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Effect of Cryogenic Treated and Untreated Tool on its Tool Life-Review

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Abstract: ***In This review paper, presents the information mainly on cryogenic treatment technology on cutting tools, Cryo-treatment is a supplementary process to conventional heat treatment, involves deep freezing of materials at cryogenic temperatures to enhance the Physical and Mechanical properties. The execution of cryoprocessing on cutting tool materials increases wear resistance, hardness, and reduces tool consumption and down time for the machine tool set up, thus leading to cost reductions. The objective of this review paper is comparison between cryogenic treated tool (HSS) and untreated tool (HSS) and also shows new development in predicting tool life and tool wear.***

Keywords: Cryogenic treatment, HSS Tool, Tool life, Tool wear, Liquid nitrogen.

1. Introduction

The commonly used cutting tool material in conventional machine tools is high speed steel. As the technology has been more rapidly advancing, cutting tool materials such as cemented carbides and ceramics are needed to machine many difficult to machine materials at higher cutting speeds, and metal removal rates (MRR) with performance reliability [2].

In recent years, increased interest in the effects of low temperature on tool and die materials, particularly HSS tools has been Tested. Over the past few years, there has been an increase in the application of cryogenic treatment to different types of materials. Research has shown that cryogenically treated tool increases Tool life, and in most cases provides additional qualities to the Tool, such as stress relieving, hardness, toughness, etc. In the research area of cutting tool, which includes High speed steel (HSS) [2].

Mohan Lal et al. [3] studied the improvement in wear resistance, and the significance of treatment parameters, in different tool and die materials. It has been found that cryogenic treatment imparts nearly 110% improvement in cutting tool life. Cohen et al. [6] proved that the power consumption of cryogenically treated (HSS) tools is less, when compared to the untreated (HSS) tools. Cryogenic treatment of tool steels is a proven the technology to increase the wear resistance, and extend intervals between component replacements for blades, machining mills, etc., and hence improves surface quality of the different machined parts. Correct mechanical configuration, Combining optimized lubrication, and cryogenic treatment of wearing parts results in the maximum performance of lubricated components, and can significantly extend the component life.

1.1 Cryo Treatment

Cryo-treatment is a supplementary process to conventional heat treatment, that involves deep freezing of materials at cryogenic temperatures (-190 °C) to enhance the mechanical and physical properties. The execution of CT on cutting tool materials increases wear resistance, hardness, dimensional stability, but at the same time, reduces tool consumption and down time for the machine tool set up, thus leading to cost reductions. The dry cryogenic process is precision controlled and the materials to be treated are not directly exposed to any cryogenic liquids. Overall, all the treated materials retain their size and shape. Cryogenically treated materials with some occasional heat treatment generally improve hardness, toughness, stability, corrosion resistance and reduced friction, cryogenic treatment has been successfully applied to die and HSS ferrous [4].

1.2 Treatment Profiles

A fundamental distinction among different CT processes is given, by the parameters of the cooling warming cycle, and especially on the minimum temperature reached during the cycle. These are categorized as [1]

1. Shallow Cryogenic Treatment or Subzero Treatment: the samples are placed in a freezer at -80 °C and then they are exposed to room temperature.
2. Deep Cryogenic Treatment: the samples are slowly cooled to -196 °C, held-down for many hours and gradually warmed to room temperature.

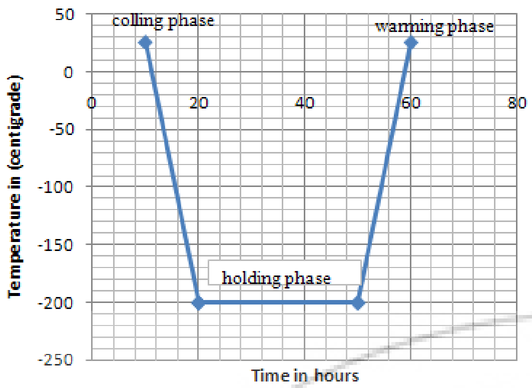

Figure 1: Cryogenic Treatment temperature profile

Cryo-treatment are listed below:

a) In some cases, the actual T_{min} could be higher than the nominal one because of thermal insulation limits.
b) Each new material needs to be treated and tested at different temperature levels (i.e. -190 °C, -130 °C and -80 °C), in order to identify optimum treatment conditions and investigation of micro-structural changes.
c) In most cases, Hold time of 24 hours is enough to obtain results and the same over 36 hours does not bring significant improvements.
d) Cooling rate is one of the most critical parameter, which must not exceed 20-30 °C/h in order to prevent the rupture of the components because of the cooling stresses. Shown in Fig.1.
e) Warming rate is not closely controllable and little importance to this parameter despite of some suggested literature about carbides precipitation during the warming phase [4].

