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Performance analysis of cryoprocessed conventional HSS M2 drill and P/M HSS M3 TiN coated tap and its effect on the substructure

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ABSTRACT

The experimental study investigates the performance of cryogenically treated conventional uncoated H.S. S. M2 Drills and P/M H.S.S. M3 TiN coated taps. The fermentation factors and their assigned values maintained constant throughout the study were soaking temperature of -185°C , soaking time of 16 h, cooling rate $1^{\circ}\text{C}/\text{min}$ to $2.5^{\circ}\text{C}/\text{min}$ followed by soft tempering at temperature 100°C and soft tempering time of 1 h. For conventional uncoated H.S.S. M2 drills, the speed and feed rate were offset by 10% on lower side and higher side of the datum. For P/M H.S.S. M3 TiN coated taps, the speed and feed rate were offset by 5 % in the steps of three on the higher side of datum. It has been observed that tool life of conventional uncoated H.S.S. M2 Drills is improved by 100% or twice with 10 % increase in speed and by 80 % or 1.6 times with 10 % increase in feed rate. The tool life of P/M H.S.S. M3 TiN coated taps increased by 175 % or 3.44 times with 10 % increase in speed and feed rate as compared to the datum parameters. TiN coated taps shows maximum tool life without any damages or dislodgement to the coated surface. Therefore the adherence of coating is found to be strong without any interfacial imperfection between the matrix and the coating. The increased tool life of such coated tools can be attributed to decreased surface roughness values. The improved performance of the drills can be attributed to refinement in carbides which increases wear resistance during cutting.

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1. Introduction

The desirable properties of High Speed Tool steels include high strength, good hot hardness, toughness and wear resistance. After machining the tools or components as per the drawing specifications, tool steels are subjected to heat treatment and deep cryogenic treatment wherein these desirable properties are improvised throughout the cross section [1]. These tool steels find numerous applications in the manufacture of single point cutting tools as well as multi point cutting tools like drills, taps, milling cutters etc.. In general, the tapping operation becomes very complicated with respect to the other cutting operations as larger portion of the cutting edge cuts. P/M manufactured taps are

introduced as P/M route provides high amount of evenly distributed primary carbides. Published literature on HSS Drills subjected to cryogenic treatment is available and performance reports suggest the improvement in wear resistance and hardness. A commonly proposed mechanism is the precipitation of fine carbide particles during cryogenic treatment.

The various stages of manufacturing cutting tools includes the machining followed by a heat treatment process to increase the hardness and wear resistance. Introducing cryogenic treatment to the already heat treated tools shows improved wear resistance and hardness. Also the electrical and thermal characteristics of the materials used can be improved with cryogenic treatment. The literature shows that with the cryogenic treatment applied to cutting tools, tool wear and cutting conditions could be improved from hundred to few hundred percent in the tool life [2–4]. Till date, numerous publications investigated deep cryogenic

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treatment of conventionally produced tool steels. However, little attention has been paid to materials produced by alternative routes such as powder metallurgical tool steels. This production route can achieve a more homogeneous microstructure compared to conventionally produced steels [1,5]. The deep cryogenic treatment (-196°C) of quenched and tempered high speed steel tools improves their properties; in particular, it increases the hardness and improves the hardness homogeneity, reduces the tool consumption and the down time for the equipments set up, thus leading to about 50% cost reduction [5]. In the study of Wear Stabilisation in Cryoprocessed Cobalt-Based High Speed Steel the microstructural features reveals the carbide density variation with varying time, it is noted that maximum carbide density is observed at 16 h of cryosoaked time and thereafter fall in carbide density is seen which might be the result of coarsening of carbide. The overall fine carbides are more than that of coarse carbides in all cryotreated samples. Carbide density for fine carbides is relatively more, suggesting high driving force for carbide precipitation of certain type of carbides [6]. In the metallurgical investigation of cryogenically cracked M35 tool steel, it was found that as-hardened specimen when cryotreated increases hardness and residual stresses. The kinetic of carbides precipitation is found to be governed by the amount of cryosoaking time which varies from 4 h to 48 h. It was concluded that excessive accumulation of residual stresses at cryogenic temperature is the prime parameter for the cracking to occur by way of shear fracture and the responsible factors are resolved using the proposed failure mechanism [7]. When the tool steel materials are subjected to deep cryogenic treatment the decomposition of martensite and precipitation of ultrafine carbides takes place. Here in the deep cryogenic treatment process, volume contraction takes place thus the crystalline lattice tends to decrease and martensite becomes thermodynamically unstable. Martensite decomposes precipitating out carbon atoms and the thermodynamic driving force increases. At low temperatures there is a difficulty of diffusion of carbon atoms and so the decomposition of martensite and formation of ultrafine carbides at very low temperatures of -196°C will not take place unless the temperature is increased. Thus in deep cryogenic treatment the decomposition of martensite and precipitation of fine carbides is similar to that observed in tempering process, but herein deep cryogenic treatment the transformation of the structure takes place at a much lower range of temperature thereby leading to much smaller precipitated carbides and more diffused [8].

