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A Review of Cryogenic Treatments to Steels

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Abstract: There are various methods used to enhance the properties of materials and commonly adopted are conventional heat treatment, coatings of harder materials on the surface of base materials, in addition to conventional heat treatment cryogenic treatment is also used. In the cryogenic treatment materials are subjected to temperature below 0˚C and range up to -196˚C or in some cases -269˚C. The sub-zero treatment and various cryogenic treatments like shallow cryogenic treatment (SCT), deep cryogenic treatment (DCT) are used by researchers to know the effects on tool steels and other steel materials also. It is observed that cryogenic treatment improves the mechanical and tribological properties of most of steels. Cryogenic treatments of metals reduce the retained austenite and convert it into martniste content which improves the performance of materials. In this work a review of different cryogenic treatments on steel materials is planned to study.
Keywords: Cryogenic treatment, DCT, austenite, martensite, steels, etc.

I. INTRODUCTION

The area of cryogenics is defined as the temperature range below -100°C (-148°F), extending down to absolute zero, -273°C (-450°F) [20].The applications of cryogenic treatment are in practically every industrial sector viz. machining, casting, injection moulding, forging, welding, automotive, aerospace, electronics, steel, timber industries, mining, agriculture, motorsports, etc. Some examples of parts that can improve their performance and increase their lives are: knives, machining tools (drill bits, carbide inserts, mills, hobs, broaches…), saws, punches, dies, rolls, moulds, electrodes, gears, shafts, bearings, springs, cables. When a wear or fatigue problem occurs or more life is needed there could be a good chance for using cryogenic treatments, L.A. Alava [19].

II. CRYOGENIC TREATMENT

What is cryogenics? The area of cryogenics is defined as the temperature range below -100°C (-148°F), extending down to absolute zero,-273°C (-450°F).

The word cryogenics means related to cold, being derived from Greek words “kryos” which means “icy-cold” and “genes” which means “born”. According to authorities at Arthur D. Little, Inc. this word dates from about 1875, but it does not seem to have been used to any great extend before about 1955; prior to that date one finds most authors using the term “low temperature: to describe the really low temperature research and applications of the science of cryogenics, which date back to about 1900 when the cryogenic gases were first produced [20].

One of the cryogenic treatments used by Flavio J. da Silva et al. [18] is as shown in Fig.1.The treatment consists of heating the metals to its austenitizing temperature which differ from metals to metals with specific rate. Then cool down to room temperature (quenching). After this again heating the metals to certain temperature to perform tempering which may be single, double or triple times. Sometimes tempering may not be used and metals are subjected to cryogenic temperature may be up to -196˚C. Then hold the components at that temperature for certain time called as soaking time. Reheating the components at certain rate to predetermined temperature and holding them for certain time and bringing it to room temperature. This is also a tempering operation which may be single, double or triple times as per requirement of desired properties of metals.

III. LITERATURE REVIEW

In this paper the work conducted by various researchers is presented.

Flavio J. Da Silva et al. [1] studied the performance of cryogenic treated HSS tools comparing with tools of the same material but conventionally heat treated (CHB), during machining and during abrasion tests. The cutting tools used in the machining tests were of M2 high speed steel with the dimensions of 10mm×10mm×102 mm, Twist Drills of M2 high speed steel with 7.5 mm of diameter and special milling cutter of M2 high speed steel with a3μm TiN coating.

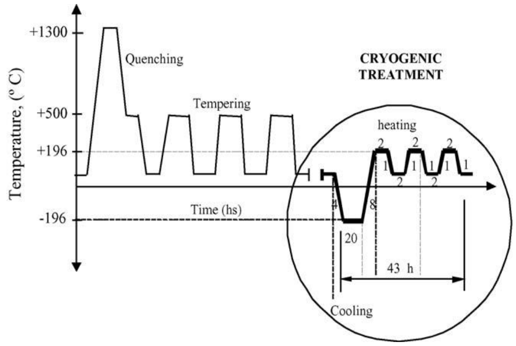

Fig. 1: The processing routes of the cryogenic treatments

A recommended thermal cycle for this tool material was used, consisted of a cooling to a temperature of −196°C followed by three cycles of heating to temperatures in the order of +196° C for tempering; lasting a total of 43 h. Fig. 1 illustrated this thermal cycle.They concluded that hardness and microhardness were not affected by cryogenic treatment. The cryogenically treated samples showed almost 0% of retained austenite. This meant that practically the 25% in volume of the retained austenite observed in the untreated sample, the cryogenic treatment transformed it into martensite. The superior performance of treated tools over untreated tools gave a difference of 44% in some cutting conditions in Brandema rapid facing test. The difference on the percentage of retained austenite of the cryogenically treated and untreated samples not altered the abrasive wear rate at the conditions used for the sliding abrasion tests. This was perhaps due to the ability of the austenite of the untreated samples to harden during plastic deformation because of work hardening or by its transformation into martensite. These occurrences might compensate the gain obtained by precipitation of fine carbides in the cryogenically treated samples. The performance of treated M2 HSS twist drills was increased. The gain observed during drilling steels accepting catastrophic failure as the end of tool life criterion varied from 65% to 343% based on the cutting conditions used. The shop floor performance of cryogenically treated HSS milling cutters presented worse performance compared to untreated tools. In general the cryogenic treatment had favourable influence on the performance of tools tested. This meant that based on the application the cryogenic treatment may be a good another way for having productivity enhancement.

