

# Comparison of influence of shallow and deep cryogenic treatment on HSS tool

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**Abstract**— Recently, cryogenic treatment of cutting tool materials is widely being accepted as a complementary treatment used for enhancing the physical and mechanical properties of the material. Reports have been made regarding improvements in the wear resistance, toughness, fracture resistance, increased hardness, better thermal conductivity, lower chemical degradation and favorable residual stress condition for various grades of tool steels and tungsten carbide inserts. It is a one-time treatment that influences the entire bulk of the component, unlike surface treatments.

The current study deals with comparing the influence of shallow and deep cryogenic treatment on performance of single point HSS cutting tool. In this study, the hardness and tool life of cryogenic treated and non-treated cutting tool is been compared. Also, the microstructural changes is been studied for cryogenic treated tool to understand the most probable metallurgical mechanism behind the enhancement of performance of HSS cutting tool.

**Keywords**— About shallow cryogenic treatment, deep cryogenic treatment, HSS tool, tool life, hardness

## I. INTRODUCTION

Metal cutting process forms the basis of the engineering industry and is involved either directly or indirectly in the manufacture of nearly every product of our modern civilization. facilitated the application of higher speeds at each stage of development. Traditional tool materials such as HSS continue to undergo substantial improvement in their properties through suitable modifications in their composition by optimizing the processing technique as well as incorporating various surface treatments. As a result of these technological advances HSS are still in use having surviving competition from carbides and ceramics.

In the conventional heat treatment of tool steels, the problem of retained austenite after heat treatment has prevailed since the development of the tool steels [1]. This retained austenite effects mechanical properties of tool steel and also results in generation of internal stresses. One of the potential solutions to reduce retained austenite in the matrix of martensite is treating the material at lower temperatures, termed as cryogenic treatment. [2] [3] [4]

Over the past few years there has been an increase in interest in the application of cryogenic temperature to different materials. Some literature says that the cryogenic treatment can improve the life span would depend a lot on the cutting conditions. Hence various research works are being carried out to study the effects of this treatment on the performance of various cutting tools so that it could be added to the regular heat treatment cycle for the components the production sector manufacture.

Cryogenic treatment is a one-time permanent treatment process and it affects the entire cross-section of the material usually done at the end of conventional heat treatment process but before tempering. Also it is not a substitute process but rather a supplement to conventional heat treatment process.

Cryogenic treatment can be classified as shallow cryogenic treatment and deep cryogenic treatment. Difference between shallow and deep cryogenic treatment is majorly in its optimal temperature of treatment and holding time. Optimal treating temperature for shallow cryogenic treatment is around  $-80^{\circ}\text{C}$  and that for deep cryogenic treatment is around  $-190^{\circ}\text{C}$ . Holding time for shallow cryogenic is generally between 5 hours to 8 hours, whereas in deep cryogenic treatment holding time may vary from 16 hours to 48 hours.

The aim of this study is to evaluate and compare the effect of shallow and deep cryogenic treatment on the properties and performance of single point high speed steel.

## II. PROBLEM STATEMENT

Recently the applications of high speed tools and high speed machining have increased due to the need for high precision and high accuracy machining. However, the high speed machining also accompanies problems of tool wear and high reduction in tool life. Hence the requirements of technique to improve the properties of tool were required.

Cryogenic treatment is proven to be the important supplementary process to increase the properties of different materials. Cryogenic treatment on different carbides tool have resulted in the improvement to the wear behavior and hardness, transformation of retained austenite, precipitation of carbides, tensile and fatigue behavior, residual stress, toughness.

The scope of the case study is to evaluate and compare the effectiveness of both shallow and deep cryogenic treatment in improvement of properties and tool life of HSS cutting tool. Also will supplementing cryogenic treatment to conventional heat treatment process will aid the manufacturers to attain better wear resistance of steel components.

## III. MATERIAL USED

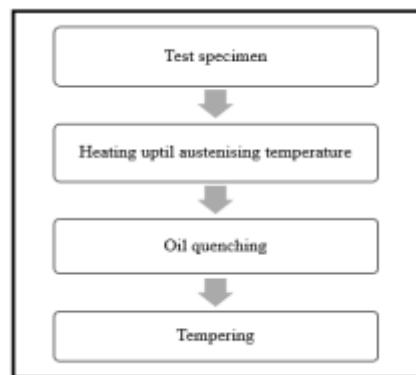
In current case study the T 42 grade of high speed steel is used to evaluate the effect of cryogenic treatment and compare it with the non-treated tool. The chemical composition of HSS tool is as follows:

