



INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EFFECT OF CRYOGENIC TREATMENT ON MECHANICAL PROPERTIES OF STEEL- A REVIEW

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ABSTRACT

Steel is known for its strength and ductility. The contribution of strength and ductility adds to give steel greater values of toughness and resistance to shock. It is well known the properties of steel can be controlled by controlling its composition or by heat treatment.

Steel is an alloy of iron with definite percentage of Carbon ranging from 0.15% - 1.5 %. These plain Carbon steels are classified on the basis of their Carbon content, as their major alloying element is Carbon steel with low Carbon content and has the same properties as iron i.e. soft but easily formed. As the Carbon content rises, the metal becomes harder and stronger but less ductile.

Although the number of steel specifications runs into thousands, plain carbon steel accounts for more than 90% of the total steel output. The reason for its importance is that it is a tough, ductile and cheap material with reasonable casting, working and machining properties and also amenable to heat treatment to produce a wide range of properties. An effort has been made to review many research papers done by various researchers experimented to alter the properties of steel group materials through various heat treatment processes particular effort has been made to study the effect of conventional, shallow and deep cryogenic heat treatment on mechanical properties of the medium Carbon steel group material.

Influence of deep cryogenic processing in between quenching and tempering (QCT) on the Carbide precipitation, distribution of Carbide particles and the tribological behavior of a commercial steels and tool steel has been examined. The mechanical properties such as strength, hardness and wear resistance of the samples treated by quenching and tempering and QCT have been discussed.

In the present paper, an attempt has been made to review the literature on metallurgical changes that occurred during the cryogenic treatment of steel group materials which is responsible for improving the mechanical properties by the transformation of retained austenite to martensite and precipitation of fine carbides.

KEYWORDS: 2-6 Keywords are required (10pt Times New Roman, Justified).

INTRODUCTION

Heat treatment process is widely used to achieve high mechanical properties. The major requirements of medium carbon steel are high yield and tensile strength, toughness and high fatigue strength. These desirable properties of medium carbon steel can be achieved by adding suitable alloying elements and secondly by heat treatment. Annealing, normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. In normalizing, the material is heated to the austenitic temperature range and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlitic matrix, which results in strength and hardness higher than in as received condition [1, 2]. In hardening the steel or its alloy is heated to a temper high enough to promote the formation of austenite, held at that temperature until the desired amount of carbon has been dissolved and then quench in oil or water at a suitable rate. Also, in the harden condition, the steel should have 100% martensite to attain maximum yield strength, but it is very brittle too and thus, as quenched steels are used for very few engineering applications.

By tempering, the properties of quenched steel could be modified to decrease hardness and increase ductility and impact strength gradually. The resulting microstructures are bainite or carbide precipitate in a matrix of ferrite depending on the tempering temperature. Steel is an alloy of iron with definite percentage of carbon ranges

from 0.15 % - 1.5% plain carbon steels are those containing 0.1% - 0.25%. There are two main reasons for the popular use of steel:

1. It is abundant in the earth's crust in the form of Fe_2O_3 and little energy is required to convert it into iron.
2. It can be made to exhibit great variety of micro structures and thus a wide range of mechanical properties.

In tool steels, the presence of high carbon and high alloy elements is said to influence temperature characteristics of martensite and eventually leads to lowering the start (M_s) and finish (M_f) transformation temperatures [9]. The latter lies well below the ambient temperature for commercial tool steels. Therefore, conventional hardening treatment of those steels fails to convert a considerable amount of austenite into martensite. The retained austenite is soft, and it decreases desirable properties such as hardness and wear resistance. Furthermore, retained austenite is prone to transformation into martensite at the service conditions of tool steels. The untempered freshly formed martensite is very brittle and hence undesirable. In addition, transformation of austenite to martensite is associated with approximately 4% volume expansion that leads to the components distortion and dimensional changes and even failure in extreme working conditions. If the working temperature lies between 200°C - 350°C, there is a probability of converting the retained austenite to a mixture of ferrite and cementite. This transformation results in volume expansion and dimensional changes. Therefore, one of the major challenges is the heat treatment of tool steels is minimizing or eliminating the amount of retained austenite.

The tempering process reduces the amount of retained austenite. However, this process has its own shortcomings as it leads to excessive softening of the matrix and coarsening of any residual carbide, resulting in lower wear resistance. Alternatively, cryogenic treatment is a supplementary heat treatment that is performed on some tool steels before tempering as an effective method for decreasing retained austenite and increasing wear life. Decades ago, the Swiss watchmakers used cryogenic treatment to improve wear resistance and stability of these watch components by keeping these components in the icy mountains and under layers of snow [9]. Cryogenic treatment is generally classified as either so called "Shallow cryogenic treatment" (SCT) at temperature down to about -80°C or deep cryogenic treatment (DCT), at liquid nitrogen temperatures of -196°C. The greatest improvement in desirable properties using cryogenic treatment will be achieved if the treatment takes place quickly after the quenching process and before tempering.

