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TO STUDY THE EFFECT OF CRYOGENIC TREATMENT ON SINGLE POINT CUTTING TOOL MATERIALS FOR FINE TURNING

Rahul Chopra[1], Er. Jasvir Singh Tiwana[2], Dr. Neelkanh Grover[3]
[1]Mechanical Engineering, GZSPTU ,CAMPUSBTI (Pb), India
[2] Mechanical Engineering,GZSPTU ,CAMPUSBTI (Pb), India
[3] Mechanical Engineering,SBSSTC, FZR (Pb), India

Abstract--Cryogenic treatment (CT) is the supplementary process to conventional heat treatment process in steels, by deep–freezing materials at cryogenic temperatures to enhance the mechanical and physical properties of materials being treated. Cryogenic treatment (CT) of materials has shown significant improvement in their properties .Various advantages like increase in hardness, increase in wear resistance, reduced residual stresses, fatigue Resistance, increased dimensional stability, increased thermal conductivity, toughness, by transformation of retained austenite to martensite, the metallurgical aspects of eta-carbide formation, precipitation of ultra fine carbides, and homogeneous crystal structure. Different approaches have been applied for CT to study the effect on different types of steels and other materials. This paper aims at the comprehensive analysis of strategies followed in Cryogenic Treatment process and their effects on properties like TWR, MRR and Roughness on HSS by application of appropriate types of CTs from cryogenic conditioning of the process.

Keywords--Cryogenic Treatment, Carbide formation, Soaking temperature, Wear resistance, Surface roughness, Tool wear and tear.

I. INTRODUCTION

Machining is the most widespread metal shaping process in mechanical manufacturing industry, which is growing very fast in today's era of globalization. To achieve manufacturing competitiveness, the production process should be reviewed and upgraded in addition to optimization of resources. Increasing productivity and reducing manufacturing cost have always been keys to successful businessman[1]. The major three factors which are responsible for economics of manufacturing are material cost, labour cost and tooling cost [2].

In the continual search for the cost effectiveness in manufacturing, there is a continuous need to reduce tooling costs to meet budget requirements.Therefore, a 50% increase in tool life only can reduce total cost per component by 1% [3].Development of new material and manufacturing technologies needs more resistant tool materials with excellent productivity. High Speed Steel (HSS) can also be included in this list since this tool material is fairly well used in the industry to date, although being developed more than a century ago. Its main applications are for drills, taps, milling cutters, broaches and also bits where the economical cutting speed is too low to think about carbide tools [4].
Evolution of Cryogenic Treatment process.

The science and technology of producing a low temperature environment is referred to as cryogenics. The word Cryogenics has its origin in the Greek language where "Cryos" means frost or cold and "gen" means generate. Cryogenic processing has been around for many years but is truly in its infancy when compared to heat-treating [5].

1. Process of Cryo-Heat-Treatment

The complete treatment process of the steels consists of hardening that is Austenitizing and quenching, Cryo-treatment or Deep Cryogenic Treatment (DCT), and Tempering. To achieve better microstructure of the steel to get most desired properties, it is recommended by the most researchers to execute DCT after completion of quenching and before tempering in conventional heat-treatment cycle as shown in Fig-1. The complete process sequentially consists of the steps austenitizing, quenching, cryoprocessing and tempering.

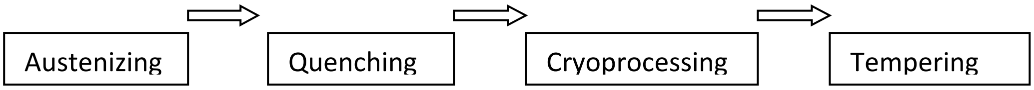

Fig. 1 Heat treatment sequence for maximizing martensitetransformations[6]

[7] Studied Influence of varied cryo treatment on the wear behavior of steel and has been demonstrated that, deep cryogenic processing (C) was incorporated intermediate between hardening (Q) and tempering (T) in cryo treatment (QCT), the details of each step being illustrated in Fig.-2(a). The cryogenic processing was done by uniform cooling of the samples to 77 K, and holding the samples at this temperature for different time durations (0, 12, 36, 60 and 84 h), followed by uniform heating to room temperature. A typical time-temperature profile of Deep Cryogenic Processing is illustrated in Fig.-2 (b)

