DEEP CRYOGENIC TREATMENT OF HIGH SPEED STEEL

Aleksander CISKI

Institute of Precision Mechanics, Duchnicka 3 St.,01-796 Warsaw, Poland, ciski@imp.edu.pl

Abstract

This experimental study investigates the properties of HS6-5-2 high speed tool steel subjected to deep cryogenic treatment (DCT) carried out at -180 °C. Microstructures of conventionally and DCT treated samples were examined with aid of scanning electron microscopy. The characteristic feature of deep cryogenically treated steel, distinguishing it from steel heat treated in a conventional way, was significant refinement of martensite plates. Material processed in this manner was found to exhibit slight decrease in hardness and considerable increase in impact strength. Deep cryogenic treatment caused the decrease of steel's intensity of wear for about 36 %. However, this result was obtained during wear test carried out under a load of 100 MPa, while under four times higher load, slight worsening of tribological properties was observed. In the study, performance of deep cryogenically treated twist drills in drilling of ISO C45 constructional steel was evaluated in terms of tools in-service life. The assessment of the durability of drills was based on the occurrence of acoustic emission, as a symptom of obtaining the critical dulling. A general worsening of drills durability was observed after DCT treatment.

Keywords:

Deep cryogenic treatment, high speed steel, drills

1. INTRODUCTION

The literature findings show that the improvement of the properties of high-speed steel can be made through the use of the additional heat treatment operation – deep cryogenic treatment (DCT). One of the first studies of tool steels subjected to cryogenic treatment showed an increase in wear resistance, in comparison with steel subjected to conventional heat treatment. Described in the article an in-service durability test of slitter knives, carried out under industrial conditions, confirmed these results [1]. Similar results were presented in subsequent articles [2], where, in addition to increasing the service-life of the disc milling cutter, authors observed an increase in bending strength and toughness of W6Mo5Cr4V high-speed steel. This phenomenon was accounted for the modified morphology of martensite and the presence of ultra-fine carbide precipitations. The study carried out by authors of article [3] confirmed these reports. Precipitations observed with aid of high resolution transmission electron microscope were described as the carbides coherent or semi-coherent with the matrix, with the crystallographic structure of the type identified as B1. In the literature there are also findings about the worsening of wear properties of tool steels after DCT. An example is the article [4], in which deep cryogenic treatment led to reduction in resistance to wear of Böhler S600 high-speed steel (HS6-5-2 steel equivalent).

2. RANGE OF WORK

The aim of his work was testing of wear and mechanical properties, as well as determining the changes in the microstructure of HS6-5-2 high speed steel subjected to deep cryogenic treatment. Substructure of steel heat treated in the same way was the subject of the previous article [3].

Quenching of samples was carried out in a SECO/WARWICK vacuum furnace with high pressure nitrogen quenching. The process of deep cryogenic treatment was carried out in a CRYO-TEMPER cryogenic processor. The baseline heat treatment mode comprised vacuum quenching and three tempering cycles for secondary hardness. Heat treatment with deep cryogenic treatment was carried out just after quenching with subsequent single tempering operation. Applied combinations of heat treatment operations and their parameters are given in table (**Tab. 1)**.

Tab. 1 Heat treatment modes of HS6-5-2 samples

Heat treatment	Parameters
CHT	Austenitize (1200 °C), quench (N_2, 4 bar), temper (550 °C)
DCT	Austenitize (1200 °C), quench (N_2, 4 bar), DCT (-180 °C /24 h), temper (550 °C)

3. RESULTS OF LABORATORY TEST

3.1 LM and SEM imaging

Light microscopy analyses were conducted with aid of NIKON Eclipse LV150 microscope. Microstructure of HS6-5-2 steel specimens after conventional heat treatment consisted of a tempered martensite, primary carbides and carbide phases, which precipitated from the martensite during tempering, and small amount of retained austenite (**Fig. 1a**). Primary carbides formed local bandings with a width of about 5 μm and the distance of about 30 μm. The microstructure obtained after quenching, deep cryogenic treatment and tempering for secondary hardness was similar to the microstructure observed in mode CHT (**Fig. 1b**). In each of the heat treatment modes the quantity and size of primary carbides remained the same, primary austenite grains size (8÷10 μm) corresponded to the grain size number 10÷11 on the ASTM scale.