In the deep cryogenic temperatures, finely dispersed η carbides are precipitated as well as eliminating retained austenite. Some researchers have pointed out better carbide distribution and increased carbide particles by using deep cryogenic treatment. Improvement in hardness, wear resistance, bending strength, dimensional stability, fatigue resistance and fracture toughness have also been reported by researchers using cryogenic treatment.

Heat treatment of tool steel includes hardening and tempering cryogenic treatment is modern tempering of tool steel to improve hardness and impact or toughness of parts after quenching. This process typically involves slowly cooling a mass of parts to very low temperature and holding them at this temperature and holding them at this temperature for suitable time then slowly heating to ambient temperature. Hot work tool steel already at this stage of design of their chemical compositions anticipated to be subjected to medium and high tempering temperature in order to obtain stable microstructure of stabilized properties during work [7].

Cryogenic quenching treatments have been accepted and well adopted in commercial practice as an effective method for completing martensitic transformation in alloyed and Case hardened steels as illustrated in [4]. Noted for improving wear resistance, the cryogenic treatments, usually involving cooling within the temperature range from -120°C to 195°C, replace popular dry ice and mechanical refrigeration treatments applied before a single or multiple tempering steps. However, reported wear resistance improvements vary between a few and a few hundred percent, and conflicting results are presented for the change in impact resistance of treated steels [4].

DISCUSSION ON EFFECT OF CRYOGENIC TREATMENT AND COOLING RATE ON PROPERTIES OF FERROUS BASED MATERIAL

Wear is responsible for catastrophic failure of some machine component. This process occurs between hard particles and the working surface. Methods to enhance the life of the component are based on application of wear resistant material or formation of hard wear resistant surface material the wear rate of stress depends on their chemical constituents and conventional heat treatment as outlined by Suchanek and Kuklik (2009).

Suheel Kaila (2010) pointed out that cryogenics is an exciting, important and inexpensive method to increase the life of steel component. It improves abrasive wear resistance, erosion and corrosion resistance and stabilizes the strength characteristics of the steels.

Two kinds of treatments namely shallow cryogenic treatment (SCT) and deep cryogenic treatment (DCT) are adopted by the researchers. The shallow cryogenic treatment is otherwise termed as sub-zero treatment or cold treatment. By shallow cryogenic treatment the conventionally quench hardened steels are directly put in a freezer

kept at -80oC and soaked for 5 hours to attain thermal equilibrium. By Deep cryogenic treatment, the conventionally quench hardened steels are slowly cooled from room temperature to -196oC at 1.24oC per minute, soaked at -196oC for 24 hours and finally heated back to room temperature at 0.62oC per minute. This technique has been proved to be efficient in improving the mechanical and physical properties of materials such as alloys, metals, composites and plastics. During the last decade cryogenic treatment techniques have been developed and are now broadly used by industry to improve the mechanical properties of steel components.

ZbigniewZurecki[4] pointed out that experimental heat treatment schedules applied to A2 steel confirmed that cryogenic quenching results in a moderate improvement of wear resistance and hardness at the cost of impact resistance. Cryo-treated material was more resistant to diamond stylus scratching as well as interfacial sticking during sliding against a steel ball of comparable hardness. Results confirmed that in order to be effective, cryogenic treatments need to be carried out soon after martensitic quenching from austenitic temperatures and before tempering. No additional benefits are observed of

liquid Helium(LHe)-quenching and liquid nitrogen(LIN)- quenching in alternating magnetic field, beyond what may be expected for the competitively run conventional, LIN- based cryogenic treatments. Also pointed out that, future work should focus on a technologically important effect of room temperature aging before cryo-quenching, phase identification of dark carbides, fractography of cryo-aged and embrittled steels, the role of interstitial gas atoms, and exploration of cryo-treatments of ferrous alloys known for strong aging effects. Ex: structural powder metallurgy steels and iron castings.

K.Amini et al[9] pointed out that the martensitic transformation start and finish temperatures in 80 CrMo125 steel were 254oC and -87oC respectively. Therefore, DCT is necessary to minimize or eliminate the amount of retained austenite. It is observed that, in DCT the amount of retained austenite decreases and precipitation of tiny carbides occurs: therefore, hardness in DCT is higher than that in conventional heat treatment (CHT) at all tempering temperatures.

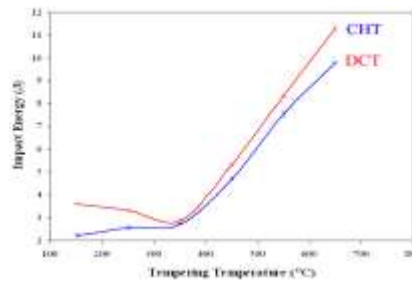


Fig.1 Effect of tempering temperature on impact energy after DCT and CHT treatments

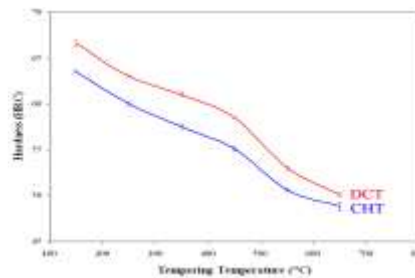


Fig.2 Hardness of the samples for different tempering temperatures after DCT and CHT treatments

