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Effect of Cryogenic Treatment on Various Materials: A Review

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Abstract

This study deals with the effect of various type of cryogenic treatments on different tool materials. This is the most advanced method which is quite popular in now days. The tool wear occurs constantly when used in manufacturing, forming and cutting process [1] which increases the total cost of production and this cost can be controlled by cryogenic treatment. The cryogenic process effect both the mechanical and metallurgical properties. The effect of cryogenic treatment varies according to the material. In this study effect of cryogenic treatment in various material has been discussed.

Keywords

SCT, DCT, ANOVA

Introduction

Cryoprocessing is a form of conventional heat transfer process which is being used form 1930s and 1940s to improve the performance of cutting tool steels[2].Now-a-days cryogenic treatment is used to reduce the tool wear because the tool wear gradually in manufacturing, cutting and forming process[1]and increase the cost of production.The basis process starts with keeping the material at a very low temperature for some period of time and then gradually taking it back to the room temperature. The gases used for cryogenic are generally noble gases in liquefied form, LN2 (Liquid Nitrogen) is the most widely used. From the Nineties, the interest in cryogenic has been applied to many different parts i.e. motor racing parts, gun barrel, knives, dies etc. [3]. The mechanism behind the property enhancement has beennot clearly identified however people has given different hypothesis about it. The cryogenic treatment is classified into two categories:

(a) Shallow Cryogenic Treatment – The study below 180K.
(b) Deep Cryogenic Treatment – The study above 180K.

The parameter for the treatment are Minimum temperature, holding duration, cooling rate and warming rate. The values of these parameter varies according to the different materials. Each new material need to be tested and treated at different temperature level before selecting a particular temperature value, however most significant results are

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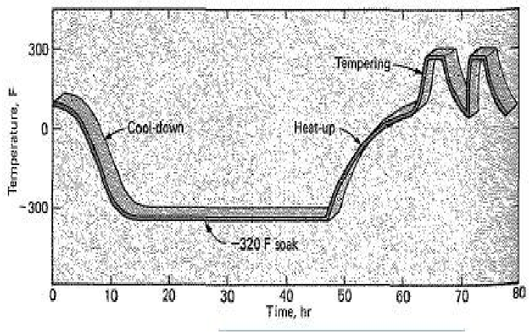
obtained at 24hr.The temperature range for different materials is shown in table 1. Until the end of sixties cryogenic treatment was performed by directly dipping the material to LN2 which result inthe generation of crack. For this the cryogenic treatment is done in few steps that consist of cool-down followed by soaking and then tempering as shown in fig below:



The ANOVA of wear results shows that the most significant factor was soaking temperature (72%) followed by soaking time(24%) and cooling rate (10%) however tempering after DCT is of little importance (2%) while the tempering time is found to be irrelevant. The three different types of cooling system are as follows [4]

First Author	Material	Tmin[K]	Time duration [hr]
Huang, [5]	AISI M2 tool steel	77	168
da Silva, [6]	AISI M2 tool steel	77	20
Leskovsek, [7]	AISI M2 tool steel	77	1
Mohan, [8]	AISI M2, T1, D3tool steel	From 163 to 93	6 and 24
Molinari, [9, 10]	AISI M2, H13 tool steel	77	35
Yun,[11]	AISI M2, T1 tool steel	77	24 and 48
Gordo, [12]	M3/2 HSS matrix with Nb and Ta	77	35
Meng, [13]	Fe-12Cr-Mo-V-1.4C tool steel	223 and 93	
Meng, [14]	Fe-1.4Cr-1C bearing steel	223 and 93	1
Bensely, [15, 16, 17]	En 353 carburized steel	193 and 77	5 and 24
Preciado, [18]	Carburized steel	83	22