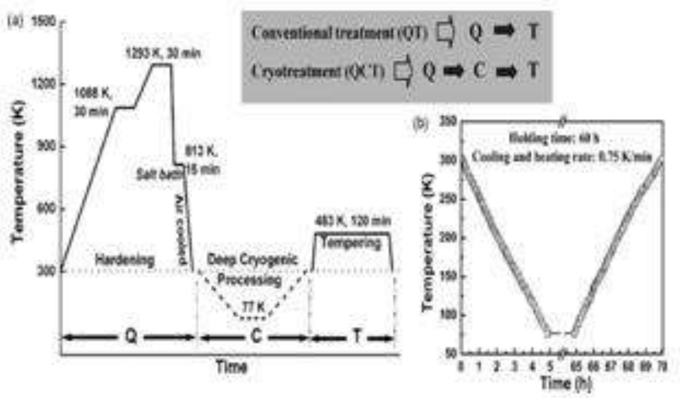

Fig.-2(a) Schematic representation of the heat treatment schedule consisting of hardening (Q), deep cryogenic processing (C) and tempering (T) cycles, and Fig.-2(b)shows typical time-temperature profile of a deep cryogenic processing cycle.[8].

2. Process of Cryo-Treatment

Cryotreatment is add-on process to conventional heat treatment by deep-freezing steels at cryogenic temperatures to enhance mechanical properties of steels being treated. Various advantages like increase in wear resistance, reduced residual stress, increase in hardness, dimensional stability, fatigue resistance, toughness by transformation of retained austenite to martensite and precipitation of ultra fine carbides. Cryotreatment technology is inexpensive an eco-friendly, non-toxic and non-explosive.Deep cryogenic treatment (DCT) commonly refered to as cryotreatment, is an add- on process to conventional heat treatment (CHT) of steel.

Any changes in property are attributed to the micro-structural changes. Thus in tool steels, the following are the possible processes changes that need to be considered for the property change **[9].**

Rate of Cooling

Slow rate of lowering down to the lowest most temperature would be helpful to achieve maximum improvement in wear properties and to avoid any micro-cracking, the value may be to 1K/min. Fast cooling rate reported to creation of non stationary defects in the crystal structure. The change in cooling rate significantly affects the material properties. **[9]** explained that cooling rate does affect wear resistance of the final product and that with increase in cooling rate, wear resistance of the steel decreases. His analysis is also shown in Fig.- 4.

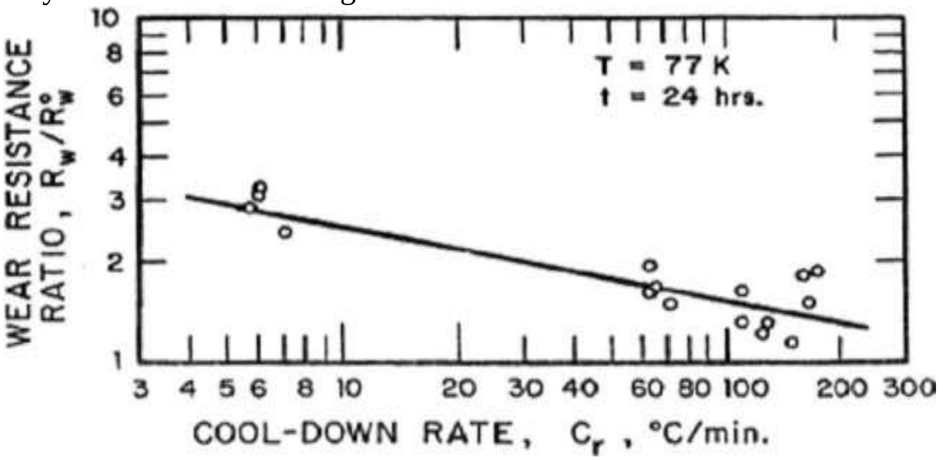

Fig. 3 Variation of the wear resistance ratio of steel with cool down rate during Cryogenic Treatment [9].

