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Experimental Analysis using Established Parameters for Cryogenic Treatment on High Speed Steel Tool

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***Abstract*— *The experimental analysis on cutting tool material is done with referring the established parameters for Cryogenic Treatment. The pilot experimentation is carried out using the Conventional heat treated tool bits as supplied condition and Cryogenic treated tools. The three grades of high speed steel are identified for the investigation purpose and for pilot experimentation H.S.S. T42 grade is selected. The tool material procured is strictly as per the grade specifications for the investigation of effect of cryogenic treatment on tool life. The established parameters for cryogenic treatment are identified referring to previous published research and machining parameters as per the industry specifications. The pilot experimentation using Untreated and treated tools are subjected to turning operation on CNC turning center for a definite work material and machining parameters such as cutting speed, feed and depth of cut are identified. Single point cutting Tool geometry is maintained as per the tool signature and length of the tool is maintained as per the limitations of the machine. The Surface Roughness of the machined work piece is measured using the Taylor Hob-son Surface Roughness tester and the Tool wear is measured using the Tool Makers microscope. The results are tabulated. An experimental effort to understand the effect of Untreated and Cryogenic treated tool on the tool life is the outcome of this paper. The outcome of this paper forms the basis of experimentation using the Orthogonal array for all the selected grades of the material.*

Keywords*— *Cryogenic treatment, Cryogenic Parameters, Tool life

I. INTRODUCTION

Manufacturing industry is growing and becoming competitive day by day. Gone are the days of monopoly in manufacturing of products. The production processes, various machine tools, cutting tools, various coatings, lubricants, tool materials and various outsourced processes are advancing and thus increasing the competition and consciousness amongst the users. The demand and competition in the manufacturing industry in the latter half of the nineteenth century have led to the development of improved machine tools, cutting tools and production processes. Tool Life is one of the most important considerations in metal cutting, while selecting parameters for economical metal removal rate. Tool materials have improved rapidly during the last decades and, in many instances, the development of new tool materials has necessitated a change in the design trend of machine tools to make full use of the potentialities of tool materials of high productivity.

Every year the competition is increasing as the whole globe is coming close as one market place overcoming all the barrier led by various countries. The technology transfer and the products manufactured are all gaining momentum with a view or fear of getting obsolete.

The cutting tool technology however finds some mixed response from the industry. The development of cutting materials from Carbon tool steels, High Speed Steels, and cast alloys to Carbides and Ceramics has facilitated the application of higher cutting speeds at each stage of development, because of improvements achieved in the properties of tool material. Further referring to the increased hardness levels, use of Carbides manufactured by Powder Metallurgical technique and further Ceramics increased showing radical changes in the design of tailor made tool holders and cutters, here the brazed carbide tip tools gained a lot of importance and edge over the High Speed Steels. Using the Powder Metallurgical Route the tungsten carbide cemented tips were coated. Coating the carbide tips again added to the savings and improvement in tool life thus leading the concept of throwaway tipped tools, where the insert is held mechanically and is discarded after use. This represents a major advance in the metal removing technology of modern times. The

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additional or supplementary processes such as hardening and tempering also leads to improvement in tool life. Improvement in mechanical and physical properties increases the tool life and cost effectiveness of tool materials. One such promising but not yet explored to the fullest is the cryogenic treatment given to tool materials. Cryogenic processing is quickly earning respect as a technique for increasing the durability and dimensional stability of manufactured parts. Using cryogenic treatment the wear resistance of tool steel can be significantly improved by slowly cooling the tool steel to cryogenic temperatures[1]. Although the benefits of cryogenic treatment can be supported by numerous unscientific examples, they need to be tested using the parameters used on day to day to basis in the manufacturing industries.