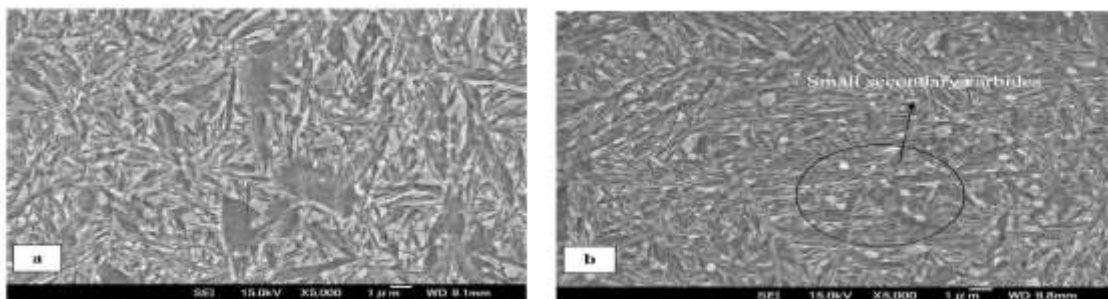


Fig.3 FSEM micrographs of 80CrMo125 tool steel after a)CHT, b)DCT.

Note that carbides in (b) are smaller and homogeneously distributed than (a).

It was also concluded that the dimensional stability is higher in DCT compared to that in CHT. This is attributed to a decrease in the amount of retained austenite and also the amount of α -ferrite.

Dr. Amin et al[7] studied the effect of cryogenic treatment of hot work tool steel type(56NiCrMoV7) on the microstructure and mechanical properties. Three different temperature(-50oC. -100oC and -150oC)were selected at different soaking time (1 hour, 2hours and 3 hours) respectively. All cryogenic treatments wereadopted after hardening by air and oil respectively. It was concluded that the property enhancement for this tool steel can be contributed by conversion most of retained austenite to martensite accompanied with higher dislocations density that leads to the precipitation of fine carbides during the cryogenic treatment especially at the samples quenched by oil and treated at (-150oC) with soaking 1 hour.

P.I. Patil[12] studied the effect of cryo-treatment on different types of steels (AISI 4340), D2 tool steel, M2, D3 steel HSS, H13 tool steel) and reported the complete process of cryo- Heat treatment and must be as follows.

- Austenitizing
- Quenching
- Deep Cryogenic Treatment and
- Tempering

preferably immediate one-by-one sequentially in a cycle. .

Prior to DCT Austenitizing, temperatures plays vital role for improving the properties of steel like wear resistance, hardness and toughness etc. Each material to be assessed separately for selecting the optimum austenitizing temperature and should be co-related to the required desired properties after DCT.

More useful work has been reported by several researchers, but there are many ambiguities in parameters like austenitizing temperature, quenching temperature, rate of cooling soaking temperature, soaking period, rate of warming up, tempering temperatures and tempering period needs further investigations and optimize all the parameters of DCT process for various level of the above parameters results in to enhance the product quality, productivity and wider acceptance in the industries.

M.Pellizzari and A.Molinari[5] applied DCT on two cold work tool steels and reported that deep cryogenic treatment increases wear resistance of cold work tool steel, in particular when carried out just after quenching, prior to tempering. Additional benefits are obtained by replacing the second tempering step by a stress relieving at lower temperature. The maximum effect has been observed in α 110CrMoV82 steel, in which secondary hardening occurs through precipitation of carbides rather than through the decomposition of retained austenite, like in α -115CrMoV121.

The effect is more pronounced when cryogenic cycle is carried out immediately after quenching. The influence of DCT on tempering curves was also investigated and the effect on retained austenite transformation was highlighted. By means of differential scanning calorimetry(DSC) and dilatometry, tempering transformations were investigated,confirming that DCT mainly enhances destabilization of martensite by activating carbon clustering and transmission carbide precipitation.

D. Das et al[11] reported that influence of deep cryogenic processing in between quenching and tempering [QCT] on the carbide precipitation and the tribological behavior of a commercial AISID2 steel has been examined. The developed microstructure has been characterized with anemphasis to understand the influence of QCT vis-à-vis conventional quenching and tempering(QT) on the nature, size, morphology and distribution of carbide particles. The mechanical properties such as hardness and wear resistance of the samples treated by QT and QCT have been evaluated employingvickers indentation and sliding wear techniques respectively. It has been demonstrated that deep cryogenic treatment leads to considerable micro-structural changes which results in enhanced tribological properties.

T.Yugandhar et al[18] in their investigation, the results of practice focused on deep cryogenic treatment at -196oC of AISI 0-1, D-2 and H-12 tool steel. The studyidentified martensite decomposition and precipitation of fine n-carbides as th main mechanisms responsible for the beneficial effects of deep cryogenics.

Mechanical properties of the alloy tool steels subjected to cryogenic treatment are optimized if -196°C “extended quench” is followed with single conventional temper. The implication is that the multiple tempers commonly incorporated in conventional heat treatments can be eliminated. The precipitates of n-carbides in tool steel occur only during the temper that follows deep cryogenic treatment, and lengthens the tool life as the amount

of n-carbides increases. The amount of η -carbides that forms is directly proportional to the tempering time and temperature.