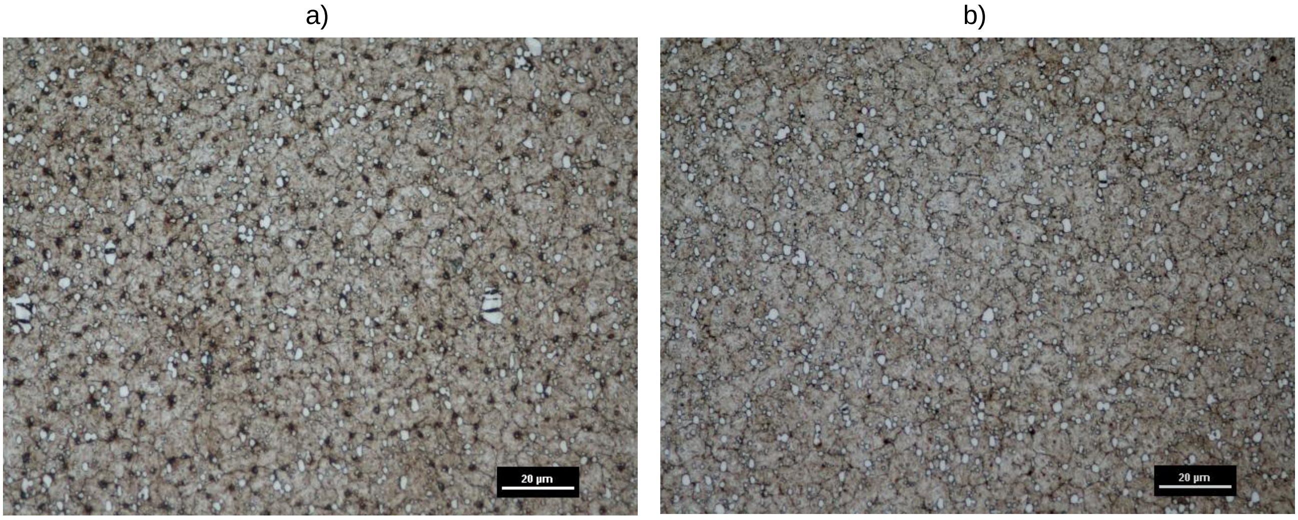

Fig. 1 LM micrographs of HS6-5-2 samples: a) CHT, b) DCT

Scanning electron microscopy analyses were conducted with aid of scanning electron microscope HITACHI HD2700. Spherical shape carbides (VC) with diameter of about 1 μm were generally located within the martensite grains, whereas these oval-shaped carbides (M_6C), with a diameter of about two times higher, at the grain boundaries. In samples heat treated in mode CHT plates of martensite had length of about 1÷2 μm and width of about 0,3÷0,4 μm (**Fig. 2a**), while in deep cryogenically treated samples these dimensions were an order of magnitude shorter and thinner (**Fig. 2b**).