2. Cryogenic System

A cryogenic system is an equipment which allows controlling of temperature (i.e. cooling and heating rate), especially cooling in the cryogenic range in a chamber, using cryogenic fluid like liquid helium or nitrogen. During Sixties Cryogenic treatment was done by direct immersion into liquid nitrogen, which produced catastrophic result of cracking the components. But later, the cryogenic treatment system developed by Ed Busch (Cryo-Tech, Detroit, MI) in the late 1960‘s and later improved by Peter Paulin with a temperature feedback control on cooling and heating rate which, prevented sudden temperature changes and lead to the development of efficient CT process.

Types of cryogenic cooling systems commonly used are:
a. Gradual Immersion: The samples are immersed into the liquid nitrogen for a specific time, and then they are extracted and gradually led back to the room temperature by means of a flow of temperature controlled air.
b. Direct Nebulization: The liquid nitrogen is nebulized directly in to the chamber and a fan, allows to obtain homogeneous temperature distribution and the liquid nitrogen is dispersed around the samples.
c. Heat Exchanger: The liquid nitrogen flows through a heat exchanger and the output cooled gas is diffused inside the chamber by a fan. There is no contact between nitrogen and samples [6][1].

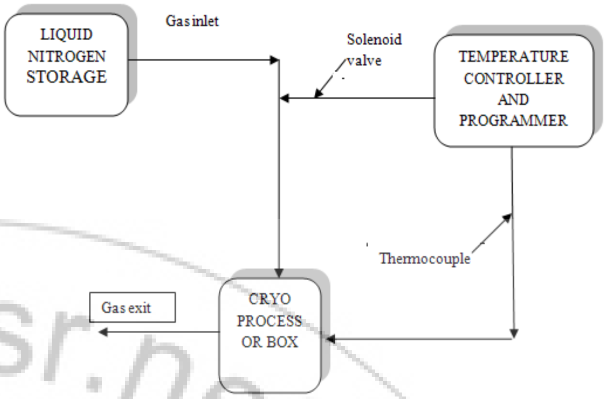

Figure: 2 cryogenic treatment procedures

Out of above three processes, concept of third procedure of cooling system is generally used widely. Liquid nitrogen is allowed to flow from storage tank through inlet pipe and allowed to enter into cryogenic chamber (also called as Cryoprocessor-box). Temperature is controlled through computer programming software Delta TTM and desired cooling rate can be set. The cooling effect is provided by LIN to the sample but no direct contact is allowed, between them. A fan is used for uniform distribution of temperature inside the chamber. After reaching the temperature set by programmer thermocouple sends a signal to system controller, through feedback mechanism, and hence, temperature controller regulates the flow of LIN in the chamber and stop further cooling. The LIN gets converted and leaves the system as nitrogen gas.[6].

3. Effects of Cryogenic on Properties of Tool Materials

Aleksander CISKI. [12] has conducted experiment on Deep cryogenic treatment of high speed steel. 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. It has been observed that the 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.

Lakhwinder Pal Singh *et al.* [30] has conducted experiment on effects of cryogenic treatment, on the cutting tool durability. High-speed steel (HSS) tools are the most commonly used tools in medium and small scale industry.

Cryogenic treatment can be used to increase the tool life. Studies on cryogenically treated cryogenically treated cutting tools show micro structural changes in the material, which can influence the life of the tools significantly. This research paper primarily reports performance of cryogenically treated HSS tools as compared to untreated HSS tools. The results show that Cryogenic treated HSS tools exhibit better performance based on tool wear. The microstructure it has been that found more refined and uniformly distributed after cryogenic treatment of High speed Tool (HSS) tool. Taguchi L_{25} orthogonal array was considered for conducting the experimentation, and ANOVA used for statistical data analysis. Their Three parameters such as cutting speed, feed rate, and depth of cut at different levels were considered in this research study. ANOVA results shows that the cutting speed is the most significant parameter followed by feed rate in both the cases.

N. R. Dhar *et al* [8] et al has conducted experiment on cutting temperature, surface roughness, tool wear, and dimensional deviation in cryogenic machining The present work shows the experimental investigation in the role of cryogenic cooling by liquid nitrogen jet on tool wear, cutting temperature, dimensional deviation and surface finish in turning of AISI 1060 steel at industrial speed-feed combination by coated carbide insert. The results of the present work indicate substantial benefit of cryogenic cooling on tool life, surface finish and dimensional deviation. This may be attributed to mainly reduction in cutting zone temperature and favorable change in the chip tool contact. Further it was evident that machining with soluble oil cooling failed to provide any significant improvement in tool life rather surface finish deteriorated.

