

# Cryogenic Technique for the Steel Heat Treatment

Sanjay Murari, Sunil Bhujangannavar

**Abstract**— Considering the wide uses of steel, it is surprising to many people that there is still much do not know about it. This paper will review what is known about cryogenic tempering and future research plans to improve our understanding of these important phenomena. Cryogenics or deep freezing have been around for quite some time. Cryogenic processing had its US origins in 1940s. Cold treatments or sub zero treatments are done to make sure that there is no retained austenite during quenching. Cryogenics is a relatively new process and to eliminate retained austenite, the tempering has to be lowered, but one that using correct procedures can bring substantial economic benefits. In cryogenic treatment the material is to be deep freeze temperatures of as low as  $-185^{\circ}\text{C}$  ( $-301^{\circ}\text{F}$ ). The austenite is unstable at this temperature and the whole structure becomes martensite. This is the reason to use cryogenic treatment. Processing is not a substitute for heat treating if the product is properly treated or if the product is over heated during remanufacturing or it is over stressed during use. Cryogenic processing will not in itself harden metal like quenching and tempering, it is an additional treatment to heat treating. The benefits of this process includes; reduction of abrasive and adhesive wear, improved machining properties resulting from permanent change of structure of the metal, reduction of frequency and cost of tool remanufacturing and reduction of likelihood of catastrophic tool failure due to stress fracture. In the present study, the cryogenic technique is applied by exposing the steel to deep freezing environment for 24 hours and slowly raised to room temperature. Cryogenic processing makes changes to the structure of the materials being treated and dependent on the composition of the material, it performs three things; viz. retained austenite turned to martensite, carbide structures are refined and stress is relieved.

**Index Terms**— Austenite, Cryogenic heat treatment, Eta carbides, Liquid nitrogen, Martensite, TTT diagram.

## 1 INTRODUCTION

Cryogenic tempering takes place in a chamber, where materials are gradually lowered in temperature. Shallow cryogenic tempering is performed at about  $-120^{\circ}\text{F}$  ( $-85^{\circ}\text{C}$ ) for 10 hours or so, where as deep cryogenic tempering takes the material below  $-300^{\circ}\text{F}$  ( $-185^{\circ}\text{C}$ ) for more than 24 hours. The materials are then slowly raised to room temperature and usually annealed at about  $300^{\circ}\text{F}$  ( $149^{\circ}\text{C}$ ). Only deep cryogenic tempering has shown to give the greatest improvement in wear resistance. Controlled experiments and industrial experience have demonstrated that many materials benefit from this treatment. Increased wear life and better corrosion resistance, while at the same time maintaining or even improving toughness have been observed. However, few materials benefit more than tool steels. Tool steels that are deep cryogenically treated will typically last more than 50% longer than as quenched specimens. In additional, tool steels have been studied extensively to understand cryogenic phenomena. Therefore, we will discuss the present understanding of the cryogenic tempering in these metals. Even the ancients knew that the rapid quenching of steel from elevated temperatures made it harder. We know that this rapid quenching produces a metastable phase in steel called martensite. This transformation process is rapid diffusionless.

- Sanjay Murari is currently pursuing B.E. degree in Mechanical engineering in Vishveshvarayya Technological University, India, PH-07204745646. E-mail: [murarisanjay70@gmail.com](mailto:murarisanjay70@gmail.com)
- Sunil Bhujangannavar is pursuing B.E. degree in Mechanical engineering in Vishveshvarayya Technological University, India, PH-09538262903. E-mail: [sunilrb\\_hit@yahoo.com](mailto:sunilrb_hit@yahoo.com)

