hardness of the parts. After hardening, most steels are still subjected to low-temperature tempering at temperatures not exceeding the decomposition boundary of the hardening phase.

In this paper, we study the effect of the cooling rate of small parts, mainly, at the time of the onset of martensitic transformation. With a decrease in the product size, the heat transfer from the surface of such a part, due to its high specific surface, becomes so large that quenchers created for widespread use no longer provide the required performance characteristics in this case. The cooling rate in aqueous solutions and oils increases significantly at the stall temperature of steam jacket from the part surface. In many steels, the temperature of the onset of martensitic transformation is higher, and therefore, such a transformation does not have time to go through fully while retaining a certain amount of residual austenite in the structure. For massive parts, heat continues to flow from depth to surface, positively affecting the quenching parameters. Since the heat capacity of small parts is generally small, as a result of such heat transfer, they are inferior in hardness to massive products. Tin and fusible alloys are of interest in solving this problem for several reasons. These melts do not boil in the hardening temperature range, which means that it is possible to adjust the hardening rate by the mass ratio of the part and the melt in which it is immersed. Also, the character of the cooling curve can be influenced by the initial melt temperature. This temperature should be slightly higher than the crystallization temperature of the hardening melt; for tin it is 232 °C, which is not always suitable.

2. Experimental method

The studies were carried out using two laboratory mufflers, in one at a temperature of 240 °C there was a crucible with tin melt. For hardening, the crucible was taken out of the furnace and placed on a heat insulator, after which a probe with a thermocouple heated to the temperature of 880 °C in the second furnace was immersed in the melt. Data from the probe was recorded by a recording device KSP-4. In the second part of the experiment, a comparison of the hardness of quenching results was made, both in tin and traditional – in mineral oil (samples of steel 40KHN, DI42, U8, 65G) and in water (samples of steel St20) of larger and smaller mass. After quenchers, the samples were placed under a stream of dry air at room temperature for final cooling. Hardness was measured on a diamond pyramid hardness machine ZIP TK-2M on the HRC scale (and HRB for St20). The relative error of all measurements did not exceed 4%.

3. Results and discussion

To compare the cooling curves, the probes of the model alloy 12Kh18N10T with a mass of 40, 17, and 3 grams were hardened in quenchers (oil, water and tin) of the same mass of 800 g. Fig. 1 shows the cooling curves: w40 is for a probe weighing 40 g, hardened in water-bath; o40 – probe 40 g oil-; t40 – probe 40 g tin-; t17 – probe 17 g tin-; t3 – probe 3 g tin-bath hardened.

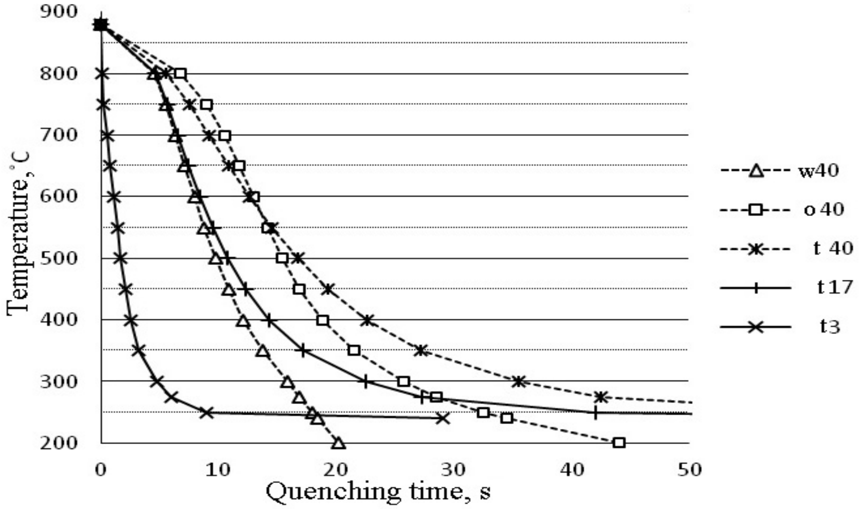

Fig. 1. Probe temperature of alloy 12X18H10T versus hardening time.

From the given cooling curves (Fig. 1), it follows that in the upper temperature range (600 ... 800 °C), when the products are water- and tin-quenched, the cooling rate of the oil-quenched products is slightly higher, and, therefore, in the structure of the latter, the eutectoid mixture manages to partially form on the alloy surface by diffusion: sorbitol and troostite, thus reducing their mechanical characteristics compared to water- and tin-hardened alloys. However, below 400°C during quenching in oil (as opposed to quenching in water), the rate becomes lower, which increases the time for the formation of martensite. In this regard, curves for hardening steel in tin look quite promising: even for the smallest probe with alloy, a decrease in the cooling rate is observed in a favorable temperature range. In order to study the effect of sample sizes on the hardening rate, experiments were conducted on the effect of various quenching media. The probe weighing 17 g was quenched in tin in different proportions with the mass of the quenching medium: 1:10, 1:21, 1:37, and 1:47. In Fig. 2 cooling curves 10, 21, 37, and 47 correspond to the above proportions.