Multilayer CVD coated ISOP-30 tungsten carbide turning tool inserts with coating of net coating thickness25µm (1st layer – TiN-1.5 µm, 2nd layer – TiCN-12.5 µm, 3rdlayer – Al_2O_3-6 µm, 4th layer – TiN-5 µm.) with chip breaker of ISO specification CNMG 12 04 08 were used to test the machining performance treated at low temperature by T.V. Sreerama Reddy et al. [2]. The low temperature treatment of -110°C and holding for 24 h was given to the inserts. They found that the flank wear resistance and tool life of the low temperature treated inserts were better when compared to untreated inserts. The improvement in flank wear resistance was 21.2% and improvement in tool life was 11.1%. The main cutting force was lesser as compared to untreated inserts. The surface finish of C45 work piece was better on machining with low temperature treated inserts compared with untreated inserts at all cutting speeds. As well as there was decrease in main cutting force of 2%, and improvement in surface roughness of the work piece of 8.42%.

T. V. Sreerama Reddy et al.[3] evaluated the machinability of C45 steel with deep cryogenic treated tungsten carbide cutting tool inserts. Multilayer CVD coated ISO P-30 tungsten carbide turning tool inserts with net coating thickness of 25µm (1st layer – TiN-1.5 µm, 2nd layer – TiCN-12.5 µm, 3rd layer – Al2O3-6 µm, 4th layer – TiN-5 µm.) with chip breaker of ISO specification CNMG 12 04 08 were used for the investigation. The cutting tool inserts (Kennametal, India) of 4 mm thickness and rhomboidal in shape were used. The cryogenic treatment, used was a gradual lowering of temperature from room temperature to -176°C at the rate of about 2°C per minute and holding the temperature at -176°C for 24 h, then subsequently raising the temperature back to room temperature at the rate of 2°C per min. They observed that machinability of C45 steel workpiece was better on machining with cryogenic treated inserts than when machining with untreated inserts. The tool life of cryogenic treated inserts was more in comparison with the untreated inserts in all cases. The main cutting force for the treated inserts was less in case of treated inserts. The surface finish of the work piece was also better, when the workpiece was machined, with cryogenic treated inserts in all cutting speeds. Overall it was seen that, subjecting tool to cryogenic treatment results in better machinability because of increase in thermal conductivity of the tungsten carbide, which resulted in decrease in tool tip temperature during turning operation. This was a definite advantage. As well as the cryogenic treatment also resulted in better machinability due to increase in hot hardness of the tungsten

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carbide. All these indicated that cryogenic treated tool tips were subjected to lesser tool wear and there was increase in the tool life, reduced cutting force and gave better surface finish compared to untreated tool.

To test the wear behavior of cryogenically treated single point coated tungsten carbide inserts an attempt was made to critically examine the effect of cryogenic treatment coupled with hard surface coating on the wear behavior and machining performance of tungsten carbide inserts over a range of cutting speeds, by A.Y.L. Young ,et al. [4]. For this the untreated and cryogenically treated cutting tool inserts were tested at various cutting speeds. The cryogenictreatment applied was first inserts were placed in a chamber. Then temperature was slowly lowered over a period of 6 h from room temperature to about -184°C hold steady for about 18 h. Later temperature was slowly raised over a period of 6 h to room temperature. Then inserts were tempered. They deduced the following outcomes: under certain conditions, like prolonged exposure to high temperatures during long continuous cutting operations, cryogenically treated tools can lose their superior properties. Cryogenically treated tools performed better when compared to untreated tools when performing continuous cuts for short periods of time, as well as when performing repeated cuts with breaks in between, gave decreased tool wear, and increased resistance to chipping. Cryogenically treated tools subjected to extended periods of high temperature at the cutting edge lost their wear resistance, which means that high temperatures altered the property of the treated tool. Therefore the state of cryogenically treated materials was not a permanent state, however a metastable one. In case of cryogenically treated tools performing repeated cuts with breaks in between were able to cool down between cuts, and recovering some property that allowed them to retain their superior wear resistance and superior resistance to chipping, compared to untreated tools. Cryogenically treated tools performed best when the tool temperature was kept low and their effectiveness can be extended with the use of coolants or suitable methods of cooling were used to keep the tool temperatures low. The validity claimed that cryogenic treatment can improve the lifespan of cutting tools would depend a lot on the cutting conditions. Tools under mild cutting conditions have gain from cryogenic treatment, and heavy duty cutting operations with long periods of heating of the cutting tool will not benefit from it.