Soaking Period

The period for which the samples are held at low temperature is known as soaking period. It may vary from 8h to 40h. The long "soaking period" is necessary to allow transformation of retained austenite to martensite, and to precipitated to fine carbides and the crystal lattice to achieve the lowest energy state possible throughout the material, whereas evidence have also shown that this change begins within the first 8h.

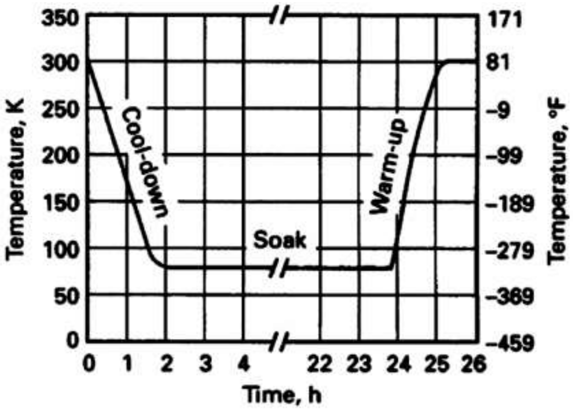

Fig. 4 Plot of temperature versus time for the cryogenic process.Soaking temperature is -196°C [9].

Soaking Temperature

Soaking temperature is the temperature at which the samples are held to be cryogenically treated by using liquid nitrogen. Samples can be soaked to a minimum of −196°C (77K), the boiling temperature of nitrogen. Many researchers believe that depending upon the material, complete transformation takes place at the lowest temperature.

Tempering

Tempering is the process of reheating the steel at predetermined temperatures which is lower than the transformational temperature to obtain different combinations of mechanical properties in steel. Tempering as-quenched martensite precipitates fine carbides, which are named as transition carbides. Nucleation of these carbides relieves micro-stresses in the brittle primary martensite and prevents micro cracking on surface of the steel. Tempering reduces residual stresses, increases ductility, toughness and ensures dimensional stability.

In the continual research the effect of cryogenic cooling on the turning process of C-60 steel bar of 200mm diameter and 750mm length. The three cooling conditions are used that are cryogenic cooling, dry and wet tuning conditions. These three conditions are applied on turning process one by one and there results are compared on the basis of surface roughness, dimensional deviation.

In order to study the effect of cryogenic treatment both of shallow cryogenic treatment (SCT)and deep cryogenic treatment (DCT) on the residual state of 4140 steel. The SCT is carried out at -80°C for 5hr and the DCT is carried out at -196°C for 24hr between quenching and tempering. And the author observed that after cryogenic treatment the residual stress increase both in the SCT and DCT through X-ray diffraction technique**D. Senthikumar, I. Rajendra, et al. (2010)**. But in case of DCT the stress increase largely and more than the SCT. But after tempering the stress released to a great extent.

II. EXPERIMENTATION

Turning is a widely used machining process in which a single point cutting tool removes material from the surface of a rotating cylindrical workpiece. Three cutting parameters i.e. **speed, feed rate and depth of cut** must be determined in a turning operation.High Speed Steel was selected to investigate the effect of cryogenictreatment on tool life which is generally used as single point cuttingtool in the industry. Tools have been subjected to two different computerized controlled cryogenic treatment conditions. In order to avoid thermal shocks from rapid cooling and heating, the specimens were cooled down and heated up slowly, to and from the cryogenic temperature (–110°C and –196°C) at the rate of 0.5°C/min. and the tools were not exposed to liquid nitrogen. The methodology adopted is shown in the figure below:-

Raw Material

Inter Critical Heat Treatment
for about 40min.

Quenching in water

Deep Cryogenic Treatment
at -193°C for about 28 hrs.

Tempering at 150°C for 1 hr

Fig 5 Process Flow Chart of Deep Cryogenic Treatment

Base material

Mild Steel is the most common form of steel. It may also contain lead (free cutting mild steel) or sulphur (again free cutting steel called re-sulphurised mild steel). It is generally available in round rod, square bar, and rectangle bar. It has a good combination of all of the typical traits of steel strength, some ductility, and comparative ease of machining.

