EFFECT OF CRYOGENIC COOLING ON THE STRUCTURE, HARDNESS, AND SURFACE QUALITY OF 60C2A SPRING STEEL

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Experimental results for the effect of the cooling mode on the characteristics of a structural steel are presented.

It is well known that cold treatment of alloys substantially affects their characteristics. Studies of changing the properties by means of cooling modes are very useful for development of materials with better characteristics. Cold treatment of high-carbon tool steel is of great practical interest.

Hardened high-carbon steels have the peculiarity that, besides martensite, they contain an increased amount of residual austenite. Since in steels with a carbon content of more than 0.5% the temperature of complete martensite transformation of steel is below 0°C, cold treatment of steel should result in additional martensite production and, therefore, in higher hardness, wear resistance and stability of the size of the product.

As shown by analysis of foreign publications [1-3], at present leading companies constantly use cold treatment of blanks and products. It is reported that good results are obtained with deep cooling (down to 5 K). Usually cold treatment consists in immersion of a workpiece in liquid nitrogen (77 K) or in a box containing a mixture of an organic liquid and solid carbon dioxide (203 K) [3, 4]. However, the procedure cannot be applied in every case as high cooling rates produce a strong heat shock that may produce deformations and cracks. Since structural changes in steels subjected to cold treatment are not fully understood as yet, experimental studies of the cooling processes are very important in order to find optimal modes of treatment and to obtain high-quality products.

In this article the results of an experimental study of the effect of cold treatment modes on the properties of steel are presented (analysis of the surface condition, hardness and structure).

Figure 1 shows a schematic diagram of the setup developed especially for the experimental study. A standard helium cryostat KG-15/150-1, which allowed operation in the range from room to helium temperatures, was used as the working chamber to cool small specimens and workpieces (with a diameter up to 120 mm). The cryostat allowed the specimen to be treated both by immersion in liquid nitrogen (liquid nitrogen filled the working volume) and by cooling in nitrogen vapor with heat conduction through the gas toward the cold wall and also by radiation toward the cold wall only (the working volume under vacuum). This scheme provides a wide range of variation of the cooling rate.

The specimens were kept at a preset temperature with the aid of an adiabatic membrane. During the heat treatment process the specimen temperatures were measured by thermocouples and recorded by a digit printer. That experimental setup was used for cold treatment of specimens (collets) made of GOC2A steel (0.57-0.65% C; 0.6-0.9% Mn; 1.5-2% Si) with a high limit of elasticity and reasonably high viscosity and plasticity.

Initially, all the specimens were exposed to traditional hardening under the process chart conditions: heating in a CH33/6/2/10 electrical chamber furnace to a temperature of 870 ± 10°C, cooling in oil after an interval of 7-10 min; washing. Then the specimens went through cold treatment and tempering.

Figure 2 shows temperature variation curves for collets immersed in liquid nitrogen and then heated in air (experiment No. 1). It is seen that in this case the cooling rates are rather high ($\sim$6 deg/sec for specimen No. 1 and $\sim$2.5°/sec for specimen No. 2) and they cannot be controlled. At the start of cooling the temperature variation rates are especially high and reach tens of degrees per second. The heating rate of a specimen under natural convection conditions is maximal at the beginning of the heating process, not exceeding 1°/sec. High cooling rates give rise to internal stresses between

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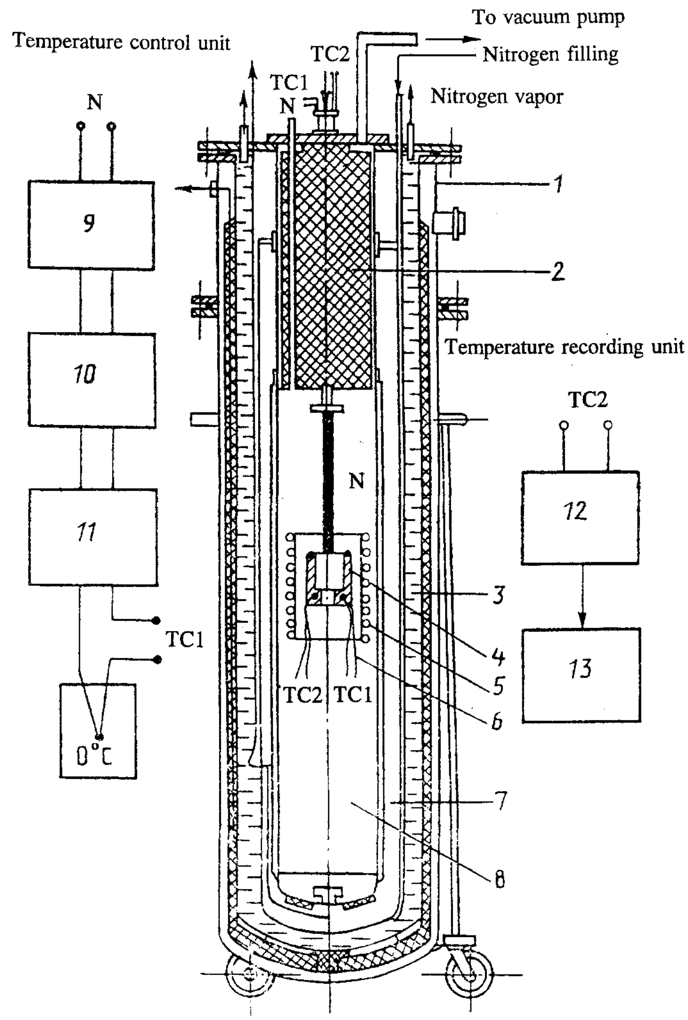