With the primary aim to search for the optimum cryogenic processing time, t_{cp} for achieving the maximum wear resistance of AISI D2 steel and as well an attempt had also been directed to correlate the nature of wear resistance with the variation of amount of population density of secondary carbides along with the macro and micro hardness values, subjected to different cryogenic processing time was investigated by D. Das et al. [5]. For this work specimen blanks of 24 mm ×16 mm × 85 mm dimension were subjected to cryotreatment. The particulars of cryogenic processing (CP) in-between hardening and tempering treatments were illustrated in Fig.2.

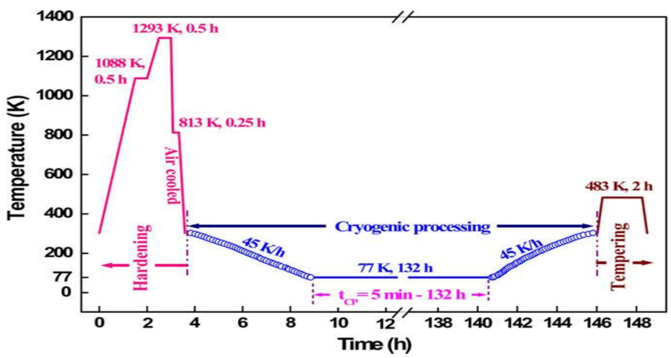

Fig. 2 Employed heat treatment schedule for D2 steel along with typical time–temperature profile for 132 h of soaking time in cryogenic processing (t_{cp}). Only the t_{cp} was varied from 5 min (considered as 0 h) to 132 h.

The conclusions obtained were: from comparison of Wear Rates (WR) of differently cryotreated specimens revealed that the WR vary significantly with the soaking time for the employed normal loads. The WR first decreased, reached a minimum at 36 h and then showed an increasing tendency with the increasing soaking time. From the examinations of worn surfaces and wear debris there was severe–delamination wear for all the investigated specimens. The morphological structures of the worn surfaces and the generated wear debris supported well with the estimated WR of the differently treated specimens. Soaking duration exhibited noteworthy effect on the precipitation behavior of secondary carbides (SCs). The amount and population density of SCs exhibited excellent relationship with the variation of the estimated average wear resistance of the cryotreated specimens. From the present results it was inferred that there exists an optimum soaking duration for cryotreatment of tool/die steels to achieve the best combination of desired microstructures and wear properties. The optimum soaking time for cryotreatment of AISI D2 steel was around 36 h.

The major aims of this investigation was to address the problem regarding wear resistance of cryogenically treated steels through organized and systematic wear experiments on differently treated specimens of AISI D2 steel. Another aim was to unfold the influence of the duration of cryogenically treated specimen on the enhancement of wear resistance at varying experimental conditions, D. Das, et al. [5]. Specimen blanks of 24mm×16mm×85mm dimension were subjected to conventional and cryotreatment in separate batches. The conventional treatment (QT) consisted of hardening (Q) at 1293K, 30 min. and single tempering (T), at 483 K, 120 min. Deep cryogenic processing (C) at 77 K was incorporated intermediate between hardening (Q) and tempering (T) in cryotreatment (QCT). 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. They inferred that wear resistance of the AISI D2 steel got noticeably enhanced by cryogenic treatment, compared to CHT irrespective of holding time at 77 K. But the extent of improvement of wear resistance was dependent on the wear test conditions, responsible to control the active mechanisms and mode of wear. Improvement in wear resistance was credited to the absence of retained austenite and more homogeneous distribution of large number of finer secondary carbides in the former specimens. The degree of improvement depended on the test conditions. Hardness was found to increase marginally by cryotreatment in contrast to significant increase in their wear resistance. The mode of wear and the operative wear mechanism were like for all of the cryotreated specimens at the selected test conditions. But the mode of wear changed from mild to severe in the cryotreated specimens based on magnitude of load. Wear resistance increased with increasing holding time up to 36 h at 77K beyond which it showed monotonic decrease with further increase in holding time.

The aim if this work was to study the effects of time, temperature and stabilization phenomena in cryogenic treatment on the wear behaviour of D6 tool steel, A. Akhbarizadeh et al.[7]. From a commercial D6 steel rod with a diameter of 50 mm specimen disks of 5 mm thick were cut for wear tests. SCT and DCT treatments were given to the samples was as shown in Table 1.