**Table No. 01**  
**Chemical Composition of T42 Grade HSS Tool.**

<b>C</b>	<b>1.25-1.40</b>	<b>Mo</b>	<b>2.75-3.50</b>
<b>Si</b>	<b>0.0-0.40</b>	<b>V</b>	<b>2.75-3.25</b>
<b>Mn</b>	<b>0.0-0.40</b>	<b>W</b>	<b>8.50-9.50</b>
<b>P</b>	<b>0.35</b>	<b>Co</b>	<b>9.00-10.00</b>
<b>S</b>	<b>0.35</b>	<b>Ni</b>	<b>0.0-0.40</b>
<b>Cr</b>	<b>3.75-4.50</b>		

## IV. CONVENTIONAL HEAT TREATMENT

The conventional heat treatment used to enhance the properties of HSS tool is hardening and tempering. Hardening hardens the steel and tempering increases the toughness. Hardening operation consists of rapidly cooling the specimen from austenising temperature, typically within the range of 815 to 870 °C. Tempering of steel is a process in which previously hardened steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness, but also to increase the grain size of the matrix. Steels are tempered by reheating after hardening to obtain specific values of mechanical properties and also to relieve quenching stresses and to ensure dimensional



**Figure No 01 – Conventional Heat Treatment Process**

## V. CRYOGENIC TREATMENT

Cryogenic treatment is a supplementary process to conventional heat treatment, that involves deep freezing of materials at cryogenic temperatures. The process of cryogenic treatment involves cooling the material until cryogenic temperatures at a constant cooling rate, holding the material at that temperature for specific time, then bringing the material back to the room temperature at constant heating rate as shown in figure 4.2. The important parameters of the cryogenic treatment that affects the final result are as follows:

- a) Soaking temperature
- b) Soaking period or holding time
- c) Ramp up rate
- d) Ramp down rate.

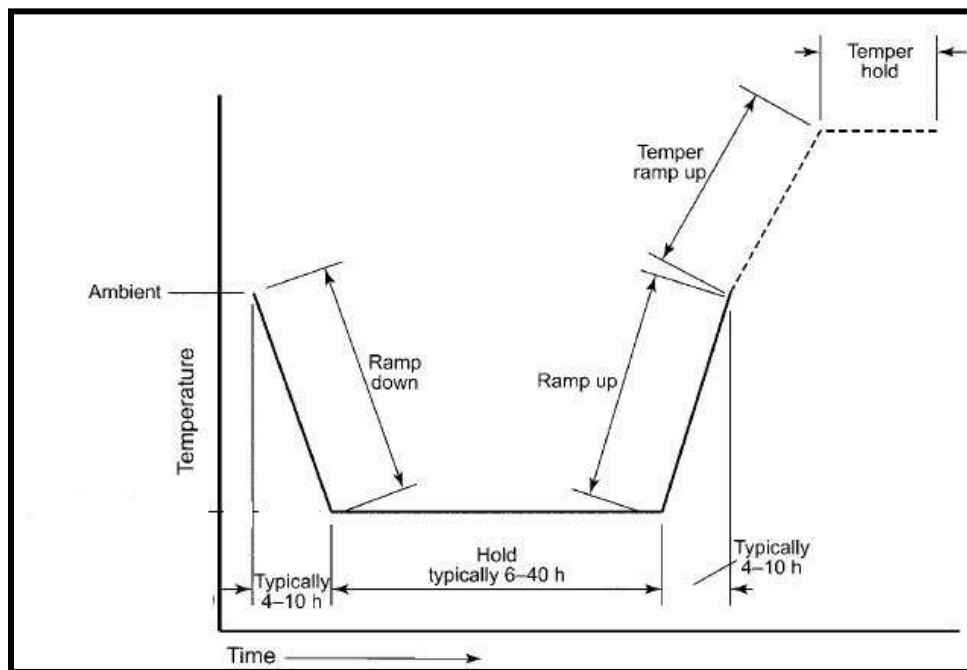


Figure No 02 – General Time Temperature Curve Of Cryogenic Treatment

### 5.1 Shallow Cryogenic Treatment

In case of shallow cryogenic treatment the optimal treating temperature is around  $-80^{\circ}\text{C}$  & holding time varies between 5 hours to 8 hours. Also, there is not any specified ramp up and ramp down rate in shallow cryogenic treatment.