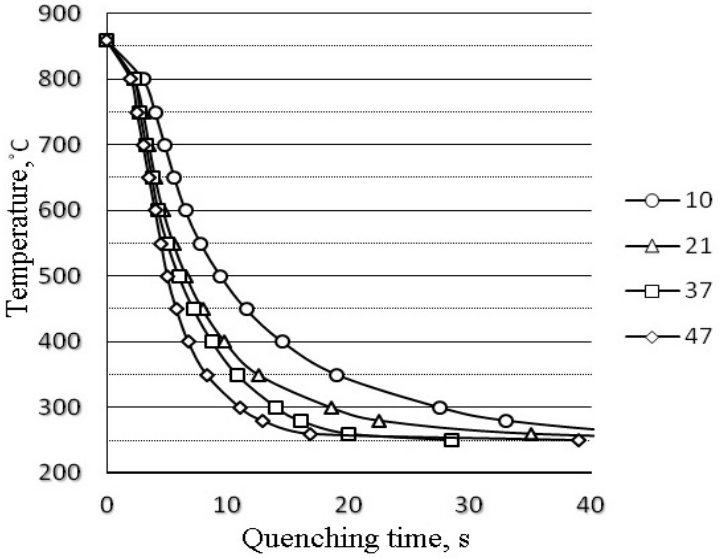

Fig. 2. The dependences of the temperature of the probe weighing 17 g versus quenching time, with various masses of quenchers.

From Fig. 2 it follows that by changing the mass ratio of part to tin, it is possible to control the steepness of the temperature drop smoothly and thereby prevent excess stresses in the part at the quenching time. In this case, it becomes possible to bring them to a minimum due to a change in the initial temperature of the melt. In other words: it becomes possible to change the scale of the temperature curve horizontally by changing masses; and the initial temperature of the melt is to scale vertically. In addition, a further 20 mass ratios were studied in the range from 1: 4 to 1:18, which also confirmed the trend shown in Figs. 1 and 2. Accelerated cooling of samples in the temperature range from 880 °C to 700 – 650 °C prevents the formation of sorbitol and troostite on the sample surface. The rate of accelerated cooling, as shown by experiments, depends on the proportion of the masses of the probe and the melt. It can be assumed that during quenching between the surface of the part and liquid tin there is an air gap. In the case of quenching in oil or water, it is either absent or filled with superheated steam, which contributes to the stage of bubble heat transfer. Naturally, when quenching in a tin melt, an air gap appears due to either poor wetting or due to an oxide layer that occurs when a part is heated, which prevents heat exchange.

The second part of the experiment. For comparison (Table 1), samples of various steels (40KHN, DI42, U8, 65G) are subjected to quenching in oil or tin with different temperatures of the onset of martensitic transformation (except for low-carbon steel St20 not susceptible to quenching with martensite forming). Table 1 shows: steel grades, sample masses, hardness after oil- (water for St20) or tin-bath hardening.

From the above table it follows that in samples with low masses, hardened in oil, martensite does not have time to form, which affects their hardness. Quenching in the molten tin ultimately gives a positive effect. For low-carbon steel St20, the most effective in terms of solid characteristics is, in contrast to medium-carbon steels, quenching in water with the highest cooling rate.

Table 1

Steel grades, sample masses, hardness after hardening

Steel grade	Mass (g)	Hardness (HRC)	
		Oil-bath hardening	Tin-bath hardening
40ХН	30	53	55
	5	51	54
ДИ42	20	54	55
	2	47	57
У8	20	57	62
	8	62	63
65Г	15	51	55
	3	35	62
Ст20		Water-bath hardening	Tin-bath hardening
	32	82(HRB)	57(HRB)
	7	84(HRB)	65(HRB)

Thus, a decrease in the mass (dimensions) of parts turnes out to be a sensitive parameter in the case of typical quenching media: the required hardness is achieved for small parts by quenching in tin melt (hot medium), i.e. by reducing the cooling rate in the martensitic interval; in the case of special alloy steels (spring manganese steel 65G), even a noticeable increase in hardness is achieved.

Modeling of martensitic transformation and similar thermally activated processes in the case of these steels, however, is planned already in our following works.

4. Conclusions

The method of quenching in tin or other low-melting alloys justifies itself to a large extent for small parts with a large specific surface, made of steel grades with a high temperature of the onset of martensitic transformation. This method allows us to adjust the nature of the cooling curves in a wide range of temperature values and not only to achieve an increased martensite content (in the case of bainite, if necessary) in the part, but also avoid supercritical stresses leading to the formation of hardening checks. Despite the apparent high cost, this method will justify itself with the quality of low-capacity parts. Currently, the issue of hardening of small parts becomes particularly relevant in connection with practical applications in nanotechnology [5] and with the miniaturization of high-tech devices.

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References

1.Technologie der Wärmebehandlung von Stahl / Herausg.: H.J. Eckstein. – Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, 1976. – 672 S.

2. **Skorbyaschensky, E.S.** Comparison of electrolysis methods of diffusion coating of titanium parts with boron / E.S. Skorbyaschensky, S.N.Antropov // Visnik Dniprop. un-tu. Seriâ Fizika, radioelektronika – 2017. – Iss. 24, Vol. 25. – P. 42 – 46.

3. **Bashev, V.F.** Features of the influence of thermal modes of cooling on processes of nonequilibrium crystallization of materials from the liquid state / V.F. Bashev, S.I. Ryabtsev, A.I. Kushnerev, N.A. Kutseva, S.N. Antropov, E.S. Skorbyaschensky // Journal of Physics and Electronics. – 2018. – Vol. 26(2). – P. 45 – 50.

4. **Obodan, N.I.** The Influence of Special Design Features of Cylinders on Their Vibration in Liquid / N.I. Obodan, N.B. Makarenko, A.N. Polishko // Strength of Materials. – 2002. – Vol. 34, Iss. 2. – P. 181 – 186.

5. **Poplavko, Yu.M.** Electronic Materials. Principles and Applied Science. – Elsevier, 2019.– 707 p.