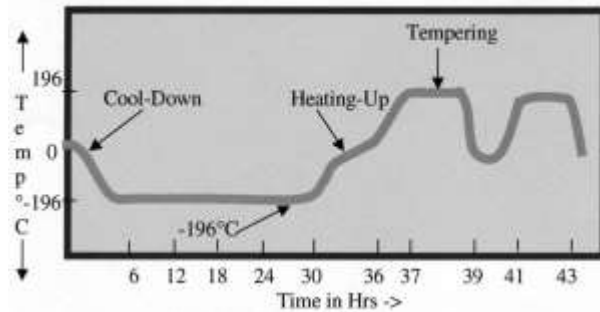


Fig.4 A typical cryogenic treatment for tool steels

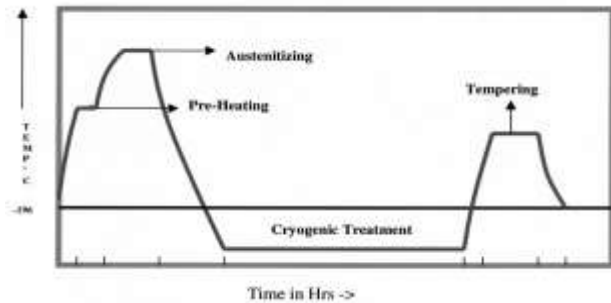


Fig.5 Typical heat treatment cycle using cryogenic treatment.

T.Yugandhar et al[18] pointed out that cryogenic treatment improves mechanical properties like hardness, wear resistance, toughness and resistance to fatigue cracking. The possible reasons for this improvement are as follows:

1. According to one theory of this treatment, transformation of retained austenite is complete- a conclusion verified by x-ray diffraction measurements.
2. Another theory is based on the strengthening of steels by the precipitation of submicroscopic carbides. An added benefit is said to be a reduction in internal stresses in the martensite developed during carbide precipitation, which in turn reduces tendencies to micro-crack.

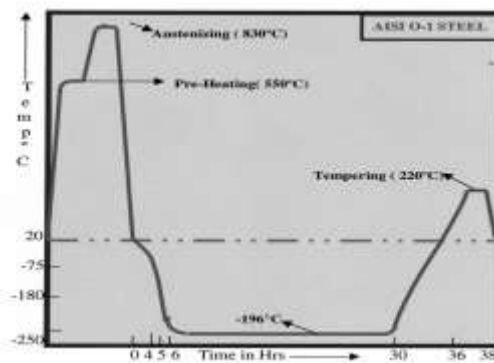


Fig.6 Cryogenic treatment cycle practiced by NFC, Tool Room

Rahul H. Naravade et al[10] investigated that the effect of cryogenic treatment on the wear behavior of D6 tool steel were studied. For this purpose, two temperatures were used: -63°C as shallow cryogenic temperature and -185°C as deep cryogenic temperature. The effect of cryogenic temperature (shallow and deep), cryogenic time (kept at cryogenic temperature for 20 hours and 40 hours) on the wear behavior of D6 tool steel were studied. Wear tests were performed using pin-on-disc wear tester to which different loads and different velocities were applied. The findings showed that the cryogenic temperature decreases the retained austenite and hence improves the wear resistance and hardness. Due to more homogenized carbide distribution as well as the elimination of the retained austenite, the deep cryogenic treatment demonstrated more improvement in wear resistance and hardness compared with the shallow cryogenic treatment. By increasing the keeping time at cryogenic temperatures, more retained austenite was transformed into martensite, thus the wear resistance was improved and further hardness observed. The combination of heat treatment would have to be optimized.

For that purpose Design of experiment (DOE) is performed. The DOE is done with the help of statistical tool i.e.Minitab 16. Produced optimum runs with the help of response surface methodology (RSM) by Box-Behnken design.

A.R.Hake and Thavale et al[17] investigated the effect of cryogenic treatment on mechanical properties of SAE 8620 and D3 tool steel experimented on these steels: both conventional and cryogenically treated. The treatment conducted on D3 steel is hardening at 950°C and triple tempering at 150°C done and designated by D3HTTT as conventional treatment. Secondly, for the 2nd sample of D3 steel is hardened at 950°C and tripled tempered at 150°C followed by cryogenic treatment at 185°C for 16 hours soaking, soft tempered at 100°C

designated as D3HTTTC16. SAE8620 steel hardened at 920°C followed by single tempering at 300°C referred as SAE8620HT. Similarly for 2nd sample of the same material were hardened at 920°C and single tempering at 300°C followed by cryogenic treatment at -185°C for 16 hours and then soft tempered at 100°C referred as SAE8620HTC16.

Table 1: Boiling temperature of cooling media

Sl. No.	Element	Boiling Temperature
1	Oxygen	-183 °C
2	Nitrogen	-196 °C
3	Neon	-247 °C
4	Hydrogen	-253 °C
5	Helium	-269 °C
6	Carbon dioxide	-80 °C

The researchers concluded that, the micro structural analysis revealed that, conventional treated D3 steel revealed mostly uneven size carbides, but in cryo treated conditions uniform distribution of fine carbides are seen, while conventionally treated SAE8620 microstructure depicts coarse plate type tempered martensite with no visible carbides. It exhibits dense tempered martensite with distinct fine carbides after the cryogenic treatment. The hardness and impact energy of both cryo treated D3 and SAE8620 steels was higher than conventionally treated ones.