Kollmer, [19]	AISI 4140 cold rolled steel	89	6-10
Zhirafar, [20]	AISI 4340 low alloy steel	77	24
Yong, [21]	ASSAB 760 medium carbon steel	89	18
Yang, [22]	13Cr2Mn2V high Cr white iron	77	3
Liu, [23]	3Cr13Mo1V1.5 high Cr cast iron	77	3
Darwin, [24]	SR34 18% Cr martensitic stainless steel	from 193 to 89	6 to 36
Ianamura, [25]	Fe-18Cr-8Ni austenitic stainless steel	195	
Myeong, [26]	Fe-18Cr-8Ni austenitic stainless steel	197	3
Singh, [27, 28]	AISI 304L welded joints	88	30
Zhisheng, [29]	Cr-Zr-Cu alloy electrodes	123 and 103	2 and 4
Chen, [30]	Al alloy	89	24
Lulay, [31]	7075-T651 Al alloy	77	2 and 48
Trieu, [32]	UHMWPE	89	14
Senthilkumar [33]	EN-19	77 to 193	5 and 24
Lulay [34]	7075 Aluminum Alloy	77	2 and 48
Ozbek [35]	Cemented carbide	128	12,24,35,48 and 60
Sendooran [36]	HSS	77	0.5

1. Gradual Immersion: The sample are directly immersed in liquid nitrogen for some time then they are extract and gradually led back to room temperature by means of temperature controlled air.
2. Heat exchanger: The liquid nitrogen flows through heat exchanger and the cooled gas at output is diffused by a fan inside a chamber.
3. Direct Nebulization: The LN2 is nebulized directly in a chamber. A homogenous distribution is obtained by a fan.
4. Hybrid: It is the combination of nebulization and gradual immersion.

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Effect on the material microstructure

Ferrous Alloy: Ferrous materials are those which composed of Iron. The improvement of mechanical properties can be described to different phenomenon:

(a) Complete Transformation of retained austenite to martensite -Retained austenite is always present after heat treatment and it is softer grain structure. Retained austenite is transformed into the harder, more durable grain structure - martensite by applying cryogenic treatment. After heat treatmentthe range of retainedaustenite in a material may be as high as 50 % or as low as 3 %.

(b). Residual stress removal-The residual stress inside the material are the main reason for material failure or its wear. Cryogenic treatment reduces the wear by compacting thus eliminating the residual stress.

(c) Fine dispersed carbide precipitation- Fine 'neta' carbide particles formed during the long cryogenic soak that are completely different in their structure as compared to regular carbide. These are in addition to the larger carbide particlespresent before cryogenic treatment and produces a more homogenous distribution. Liu et al.[37] studied the effect of cryogenic treatment on microstructure, hardening behavior and abrasion resistance of 3Cr13Mo1V1.5 high chromium cast iron. It was found that the precipitation of secondary carbides accelerates by Cryogenic treatment and also at a lower temperature it makes the secondary hardening peak advanced. Cryogenic treatment can markedly boost abrasion resistance and hardness of high chromium. DCT can reduce austenite content after sub critical HT but cryogenic treatment can't completely transform retained austenite to martensite. The abrasion resistance is maximum when the retained austenite percentage in matrix is 20% and if it is less than 20% it decreases sharply. Mohandoss R.[38] performed cryogenic treatment of EN – 19 alloy steel material to improve its mechanical behaviour. The material was deep cryogenic treated at -191 for 24hrs. The mechanical behaviour of untreated EN-19, case carburized EN-19 and carburized and cryogenic treated EN – 19 were found by conducting tests such as tensile testing, impact strength and Rockwellhardness. The tensile strength in cryogenic treatment is increased by 22.62% and in carburised it is increased by 7.94% as compared to un-treated material. The hardness in cryogenic treated steel is increased by a amount of 55%. The result also shows that ductile material is converted to brittle material by the application of cryogenic treatment.Amini et al. [39] investigated on the tool steel 1.2080 having diameter of 50 mm about the time duration of the liquid nitrogen applied for the deep cryogenic heat treatment process and studied about the changes occurred in the micro structure, in the distribution of the carbide and in the carbide percentage, hardness and the micro hardness. Authors performed these analyses via the scanning electron microscope, transmission electron microscope, X-ay diffraction and optical microscope. By the deep cryogenic heat treatment there is increase in the percentage of the carbide and the austenite is removed. Due to improvements in the deep cryogenically cooled samples the hardness and the micro hardness is increased. In application durations more than 36 hours, the hardness and the micro hardness is decreased due to the decrease in the carbide percentage in the sample as compared to the uncooled samples In other words we can say that at the 36 hours for the application of liquid nitrogen the hardness, micro hardness and microstructure uniformity and carbide percentage attained its optimum value. Khan et al.[40]in their work modified a tool to apply liquid nitrogen as coolant during the machining of SS with carbide tools coated with titanium carbonitride through a tool hole. This modified tool provides effective cooling and increases tool life to four times. At higher cutting speed cryogenic cooling were more effective.Srivastava et al. [41] Studied the effect of cryogenic treatment on copper electrode using EDM on M2 grade HSS to calculate EWR and SR. They found that EWR and SR are lower in cryogenic EDM compared to conventional EDM for the same set of parameters. The use of liquid nitrogen leads 20% reduction in tool wear.