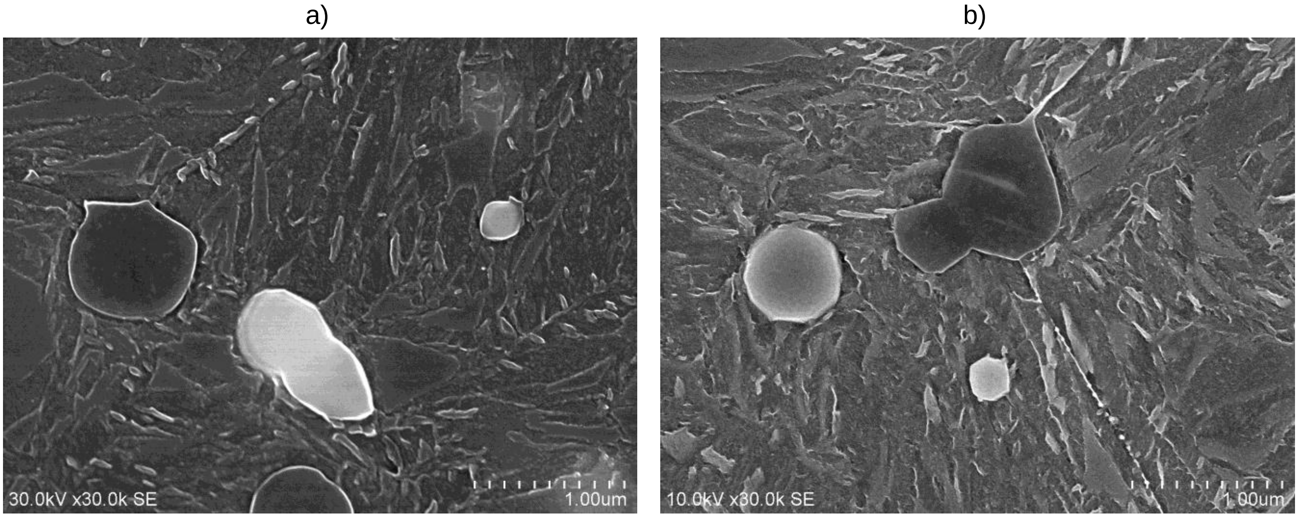

Fig. 2 SEM micrographs of HS6-5-2 samples: a) CHT, b) DCT

3.2 Hardness

Surface hardness measurements showed that the steel after conventional heat treatment for the secondary hardness had a hardness of about 65,5 HRC (**Tab. 2**). Samples after quenching, deep cryogenic treatment and tempering had lower hardness of about 64,7 HRC, probably resulted from a change in morphology of the martensite crystals and accelerated processes of coagulation and coalescence of dispersed carbides, which nucleation occurred during DCT (**Tab. 2**).

Tab. 2 HRC hardness of HS6-5-2 samples

Heat treatment	Hardness, HRC	Standard deviation
CHT	65,5	0
DCT	64,7	0,27

3.3 Impact strength

Impact strength measurements were carried out with the Charpy method, on specimens with u-shaped notch, with notch fillet radius of 1 mm. Test was conducted in accordance with PN-EN 10045-1:1994 standard, using the WMP impact hammer with the pendulum's initial energy of 50 J. There was observed large increase of impact resistance, caused by deep cryogenic treatment and tempering (**Fig. 3**).

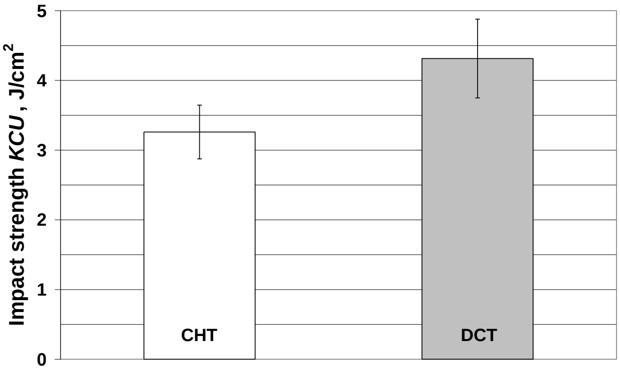

Fig. 3 Impact strength of HS6-5-2 samples

3.4 Wear test

The wear of specimens was estimated by means of the friction test in three rollers-cone system, (in accordance with Polish Standard PN-83/H-04302). For this work loading of 100 and 400 MPa unit pressure was applied. Tests were conducted with drop lubrication at a rate of 30 drops of Lux-10 oil per minute.

The parameter defined as the intensity of wear, reflecting the tangent of the slope angle of line of wear to the time axis, was calculated according to the formula (1):

$$I_l = \frac{Z_l}{t_s} \tag{1}$$

where:

I_l – intensity of wear, μm/min,

Z_l – value of wear in range of steady wear, μm,

t_s – time of wear in range of steady wear, min.