Even when diamond or poly crystalline diamond is used as tool material, still HSS tools are not obsolete as on date. Technologies like the cryogenic treatment shows promising results with the alloy tool steels. The encouraging fact about cryogenic treatment is that whether one uses HSS, or any other type, all show very significant gains after cryogenic treatment. Although there are many theories as to why cryogenic treatment is effective, actual measurements of results have remained relatively difficult to obtain. An interesting aspect of the process is that the treated tool or apart shows no visible changes in color, size, or any other property that can readily be visually detected. As a result the advantage of what began as Space Age technology many years ago is still largely unknown to many companies. The exact mechanism in the enhancement in tool life and the scientific reason needs to be investigated as it shows significant variations due to the dependence on various cryogenic parameters. On the Web are commercial sites which proclaim to have all the know–how of cryo processing but frankly admit that they do not have any research support. However there is some literature available, which clearly indicates that there is substantial change or improvement in the war resistance of the Die steel[2]the introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. HEAT TREATMENT TO TOOL MATERIAL[3 4 5]

Any cutting tool material should be and is subjected to hardening and tempering. All the manufacturers and end users are aware of the outcome of hardening and followed by tempering. The progress in this direction led to use of hardening followed by multi tempering cycles. It includes double tempering or triple tempering also. These developments are in practice. With the advent of cryogenic processing in which the materials are subjected to the sub-zero temperatures, the treatment can impart increase in tool life, by converting retained austenite in to martensite and further subjecting the tool to high temperature tempering for the precipitation of the alloy carbides. This increase in tool life is judged on the basis of increase in hardness. Conventionally HSS are thermally processed by carefully heating to austenitization temperature followed by quenching in a suitable medium followed by tempering or multi-tempering to obtain highest possible hardness. Hence the micro-structure of HSS after thermal processing consists of martensite, tempered martensite, alloy carbides and un-transformed austenite. The amount of untransformed austenite decreases with more number of tempering cycles.

The martensite transformation is temperature and carbon dependent. The Ms and M_f temperatures vary with carbon content of the steel. The HSS tools are invariably of high carbon variety and the martensite transformation never goes to involve cooling (quenching) up to room temperature. Hence transformation can be further enhanced by cooling below room temperatures (Between 55^0C to 120^0C for different grades)[3]. It was a general notion that, obtaining maximum hardness is the sole criterion for getting greater tool life and hence the subzero treatment will be helpful in keeping austenite as maximum possible and maximum hardness will be obtained. However it is well known that change in the hardness after sub-zero treatment is hardly by a margin of 1.5 to 2 Rc. Also it has been proved that there is no appreciable change in the hardness even after cooling below sub-zero temperatures[5]. There are now evidences in the literature and practice that there is substantial increase in the wear resistance of the tools by treating to extreme cold temperatures and hence increased tool life.

III. METALLURGICAL ASPECTS RELATED TO CRYOGENIC TREATMENT [2,5,6]

The study and use of materials at very low temperatures is referred to as cryogenics. The word, "Cryogenics" comes from two Greek words – "kryos" which means cold or freezing and "genes" meaning born or generated. The upper limit of cryogenic temperatures has not been agreed on, but the National Institutes of Standards and Technology has suggested that the term Cryogenics be applied to all temperatures below – 150^0 C (-238 ^{0}F or 123 above absolute zero on the Kelvin scale).

Deep sub-zero treatment of metals and alloys is a deep stress relieving technology. Whenever material machining, forming, stamping, grinding, wire cutting, EDM, etc. it is subjected to stresses. The stress manifests itself in the nature of defects in the crystal structure of materials. The most commonly observed defects are in the form of vacancies, dislocations stacking faults etc. As the level of stress increases, the density of these defects increases, leading to increase in the inter atomic spacing. When the distance between the atoms exceeds a certain critical distance, cracks develop and failure takes place.

The third law of thermodynamics states that entropy is zero at absolute zero temperature. Deep subzero treatment uses this principle to relieve stresses in the material. The materials are subjected to extremely low temperatures for a prolonged period of time leading to development of equilibrium conditions. This leads to ironing out of the defects in the material and also attainment of the minimum entropy state. Grain shape and size gets refined and is made uniform. Defect elimination takes place and inter atomic distances are reduced. When the material is brought back to room temperature, the defect level reflects on equilibrium concentration. Compaction of the crystal structure leads to much superior abrasive, adhesive and erosive wear resistance and enhances corrosion resistance as well as fatigue strength and resilience.

First, super cold treatment apparently converts any retained austenite into Martensite, and the Martensite is tempered as the steel returns to the room temperature. The martensitic structure resists plastic deformation much better than the austenitic structure, because the small carbon atoms in the martensitic lattice 'lock together' the iron atoms more effectively than in the more open centered cubic austenite lattice. Tempering the Martensite makes it tougher and better able to resist impact than untempered Martensite. Martensite is harder and more wear resistant structure.