The cryogenically treated D3 and SAE8620 steels depicted reduction in wear rate by 52% and 65% respectively with respect to conventional treatment. However, wear rate of both cryo treated steels are in close proximity by 5%.

M.Arockia and D. Mohan Lal[19] work carried out on EN52 and 21-4N valve steels. Researchers pointed out that the deep cryogenic treatment has the potential to improve the impact behavior of valve steels.

- ▶ The improvement in the impact energy of the EN52 DCT samples is 23% when compared to that of the CHT samples. Cryogenic treatment increases the driving force for the nucleation of carbides, and facilitated the precipitation of a higher number of finer carbides, resulting in higher toughness valves.
- ▶ Fine platelets of martensite are formed from the retained austenite and promote the precipitation of fine carbides by a diffusion mechanism during tempering.

The fracture surface of the DCT specimen show more secondary cracking and it is due to severe bubble coalescence along the grain boundaries. The presence of microdimples on the fracture facets shows that a considerable amount of plastic deformation has occurred prior to the fracture resulting in increased impact energy of the cryo-treated specimens. This study confirms that deep cryogenic treatment can very well be adopted for improving the impact strength of these valve steels.

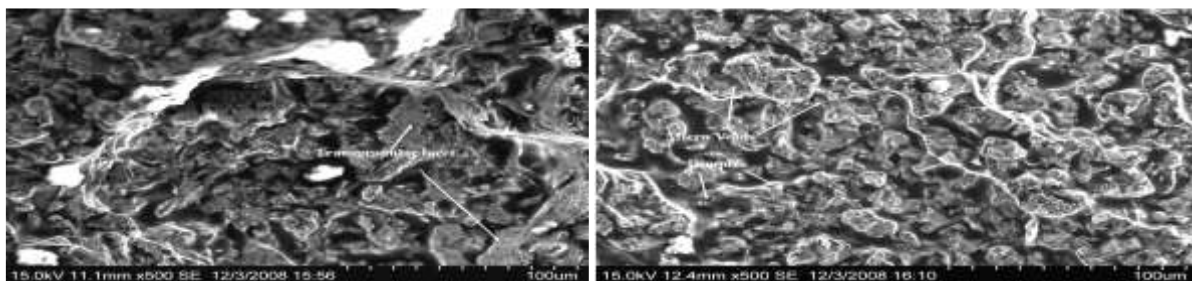


Fig.7 Fractured image of the En-52 CHT Specimen Fig. 8 Fractured image of the En-52 SCT Specimen

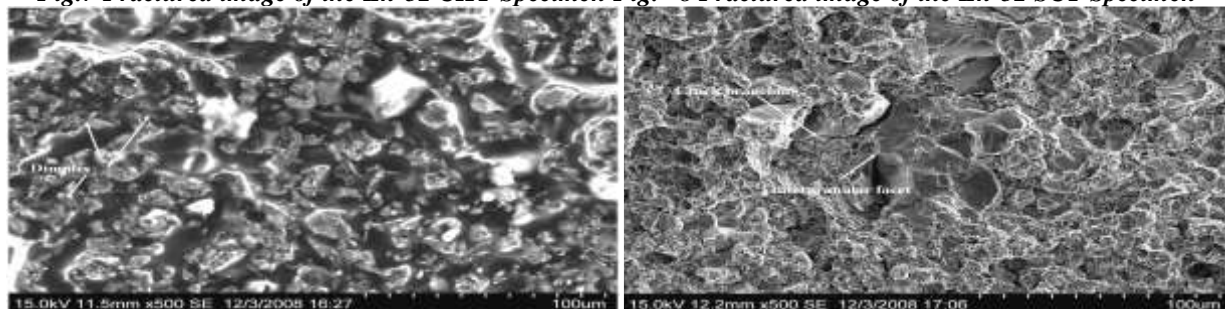


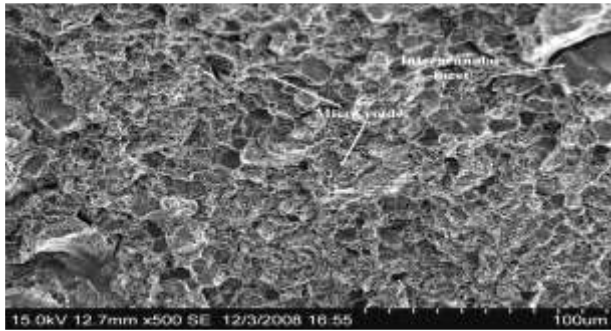
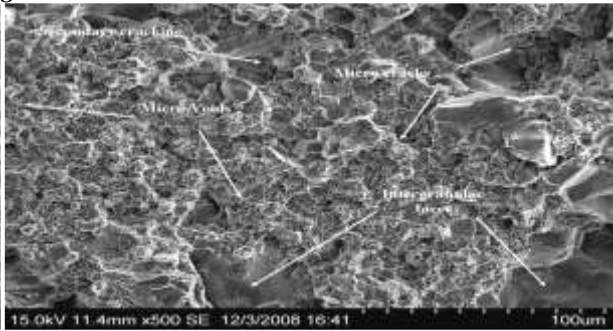
Fig.9 Fractured image of the En-52 DCT Specimen**Fig.10 Fractured image of the 21-4N CHT Specimen**

Fig.