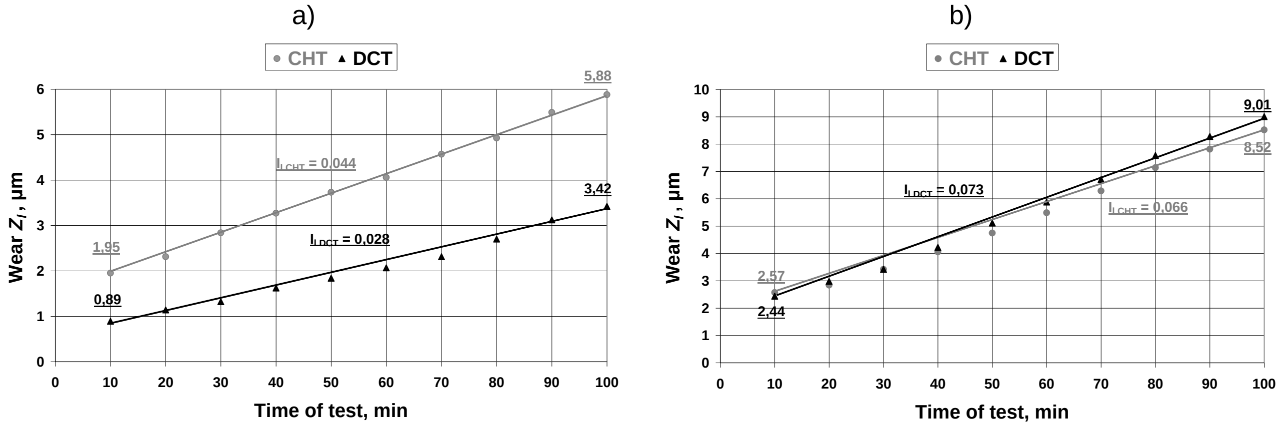

Fig. 4 Value of wear vs. time of test for HS6-5-2 samples a) at 100 MPa, b) at 400 MPa

Wear test carried out under the load of 100 MPa showed that the lowest wear after 100 minutes of test was recorded for the steel after quenching, deep cryogenic treatment and tempering. When compared with the wear value for steel after conventional treatment, wear rate after 100 minutes was decreased for about 42 % (**Fig. 4a**). Calculated intensity of wear of DCT treated samples was 36 % lower than intensity of wear obtained for samples heat treated in conventional manner. Increase of tribological properties may be the effect of decreased content of retained austenite caused by deep cryogenic treatment and formation of ultra-dispersive carbide precipitations, which are more resistant to cracking during friction.

Results of tests carried out under four times higer loading conditions (400 MPa) showed slight worsening of tribological properties of steel subjected to DCT (**Fig. 4b**). Maximum value of wear was higher for about 6 %, while wear intensity was higher for about 11 %, in comparison with properties of samples heat treated in conventional way.

4. IN-SERVICE LIFE TEST OF HS6-5-2 DRILLS

In-service life test of ø5 twist drills was carried out using vertical machining center GF AgieCharmilles MIKRON VCE 600 Pro. Durability test consisted in machining of blind holes with a depth of 15 mm (three times the drill diameter) in the plates of ISO C45 steel with a hardness of approximately 220 HB. Cutting parameters were selected based on recommendations from the manufacturer of drills and were as follows:

- Cutting speed V_c = 26 m/min,
- Feed f = 0,12 mm/rev,
- Cutting oil SWISSCOOL7733 given directly to the cutting zone.

Heat treatment parameters of drills are given in table (**Tab. 3**).

Tab. 3 Heat treatment modes of drills made of HS6-5-2 steel

Heat treatment	Parameters
CHT	Austenitize (1180 °C), quench (N_2, 4 bar), temper (560 °C, 560 °C, 510 °C/2h)
DCT	Austenitize (1180 °C), quench (N_2, 4 bar), DCT (-180 °C /32 h), temper (560 °C, 560 °C, 510 °C/2h)

The assessment of the durability of drills was based on the occurrence of acoustic emission, signaling a critical blunting. For each variant of the heat treatment drilling procedure was carried out five times, in order to obtain reliable data for statistical analysis (determination of the standard deviation of measurements).