Fig 6. Mild Steel (Work piece) after machining on Lathe

Tools

The HSS single point cutting tool have been used for experiment. The HSS (High Speed Steel) is one of the extensively used tool material to perform various operations on the lathe machine. The Miranda tool have been used for experimentation.

Fig 7 High Speed steel and Carbide Single point cutting tools

Miranda Square Tool bits are made from many grades of HSS. Here we have used M35 which contains 5% cobalt. In our experiment we have used bits with width (W) 12mm and Length (L) 100mm. These bits come with small tilt angle which is about 15° on the both end of the tool bit.

Cutting Angles

The cutting angles depends on various factors which are given below. For this we referred the Miranda tool booklets provided by company and we choose the only recommended angles from it for HSS tool bits to machine mild steel of SAE grades. These cutting angles are shown in table below; **Table 1** Different angles of cutting tool.

Tool Signature	
Top Rake Angle	14°
Back Rake Angle	4°

Cutting Edge Angle	60°
Side Clreance Angle	8°
End Clreance Angle	8°
Included Angle	90°
Nose Radius	0.4mm

Input process parameters

- Speed (m/sec)
- Feed
- Depth of Cut (mm)

Table No 2shows list of input process parameters

S.No.	SPEED (mm/sec.)	FEED RATE (mm/rev.)	DEPTH OF CUT (mm)
1	10.5	0.15	1.0
2	21.6	0.25	1.5
3	33.5	0.30	2.0
4	47.8	0.37	2.2

Output parameters

Material removal rate (MRR)

Material removal rate was calculated by calculating the difference between the final weight (after machining) of the sample and initial weight (before machining) of the sample. Each experiment was repeated three times and mean of the material removal was taken.

Tool wear rate (TWR)

Tool wear rate was calculated by calculating the difference between the final weight (after machining) of the tool and initial weight (before machining) of the tool. Each experiment was repeated three times and the mean of the tool wear rate was calculated.

III. RESULTS AND DISCUSSIONS

Tool wear Rate TWR attain using treated and non treated Carbide Tools. It is observed that with the increase in Speed, TWR also increases however, TWR in cryogenic treated tool is less as compared to non-cryogenic treated Carbide Tool.

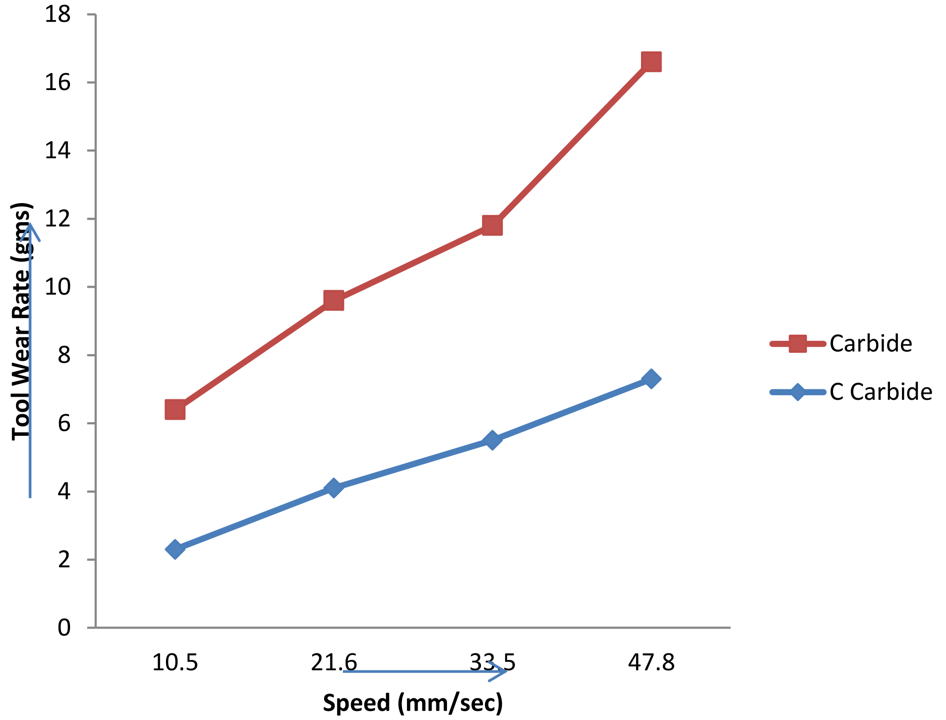

Figure No 8 TWR attain using treated and non treated Carbide Tool

Effect of Speed & Cryogenic treatment on TWR of High speed steel tool

It is observed that with the increase in Speed value, Tool Wear Rate also increases. However, TWR in cryogenic treated tool is less as compared to non-cryogenic treated HSS tool.