**11 Fractured image of the 21-4N SCT Specimen****Fig.12 Fractured image of the 21-4N DCT Specimen**

K. Odusote et al[3] studied the effect of oil and water quenching of steel on mechanical properties of medium carbon steel. Samples of medium carbon steel were examined after heating between 900°C – 980°C and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. The mechanical behavior of the samples was investigated. The tensile strength and hardness values of the quenched samples was relatively higher than those of the as cast samples.

The samples quenched in palm oil displayed better properties compared with water quenched samples. This behavior was traced to the fact that the carbon particles in palm oil quenched samples were more uniform and evenly distributed, indicating the formation of more pearlite structure, than those quenched in water and the as received samples.

Researchers pointed out that the hardness measurement showed that water quenched samples had higher vickers hardness compared to oil quenched samples. This may be due to faster cooling rate of water, resulting in highest free carbon in martensite. Furthermore, presence of fine dispersion of small particles in the pro-eutectoid ferrite and pearlitic ferrite, which will hinder the dislocation movement, many have also contributed to higher hardness value of the water quenched sample.

It has been established that palm oil can also be used as a quenching medium for medium carbon steel, since mechanical strength of some of the samples quenched with palm oil improved when compared with those of the as received samples. Quenching in water resulted in higher tensile strength and hardness possibly due to formation of martensitic structure after quenching. Palm oil cooling improves the ductility of the steel because of its lower cooling rate compared with water. Thus, palm oil will be a viable quenching medium, where improve elongation of the sample is critical.

M.Pellizzari [20] investigated that the influence of DCT on the properties of four wrought and PM high speed steels was investigated. Hardness and fracture toughness (K_{Ic}) were measured to highlight the possible influence of DCT carried out before and after tempering. Dry sliding wear test were carried using a block on disc configuration. The properties of the two wrought steels, HS6-5-2(AISIM2) and HS6-5-2-5(AISIM35), highlight a well-defined influence of DCT. HS6-5-2 shows a remarkable improvement in abrasive wear resistance without any hardness increase.

The most promising result is obtained by carrying DCT before tempering. The opposite occurs by HS6-5-2-5, containing about 4.8% cobalt, whose wear resistance decreases in any treatment condition including DCT. PM steels show less significant changes in properties, since these are mainly controlled by the high amount of evenly distributed primary carbides which are not influenced by DCT. A slight increase in wear resistance was observed for HS6-5-3-8, namely HS6-5-3. A general worsening was observed for HS6-5-3-8 namely HS6-5-3 plus 8% Cobalt. In the light of results here presented cobalt seems to play a negative effect with respect to the low temperature conditioning of martensite.

V. K. Murugan et al [5], carried out the investigations on the study of the effects of heat treatment on the mechanical properties of medium carbon steel. Samples of medium carbon steels were examined after heating at 900°C and soaked for 60 minutes in a muffle furnace and quenched in oil. The hardness value, tensile strength and toughness of the quenched samples were relatively higher than those of the as received samples. The tempered samples gave an increase in tensile strength and hardness than untreated samples. Comparing the mechanical properties of tempering sample with hardened sample, it was found that there was decrease in toughness and percentage of elongation. The quench and subsequent tempering of the steel in the temperature range 250°C to 550°C resulted in a corresponding decrease in tensile strength. In the above tempering temperature range, toughness of the steel gradually increased with increase in temperature. The result of the yield strength receives more value at

350°C compared to the corresponding tempering temperature. The percentage of elongation is received a lower value at 450°C compared to the other tempering temperature.

Ashish Verma and Praveen Kumar Singh [1] investigated that, the influence of heat treatment on mechanical behavior of AISI1040 steel; it is one of the grades of the medium carbon steel containing 0.40% carbon in its composition. Specimen of quenched/ hardened AISI1040 steel was tempered at temperature (650°C, 450°C, and 250°C) for 60, 90 and 120 minutes to modify desired properties. The mechanical behavior, particularly, UTS, yield strength, elongation and hardness were investigated.

Researchers pointed out that the UTS, yield strength decreases while the elongation increases with an increase in tempering temperature and tempering time of different tempered specimen. The hardness of quenched/ hardened specimen decreases with an increase in tempering temperature and tempering time. Furthermore, increasing temperature and lowering time produces approximately same result as decreasing temperature and increasing time. Researchers summarize that the tensile strength and yield strength decrease, whereas elongation increases with increase in tempering temperature and tempering time. For a given tempering time, the tensile strength and yield strength decrease whereas the elongation (ductility) increases by increasing the tempering temperature. Tensile strength decreases continuously by increasing tempering temperature and time. The higher is the tempering temperature, the lower is the hardness or the more softness (ductility) induced in the previously quenched specimen. The longer is the tempering time (keeping the temperature constant), the higher is the ductility induced in the specimen as a result of the grain rearrangement.