## 2 WHAT IS CRYOGENIC HEAT TREATMENT?

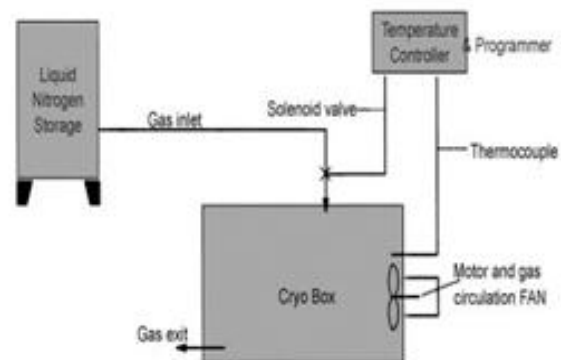


Fig. 1

### 2.1 DEFINATION AND PROCESS

Cryogenic heat treatment is the ultra low temperature processing of materials to enhance their desired metallurgical and structural properties. The temperature is about  $-196^{\circ}\text{C}$  ( $77\text{K}$ ). Ultra cold temperatures are achieved using computer controls, a well insulated treatment chamber and liquid nitrogen ( $\text{LN}_2$ ). The entire process takes between 36 to 74 hours, depending on the weight and type of material being treated. Strict computer control and proper processing profiles assure that optimum results will be achieved with no dimensional changes or

chance of thermal shock. The process is not a surface treatment; it affects the entire mass of the tool or component being treated, making it stronger throughout. Slowly cooling a tool steel to deep cryogenic temperatures and soaking it at this low temperature for a number of hours changes the material's microstructure. In ferrite steels, it is the transformation of austenite, a large soft crystal, into martensite, a smaller, harder, more compact crystal. The amount of martensite formed at quenching is a function of the lowest temperature encountered. As the temperature reduces to  $-185^{\circ}\text{C}$ , carbides start to grow throughout the structure. The net result is that the crystal structure is transformed with the boundary adhesion between the various crystal elements. The martensite and fine carbide formed by deep cryogenic treatment work together to reduce abrasive wear. The process curve is as shown below in figure.

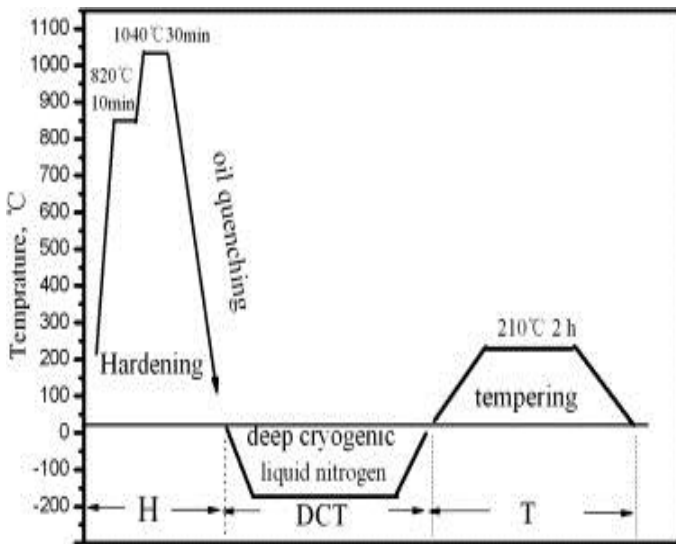


Fig. 2

## 2.2 CHANGE OF PHASE

To form the martensite the steel must initially be in the face center cubic (FCC) form of iron called austenite ( $\gamma$ ). To establish austenite in the steel, one typically has to "soak" the steel at temperature above  $750^{\circ}\text{C}$ . There is another form of iron called ferrite. If the steel is ferritic ( $\alpha$ ), it cannot form martensite. Below figure shows the description of transformation with temperature.

