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PROPOSAL OF PROCEDURE FOR HEAT TREATMENT OF TOOL STEEL BEFORE ELECTROEROSION MACHINING

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ABSTRACT:
The paper deals with heat treating of material assigned for shearing tools production by progressive electroerosion method of machining. The main aim of the contribution is to describe in detail the procedure of heat treatment of tool-steel blocks made from steel EN ISO 9676 X210Cr12 (STN 19 436) including processes taking place inside basic material. Proposed procedure was realized on experimental steel block in particular conditions of company that produces shearing tools. Results of the experiment were verified from the view point of achieved resultant hardness quality of basic material after martensitic hardening and 2-phase tempering in vacuum furnace, applying Rockwell method. The paper also presents possible causes of semiproduct quality insufficiencies including heat treating defects, and gives recommendations for preventing of production wasters.

KEYWORDS:
electroerosion machining, hardening, tempering, heat treating, hardness of surface.

1. INTRODUCTION

Because of its favourable mechanical properties, tool steel EN ISO 9676 X210Cr12 (STN 19 436) belongs to materials most used for shearing tools production. It is a chrome steel with high wear-resistance, and resistance to dimension variations at high temperatures. Since the given material is of high strength, demanding machining conditions are to be expected too. Effective, and at the same time the most used method for production from this steel appears to be electroerosion machining which ensures high quality and machining precision. [1,2] In certain cases, it is the only method that enables production of complicated internal shapes of shearing tools and keeping of high cut contour precision. In addition, this method does not impose any restrictions concerning material strength, because material removal is carried out by electric discharge, and not by mechanical impact of cutting tool, as it is usual at conventional machining. To satisfy all the quality requirements on shearing tools, it is necessary to apply heat treatment on semiproduct before actual machining process. Unsuitable or low-quality heat treating has significant impact not only on resultant quality and precision of shearing tool, but, above all, on its operating life.

2. EXPERIMENTAL HEAT TREATMENT PROCEDURE OF THE SAMPLE

In shearing tools manufacturing, it is necessary to prepare basic material block at first. Dimensions of the block represent outer dimensions of the shearing tool. The block can be made by conventional machining, e. g. milling, grinding, etc. [3] Due to rough machining of basic semiproduct, an internal stress in steel block is present. It is necessary to remove this internal stress by interstage annealing, especially after substantial material removals at cutting operations but, first of all, for non-symetric shapes of semiproducts. Concerning tools such as shearing tools that must withstand extreme stress, it is vital to harden semiproducts to high hardness values in order to increase their operating life. However, the hardening causes high internal stress due to different cooling intensities of block surface and block core. This stress must be removed by tempering. Otherwise material deformations could emerge during electroerosion cutting, and in extreme cases, brittle fracture may occur due to extreme internal stress.

3. ANNEALING OF THE SAMPLE FOR INTERNAL STRESS REMOVAL

The sample (during experiment it was steel block of dimensions 250 x 250 mm, 100 mm thick) was placed into vacuum furnace with temperature 260°C. After equalizing of surface and core temperatures, the furnace temperature was increased to 650 °C, with start-up time to annealing temperature 80 min. Then 2 hours holding time followed. The block was then cooling in furnace to 400 °C, and next it was cooling to surrounding temperature freely in room air (Fig. 1).

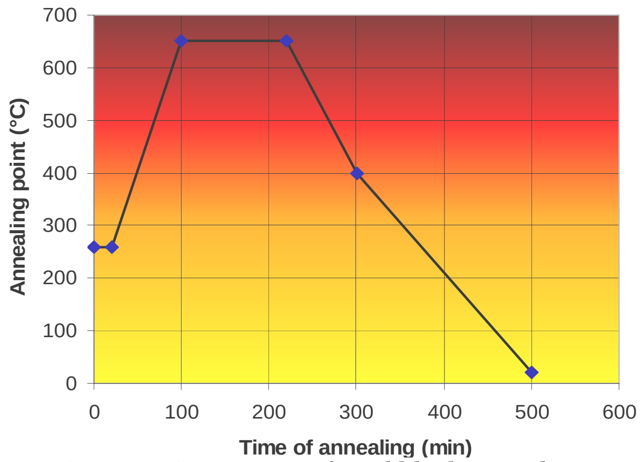

Figure 1. Time course of steel block annealing

To prevent decarburization of sample surface, the annealing was carried out in vacuum furnace. As an alternative, annealing in inert atmosphere can be applied.