This study aims to evaluate the performance of conventional HSS M2 Drills and P/M TiN Coated HSS M3 Taps and analyze the effect of post-cryogenic treatment on wear mechanism and its interrelation with microstructure features, hardness and thereby provide a scientific base to optimize the tool life considering datum operating parameters and offsetting the operating conditions.

1.1. Selection of material

The Chemical composition of the Drill material was analyzed using vacuum emission spectrometer (VES) and found to be C-0.87, Mn-0.22, Cr-4.10, Mo-4.87, V-1.70, W-4.23, Co-0.63, Si-0.28, S-0.012, P-0.050 and conforms to AISI M2 High Speed Tool Steel. The Chemical composition of the tap material was also analyzed using vacuum emission spectrometer (VES) and found to be C-1.25, Mn-0.23, Cr-4.24, Mo-4.92, V-2.65, W-4.31, Co-0.67, Si-0.51, S-0.013. The chemical composition of tap conforms to AISI M3 PM High Speed Steel.

1.2. Cryogenic treatment

The Conventional HSS M2 Drills and P/M TiN Coated HSS M3 Taps were hardened and tempered as supplied condition. The

experimental set up includes, Computer controlled Cryoprocessor (Make Sandmar, Mumbai) as shown in Fig. 1f or providing the Cryogenic Treatment. The cryogenic treatment -185°C at a cooling rate of $2.5^{\circ}\text{C}/\text{min}$ is given to conventionally heat treated tools. The cryosoaking period was 16 h and after the cryosoaking period the tools were immediately transferred and stored in a highly insulated thermocol box until the specimens attain the room temperature. The entire cryotreated tools were soft tempered at temperature 100°C for 1 h to relieve cold stresses. The process parameters for the material under study are available in the published literature [7].

1.3. Metallography

Microstructural analysis was carried out by an image analyser with inverted microscope (Make: Carl Zeiss, Germany, model 115 Axiovert 40 Mat) and scanning electron microscopy (Make: JOEL-JSM-6360A). A freshly prepared etchant 4% nital was used for revealing micro constituents of Conventional HSS M2 Drills and P/M TiN Coated HSS M3 Taps. Rockwell hardness tester (C-scale) was used for measurement of Hardness. An average of five readings was reported as a measure of hardness.

1.4. Experimental settings and observation of tool life

All experiments on drill and Tap are carried out for wet condition only. The cutting fluid used is a water oil emulsion. Throughout the test on drills the bearing number 2215 OR is kept constant. Also for the drill change, GO-NOGO Plug gauges are used for acceptance throughout the tests. Early indication of drill change is the variation in noise while machining noted by the operator. Observations are recorded for Conventional Uncoated Dia.9.0 mm H.S.S. M2 drills, with Variable Speed, Constant Feed of $32\text{ mm}/\text{min}$ ($0.091/\text{rev}$) and Constant Depth of Cut of 66 mm. Testing Parameters for trial no. 1 are in accordance with the present parameters on which the drills are presently used, referred to as datum. Parameters for trial no. 2 are offset on higher side of datum by +10 percent speed in m/min with feed per revolution and depth of cut in mm being constant. Parameters for trial no. 3 are offset on the lower side of datum by -10 percent speed in m/min with feed per revolution and depth of cut in mm being constant.