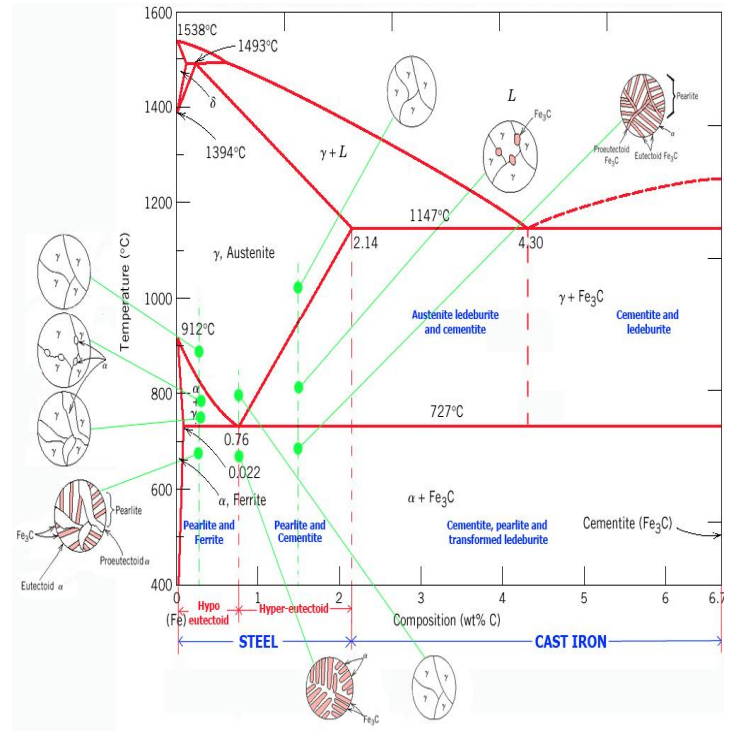


Fig. 2.1

The martensite reaction occurs as the FCC austenite transforms to a BCT (Body Centered Tetragonal) martensite. Carbon atoms are trapped in interstitial sites during the rapid transformation, as the carbon content increases a greater number of carbon atoms are trapped. If the temperature quench is not rapid, stable pearlite, bainite and other constituents can form.

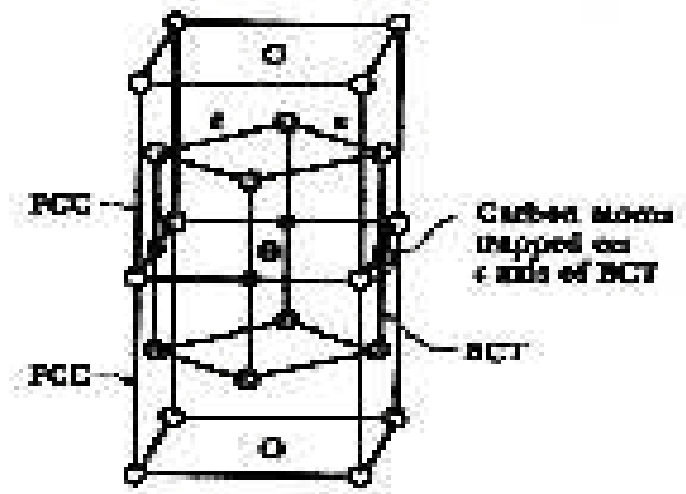


Fig. 2.2

### 3 EXPERIMENT RESULT & DISCUSSION

As the steel is quenched, the martensite starts to form at a given temperature for the material. This temperature is called the martensite start temperature ( $M_s$ ). To completely form martensite, the martensite finish temperature must be reached before pearlite and cementite can start to form. This mechanism can be seen on a time-temperature-transformation chart (TTT chart) shown below in figure.

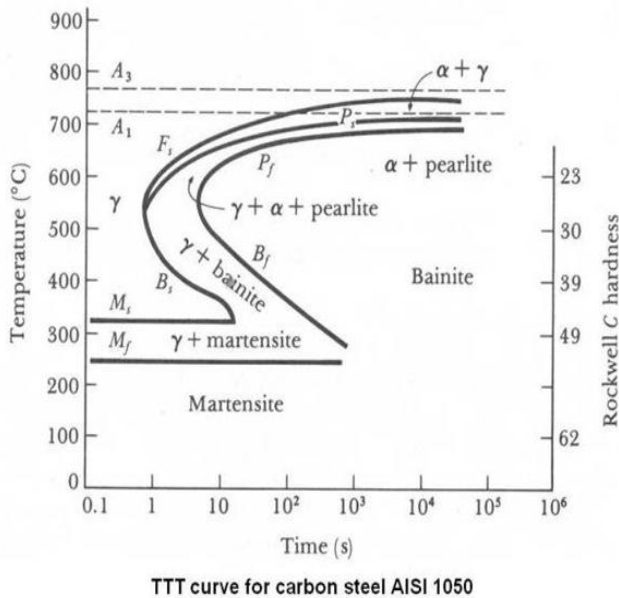


Fig. 3 (a)