4. HARDENING OF THE SAMPLE FOR BASIC MATERIAL HARDNESS INCREASE

Heating up of the block to hardening temperature was done this way: the block was placed into the cooled-down vacuum furnace and heated up by heating rate 220 °C.h^{-1} to 850 °C with holding time until temperatures equalized through the whole cross-section. From the temperature of the last pre-heating, rapid heating to hardening temperature was applied. When hardening temperature on the surface was reached, holding time approx. 70 min. followed in order to equalize temperatures of the surface and of the core of the steel block. Immediately after temperature equalizing of the surface and of the core, rapid cooling followed before the surface temperature could drop below 960 °C. Hardening medium was oil with temperature 80 ÷ 100 °C, which is the only possibility to achieve sufficient cooling rate especially in blocks of substantial thickness. In this case, air-flow hardening cannot be applied because in blocks of dimensions above 200 x 120 mm or diameters above ∅160 mm with maximum cooling air pressure of 1 MPa the segregation of carbides on grain edges would occur, together with bainite or pearlite generation. This would eventually lead to deterioration of material mechanical properties.

From the diagram (Fig. 2) it can be concluded that the highest hardness of EN ISO 9676 X210Cr12 steel can be reached at hardening temperature of approx. 960 °C. Since during experiment hardening temperature 1020 °C was applied, it can be assumed that resultant hardness after hardening will range in 63 ÷ 64 HRC. [4]

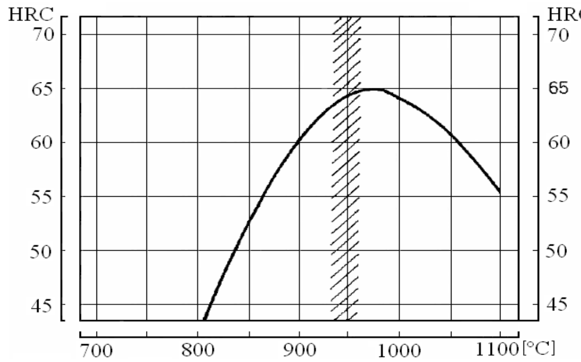

Figure 2. Dependence of resultant hardness of steel block (material EN ISO 9676 X210CR12) on hardening temperature

In order to achieve optimal steel structure and thus optimal mechanical properties, it was inevitable to cool the block with maximum possible rate, taking into account block shape and its possible deformations, and also CCT (Continuous Cooling Transformation) diagram. To ensure these requirements, oil was applied as a cooling medium.

Following figure shows three possible cooling courses at hardening of EN ISO 9676 X210 CR12 steel for fulfilling the requirement of resultant martensitic structure.

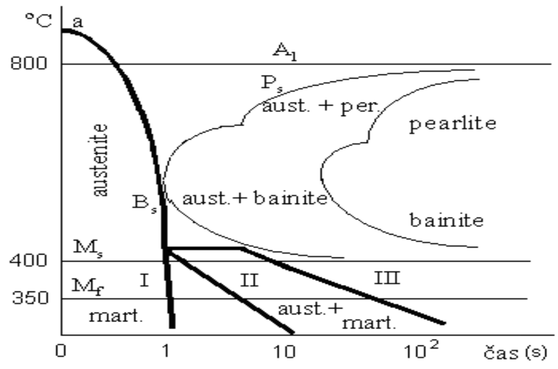

Figure 3. Influence of hardening rate on structure change of EN ISO 9676 X210CR12 steel in cct diagram

Line I in diagram shows continuous course of hardening. Transition through temperatures Ms and Mf is sharp, with consequence of enormous stress inside material.

Line II shows broken course of hardening, where at first, rapid cooling to temperature closely above Ms is applied, then the intensity of cooling decreases, this leads to a decrease of internal stress.