M.Dhananchezian *et al.* [24] et al have conducted experiment on Taguchi's Technique in Machining of Metal Matrix Composites This paper presents the study on Taguchi's optimization technology, which is applied to optimize cutting parameters in turning of age hardened Al6061-15% vol. SiC 25μm particle size metal matrix composites with Cubic Boron Nitride inserts (CBN) KB-90 grade using steam as cutting fluid. Analysis of variance (ANOVA) is used to study the effect of process parameters on the machining process. This procedure reduces the need for repeated experiment time and conserves, the material by the conventional or old procedure. The turning parameters evaluated are feed, speed, depth of cut, nozzle diameter. A series of experiments are conducted using PSG A141 lathe (2.2kw) to relate the cutting parameters on surface roughness, cutting force, tool wear, thrust force, and feed force. The measured results were collected and analyzed with the help of the commercial software package MINITAB16.1. As well, an orthogonal array, signal-to-noise ratio is employed to analyze the influence of these.

Mr. Sandip B.Chaudhari *et al.* [16] founds improvement in wear resistance, and hardness by cryoprocessing is attributed to the combined effect of conversion of the retained austenite to martensite and precipitation of η-carbides in case of tool steel. The phenomenon responsible for improvement in wear resistance in carbide cutting tools, is the combined effect of increased number of η phase particles and increase in bounding strength of binders used. Cryogenic treatments substantially decrease the wear rate of the AISI M2 HSS compared to the conventional treated ones. However, the improvement in wear rate by deep cryogenic treatment is significantly higher than that achieved by shallow cryogenic treatment.

Muammer Nalbant *et al.* [20] in his experiment founds cutting condition affects the maximum cutting forces and torque. The maximum cutting force and torque in cryogenic machining are observed to be more than those in dry cutting of about 3.3% to 6.5% and 7.9%. Also Cutting speeds affect the maximum cutting forces and the maximum cutting torque. Cutting forces increase with increasing cutting speed. However, the maximum cutting torque decreases with increasing cutting speed.

Simranpreet Singh Gill [22] in his work shows the effects of cryogenic treatment on M2 HSS turning tools summarizes that the shallow cryogenic and deep cryogenic treatment can significantly enhance the service life of M2 HSS turning tools, however the tools subjected to deep cryogenic treatment stand to gain relatively more as compared with shallow cryogenically treated tools. The recorded maximum tool life enhancement over traditionally heat treated tools in the present study is approximately 35% for shallow cryogenically treated tools and 50% for deep cryogenically treated tools. Also deep cryogenically treated turning tools of M2 HSS perform more consistently as compared to shallow cryogenically treated as well as traditionally heat treated tools.

S.Sendooran *et al.* [23] shows deep cryogenic treatment is a secondary hardening. This deep cryogenic treatment is depends only on temperature not on soaking time. In this process retained austenite structure was completely converted into martensite structure and hardness is improving about 17%.

4. Improvement in Tool life Properties

There is an increase of tool life by 19.2% for cryogenically treated HSS, and in comparison to the untreated tools. Hence it is evident that there is increase in tool life Fig.3 and Fig.4 both fore cryogenically treated HSS tool. The superior performance of cryogenically treated HSS can be attributed to the transformation of almost all retained austenite into martensite, [28] and [1]. The results for cryogenically treated HSS to be in accordance with the results obtained by Lakhwinder Pal Singh, [30]. Gopal Krishna, P. V. [19] et al has conducted experiment on. Tool wear is a worn portion over the flank and face of the tool. Tool wear is significant for determining tool life, and hence it influences the machining economics. The wear measurements are carried by using a tool makers microscope in the present investigations. Investigations are carried on different work materials such as, EN8 and EN24. Improvement in tool life up to 90% is observed for soft material AISI 1040 and enhancement up to 39% is observed on EN24. These investigations are aimed at benefiting small industries that use aforementioned tool work combination. Regression models are constructed for the tool wear for both untreated machining and cryogenic treated machining.