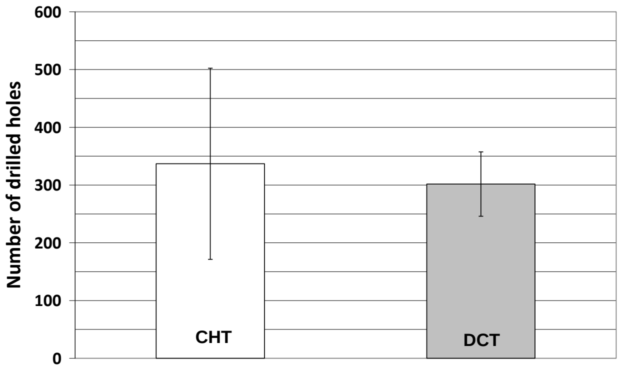

Fig. 5 Number of drilled holes

Durability of drills in blind drilling in the C45 steel was evaluated by the number of holes made until the occurrence of conventional signal of dulling. In-service life of twist drills after deep cryogenic treatment was about 10 % lower than life of tools heat treated in a conventional manner (**Fig. 5**).

5. DISCUSSION

The subject of examinations were the properties of deep cryogenically treated HS6-5-2 high-speed steel. Results of tests were compared with the properties of steel subjected to conventional heat treatment (quenching and triple tempering).

In case of microstructure of steel, observed with the use of SEM, the characteristic feature of deep cryogenically treated HS6-5-2 steel, distinguishing it from steel after conventional heat treatment, was significant (about ten times) reduction of dimensions of martensite plates.

Steel subjected to quenching, deep cryogenic treatment and tempering had significantly lower hardness. This result is inconsistent with, observed by other authors [5], considerable (from 1 to 3 HRC) increase of hardness. The decrease in hardness may be explained with different crystal morphology of martensite grain, and connected with this process change of strengthening mechanism and the formation of additional, micro-dispersive carbide precipitations (during tempering), which nucleation began during DCT.

The deep cryogenic treatment, according with expectations, caused increase of tribological properties of steel. Maximum value of wear was lower for about 42 %, while wear intensity was lower for about 36 %, in comparison with properties of samples heat treated in conventional way. However, this result was obtained during the three rollers-cone test, under load of 100 MPa, while under four times higher load, slight worsening of tribological properties was observed.

After deep cryogenic treatment and tempering of steel, there was considerable increase in its impact strength. The slight increase of impact strength are consistent with literature, e.g. papers [2, 4, 5].

The key deciding factor for selection of heat treatment route for high speed steel tools should be the actual properties of tools, determined by the test carried out under industrial conditions. The performance of deep cryogenically treated twist drills in drilling of ISO C45 constructional steel was evaluated in terms of tools in-service life. The assessment of the durability of drills showed the general worsening of drills durability, in comparison with durability of drills heat treated in a conventional manner. However, it should be noted that the obtained results were scattered, which can be explained by inaccurate manufacturing of drills (misalignment of drills caused by poor workmanship) or the occurrence of segregation of carbides in their microstructure (material defects).

6. CONCLUSIONS

The obtained results only partially acknowledged the data considering the advantages coming for the use of deep cryogenic treatment, which can be found in literature:

- Deep cryogenic treatment of HS6-5-2 steel led to reduction of dimensions of martensite plates, significant decrease of hardness and considerable increase of impact strength.
- Despite of 36 % lower wear intensity of steel, determined during three rollers-cone test under load of 100 MPa, industrial test of actual drills showed the general worsening of durability of DCT treated drills.
- Test of resistance to wear by three rollers-cone method, carried out under 400 MPa load, adequately simulated the conditions during drilling in constructional steel. Result of the intensity of steel wear estimated by this method and under high loading conditions coincided with the results of durability of drills.

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