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Research Article

Experimental Investigation on Deep Cryogenic Treatment of Tool Steel

Nishigandha S. Patel†, D. S. Shevade†, S.P. Chaphalkar‡, Mandar M. Lele†

†Mechanical Department, MITCOE, Pune, India
‡Mechanical Department, Pimpri Chinchwad College of Polytechnic, Pune, India

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Abstract

Deep cryogenic treatment is permanent-effect process. It is carried out on steel components so that the material is cooled slowly to the cryogenic temperature. It is held at cryogenic temperature for a specified period of time and then brought back to room temperature at a slow rate, followed by low-temperature tempering. The HSS taper shank twist drill (grade M2) was chosen for shop-floor testing as well as metallurgical investigation and cryotreated at 77 K for different soaking periods (18 – 24 hrs) have been examined with respect to their micro-structural. The shop-floor test indicates an increase in the life of a tool cryotreated with 24 hrs soaking was nearly 301% and decrease in the wear rate was about 56% compared with the control. Metallurgical investigation showed no significant improvement in hardness following cryogenic treatment, but an increase in carbide precipitation by 63% and a 42% reduction in wear rate when compared with the control.

Keywords: *M2 high-speed steel drill; Deep cryogenic treatment; Carbide precipitation; Wear resistance*

1. Introduction

[1]The primary objective of the heat treatment of tool steel is to impart a high level of wear resistance. One of the major problems is the content of retained austenite, which is soft, unstable at low temperature and transforms into brittle martensite during use. Transformation of austenite to martensite is associated with approximately 4% volume expansion, which causes distortion of the components. Thus, either sub-zero treatment or multiple tempering at relatively high temperature and/or for longer is used for minimizing the austenite content of tool steels. The sub-zero treatment is popularly called cold treatment (193–213 K) or cryogenic treatment (77–148 K) as mentioned (Barron, 1982).In this paper, deep cryogenic processing (77 K) is referred to as the cryogenic treatment (CT) that was used between the conventional hardening and tempering cycles.

The major aim of this investigation was to determine the influence of the duration of CT on the enhancement of wear resistance and tool life for tool steel thus specimens of M2-grade steel were subjected to three different lengths of soaking time, 18 hrs, 21 hrs and 24 hrs, during CT. The effect on tool life and wear resistance on these steel specimens was assessed by shop-floor tests as well as metallurgical investigation. Comparison of the results of these tests has revealed the underlying mechanism for the improvement in wear resistance theoretically as well as practically by CT and shed light on the wide scatter of the reported improvement in wear resistance of tool steels imparted by CT.

2. Research Methodology

The objectives of this research paper were to study the effects of different soaking periods and wear resistance change of the microstructure after deep CTThe taper shank twist HSS drill (M2 grade, 8.5 mm diameter) was chosen as the steel tool to be studied. The Research methodology of this study is illustrated in Fig. 2.1

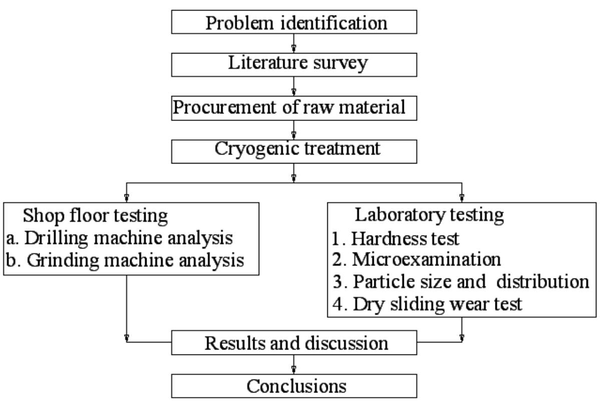


Fig. 1 Research methodology

*Corresponding author: **Nishigandha S. Patel**

3. Cryotreatment

Following Fig. 2 presents the CT cycleadopted at CryoKing

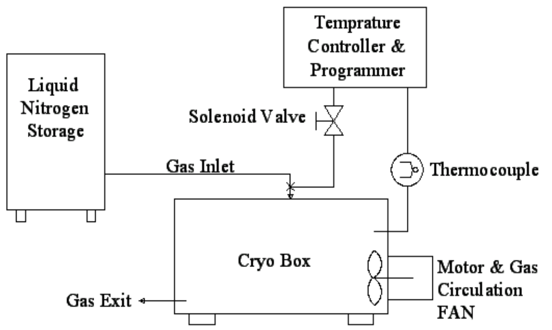


Fig. 2 Block diagram of cryogenic plant

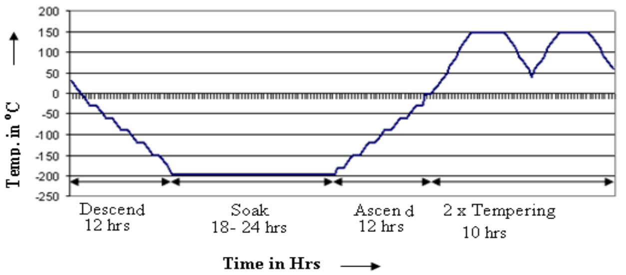


Fig. 3 Cryogenic treatment cycle

Table 1 Designations and cryogenic treatment of drill tools

Drill	Cooling time from room temp to 77 K (hrs.)	Soaking time at 77 K (Hrs.)	Heating time from 77 K to Room temp (hrs.)	Tempering time at 423 K (hrs.)†
B	12	18	12	10
C	12	21	12	10
D	12	24	12	10
E	12	24	12	00