Secondly, the cryogenic treatment of high alloy steel, such as tool steels, results in the formation of very small carbide particles dispersed in the martensitic structure. Between the larger carbide particles present in the steel. The small, hard carbide particles within the Martnesiste matrix help support the matrix and resist the penetration by foreign particles in abrasive wear. Also these carbides strengthen the material without any appreciable change in the hardness.

IV. RESEARCH REVIEW [1,7, 8]

Studies on cryogenically treated high speed steel tools show microstructural changes in the material that can influence tool lives and productivity significantly. Results in the literature show tool life improvements from 92% to 817% when using the cryogenically treated HSS tools in the industry. However, the real mechanisms which guarantee better tool performance are still dubious. The ambiguity in results suggests the need of further investigation in order to control the technique more scientifically. The authors work verified the effect of cryogenic treatment on M2 high speed steel tools after using in the tools either in laboratories or shop floor tests in an automotive industry. Sliding abrasion and hardness tests were also carried out as well as micro-structural analysis was carried out. Advantages were found for the treated tools in some of these tests.[8]

The use of cryogenic treatment (CT) to improve mechanical properties of materials has been developed from the end of the Sixties. As on date the initial mistrust about CT has been cleared up and many papers about different materials reporting laboratory tests results, micro-structural investigations and hypothesis on CT strengthening mechanisms have been published. The removal of retained austenite combined with fine dispersed eta-carbides precipitation have been widely observed and their effects on mechanical properties have been measured. Also their research review suggest some studies have pointed out a different mechanism for fatigue strengthening of stainless steels, which involves nano-martensite formation during the CT. In this reference paper the authors summarizes the state of art about CT, focusing on methods, parameters, results and assumed micro-structural mechanisms, in order to get a starting point for new researches to come.[1]

Cryogenic treatment is employed for high speed tool steels in order to enhance their wear resistance. The improvement in wear resistance is associated with a decrease in retained austenite and or by formation of eta carbide/nano-scale carbides. In this review as per the work presented by the authors, a complex alloyed high speed tool steel (M35) specimens were hardened at 1,200ºC, triple tempered at 400 º C, cryosoaked at -185º C for 4–48 h and soft tempered (100 º C). The micro-structure of the samples were characterized for hardness, carbide density, impact energy, wear loss and residual stress. Influence of these measured parameters on wear behavior was studied to understand underlying wear mechanism. The cryotreated specimens exhibited mild to stable wear transition at 16 h and then subsequent wear stabilization for all higher cryosoaking intervals.[7]

There are more references which provide the experimental results conforming to the factors and levels selected for the pilot experimentation.

V. PILOT EXPERIMENTATION

The pilot experiments was carried out on T42 tool steel grade. 3 conventionally heat treated tool bits manufactured and supplied by Birla Precision Technologies Ltd., Indian Tool Manufacturers Division having the size ½" x ½ " x 4" [12.7 mm x 12.7 mm x 101.6 mm] were selected . These tool bits were subjected

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to grinding operations for providing the standard single point tool signature for outside diameter turning. From the same lot of tool bits 3 tool bits were cryogenically treated for 2 hours immediately followed by tempering at 100° C . The composition of T42 is given in Table 1.

Table 1: Chemical Composition of T42 tool steel

C	Cr	Mo	W	V	Co
1.25%	4%	3.70%	9.70%	3.10%	10%

These tools were used for machining mild steel bright bar material on CNC Turning center of LMW Make. The process parameters such as cutting speed, feed and depth of cut-were kept constant during machining. Cutting fluid was used during machining. The machining time was kept constant for all batches. After machining the results related to the surface roughness values of the machined work piece and flank wear were tabulated to find out the change in tool life of cutting tool by application of cryogenic treatment. Surface roughness was measured using the Taylor Hobson Surface roughness tester and the flank wear was measured using the Tool Makers microscope. The results for conventionally treated tool bits are shown in Table 2 and the results for cryogenically treated tool bits for 2 hours followed by tempering at 100°C are shown in Table 3.

VI. RESULTS & DISCUSSION

The 3 conventionally heat treated and tempered tool bit points as supplied condition were given the standard single point tool signature and were subjected to machining bright bar using following process parameters.

