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Microstructural Studies on Cryogenically treated High Carbon High Chromium D3 Cold work tool steel used in hole piercing operation on Chain component

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ABSTRACT

In sheet metal stamping operations like Blanking and Piercing the punches are more prone to failure than the dies. The wear on the punches will affect the size and shape of the components produced. Hence industries are striving to innovate the ways by which the punch life can be prolonged which results in reduced punch changeover time and reduced spending on punch costs. In this study, the effect of cryogenic treatment on the properties of the piercing punches made of High Carbon High Chromium D3 Cold work type tool steels on microstructure, for improvement of tool life has been investigated. Conventionally the tool steel is heat treated by following Stress Relieving, Hardening and Tempering processes. In the present study 4 different groups of punch samples were prepared in High Carbon High Chromium D3 type cold work tool steel. First group of punches were conventional heat treated (HT). The second group of punches are cryogenically treated immediately after Stress relieving and hardening without performing tempering (HC). The third set of punches were cryogenically treated immediately after stress relieving and hardening and finally tempered (HCT) and the last group of punches were conventionally heat treated followed by cryogenic treatment (HTC). The cryogenic treatment is expected to improve the life of punches by improving the properties of the punches. The SEM and OM images of the cryogenically treated punches were taken to assess the improvement in their properties. The results showed significant improvement in properties of cryogenically treated punches favouring improvement in their life.

Indexing terms/Keywords

Cryogenic treatment, wear resistance, D3 steel.

Academic Discipline And Sub-Disciplines

Mechanical Engineering; Press Tools

Type (Method/Approach)

Experimental; Analysis

1. Introduction

Blanking and Piercing operations are widely used in sheet metal stamping processes during mass production of components among various sectors. A press is used for these operations where a press tool comprising punch tool and die surface cuts the metal into the required shape and size. While producing components by blanking and piercing operations some amount of material cutout by the cutting dies from the stock material sheet used. The shearing mechanism involved in both the blanking and piercing operations are same. But they differ in applications. If the cutout portion of the stock material is the required product the process is called as blanking and if the cutout portion is the scrap the process is called piercing. These punches are exposed to severe cyclic loads during the shearing operation, which induces adhesive and abrasive wear on the cutting edges of the punches affecting their life [1]. Punch and Die wear are the most common causes of press tool failure. Wear on punches affects the geometry of the components produced, which leads to rejection of the components [2]. Punch wear is a major cause for poor quality and dimensional variations of the components. In addition, punch wear also leads to failure of the press tool, causing wastage of time in replacing the wornout punches and increase the manufacturing cost of the components produced [3]. Due to the increased competition the metal stamping industries are looking for methods and ways to increased tool life, reduced tool cost, improved part quality and reduced lead time.

Punches and dies are exposed to severe cyclic loads and the punches has to withstand these loads without excess wear or deformation. Hence punches and dies are made of tools steels. Cold work tool steels are the most preferred type of tool steels for punches and dies as they are capable withstand high loads and having high wear resistance. Conventionally these tool steels are heat-treated to acquire required high hardness and wear resistance. The Conventional heat-treatment cycle consisting of austenitization, quenching and tempering. Even properly performed heat-treatment won't convert all the austenite into martensite in the microstructure of the steel. There will be retained austenites in the microstructure of the steel. These soft and unstable retained austenites could reduce the product life. These retained austenites are likely to transform into martensite under certain conducive conditions. But these newly formed martensite is very brittle and differs from the tempered martensites which are suitable to be used in tools. Hence transformation of retained austenite into martensite is to be carriedout to the maximum extend possible before putting them into use. The transformation from austenite to martensite is is driven farther and farther toward completion as temperature decreases and to achieve this cryogenic treatment is used [4].

Cryogenic treatment, which is sometimes called cryogenic tempering or cryogenic processing is an add-on process to the conventional heat treatment process which utilizes ultra-cold temperatures for modification of the micro-structure of metals. Cryogenic treatment involves cooling down the steel specimens to cryogenic temperature usually using liquid nitrogen at a predetermined rate, soaking at that temperature for a sufficient time duration and heat them back to room temperature at a predetermined rate. This treatment increases the hardness, wear resistance and toughness of the tool steels [5].

Researchers established that the cryotreatment promotes the transformation of retained austenite into the martensite matrix and precipitation of fine carbides and their uniform distribution in the matrix. They also documented that the cryogenic treatment contributing to improvement of wear resistance, hardness and strength [4-7]. Researchers also reported improvement in performance of cutting tool materials on turning, milling and drilling with the application of cryogenic treatment [8–12]. Though many works were reported on the performance of cryotreated tool and die steels by conducting standard wear tests like Pin-on-disk, Sliding wear test etc., little research has been done on the performance of D3 cold work tool steel in the actual shop floor test.

In this part of the study, the microstructural studies of the cryogenically treated piercing punches made of D3 Cold work tool steels which is to be tested in the shop floor production of Chain part is analysed. It is expected that the cryogenic treatment improves the microstructure of the steel which will enhance the wear resistance of the punches.