TABLE 1

Heat Treatment Condition Of The D6 Tool Steel

Nomenclature	Heat treatment	Sample No.
CHT	Conventional heat-treatment	1
SCT20	Shallow cryogenically treated at -63°C for 20 h	2
SSCT20	Stabilized for 1 week in room temperature and shallow cryogenically treated at -63°C for 20 h	3
SCT40	Shallow cryogenically treated at- 63°C for 40 h	4
SSCT40	Stabilized for 1 week in room temperature and shallow cryogenically treated at -63°C for 40 h	5
DCT	Cryogenically treated in -63°C for 20 h and deep cryogenically treated with quench in liquid nitrogen for 10 h	6
SDCT	Stabilized for 1 week in room temperature, then cryogenically treated in -63°C for 20 h and deep cryogenically treated with quench in liquid nitrogen for10 h	7

They concluded that because of the lowered retained austenite, the cryogenic treatment improved the wear resistance and the hardness of the D6 tool steel. This improvement was major in the DCT because of more homogenized carbide distribution, the retained austenite elimination and higher chromium carbide percentage compared with the SCT. As there was decrease of the retained austenite percentage in the samples kept for longer periods (40 h instead of 20 h) at shallow cryogenic temperatures, higher wear resistance and higher hardness were observed. Likewise, as a result of the decrease of the retained austenite percentage in the cryogenically stabilized samples (kept at room temperature for 1 week after quenching), the wear resistance and hardness improved, compared with the non-stabilized samples. This study by A. Akhbarizadeh et al. [8] attempted to examine the validity of the deep cryogenic heat treatment theories via the electric current flow during the deep cryogenic treatment in1.2080 tool steel. From a bar of 1.2080 tool steel with a diameter of 20 mm, disks with a height of 5 mm were cut and used to prepare the samples. The samples were austenized at 950° C for15 min followed by oil quenching. One of the samples was assumed as the reference sample and named conventionally heat treated (CHT). The samples were gradually cooled down to liquid nitrogen temperature with the cooling rate of 2°C/min, held at that temperature for 36 h and then gradually warmed up to room temperature (≈2°C/min) to prohibit severe thermal shocks. The samples which were deep cryogenically treated were named DCT. In this study, the effect of the as-quenched vacancies on the formation of nano- and micron-sized carbides during the deep cryogenic heat treatment of 1.2080 tool steel was investigated by applying an electric current with the voltage of 650 V and the current densities of 2- 4.5A, to clarify the effect of the vacancies as potential sites for carbon atoms jumping during the cryogenic treatment. These atoms produced some appropriate places for carbide nucleation during the tempering. They observed that the electric current reduced the carbide percentage and sterilized the carbide distribution and at higher current densities its destructive effect was more drastic. The electric current decreased the hardness of the samples after the deep cryogenic heat treatment as a result of a reduction in the as-quenched vacancies as potential sites for carbide nucleation. It was observed that the as-quenched vacancies responsible for carbide formation during the deep cryogenic heat treatment by providing appropriate sites for the carbon atoms jumping.

With the objective to analyze the effects of cryogenic treatment on tungsten carbide tools in turning, this work was performed by Simranpreet Singh Gill et al.[9].The commercially available square shaped coated tungsten carbide inserts of specification SPUN12–03– 08(P25, Sandvik Coromant, ISO specification) were procured. The group of inserts (4TiAlN coated inserts) meant for SCT was subjected to cooling at -110°C and held at this temperature for 18 h and gradually brought back to room temperature. Similarly, the group of inserts (4TiAlN coated inserts) meant for DCT was subjected to cooling at -196°C and held for 38 h and gradually brought back to room temperature. In this study, the coated tungsten carbide inserts were cryogenically treated under dry condition where the inserts being treated were not exposed to the liquid nitrogen to eliminate the risk and damage of thermal shock. Also, in order to avoid thermal shocks from rapid cooling and heating, the inserts were cooled down and heated up slowly, to and from the shallow cryogenic temperature (-110°C) and deep cryogenic temperature (-196°C), over a 4 and 7 h period, respectively, with the temperature being monitored by computerized control. This gave an average heating/cooling rate of 0.5°C/min. After this, two tempering cycles consisting of heating to 150°C were followed to relieve the stresses induced during cryogenic (SCT and DCT) treatment. The major outcomes of their work were that the shallow cryogenic treatment could considerably enhance the cutting life of TiAlN coated tungsten carbide turning inserts. The maximum tool life enhancement over untreated inserts in the present study was 25.53% for shallow cryogenically treated inserts. The percentage improvement in tool life of shallow cryogenically treated TiAlN coated insert decreased as increased the cutting speed. The deep cryogenic treatment showed destructive effect on the performance of TiAlN coated tungsten carbide inserts particularly at lower cutting speeds. But at higher cutting speeds, marginal gain in tool life could be obtained. Deep cryogenic treatment weakened coating–substrate interfacial adhesion bonding. Generally, deep cryogenic treatment was not recommended for TiAlN coated tungsten carbide inserts because there was no notable benefit gain. From SEM images and optical micrographs of insert flank wear, it was found that shallow and deep cryogenic treatment efficiently enhanced the cutting life of inserts by resisting the notch, chipping and plastic deformation wear considerably. The indentation test confirmed the reduction in adhesion strength of TiAlN coating on tungsten carbide substrate for deep cryogenically treated TiAlN coated inserts.