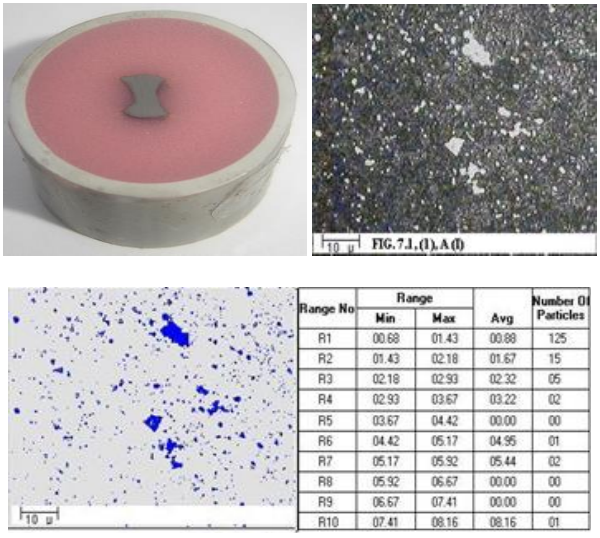
Five M2-grade taper shank twist HSS drills were chosen for study. An untreated control tool was designated as a specimen A. Details of the deep CT performed on the rest 4 test tools and their designations (coding) are given in Table 1.Two cycles of 5hrs each.

4. Shop-floor Testing of Tools.

The tools were loaded onto a radial drilling machine (BVR 3, Batliboi Ltd). Three readings were taken for the number of holes produced by each tool. Each drill was used to make holes through a mild steel (MS) plate of 35 mm thickness. The speed of rotation (224 rpm) and the feed rate (0.315 mm s^{-1}) were kept constant.

5. Laboratory Testing of Tools

Bakelite moulds of each sample as shown in Fig. 4 were prepared to allow the drill to be handled easily. For mounting, the drill was cut to the required length (minimum 10 mm) and then put into a circular mould (PVC pipe of 20 mm internal diameter). Resin that was poured into mould hardened in 5 – 10 minutes and held the drill firmly.



Range No	Range Min	Range Max	Avg	Number Of Particles
R1	00.68	01.43	00.88	125
R2	01.43	02.18	01.67	15
R3	02.18	02.93	02.32	05
R4	02.93	03.67	03.22	02
R5	03.67	04.42	00.00	00
R6	04.42	05.17	04.95	01
R7	05.17	05.92	05.44	02
R8	05.92	06.67	00.00	00
R9	06.67	07.41	00.00	00
R10	07.41	08.16	08.16	01

Fig. 4 Test specimen and its microstructures, solarized images of carbide distribution and ranges of carbide

The end of the drill was ground and then the tip was rubbed sequentially on 5 different grades of emery paper in the order 120, 200, 600, 800, and 1000 grit. The tip of the drill was then rubbed with 0.3 μm alumina powder and polished on a revolving velvet cloth wheel. Finally, the tip of the drill was etched with Vilella's reagent(1 g of picric acid in *5* ml of HCl plus 95 ml of methanol). This reagent is similar to 5% Nital (5% nitric acid in ethanol). The prepared drills were observed with an electronic microscope at magnifications in the range 800 – 1000×. Not only the Microstructures but also Carbide size and its distribution for entirespecimens is observed at three different locations. The test method is specified as ASTM standard E 3- 2001; E 407 – 1999.

5.1 Hardness testing and Behaviour

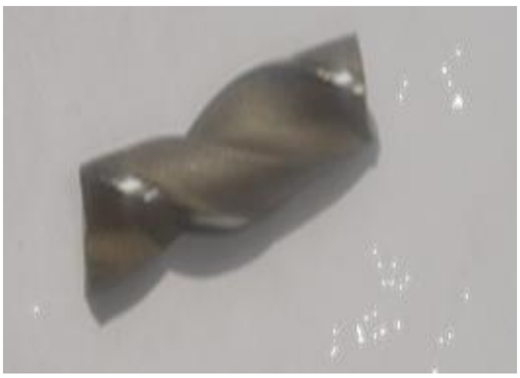


Fig. 5 Test specimen for surface and core hardness test

Core hardness and surface hardness were assessed with a hardness testing machine (model HPO 250Vickers, Germany). The test method is specified as (HV

5) IS 1501 – 2002 / (ASTM Standard E 92). Hardness was measured with a 50 N load and a dwell time of 15 s. An indentation was made on the circular face of the cylindrical sample (flute portion of drill), and care was taken to ensure that the distance between the centers of two impressions was more than three times the diagonal of the indentation. Impressions were made at the centre of the circular face of the cylindrical sample, and the diagonal of the indentation was measured using cross-wires. The Vickers hardness values corresponded to the diagonal length of the indentation, and the hardness of each sample was measured in triplicate.