Line III shows course of so-called martempering, in which the first phase of cooling is identical to the previous two courses. When the hardened material temperature closely above Ms is reached, constant temperature is held for a certain time in order to equalize temperatures on surface and in hardened material core. Holding time for EN ISO 9676 X210Cr12 material must not exceed 30 min.,

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otherwise structural change from austenite to bainite would occur. The importance of the latter hardening procedure is essential mainly in such demanding products as moulds, shearing tools, etc.

On the basis of these facts, sufficiently high cooling rate was chosen particularly in first phase of hardening, to ensure formation of hard martensitic structure. Otherwise bainite would form, this would deteriorate mechanical properties. From the mentioned possibilities, the most effective hardening procedure appears to be III (the third) way of hardening, because of low chance of hardening cracks. When surface temperature of steel block reached the range 450 ÷ 400 °C, cooling intensity was decreased for 30 min. in order to equalize surface and core temperatures. Temperature difference between the surface and the core should not exceed 95 °C during hardening.

5. TEMPERING OF THE SAMPLE FOR REMOVAL OF INTERNAL STRESS AFTER HARDENING

Directly before electroerosion, it is necessary to temper the metal block in order to reduce brittleness caused by martensitic hardening. Tempering is based on partial structural change of the material and is accompanied by undesirable phenomenon: hardness decrease of basic material. Minimal hardness decrease of basic material occurs at tempering temperature up to 180 °C, when tetragonal martensite transforms into cubic martensite. Applying of temperatures ranging from 180 °C to 300 °C causes significant decrease of material brittleness that is a result of residual austenite transformation into bainite. At temperatures above 300 °C, extreme brittleness drop occurs accompanied with significant hardness decrease of basic material as a consequence of total martensite decomposition into fine ferritic structure with spheroidal cementite. From the viewpoint of optimal ratio of hardness and brittleness decrease of basic material, it is appropriate to apply tempering temperature 220 °C. For experimental steel block, 2-phase tempering at the same temperature (220 °C) was applied, whilst this temperature was chosen with regard of measured hardness after hardening and after first tempering.

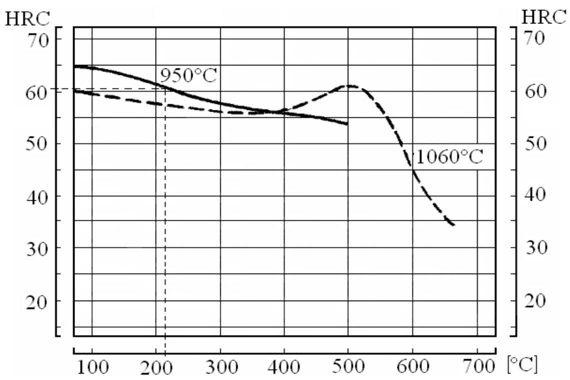

Figure 4. Dependence diagram of resultant basic material (steel X210CR12) hardness value HRC after tempering on tempering temperature

In the same way as in hardening, also during tempering it is inevitable to protect material surface from decarburization and oxidation in vacuum furnace or by inert atmosphere.

From the diagram it can be concluded that the highest hardness value of steel block basic material EN ISO 9676 X210Cr12 can be achieved by tempering if it was hardened at 1060 °C. At the experiment, lower hardening temperature was applied (approx. 1020 °C), so expected resultant hardness after tempering is approx. 58 HRC. Hardness of basic material after tempering (for removal of internal stress after hardening) drops approx. by 5 HRC. [5]

6. EXPERIMENTAL VERIFICATION OF HEAT TREATING RESULTS

Metal block hardness test after hardening at 1020°C and 2-phase tempering at 220°C was carried out by Rockwell method. [6] Following figure shows placements of hardness testing spots on experimental sample.

Table 1. Sample hardness values measured after hardening and tempering

Testing spot	Hardness values HRC of basic material		
	After hardening	After 1st tempering	After 2nd tempering
No. 1	64	60	58
No. 2	63	61	57
No. 3	64	60	57
No. 4	64	60	58
No. 5	63	61	57
No. 6	64	60	58
Mean values	63.7	60.3	57.5

Following table presents measured values of basic material hardness of the sample made from tool steel EN ISO 9676 X210Cr12 after martensitic hardening and 2-phase tempering. Overall course of hardness changes of experimental sample basic material during all heat-treatment phases is recorded in figure 5.