The main contributions of this work performed by Simranpreet Singh Gill et al. [10] was a proposal of state-of-art neuro-fuzzy inference system for modelling as well as its application for monitoring tool wear of cryogenic treated tool in turning process. Fuzzy model described in this paper was a multi input single output (MISO) system with three input parameters; soaking temperature (-110 to -196°C), cutting speed (35-55 m/s), cutting time (10-30 min) and the output as tool flank wear = Predicted depending upon input parameters (mm). Architecture of the Adaptive Neuro Fuzzy Inference System (ANFIS) applied to predict tool flank wear of AISI M2 HSS in turning.

MISO fuzzy model was developed and validated with experimental results for given conditions. The results generated by the designed ANFIS model were close to the experimental results with 97.53% accuracy. Hence model can be used by practicing engineer who would like to get quick answers for on-line intelligent control and /or optimization. The current state model was limited to turning of hot rolled annealed steel (C 45). ANFIS system was found to be very flexible and easy to understand and hence can be used as an alternative to the conventional modeling techniques. So the ANFIS technique can be introduced as a viable alternative to carry out analysis without conducting actual experiments.

D. Mohan Lal et al. [11] had done a comparative study on the wear resistance improvement of cryogenically treated samples with standard heat treated samples through flank wear test and sliding wear test. The materials considered for flank wear were M2 and T1 steels. For sliding wear test materials considered were D3 and M2. All materials were subjected to cryogenic treatment were shown in Table 2.

TABLE 2
List Of Treatment Conditions Considered For Wear Resistance Study

Cases	Purpose	Nomenclature followed
1.Hardened and tempered	Standard tool for comparing the tool life of cryotreated tools	SHT (standard heat treated)
2.Cryotreated at 93 K for 24 h	Cryogenic treatment for tool steels	CT (93/24)
3.Cryotreated at133 K for 24 h	To check the effect of lowering the temperature deep below cold treatment levels	CT(133/24)
4. Cryotreated at 163 K for 24 h.	To check the effect of lowering the temperature deep below cold treatment levels	CT(163/24)
5.Cryotreated at 93 K for 6 h	To check the significance of isothermal holding time at the treatment levels	CT(93/6)
6. Cryotreated at 93 K for 6 h and quenched in LN_2 for 2 h	To check the effects of temperature below 93 K	CT(93/6 + LN_2/2
7.Tempered and Cryotreated at133 K for 24 h	To confirm whether tempering is to be done before cryogenic treatment	TCT(133/24)
8.Tempered and Cryotreated at 93 K for 24 h	To confirm whether tempering is to be done before cryogenic treatment	TCT(93/24)
9.Titanium nitride coated	To compare the benefits of cryogenic treatment with that of surface coatings	TiN
10. Cryotreated (CT (93/24)) and then coated with Titanium	To compare the benefits of cryogenic treatment with that of surface coatings	CT + TiN
11. Titanium nitride coated and then Cryotreated (CT (93/24))	To compare the benefits of cryogenic treatment with that of surface coatings	TiN + CT

They were drawn the following conclusions: Untempered samples when cryogenically treated yielded 3%, 1% and 10.6% extra life compared to cryogenically treated T1, M2 and D3 samples respectively. So cryogenically treat without tempering was desirable. Tempered samples when cryogenically treated at 133 K for 24 h yielded negative results while cryogenically treated at 93K for 24 h gave favourable results. This meant that tempered samples if treated at more lower temperatures may be yielded more better on par with untempered cryotreated samples. Cryogenic treatment done at 93 K as per prescribed cycle yielded 20% more life in comparison with the maximum life achieved through cold treatment. Cryogenic treatment [CT(93/24] was superior to TiN coatings also. The effect of cryotreatment on TiN coating was unfavourable. TiN coating in combination with cryogenic treatment provided 45% extended tool life over cryogenic treatment alone. After first grinding it behaved like a cryogenically treated only. Samples treated at 163K for 24 h [CT (163/24)] were better compared to samples treated at 93K for 6 h[CT(93/6)]. Therefore soaking time was more important than lowering temperature. From the sliding wear test it was observed that cryogenic treatment imparts better red hardness for D3 steel than M2 steel. A statistical test of significance on the levels of improvement in wear resistance showed that the improvements experienced in CT (93/24) and TCT (93/24) were noteworthy at 95.5% level.