B.S Motagi and Ramesh Bhosle [2] studied the effect of different types of heat treatment on properties of two grades of steel one with copper and another without copper have been used. Reported the results of mechanical testing performed on various heat treated samples of two grades of steel. The samples are tempered at 200°C, 400°C and 600°C for one hour. The heat treated samples were then mechanically tested, the properties and microstructure of two grades of steel have studied. The result revealed that steel with copper has high hardness, UTS and low ductility.

Two grades of steel are subjected to different heat treatment sequences: annealing, normalizing, quenching and tempering at different temperatures at 200°C, 400°C and 600°C. Heat treated samples were mechanically tested for tensile properties and hardness.

As the tempering temperature increases the hardness of both grades of steel are decreasing. The medium carbon steel with copper has the high hardness compared to the medium carbon steel without copper. As the tempering temperature increases the tensile strength of both grades of steel are decreasing. The medium carbon steel with copper has the high tensile strength compared to medium carbon steel without copper. As the tempering temperature increases the ductility of both grades of steel were increased. The steel with copper has the low ductility compared to the steel without copper.

Joel Hemanth [6] investigation deals with the production of deep cryogenically chilled (DCC) ASTM A216 WCB steel (plain carbon group) having 0.5% chromium, subject to different chilling rates to study the effect of chilling on microstructure and mechanical properties. In this investigation, metallic, non-metallic and sub-zero chills (one each) were used. The specimens taken from casting were tested for their strength, hardness and wear behavior. Results of the investigation reveal that chilling rate and addition of chromium (0.5%) has improved both mechanical properties (strength and hardness) and wear resistance of the steel developed. Out of all the chills, sub-zero chill is found to be good in improving mechanical properties because of its high volumetric heat capacity (VHC). The researcher concluded that, type of chill and chilling rate has an effect on mechanical properties.

In this research, characterization of wear behavior of different chilled WCB steels including deep cryo-chilled steel cast using high rate heat transfer technique during solidification was studied. Research pointed out that, microstructure of the chilled steels is finer than that of the unchilled steel with random orientation of carbide particles in pearlite matrix.

Strength, hardness and wear resistance of the chilled steels are superior to those of the unchilled steel. It was found that these properties increase with an increase in carbide particles in fine pearlite matrix.

At lower load, chilled steel exhibit mild wear regime with high coefficient of friction and at higher loads they exhibited severe wear with better wear resistance than the unchilled steel. Size of the wear debris decreases

because of rapid crack propagation of brittle body under compression whereas the size of the carbide fragmentation remain approximately the same.

Rate of chilling is identified as an important parameter that affects microstructure and mechanical behavior of WCB steel.

B. Vasudeva and Joel Hemanth [14] investigated the effect of chilling rates on properties of steel during solidification and studied the effect of addition of 0.5% Nickel on microstructure and mechanical properties of the base WCB steel. In this study, the mould for the casting is prepared according to CO₂ molding procedure. Three metallic, two non-metallic and two sub-zero chills were used for the study. Care is taken to have the same metal flow rate and pouring temperature for all the test castings. The specimens taken from the casting blocks were tested for their strength, hardness and wear. The properties depend on the location of the casting from where the specimens were taken. Results of the investigation reveal that addition of nickel has no effect on mechanical properties and wear resistance but increases elongation significantly. Out of all the chilled steels, sub-zero chilled steel is found to be good in enhancing hardness and hence better wear resistance. In addition tensile strength is also found to be enhanced in sub-zero chilled steel.

From their investigation, the conclusions were drawn from the results obtained.

- Improved mechanical properties obtained in the case of sub-zero chilled steel.
- Wear rate results indicate that sub-zero chilled steel has the least wear rate compared with other chilled steels.
- Volumetric heat capacity (VHC) is identified in this investigation as an important factor which affects mechanical properties of chilled steel.
- Percentage elongation of Ni added WCB steel is maximum compared with base WCB steel.
- Addition of Ni has no effect on mechanical properties of WCB steel.

Mohammed AbdurRazak[13] studied the effects of alloying elements Chromium and Ni on low carbon steel. undissolved carbide particles refine austenite grain size. In the presence of Ni, chromium carbide is less effective in austenite grain refinement than chromium carbide in absence of Ni at temperature below 975°C. Ni does not produce any austenite grain refinement but presence of Ni promotes the formation of acicular ferrites. It was also found that Ni and Chromium as chromium carbide also refines the ferrite grain size and morphology. Chromium as chromium carbide is more effective in refining ferrite grain size than Ni.

The carburization technique is a reasonably satisfactory method in revealing the prior austenite grain boundaries in low carbon steels containing Ni and Chromium. On heating undissolved particles of chromium carbide refined the austenite grain size. In the presence of nickel, chromium carbide is less effective in austenite grain refinement than chromium carbide in absence of nickel at temperature below 975°C and reverse is true above 975°C. nickel did not produce any austenite grain refinement. Nickel and chromium as chromium carbide precipitates were found to refine the ferrite grain size. Chromium is found to be more effective in the refinement of ferrite grain size than nickel. Nickel in solution and chromium as chromium carbide precipitates increased the yield strength of the low carbon steels but the effectivity of chromium carbide precipitates in the increment of yield strength was found to be more than that of nickel. In the presence of nickel the contribution of chromium carbide to increase yield strength is more than that of chromium carbide in the absence of nickel.