The surface hardness, core hardness, carbide size and wear rate results are given in Table 4. For hardness result analysis refers Fig. 7.2. The results of the hardness test are consistent with the observations of da Silva et al. (2006) that the overall hardness of the CT steel and the normal specimens (A – D) did not change noticeably. As shown by Baldissera and Delprete, (2009) there is a slight improvement in hardness of sample D is attributed due to the conversion of austenite to martensite by CT

Table 2 Summary of laboratory tests results

Drill	Surface hardness (HV)	Core hardness (HV)	Carbide counts	Wear rate in micrometers
A	793	793	171.33	514.5
B	783	793	220.33	464
C	793	793	240.33	330
D	800	800	279.33	297
E	846	793	121.33	919.5

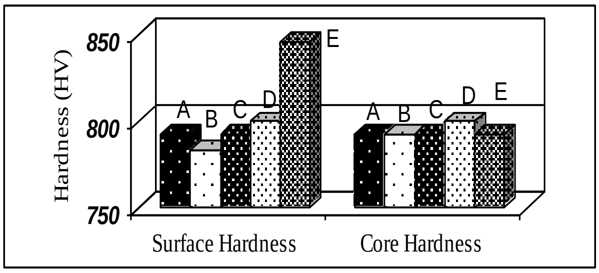


Fig. 6 Surface and core hardness comparison

5.2 Particle Size and Count

The prepared Mounted specimens in micro examination test (section 5.1), are examined with a Leco 500 image analysis system at a magnification of 800×. An image of carbide at a particular location was solarized. The in-built software determining the particle size distribution average, minimum and maximum size of the carbide in the solarized image. The amount of η-carbides formed is directly proportional to the tempering time and temperature.

5.3 Dry Sliding Wear

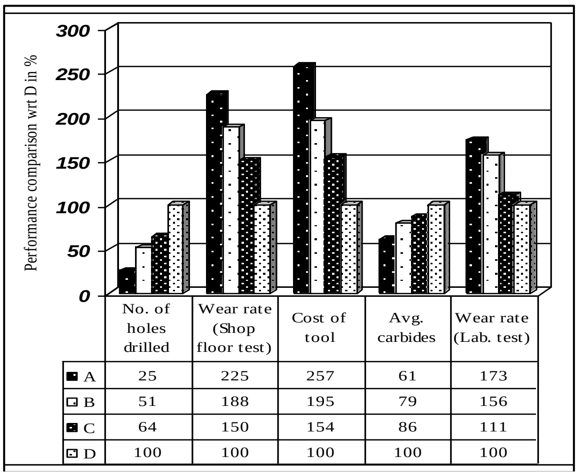


Fig.7 Overall comparison of the results for specimen D and those of the other specimens. (Specimen E was excluded from the comparison because its performance was too poor).

Dry sliding wear tests following ASTM standard G 99-05 were done with a computerized pin-on-disc wear-testing machine (TR-20LE, DUCOM, India). For each drill, a pin-shaped sample of 8–12 mm diameter and 25 mm long, was prepared from the portion between shank and the twist drill, and held in the fixed holder of the machine (Fig. 5.3). Emery paper of 200 μm of 150 mm diameter is fixed on the base of a rotating drum. In the first stage, the specimen is held against the rotating emery paper with constant sliding velocity for 1 minute so that the surface of the specimen is made smooth

Conclusions

The wear behavior and tool life of M2 HSS specimens, subjected to CT with different periods of soaking at 77 K, has been examined by shop-floor testing as well as by metallurgical investigation.

The tool life of a drill prepared by 24 hrs soaking followed by tempering was 301% longer than that of the untreated control, 97% longer than that of a CT drill with 18 hrs soaking followed by tempering, 57% longer than that of a CT drill with 21 hrs soaking followed by tempering

As per laboratory test results, The improvement in wear resistance of a drill prepared by 24 hrs soaking followed by tempering was 43 % greater than that of the untreated control, 36% greater than that of a CT drill with 18 hrs soaking followed by tempering, 10% greater than that of a CT drill with 21 hrs soaking followed by tempering, and 68% greater than that of a CT drill with 24 hrs soaking but without tempering.

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