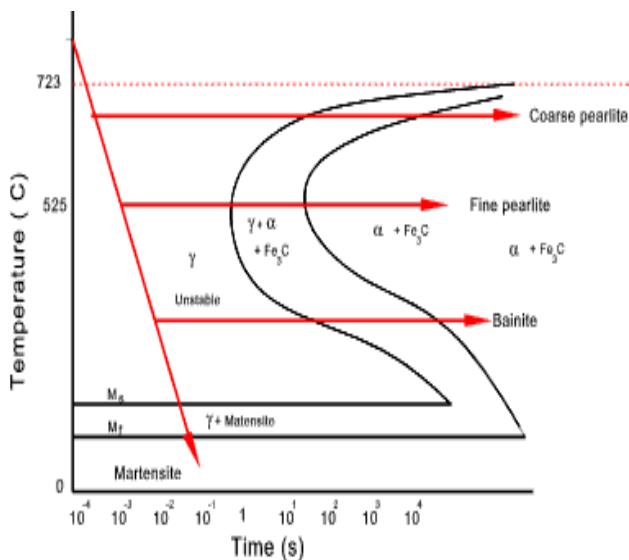


Fig. 3 (b)

The addition of carbon reduces the temperature at which martensite stops forming as we can see in the above TTT charts. The  $M_f$  temperature is the temperature at which 100% of the martensite has formed.  $M_f$  for 1050 steel (0.5% carbon) is 245°C, whereas it is 85°C for 10110 steel (1.1% carbon). The presence of other alloying materials such as manganese, chromium and vanadium tends to reduce the  $M_f$  temperature and provides the added benefit of suppressing the formation of pearlite and bainite. The combination of the carbon and the alloying metals can reduce  $M_f$  to below room temperature, with no possibility of other constituents forming. The result shows the change in microstructure of tool steel that gives best strength and good surface finish as shown in figure below.

Fig 3.1 (a)  
Before cryogenic treatment

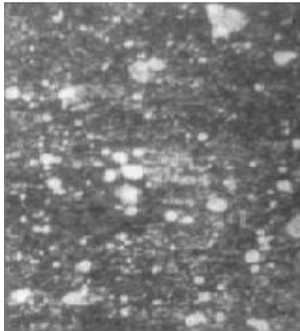
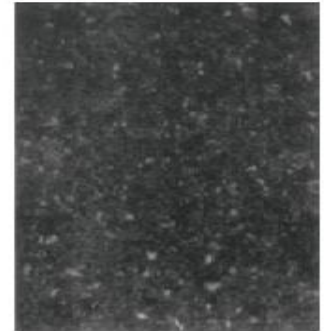


Fig 3.1 (b)  
After Cryogenic Treatment



### 4 BENEFITS OF CRYOGENIC TREATMENT

- Promotes a more uniform micro-structure.
- Reduces abrasive and adhesive wear.
- Permanently changes the structure of the metal resulting in improved machining properties.
- Improved thermal properties.
- Better electrical properties including less electrical resistance.
- Reduced coefficient of friction
- Less creep & walk, and improved flatness for critical tolerance parts.
- Easier machining, polishing and grinding for better edge and finishes
- All metals including copper and aluminum benefit from the residual stress relief that cryogenic treatment promotes.

### 5 APPLICATIONS

- Cutting tools for different machining operations: saw-

ing, milling, drilling, broaching, turning, slitting, shearing.

- Metal forming tools: dies, molds, punches.
- High precision parts: gauges, guides, shafts.
- Parts of high performance sports car engine and transmissions: crankshafts, connecting rod, piston rings, engine blocks, gear parts, camshafts.

## 6 CONCLUSION

The dramatic improvement in wear resistance in deep cryogenically treated tool steels, with no loss in toughness is most likely explained by the formation of eta carbides and the formation of fine cementite particles in the final tempered structure. It would appear that the conversion of additional martensite, although often present, is probably a secondary mechanism. This understanding supports the increase wear resistance in materials that don't readily form martensite.

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