Table No 02  
 Parameters Used For Shallow Cryogenic Treatment

Soaking temperature	$-75^{\circ}\text{C}$
Soaking time	12 hours
Medium of cooling	Dry ice

## 5.2 Deep cryogenic treatment

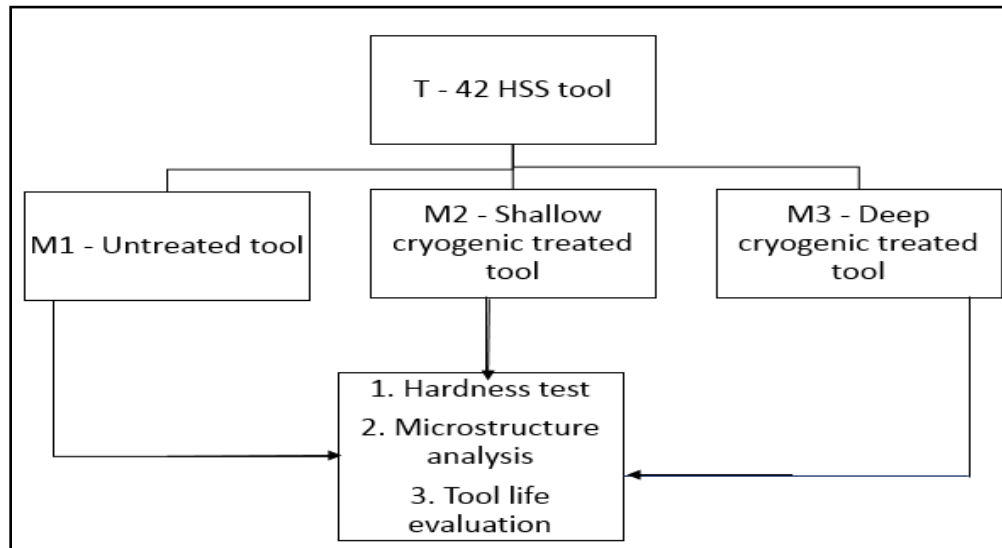
In case of deep cryogenic treatment the optimal treating temperature is around  $-190^{\circ}\text{C}$  & holding time may vary from 16 hours to 48 hours.

**Table no 03**  
**Parameters used for deep cryogenic treatment**

<b>Soaking temperature</b>	-193°C
<b>Soaking time</b>	24 hours
<b>Ramp up rate</b>	0.5°C/min
<b>Ramp down rate</b>	0.5°C/min
<b>Medium of cooling</b>	Liquid Nitrogen

## 5.3 Process Flow:

Process flow followed for carrying out the study is as follows:



**Figure no 03 – Process flow of study**

## VI. TEST RESULTS

### 6.1 Hardness

In the present work, rockwell hardness of the M1, M2 and M3 tool were tested. The hardness of cryogenic treated material has significant improvement. Following are the test results:

**Table no 04**  
**Hardness test results**

Specimen	Hardness (HRc)
M1 – Untreated	62
M2 – Shallow cryogenic treatment	68
M3 – Deep cryogenic treatment	68

## 6.2 Tool life analysis

As the cutting speed affects tool life the most, in current study, tool life at two different cutting speeds is been evaluated for M1, M2 and M3 tool. The parameters of machining and results of the experiment are as follows:

### Experiment No – 01

Operation performed -	Turning
Cutting tool -	Single point cutting tool
Cutting speed -	226 rpm
Feed rate -	0.3 mm/rev
Depth of cut -	1 mm

**Table no 05**  
**Tool analysis results for experiment no 01**

Tool	Treatment	Tool life (minutes)
M1	Non treated	16.38
M2	Shallow cryogenic treated	23.1
M3	Deep cryogenic treated	25.46

### Experiment No – 02

Operation performed -	Turning
Cutting tool -	Single point cutting tool
Cutting speed -	516 rpm
Feed rate -	0.3 mm/rev
Depth of cut -	1 mm

**Table no 06**  
**Tool analysis results for experiment no 02**

Tool	Treatment	Tool life (minutes)
M1	Non treated	14.26
M2	Shallow cryogenic treated	20.24
M3	Deep cryogenic treated	22.05

From above results it can be observed that tool life increases significantly in case of both shallow cryogenic and deep cryogenic treated tool as compared with untreated tool.

When compared to untreated tool, the tool life improves around 41% in case of shallow cryogenic treated tool and around 55% in case of deep cryogenic treated tool.

## VII. CONCLUSION

In the case study, shallow and deep cryogenic treatments were performed on T 42 grade, HSS cutting tool. Treated and untreated tool were tested for hardness and tool life. Also metallographic examination of the treated tool was done.

1. Following important conclusions can be drawn from the results of the case study:
2. Both shallow and deep cryogenic treatment has significant effect on hardness of tool. Improvement in hardness value is been observed after cryogenic treatment.
3. As compared with untreated tool, around 41% of tool life increases after shallow cryogenic treatment and 55% tool life increases after deep cryogenic treatment.
4. Shallow cryogenic treatment and deep cryogenic treatment both have significant effect on tool life of HSS.

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