From the diagram we can see hardness growth after martensitic hardening at 1020 °C by 32.7 HRC. In order to remove internal stress, 2-phase tempering at 220 °C was applied. This decreased internal stress after hardening, however, it also caused mild decrease of basic material hardness. In the first phase the decrease was 3.4 HRC, in the second phase 2.8 HRC.

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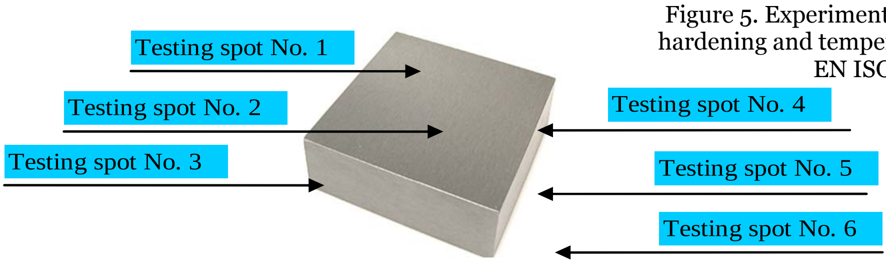

Figure 5. Experimental hardness measurement after hardening and tempering of steel block from material EN ISO 9676 X210CR12

7. CONCLUSIONS AND DISCUSSIONS OF EXPERIMENT RESULTS

The paper presents results of the proposal for tool steel EN ISO 9676 X210Cr12 heat treating. This material is assigned for shearing tools production by electroerosion machining. Selection of the material for the experiment was based on its mechanical properties, and on practical experience of tool smiths who use this material often in shearing tools production. [7] The paper describes in detail particular phases of heat treating of experimental steel block: annealing, hardening, and tempering. Proposed procedure takes into account specifics of shearing tools production by electroerosion machining technology that imposes high quality requirements on semiproducts heat treatment. In the first phase of sample heat treatment, annealing for removal of cutting-caused stress was proposed. Since shearing tools must have high hardness of basic material through the whole cross-section, the most suitable was application of martensitic hardening at 1020°C. To ensure that required hardness will be reached, i. e. that austenite will transform into martensite, it was necessary to guarantee intensive enough cooling of material during hardening. Certain risk in this intensive and at the same time non-controlled cooling is posed by material thermal expansion which generates extreme internal stress in basic material. This can cause destruction of material compactness. So it was inevitable to find optimal cooling rate, i. e. such rate that would approach higher critical martensitic temperature. To keep to this cooling rate in practice is very demanding, or even impossible in certain cases. That is why the cooling rate applied in hardening was slightly higher than critical cooling rate according to CCT diagram. The last phase of steel block heat treating was 2-phase tempering at 220°C. The result of this heat treatment was significant decrease of internal stress that appeared during intensive cooling of basic material, brittleness decreased too. Negative accompanying phenomenon was drop of basic material hardness from 63 HRC to 57.5 HRC. Experiments were carried out directly in company producing shearing tools. The results of the experiments were confronted with general knowledge from the field of tool steels heat treating.

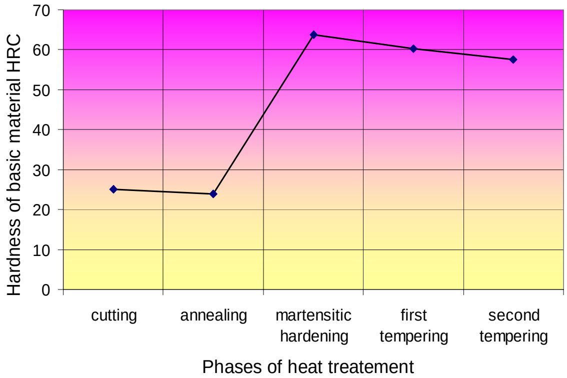

Figure 6. Hardness course in particular phases of heat treatment of steel block made from tool steel EN ISO 9676 X210CR12

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