The trials for $M20 \times 2.5$ Fette make P/M TiN Coated Taps are taken on the bearing number 1228-IR. The experimental matrix includes the same testing parameters, but as in case of taps the speed bears a constant ratio with the feed, therefore speed and so the feed are variables with only the depth of cut in mm being constant. The present parameters for tapping are already on the lower side, as it is not affordable to absorb the losses due to damage or breakage of taps in the drilled hole. To evaluate the perfor-



Fig. 1. Computer Controlled Cryoprocessor (Make Sandmar, Mumbai).

mance enhancement, the offsetting of the present parameters is done in the steps of +5 % on the higher side of datum parameters.

2. Results and discussion

2.1. Performance evaluation of Dia. 9.0 mm HSS M2 drills

The superimposed graph provides comprehensive information on selecting operating parameters for optimum tool lives. Fig. 2 can be divided into two regions which depict overall performance influenced by imposed parameters. Region I depicts the rate of increase in tool life with speed is dramatic in cryogenically treated tools, whereas it is insignificant in conventionally treated tools. However in regime II, the cryogenically treated tools attain steady state despite increase in speed. Hence there is virtually no effect on increasing tool life. But there is slight drop in tool life observed for conventionally treated tool at higher speed. Regime II is expanding with increasing speed which clearly indicates positive performance of cryogenically treated tools at higher speed. This improvement is almost two times the conventionally treated tools. The results obtained are in line with the literature available [8].

Fig. 3 depicts the superimposed graph of conventional and cryogenically treated steels. It shows the effect of feed rate on tool life for constant speed 350 rpm and depth of cut 66 mm with superimposed graph showing bands with conventional treatment drills and with cryogenic treatment on dia. 9.0 mm drills. The upper and lower boundary of envelope/domain corresponds to cryogenically treated and conventionally treated tools respectively. Increase in life of tools indicating increased wear resistance, decreased surface roughness and increased thermal conductivity of the matrix allows further heat dissipation increase during machining. It is observed that at higher feed rate the heat generation at tool tip is also high and it is imperative to extract or dissipate heat from tool cutting interface. It is well known that cryogenic treatment promotes precipitation of tertiary carbides thereby depleting the precipitated matrix of tool from heavy alloying elements, which are otherwise dissolved in the matrix by way of solid solution [9].

2.2. Performance evaluation of TiN Coated M20 × 2.5 taps

The trials for M20 × 2.5 Fette make P/M TiN Coated Taps are taken on the bearing number 1228-IR. The experimental matrix includes the same testing parameters, but as in case of taps the speed bears a constant ratio with the feed, therefore speed and so the feed are variables with only the depth of cut in mm being constant. The present parameters for tapping are already on the lower side, as it is not affordable to absorb the losses due to damage or breakage of taps in the drilled hole. To evaluate the perfor-

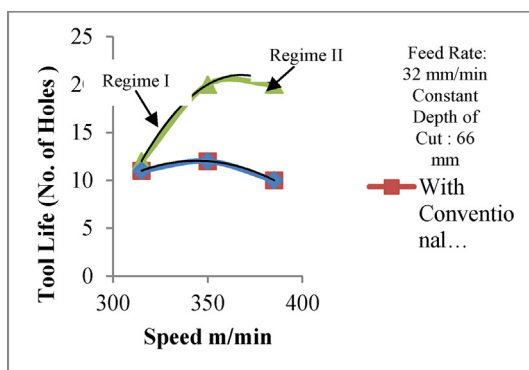


Fig. 2. Effect of speed on tool life on conventional treated and cryogenically treated drills.

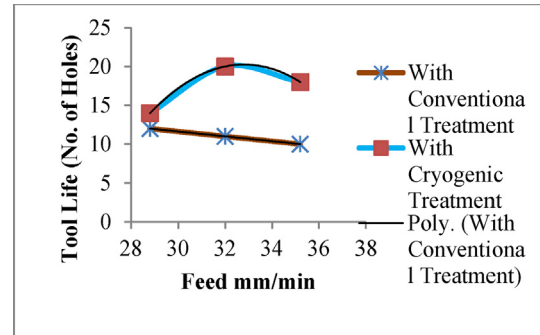


Fig. 3. Effect of feed rate on tool life on conventional treated and cryogenically treated drills.

mance enhancement, the offsetting of the present parameters is done in the steps of +5 % on the higher side of datum parameters.