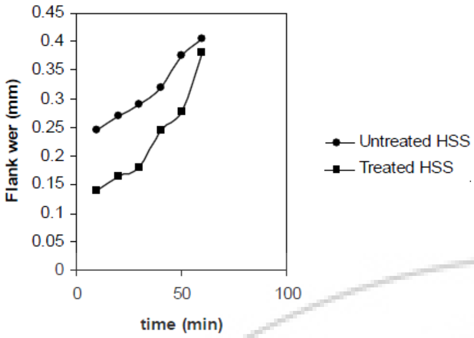

Figure 3: Flank wear development in HSS tools

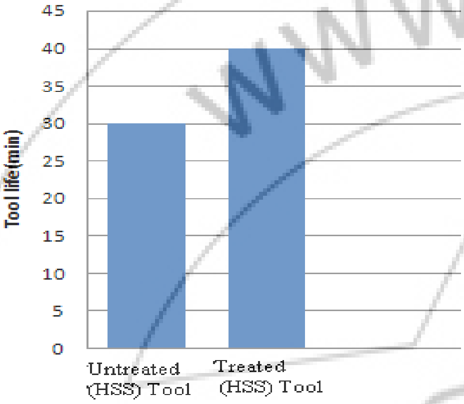

Figure 4: Tool life comparisons between treated and untreated samples

The tool life increement has shown by Lakhwinder Pal Singh et al. [30] has conducted experiment on effects of cryogenic treatment, on the cutting tool durability. High-speed steel tools are the most commonly used tools in small and medium scale industry. Cryogenic treatment can be used to increase the tool life. Studies on cryogenically treated cryogenically treated cutting tools show micro structural changes in the material, which can influence the life of the tools significantly. This Review paper primarily reports performance of cryogenically treated HSS tools as compared to untreated HSS tools. The results show in Figure.4 that CT HSS tools exhibit better performance based on tool wear. The microstructure change has been found, more refined Figure.5 and Figure.6 and uniformly distributed after cryogenic treatment of HSS tool. Taguchi L_{25} orthogonal array was considered for conducting the experimentation and ANOVA used for statistical data analysis. Three parameters such as feed rate, cutting speed, and depth of cut at different levels were considered. In this research study. ANOVA results shows that the cutting speed is the most significant parameter followed by feed rate in both the cases Figure.4 shows increase in tool life.

6. Improvement in Microstructure

Fig.6. shows the microstructures HSS samples. Not much could be inferred from this as no significant changes in. Microstructure after the cryogenic treatment observed literature [30] data indicates transformation of retained austenite into martensite as well a carbide refinement [3][29]. But it was very difficult to detect such changes with the help of an optical microscope XRD analysis was carried out for both cryogenically treated and untreated HSS tools using X-ray generator Figure.5 shows results from XRD investigations on untreated and cryogenically treated HSS samples.

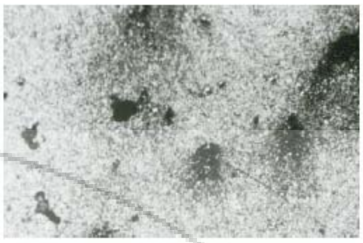

Figure 5: x200Magnification untreated (HSS) Tool

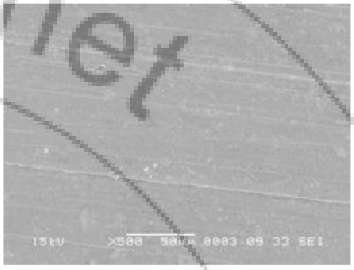

Figure 6: SEM for cryogenically treated HSS samples

SEM was carried for both cryogenically treated and untreated HSS samples to study the changes in the micro structural. Results of the SEM analysis are shown in Figure.6. For cryogenically treated and untreated HSS samples respectively.

5. Conclusions

The following conclusions may be drawn.

1. The increase in wear resistance has been attributed to the transformation of soft retained austenite into the harder martensite phase and the formation of fine carbide particles, in the metal structure. These changes are the major reasons for the dramatic improvement in wear resistance.
2. Dimensional accuracy and surface finish also substantially improved mainly due to significant reduction of wear and damage at the tool tip by the application of liquid nitrogen.
3. Cryogenic treatment can reduce the austenite content but cannot make retained austenite transform to martensite completely.
4. The cryogenic treatment process must be performed according to predefined temperature protocols, to ensure the maximum effectiveness; the cryogenic process should be carried out in a dedicated programmable cryogenic system.
5. Cryogenic treatment can increase the cutting forces which can be reducing by use of secondary liquid nitrogen.
6. The tool life is increased by 19% for M2 grade HSS single point cutting tools
7. From SEM analysis, it is evident that refinement of carbides is more in case of cryogenically treated HSS tools in comparison to that of untreated tools.

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