K H W Seah and Joel Hemanth et al[16] studied the series of microstructural and strength studies performed on hyper eutectic cast iron which was sand cast using a variety of end chills (metallic, nonmetallic, water cooled and liquid nitrogen cooled respectively). The effects of cooling rate on the dendrite arm spacing(DAS) and the ultimate tensile strength were evaluated. attempts were also made to explain these effects and to correlate the UTS with DAS.

Researchers related the DAS and solidification on the strength of various types of chilled cast iron. Different chilling techniques adopted during solidification of cast iron cast to vary the solidification rate (cooling rate) to control dendrite arm spacing (DAS) which reflects on tensile properties of the material.

The cooling rates over a wide range will have a marked effect on the dendrite cell size and DAS. The under cooling of a melt to a lower temperature increases the number of effective nuclei relative to the growth rate. The growth rate being restricted by the rate at which the latent heat of crystallization can be dissipated. On the other hand, slow cooling favours the growth from a few nuclei and produces coarse grain structures. The refining effect of an enhanced cooling rate applies both to primary grain size and to the substructure; although in the latter case the effect is on the growth process rather than on nucleation. Thus, there is a marked effect upon dendrite cell size and DAS when the cooling rates vary over a wide range.

In this investigation copper was selected as an important alloying element for hyper eutectic cast iron in view of its tremendous potential as a grain refiner. Keeping all the above in mind, this research work was planned:- to obtain experimental data for the DAS with various cooling rates.

-Analyzing the data in the light of the solidification process and to correlate the UTS with DAS.

Joel Hemanth and K.L.Rathakar et al[15] studied the effect of high rate of heat transfer during solidification of alloyed cast iron on mechanical behavior. Hypoeutectic cast iron specimens cast using chills that are water cooled and liquid nitrogen cooled (cryogenic chilling) were compared with specimens of the same chemical composition which were sand cast without any chill. The solidification behavior, number of eutectic cell, grain size and the effects of these on mechanical properties like strength and fracture toughness were recorded and analyzed. It is revealed from the investigation that sub-zero and water cool chilled cast irons exhibit severe under cooling compared to normal sand cast iron.

In this investigation three specimens were taken from the sand cast; by using water-cool copper chill, sub-zero copper chill and a sand cast without using a chill. The effect of cooling rate during solidification is studied. The influence of cooling rate on pearlite content, grain size and eutectic cell count observed from the three specimens along the length of the casting. Effects of these on mechanical properties studied and pointed out that UTS and fracture toughness increase as eutectic cell count increases until the cells become compacted.

SUMMARY

Many researchers carried out the investigation to study the effect of heat treatment on properties of low, medium carbon steel group material and some of the scholars put their effort to evaluate the properties of tool steel by the application of SCT and DCT.

In another research [1, 2] studied the effect of various types of conventional heat treatment on mechanical properties of steel (medium carbon steel group) and compared with steel cast as received condition.

Research [10] conducted elsewhere to determine the effect of DCT and SCT on tool steel. Various parameters like temperature, soaking time etc., influence on mechanical and wear behavior of the tool steels were discussed.

Some studies [5] on wear resistance of cold work tool steels with and without cryogenic treatment and study reveals that the cryogenically treated steel have better wear resistance properties.

In another research [11] discussed about the development of microstructure, precipitation of carbides and transformation of retained austenite to martensite during DCT and its impact on wear resistance is investigated.

Few researchers had took up their research on effect of cooling rate on microstructure, mechanical properties of plain carbon steel during solidification by using different types of chills.

CONCLUSION

Most of the researchers had conducted the experiments and effort has been made to improve the strength properties and wear behavior of the various steel group materials. Investigations were carried out to study the effect of addition of alloying elements on plain carbon steels. Correlations were also established with the various heat treatment processes applied on these materials.

The effort has been made to study the property evaluation of medium carbon steel group materials and tool steels by subjecting them to various heat treatment processes. Most of the researchers put their effort to improve the mechanical properties and wear characteristics of many steel group materials by subjecting them to different rates of heat transfer or various cooling rates in solid-to-solid phase transformation.

But very few researchers had studied and put their effort to improve the various properties of the materials by the application of different cooling rates by using chills during solidification and investigation in liquid-to-solid phase transformation. Hence further investigations are required to enhance the mechanical properties (such as strength, hardness, ductility and toughness) and wear characteristics using a different route by introducing cryogenic chilling effect during solidification. So far very few researchers attempted to study the chilling effect during solidification of few types of steel. Hence further investigation is also required to study the liquid-to-solid phase transformation during solidification of steel material by controlling/regulating the cooling rate and due attention also required to study the effect of addition of alloying elements on strength properties and wear characteristics of one of the ASTM Grade steel used for crushing ores/stones in mining industries.

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