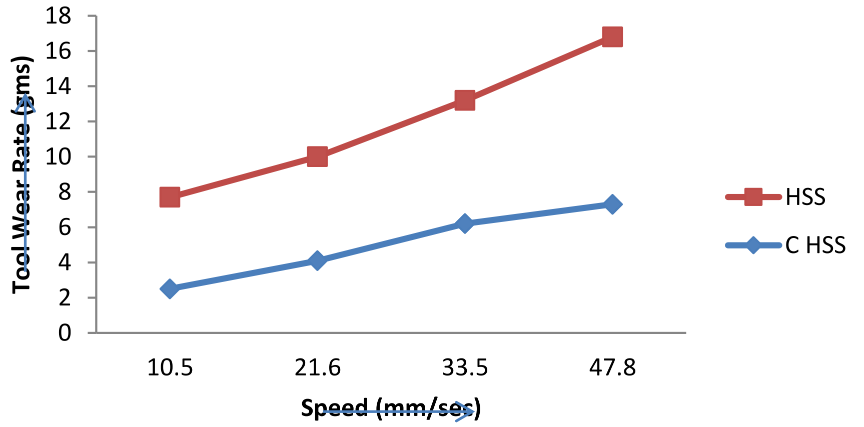

Figure No 9 TWR attain using treated and non treated HSS Tool

MATERIAL REMOVAL RATE

Effect of Cryogenic treated and non treated on MRR by Carbide as Tool

Figure 10 shows MRR achieved from treated and non treated carbide tools. It is observed that with the Cryogenic treatment of tool and increase in speed value, MRR also increases. Increase in speed lead to high heat energy production at the work piece surface that leads to High MRR along with high TWR.

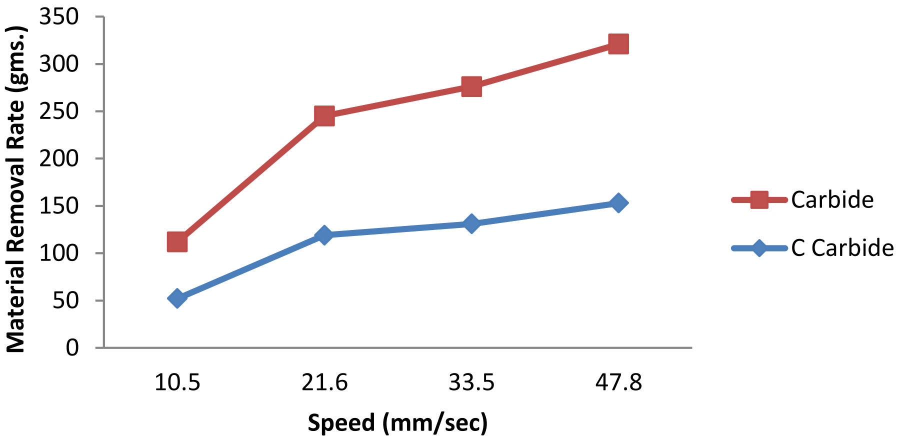

Figure No 10 MRR attained using cryogenic treated and non treated Carbide Tool

Effect of Cryogenic treated and non treated on MRR by HSS as Tool

Figure 11 show MRR achieved from treated and non treated high speed steel tool. It is observed that with the Cryogenic treatment of electrode and increase in speed value, MRR also increases. Increase in speed lead to high heat energy production at the work piece surface that leads to High Material Removal Rate along with high TWR.