Spindle speed : 700 rpm
Cutting Speed : 75 m/ min
Feed : 0.075 mm/rev
Depth of cut : 0.3 mm

The work pieces were machined for fixed time duration of 10 min. using every tool. Table 2 shows the results of Surface roughness values and Flank wear for conventionally treated T42 tool bit points. The surface roughness values were noted at 3 different locations along the length of the workpiece material.

The 3 Cryogenically heat treated and tempered tool bit points selected from the same lot of T 42 tool bits were also given the standard single point tool signature and subjected to machining bright bar using following process parameters.

Cryogenic Temperature : -185 ° C
Soaking Time : 2 hours
Spindle speed : 700 rpm
Cutting Speed : 75 m/ min
Feed : 0.075 mm/rev
Depth of cut : 0.3 mm

Again the work pieces were machined for fixed time duration of 10 min. using every tool. Table 3 shows the results of Surface roughness values and Flank wear for cryogenically treated T42 tool bit points. The surface roughness values were noted at 3 different locations along the length of the workpiece material.

Table 2 : Surface roughness values and Flank wear for conventionally treated T42 tool bits

Group	Sample No.	Surface Roughness Ra (µm)	Average Surface Roughness Ra (µm)	Grand Average Surface Roughness Ra (µm)	Flank Wear in microns (µ)	Grand Average Flank Wear in microns (µ)
N	N 1/1	4.207	3.763	3.837	0.315	0.253
		2.102				
		4.981				
	N 1/2	3.989	4.410		0.170	
		4.988				
		4.254				
	N 1/3	3.075	3.339		0.275	
		2.659				
		4.283				

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Table.3: Surface roughness values and Flank wear for cryogenically treated T42 tool bit points.

Group	Sample No.	Surface Roughness Ra (µm)	Average Surface Roughness Ra (µm)	Grand Average Surface Roughness Ra (µm)	Flank Wear in microns (µ)	Average Flank Wear in microns (µ)
C	C 1/1	2.986	2.963	2.242	0.155	0.190
		2.345				
		3.560				
	C 1/2	2.548	2.358		0.155	
		1.786				
		2.742				
	C 1/3	1.177	1.405		0.260	
		1.622				
		1.418				

The result Table 2 and Table 3 shows the average Surface Roughness values, Ra (µm) at 3 different positions and grand average surface roughness value. Also the Flank wear on 3 different tool bit points and the average flank wear is noted for both Conventionally treated T42 tool bits and cryogenically treated T42 tool bit points. The pilot experimentation clearly suggest that the selected values of the process parameters or factors show a definite wear pattern and thus the outcome of the present work can be considered as pilot experimentation for further investigation of the scientifically controlled cryogenic treatment to various grades like the M2, M35 and T42 off setting the soaking time levels and assuming one established level for each grade.

The values obtained clearly indicates that the wear of the cryo treated tools is less as compared to the wear of non cryo treated tools. Also the improvement in surface finish along with the reduction in tool wear may be considered as leading to increase in tool life.

For pilot experimentation purpose the cryogenic temperature is aptly selected and for a soaking time of 2 hours, considerable variation in the surface finish and tool wear is obtained. This confirms with the previous published literature and the mechanism leading to improved tool life is due to the conversion of the retained austenite to more harder martensitic phase and precipitation of some secondary carbides.

VII. CONCLUSION

From the surface roughness values and flank wear data obtained for Conventional heat treated as supplied tool bits and cryogenically treated tools following conclusions can be drawn:

a) The surface finish of the cryogenically treated tools is improved as compared to the conventionally treated tools.
b) The variation in the surface roughness values suggests that the conventional heat treatments can be controlled over a range of temperatures and thus the variation is observed in the surface roughness values with the conventional heat treated tool bits as well as cryogenically treated tool bits.
c) In cryogenically treated tools the variation in wear resistance is observed. From this it can be concluded that cryogenic temperature and soaking time plays an important role in improvement of wear resistance of T42 steel tools.
d) Although the soaking time duration considered over here was 2 hours at the cryogenic temperature of -185°C, still there is significant improvement in surface finish values and reduction in flank wear as compared to the conventional treated tools as supplied condition.

The objective of conducting such a pilot experimentation is met as considerable values in flank wear are noted and that there is variation in the surface roughness values. The pilot experimentation thus gives a confidence to carry forward the investigation covering the other grades which includes the M2, M35 along with the experimented T42 grade. The machining parameters and the cryogenic parameters need to be offset considering or assuming the established parameters as per the published research till date.

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