Dr. Abbas A. Hussein et al [42] studied the effect of cryogenic treatment on the properties of low carbon a858 steel. The hardness, ultimate tensile stress, yield stress, percentage elongation and impact energyfor A858 steel were all moderately increased after DCT. The fatigue limit of the steel increased by 20 KNafter DCT. The volume wear rate decreased significantly or wears resistance increased after DCT andbest wear resistance was at (15N) load. The grain boundaries after DCT were no longer visible, and thepearlite isles were globalized.

Non-Ferrous Alloy: These are those alloy that are having absence of iron. CT affects a lot range of composites and polymers. The mechanism for non-ferrous alloy is more difficult than ferrous alloy and it is still under investigation. Contraction of polymers occur at cryogenic temperature resulting in the increasing of residual stress. The effect of cryogenic process may be very less in non-ferrous alloy as compared to ferrous alloys.

Lulay K.E. et al. [43] studied the effect of cryogenic treatment on 7075 Aluminum alloy. Deep Cryogenic is performed on two specimen one for 2hr and other for 48hrs. There was no effect on any property in 2hrs cryogenic treatment specimen. The effect of 48hrs Cryogenic treatment on the Mechanical properties was about 1%. The largest % change was observed in Charpy test which was nearly 12%. Özbek et al.[35] studied the effects of different holding time of cryogenic treatment on tool wear of cemented carbide inserts during the turning of AISI 316 austenitic Stainless steel. The feed rate and depth of cut was kept constant during the machining process which were 0.3mm/rev and 2.4mm however varying cutting speed were used which were 100, 120, 140 ,160 m/min. The temperature of DCT was -1450C and the time duration taken were 12, 24, 36, 48 and 60 hr. The result obtained shows that the maximum hardness and wear resistance was obtained by DCT-24hr sample. However crater wear and flank wear were observed in all cutting parameter while notch wear was found at low cutting speeds due to BUE formation. Increase in thermal conductivity due to cryogenic treatment prevents plastic deformation. Gill et al.[44]investigates the effect of DCT on machinability of Ti 6246 alloy in electric discharge drilling (EDD) by electrolytic copper tool. To compare the accuracy of drilled holes in DCT Ti 6246 alloy and nontreated Ti 6246 alloy an attempt has also been made in terms of surface roughness and overcut. The result shows that the MRR increases by 8.50%, WR by 30.16%, and TWR by 34.78% in case of EDD of DCT Ti 6246 alloy w/p as compared with nontreated Ti 6246 alloy w/p. The DCT of Ti 6246 greatly improves the accuracy of the holes drilled. 9.01% improvement was seen for blind hole while 6.69% for side walls of holes, and 16.09% for overcut.Ahmed et al. [45] modified a tool to apply liquid nitrogen as coolant through a hole made in the tool so that liquid nitrogen can be directly applied to the machining zone during machining of stainless steel with carbide tools coated with titanium carbonitride. It was found that the tool life increased by more than four times on the application of liquid nitrogen using the modified tool.Gill and Singh[46] investigated on the machining of the Ti6264 alloy in the EDM and studied about deep cryogenic heat treatment effect on the alloy by drilling it with conducted electrolytic copper tool. And also studied about the accuracy of the drilling holes in the alloy and compared the surface roughness finish and the overcut of Ti6246 which is cryogenically cooled with one which is not cryogenically cooled. On both the workpiece total six drilling setups experiments are performed one setup of drilling for both the workpiece are 30 min, 60 min, 90 min, 120 min, 150 min, and 180 min. From experimentation it is found that the deeply cryogenically cooled Ti 6246 alloy improves the machining condition in the electric discharge machining. The improvement that has shown for different drilling times are up to 8.5% for MRR, 34.78% for TWR, and 30.16% for wear ratio. Singh and singh, [47] worked on EDM by using cryogenic electrode to increase the MRR and lowering of the TWR by using cryogenic and non-cryogenic electrode with pulse on/off and current as parameter. With the increscent in the pulse on time, tool wear rate of copper is decreased in both electrode cryogenic treated copper electrode and non-cryogenic copper electrode and tool wear rate is increased with increase in pulse off time. Tool wear rate is very less in cryogenic treated copper electrode as compared to non-cryogenic treated electrode.