Fig. 1. The experimental setup for cold treatment of alloys: 1) cryostat; 2) foam polyurethane plug; 3) nitrogen tank; 4) specimen; 5) adiabatic membrane; 6) thermocouples; 7) vacuum jacket; 8) working volume; 9) power amplifier; 10) null-balance microvoltmeter; 11) P306; 12) digital voltmeter; 13) digit printer.

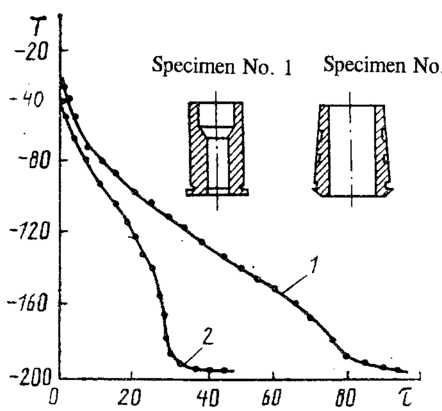

Fig. 2

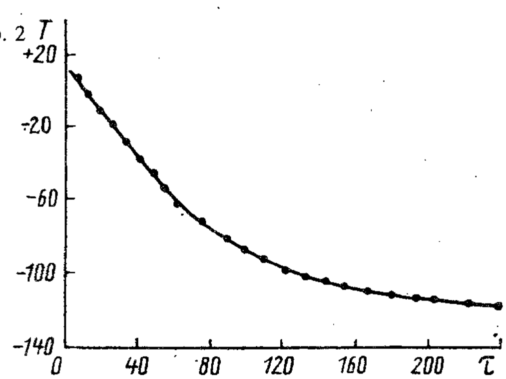

Fig. 3

Fig. 2. Time dependence of the temperature of a specimen immersed in liquid nitrogen: 1) specimen No. 1; 2) specimen No. 2: T, °C; τ, sec.

Fig. 3. Cooling curve of specimen No. 2 in the working chamber of the cryostat at atmospheric pressure. τ, min.

TABLE 1. Specimen Hardness Checking

Specimen	Hardness		
	after hardening	after cold treatment	after tempering
1	62	63	56
2	62	64	57
3	62	–	55

individual regions of a cross section and between different areas of a workpiece. This effect is very important for massive complex workpieces manufactured of low-plasticity materials.

Other specimens from the same batch were placed immediately after hardening in the cryostat working volume, cooled in air at atmospheric pressure to a temperature of $-120°C$, kept at this temperature for several hours, and then heated to room temperature (experiment No. 2). Figure 3 shows the cooling curve of specimen No. 2 in the cryostat. In this case the cooling rate is two orders of magnitude lower than that with nitrogen immersion and may be controlled by the atmospheric composition and the pressure in the working volume. In experiment No. 3 the control specimen was not cold treated. Both the control and cold-treated specimens were tempered at 300°C for 1 h in a PN-31 furnace.

The specimen hardness was checked by Rockwell's method immediately after hardening, cold treatment, and tempering. The results are given in Table 1. The hardness of the cold-treated specimens is higher, remaining the same after tempering.

The specimen structure was examined with a Polyvar-Met microscope. The troostite-martensite structure obtained fully suited the given treatment type. The cold-treated workpieces had no cracks, and their surfaces were smooth and clean. The present results clearly show that the highest increase in hardness was observed in cold treatment experiments in the cryostat working volume. This method is also more effective as regards cracking probability.

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