The objective of the work carried by V. Firouzdor et al. [12] to know the effects of deep cryogenic treatment on wear resistance and tool life of M2 HSS drills at configuration of dry high speed drilling of steels. The treatment used was: austenitizing of drills at temperature of 1100°C and gas quenching in a cool nitrogen gas and then tempering at 600°C for 2h. In deep cryogenic treatment drills slowly cooled to approximately −196°C and held at this low-temperature for 24 h and gradually brought the specimens back to room temperature. To avoid thermal shocks from rapid cooling and heating, the specimens were cooled down and heated up slowly, to and from the cryogenic temperature (−196°C), over an 8 h period. Three types of drills were tested viz. reference drills (R) with no extra treatment, cryogenic-treated drills (CT) and cryogenic with a 1h temper at 200°C treated drills (CTT). The conclusions deduced were that cryogenic treatment greatly improved the wear resistance of M2 HSS drills in case of high speed dry drilling of steels. A low-temperature tempering (200°C) after cryogenic treatment resulted highly beneficial. The fine carbide precipitation during cryogenic treatment leaded for wear resistance improvement as a result of decreasing thermodynamically potential for dissolution in the work piece material and dispersion hardening effect. Transformation of retained austenite to martensite could also help in wear resistance improvement, i.e. enhanced hardness value. Cryogenic treatment could facilitate the carbide formation and increase the carbide population in martensite matrix as well as made the carbide distribution more homogeneous. Cryogenic treatment affected the entire section of the component unlike coatings; hence similar lives can be expected after each regrinding.

Dedulal Das et al. [13] studied fracture toughness in order to relate the same with hardness and reported wear behaviour to achieve greater understanding about how DCT affects the integrity of tool/die steels. AISI D2 grade steel as hot forged bar was used to prepare specimen blanks of size 24 mm×16 mm×85mm.Specimens were subjected to conventional heat treatment as well as to different types of sub-zero treatments in separate batches. The investigated sub-zero treatments by them were cold treatment, shallow cryogenic treatment and deep cryogenic treatment having lowest quenching temperature as 198, 148 and 77 K, respectively. They observed that the obtained order of the K_{ICV} values determined by three point bend loading was in good agreement with reported plane-strain fracture toughness value of similar steel determined by standard technique. Sub-zero treatment reduced fracture toughness (K_{ICV}) of the selected steel over the same conventionally heat treated one. The degree of reduction fracture toughness varied with type of sub-zero treatment. It was lowest for DCT but highest for SCT. Fracture toughness value of cold treated specimen was seen between that of SCT and DCT. For conventionally heat treated and deep cryogenically treated specimens indicated their higher level of toughness which is in good agreement with their estimated fracture toughness values. For conventionally heat treated, cold treated and shallow cryogenically treated specimens fracture toughness value decreased expectedly resulting in increase in the hardness, reduction of retained austenite content, increase in the amount of secondary carbides and their size refinement. The relative improvement in the fracture toughness of DCT specimens was credited to its refined carbide distribution with improved ductility of the matrix.

The present study was an attempt to improve the properties of tool WC-Co inserts through different post treatments viz. a) controlled cryogenic treatment of WC-Co inserts, b) heating and forced air cooling of WC-Co inserts and c) heating and quenching of WC-Co inserts in oil bath by Dinesh Tahkur et al. [14]. Tungsten carbide–cobalt alloys in the form of cutting inserts were used. The inserts were subjected to a cryogenic treatment in which inserts slowly cooled to -196°C and soaked at this temperature for around 24 h. Then in the two post treatments of inserts viz. a) heating and forced air cooling and b) heating and quenching in oil bath, the inserts were heated for about 30 min at a temperature of 750°C and soaked for some time. In first case the inserts were cooled from 750°C to room temperature by forced air cooling and in second post treatment the inserts were quenched from 750°C in oil bath at room temperature. They were drawn the following conclusions: The solubility of tungsten carbide decreased as decreasing temperature (800°C- 600°C) range provided the basis for understanding the properties of WC-Co alloys by post treatments. In all three post treatments of WC-Co inserts considered for investigation yielded considerable improvement in microhardness. Controlled cryogenic treatment improved the wear resistance because of reason the physical changes i.e. densification of the cobalt metal binder which held the carbide particles firmly. In other two treatments from microstructure it observed that there was uniform distribution of tungsten carbide particles. X-ray diffraction (XRD) study showed formation of complex phases like W_3CO_3C and W_6CO_6C and which were resulted in the increase in hardness due to exposure of skeleton carbide matrix due to later post treatments.