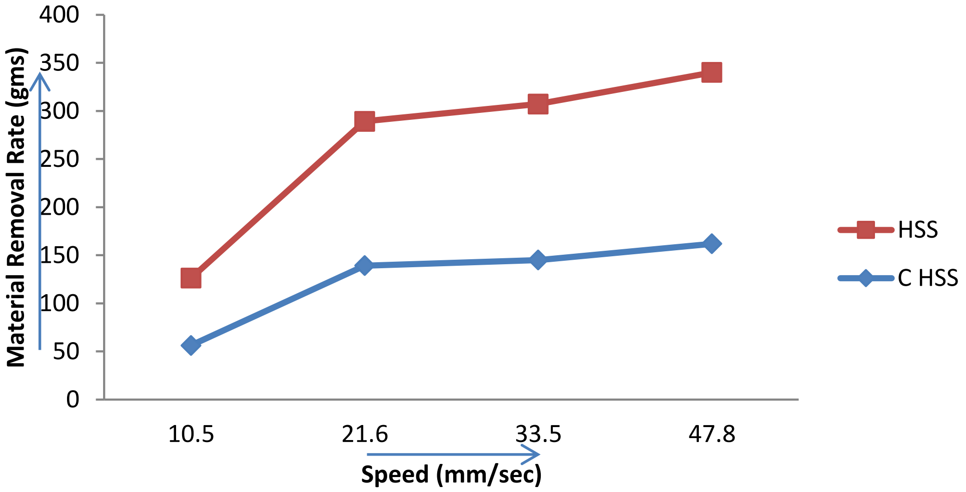

Figure No 11 MRR attained using cryogenic treated and non treated HSS Tool.

SURFACE ROUGHNESS

Effect of Carbide tool on Surface Roughness

Figure 5.3.1 Shows the surface profile produced using Carbide tool. The surface texture is not much varied about the mean value. Cavities are very less

Figure 12 SR Profile using Carbide tool

5.3.2 Effect of High speed tool on Surface Roughness

Figure 5.3.2 Shows the surface profile produced using High speed tool. The surface texture is t much varied about the mean value. Cavities produced are of high dimensions

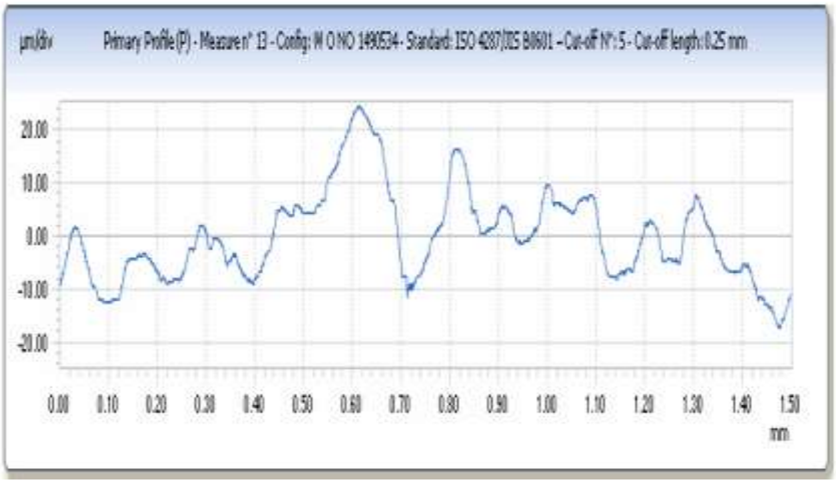

Figure 13SR Profile using HSS tool

IV. CONCULSION

- Tear and Wear Rate of Tools increase with increase in Speed however Cryogenic treatment of cutting tool lead to reduction in TWR.
- Material Removal Rate increases with increase in Speed. The cryogenic treatment of Tools result in higher MRR.
- Surface Roughness increase with increase in Speed however Cryogenic treatment leads to reduction in SR.
- Performance of cryogenically treated cutting tools and metal forming tools were improved to 3 times to that of hardened and tempered tools.
- Strength related properties, such as initial yield strength, ultimate tensile strength, hardening ratio exhibit a tendency to increase as temperature decreases. However, the threshold strains corresponding to the beginning of the hardening tend to decrease as temperature decreases.
- Cryogenic treatment can increase the cutting forces, which can be reducing by use of secondary liquid nitrogen.

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