Observations are recorded for P/M TiN Coated M20 × 2.5 taps as supplied with conventional treatment done at manufacturers end. Here the Speed and Feed are variables with Depth of Cut being maintained constant. In Fig. 4, superimposed graph showing synergistic effect of varying speed and feed on tool life of conventional and cryogenically treated TiN Coated M20.0 X2.5 Tap is shown. Parameters for trial no. 1 are in accordance with the present parameters, referred to as datum. Parameters for trial no. 2 are offset by +5 percent Speed in rpm and Feed per revolution with depth of cut in mm being constant. Parameters for trial no. 3 are offset by +10 percent speed in rpm and Feed per revolution with depth of cut in mm being constant. Parameters for trial no. 4 are offset by +15 percent Speed in rpm and Feed per revolution with depth of cut in mm being constant. Regime II is expanding with increasing speed, which clearly indicates positive performance of cryogenically treated tools at higher speed. This improvement is almost two times the conventionally treated tools.

2.3. SEM imaging

Cryogenic Treatment brings about structural changes in cutting tools made of tool steel.

Fig. 5 and Fig. 6, respectively show SEM micrographs of Conventional Uncoated Dia.9.0 mm H.S.S. M2 drill without cryogenic treatment and with cryogenic treatment respectively. Non uniform distribution of Irregular sized carbides in the matrix is seen in Fig. 5 with conventional Treatment to drills, whereas in the Cryogenically Treated drills distribution shows dense carbides along the grain boundaries with precipitation of tertiary carbides shown in Fig. 6.

There is increase in the percentage of the alloying elements at the point of carbides as well as reduction in percentage of elements

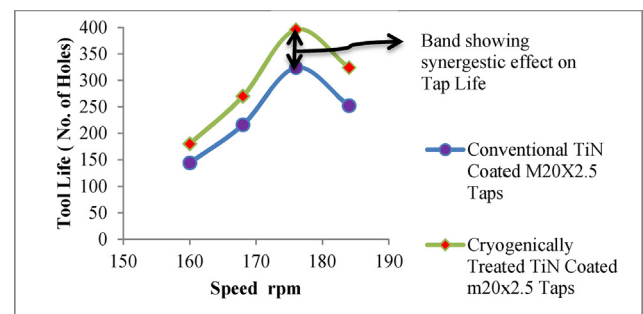


Fig. 4. Superimposed graph of conventional and cryogenically treated tap.

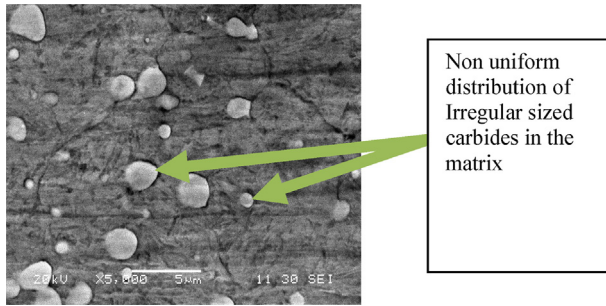


Fig. 5. Microstructure of conventional uncoated HSS M2 drills without cryogenic treatment.

forming carbides in the matrix indicating the precipitation of carbides as a result of Cryogenic Treatment as shown in Fig. 7. This can be attributed to increasing the toughness and marginal increase in the Hardness. The increase in the wear resistance can be attributed to decrease in surface roughness values of the component as the TiN coating is well adhered to the base material even after the taps were subjected to cryogenic treatment.

3. Conclusion

From the field performance analysis of conventional H.S.S. M2 Drill and of TiN Coated H.S.S. M3 Taps manufactured by powder metallurgy route, the following conclusions are drawn:-.