To highlight the application of Taguchi analysis to reach an optimal set of deep cryogenic treatment parameters for enhancing wear resistance of SR34 stainless steel this research had carried out by J.D. Darwin, et al. [15].The SR34 steel piston rings in an uncoated condition were cut into small pieces of lengths 15mm for analysis. The specimens were cryotreated. The factors and their 3 levels used were: A. Cooling rate: 0.5°C/min, 1°C/min, 1.5°C/min. B. Soaking temperature: -120°C, -150°C, -184°C. C. Soaking period: 12 h, 24 h, 36 h. D. Tempering temperature: 200°C, 250°C, 300°C. They concluded that soaking temperature was the most important factor and the maximum percentage contribution of it on the wear resistance of the SR34 piston ring material was 72%.The best soaking temperature in the possible range was -184°C. The second significant factor was the soaking period and it contributed 24% for the improvement of wear resistance. The best level for this factor was 36 h. The third important factor was the cooling rate and its maximum percentage contribution on the wear resistance was 10% and the best level was determined as 1°C /min. The tempering temperature showed very little significance and its contribution on the wear resistance was 2%. The optimum level of tempering temperature was attained at, as 250°C. The tempering period factor was not so important. But to complete the DCT process the tempering period had been taken as 1h. In case of interactions, soaking temperature versus soaking period and cooling rate versus soaking temperature showed little importance. The best interaction breakdown showed that the best levels of the corresponding factors were same as the optimum levels obtained individually. The confirmation test results were found to be within the confidence interval with 95% confidence. Both wear test conducted on untreated samples and the results were compared with that of the confirmation test results. The cryogenically treated SR34 samples as per the arrived optimum conditions improved in wear resistance by 43.8%.

J.Y. Huang et al. [16] worked to assess the cryogenic effect and to understand the cryogenic mechanism. They used a commercial M2 tool rod with a diameter of 6.35 mm. A heat treatment was consisted preheating at 0.17°Cs^{-1} to 815°C then continuously heating to an austenitizing temperature of 1100°C and holding for 1 h, followed by quenching to an ambient temperature. The cryogenic treatment was performed by soaking the samples in liquid nitrogen for 1 week. To compare both the cryogenic treated and non-cryogenic treated samples were tempered at 200°C in nitrogen atmosphere for 24 h. The outcomes were that cryogenic treatment facilitated the carbide formation and increased the carbide population and volume fraction in the martensite matrix, and made the carbide distribution more homogeneous. Due to the increase in carbide density and volume fraction which might be responsible for the improvement in wear resistance.

In this study the effect of holding duration on the microstructure, hardness and microhardness of 1.2080 tool steel in the deep cryogenic treatment was focused, Kamran Amini et al.[17]. From a commercial 1.2080 tool steel bar with the diameter of 50 mm cut into disks of 5 mm in height to prepare samples. The samples were then austenized at 950°C for 15 min and then quenched in oil to room temperature. One of the samples considered as the conventionally heat treated sample (CHT) and other sample were gradually cooled down to liquid nitrogen temperature, held them for some periods and then warmed up to room temperature. The samples were held at the deep cryogenic temperature for 24, 36, 48, 72, 96 and 120 h, and deep cryogenically treated samples given code as DCT24, DCT36, DCT48, DCT72, DCT96 and DCT120, respectively. The samples were then tempered at 180°C for one h. This work was done to investigate the effect of different soaking durations at liquid nitrogen temperature during the deep cryogenic treatment on the microstructure and hardness of 1.2080 tool steel. The conclusions drawn were: The deep cryogenic heat treatment removed retained austenite and increased the carbide percentage. Also the deep cryogenic heat treatment made a more homogeneous carbide distribution with a more uniform particle size and some newly formed nano-sized carbides. Because these improvements the hardness and microhardness of the deep cryogenically treated samples was increased. The microstructure of the deep cryogenically treated samples was changed by changing the soaking duration. For initial periods, the hardness of the samples increased. Up to the soaking duration of 36 h, the carbide percentage increased by increasing the holding duration and the carbide particle size showed a more uniform distribution, in comparison with the lower holding durations. Holding durations more than 36 h resulted in decrease of the carbide percentage compared to the DCT 36 samples and the hardness and microhardness both decreased. This reduction in the carbide percentage and uniformity was due to the bigger carbide formation during the deep cryogenic treatment, barred the formation of the fine carbides. In general the hardness, microhardness, microstructure uniformity and carbide percentage reached its optimum value at 36 h holding duration. The effect of longer holding durations more than 36 h, the carbide percentage and uniformity, hardness microhardness and carbide particle size reached steady levels in the DCT48 sample and not changed anymore.

Paul Stratton and Michael Graf [18] in this study used a carburizing steel-20MnCr5 which was carburized using typical industrial cycles, subjected to a range of cold treatments and tested its wear performance. The cold treatments applied were given in Table 3.

TABLE 3
The Heat and Cold Treatments

Treatment	Conditions
Carburising treatments	
1	Carburised to 0.8% carbon and a total case depth of 0.75mm and direct oil quenched from 850°C
2	Carburised to 1.0% carbon and a total case depth of 0.75mm and direct oil quenched from 850°C
3	Carburised to 1.0% carbon and a total case depth of 0.75mm,cooled out, reheated, and oil quenched from 850°C
Cold treatments	
a	Tempered at 150°C for 1 h
b	Cooled to -70°C for 1 h then tempered at 150°C for 1 h
c	Cooled to -196°C for 24 h then tempered at 150 °C for 1 h
d	Cooled to -269°C for 168 h then tempered at 150°C for 1 h

The conclusion drawn were that the dry wear rate of optimally carburized 20MnCr5 was reduced by about 20% due to deep cold treatment at -196°C for 24 h. Deep cold treatment at very low temperature(-269°C in liquid helium) had shown no benefit for carburized steel. In case high levels of retained austenite were present in the case of carburized 20MnCr5, cold treatment converted most retained austenite to martensite, thus the dry wear rate increased.