Effects of CT on mechanical property

The effect of both SCT and DCT on different steel grade is shown in table 2.

DCT improvement of Hardness is shown in table 3

	Tool Steel		Carburized steel		Austenitic SS		Martensite SS		High Cr Cast Iron		Aluminum Alloy	
	SCT	DCT	SCT	DCT	SCT	DCT	SCT	DCT	SCT	DCT	SCT	DCT
Hardness	na	+	+	+	na	+	na	+	na	+	na	=
Wear Resisance	+	+	+	+	na	na	na	+	na	+	na	na
Tensile strength	na	+	na	-	=	na	na	na	na	na	na	=
Yield Strength	na	na	na	na	=	na	na	na	na	na	na	=
Fatigue Life	na	na	na	na	+	+	na	+	na	na	na	=
Toughness	na	+	na	na	na	na	=	-	na	na	na	+

"+" =increasing, "-"=reducing "=" = invariant, "na"= not available

Table 2

First Author	Material	Maximum Hardness Improvement
da Silva, [6]	AISI M2 tool steel	No significant changes
Leskovek, [7]	AISI M2 tool steel	+5.26% Rockwell-C hardness
Molinari, [9,10]	AISI M2, H13 tool steels	+8.3% Vickers hardness on M2 +6.9% Rockwell-C hardness on H13
Yun, [11]	AISI M2, T1 tool steels	+2.6% Rockwell-C hardness on M2 +2.8% Rockwell-C hardness on T1
Pellizzari, [48]	AISI H13 tool steel	+6.9% Rockwell-C hardness
Pellizzari, [49]	X155CrMoV12 X110CrMoV8 cold work tool steels	No significant changes on both steels
Gordo, [12]	M3/2 HSS matrix composite with Nb and Ta carbides	+12.35% Rockwell-C hardness
Bensely, [15]	En 353 Carburized steel	+3.48% Vickers hardness
Jordine, [13]	En36A carburized steel	+17% Vickers hardness
Preciado, [18]	Carburized steel	+17% Vickers microhardness
Kollmer, [19]	AISI 4140 cold rolled steel	No significant changes
Zhirafar, [12]	] AISI 4340 low alloy steel	+2.4% Rockwell-C hardness
Yang, [22]	13Cr2Mn2V high chromium white iron	+3.2% Rockwell-C hardness
Zhisheng, [29]	Cr-Zr-Cu alloy electrodes	+3.13% Brinell hardness
Liu, [23]	3Cr13Mo1V1.5 high chromium cast iron	+5.5% Rockwell-C hardness
Lulay, [32]	7075-T651 Al alloy	No significant changes (0.5%)

Table 3

Conclusions

1- Cryogenic treatment improves mechanical properties like toughness, wear resistance and resistance tofatigue cracking. This is because of transformation of retained austenite into stable martensite.

1. Cryoprocessing can provide significant improvement in both product quality andproductivity and hence overall machining economy even after covering the additional cost of Cryoprocessing.
2. Cryoprocessing is an inexpensive one-time permanent treatment affecting the entire section of the cutting toolunlike coatings; therefore, similar lives can be expected after each regrinding of tools.

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