- (1) The field performance analysis of Conventional H.S.S. M2 Drill, it is concluded that by keeping variable speed and constant feed, 100 % life improvement with 10% increase in Speed (V_c) is observed and by keeping variable feed and constant speed, 80 % life improvement with 10% increase in feed is observed.
- (2) For TiN Coated H.S.S. M3 Taps Speed and Feed bears a constant ratio. After Cryogenic Treatment with Speed 176 rpm and Feed 440 mm/min, the Tool life of P/M H.S.S. M3 TiN Coated Taps increased by 175 % or 3.44 times with 10 % increase in Speed and Feed rate as compared to the datum parameters.
- (3) Preferential precipitation of carbides along the grain boundaries as seen under SEM due to Cryogenic treatment. The increased wear resistance can be attributed to increase population of carbides and therefore the increased hardness.

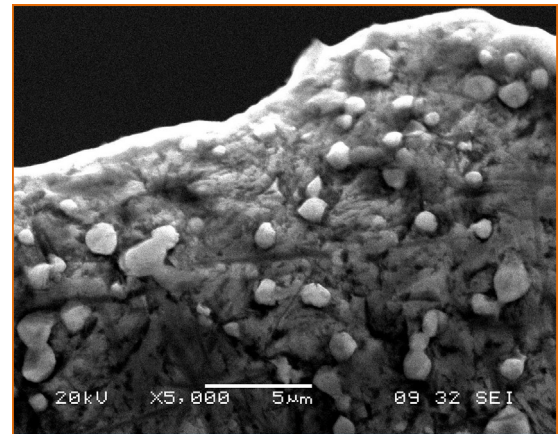


Fig. 7. Microstructure of HSS M3 TiN coated tap with cryogenic treatment.

- (4) In TiN coated taps adherence of coating is found to be strong without any interfacial imperfection between the matrix and the coating. The increased tool life of such coated tools can be attributed to decreased surface roughness values.
- (5) Drill performance can be attributed to refinement in carbides which increases wear resistance during cutting. The worn surface of conventionally treated drill shows dislodged cavities and multiple deformed layers as laminated sheets. The cavities represents place from which wear particle has been dislodged by Suh theory. In contrast to this observation, the cryogenically treated drill indicates smooth transition of profile.

CRediT authorship contribution statement

S.J. Chede: Conceptualization, Methodology, Investigation, Writing – original draft. **M.K. Chopra:** Supervision. **N.B. Dhokey:** Resources, Writing – review & editing, Visualization. **V.S. Aher:** Validation. **P. Ghosh:** Writing – review & editing.

Data availability

The data that has been used is confidential.

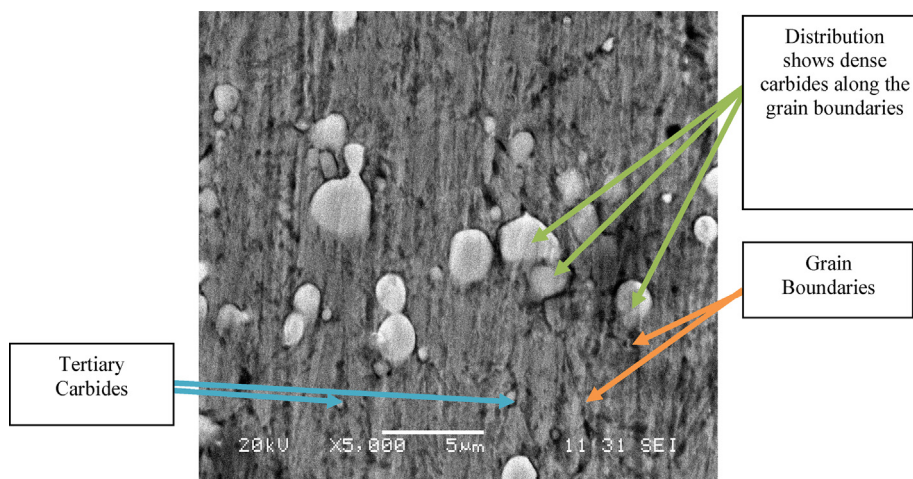


Fig. 6. Microstructure of conventional uncoated HSS M2 drills with cryogenic treatment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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