IV. CONCLUSIONS

From the study of the results obtained by performing experiments by various researchers following conclusions may be drawn:

A. Cryogenic treatment affects on entire cross section of the material. It affects on microstructure by converting retained austenite into martensite.
B. It also affects on hardness, microhardness, toughness of steel materials.
C. Cryogenic treatment of steel / tool steel materials improves the wear resistance and hence the life of cutting tools. But extent of these improvements is subject of cryogenic treatment parameters.
D. Cryogenic treatment parameters – cooling rate, soaking temperature, soaking period, heating rate, tempering temperature etc. play important role to affect on the mechanical and other properties of materials and its effect varies from metal to metal.

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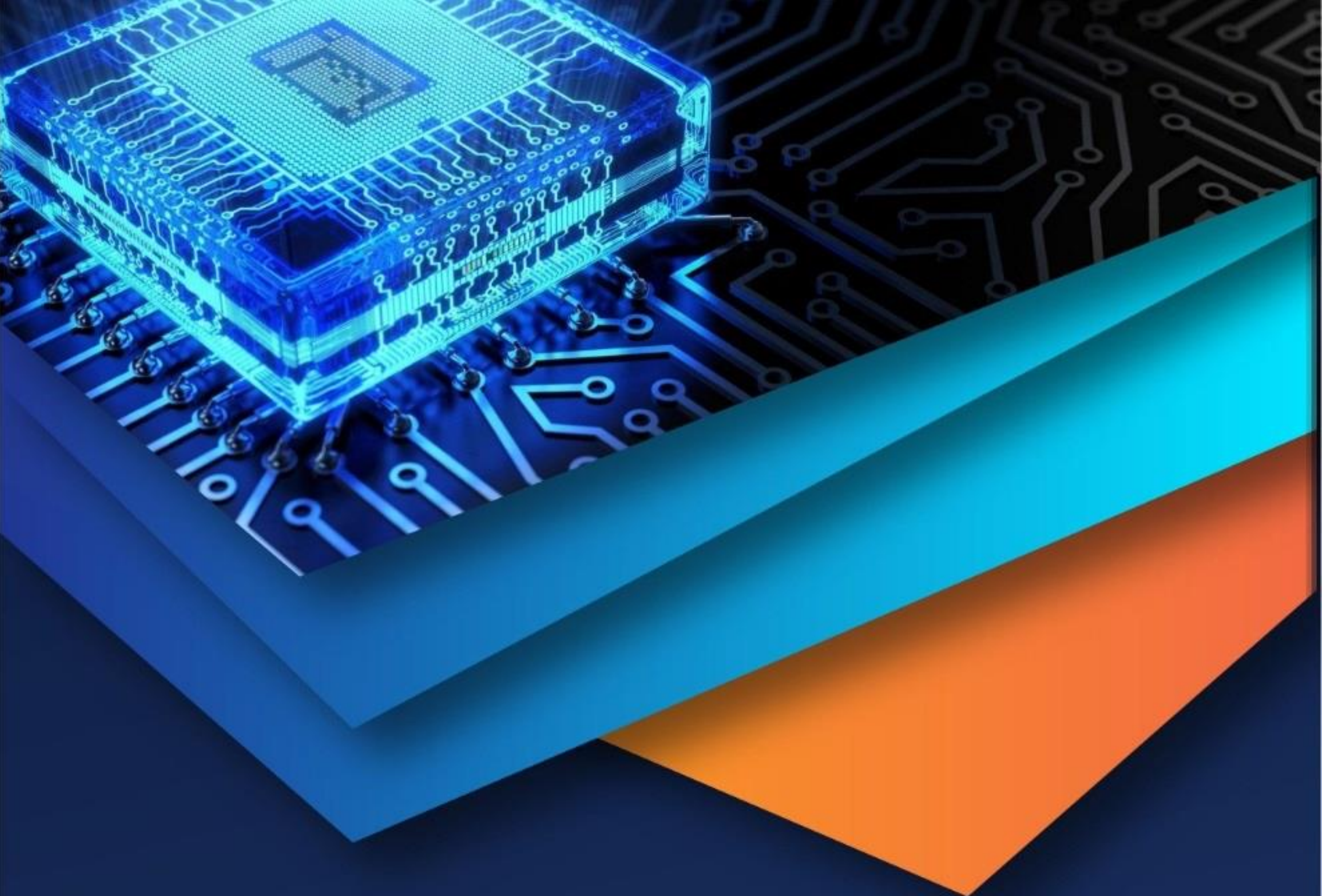

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