2. Experimentation

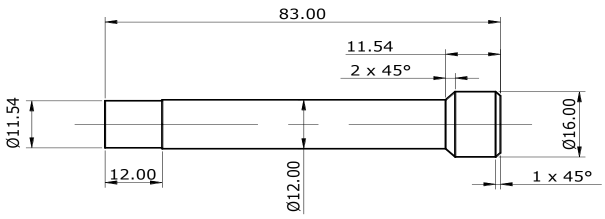
2.1 Material Selection

The piercing punches made High Carbon High Chromium D3 type cold work tool steel were chosen for studying the effect of cryogenic treatment. The chemical composition of the D3 steel as per ASTM A681 is listed in Table.1. The yield strength and tensile strength of the piercing punch material (as provided by the manufacturer of tool steel) were 850 and 970 N/mm^2, respectively.

Table 1 Chemical Composition of D3 Tool Steel as per ASTM A681

Material	% C	% Mn	% P	% Si	% V	% Cr
D3	2 - 2.35	0.10 – 0.60	0 – 0.030	0.10 – 0.60	1.00 max	11.00 – 13.50

[Piercing punches to produce chain components from the blanks made of AISI 1055 medium carbon steel sheet were made of D3 Cold work type tool steel as per the required dimensions Fig. 1.(a). An actual punch manufactured as per the size is shown in Fig. 1. (b).



(a)

(b)

Fig. 1 Piercing Punch made of D3 Steel

2.2 Treatments

The punches made of High Carbon High Chromium D3 type cold work tool steel were subjected to various treatments as indicated in Table -2 and treatment cycles followed is shown in Fig. 2.

Table 2 Treatment cycles followed to AISI D3 Piercing Punches

Treatment Category	Particulars of treatment	Nomenclature followed
Batch-1	Stress Relieving (600°C), Hardening (950°C) and Double Tempering (200°C for 2 hrs)	HT
Batch-2	Stress Relieving (600°C), Hardening (950°C) and Cryotreated (-196°C for 12 hrs)	HC
Batch-3	Stress Relieving (600°C), Hardening (950°C) and Cryotreated (-196°C for 12 hrs) and Double Tempering (200°C for 2 hrs)	HCT
Batch-4	Stress Relieving (600°C), Hardening (950°C) and Double Tempering (200°C for 2 hrs) and Cryotreated (-196°C for 12 hrs)	HTC

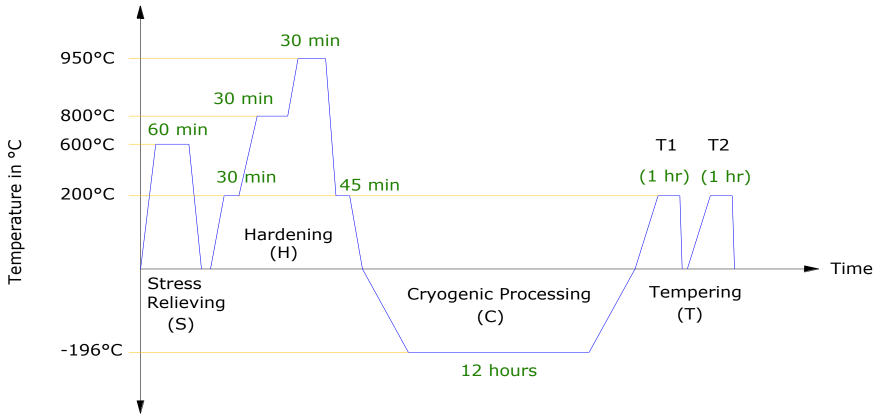


Fig. 2 Schematic Heat Treatment Schedule consisting of Hardening (H), Cryogenic Processing (C) and Tempering (T)

2.2.1 Stress relieving and Hardening

The machined punches made of D3 type cold work tool steel were stress relieved in oil fired furnace at a temperature of 600°c and soaked for 1 hour followed by furnace cooling. Hardening of D3 tool steel punches was done in oil fired furnace. The hardening is obtained in 3 steps. First, the punches were preheated at 200°C and were held for 30 minutes at that temperature followed by preaustenitation at 800°C and held or 30 minutes at that temperature. The final austenitation done at 950°C by held the punches for 30 minutes at that temperature. Then the punches were oil quenched to 200°C and held for 45 minutes before air-cooled. The punches were then used for subsequent tempering and cryogenic treatment before final machining.

2.2.2 Tempering

Double tempering of D3 type cold work tool steel piercing punches were carried out in oil fired furnace. Punches in Batch-1 and Batch-4 after hardening were immediately subjected to first tempering at a temperature of 200°C with 1 hour soaking, followed by air cooling to room temperature. After air cooling the punches were subjected to second tempering for the same temperature and duration and air cooled. The punches in Batch-3 were tempered following the similar procedure after Hardening and Cryotreatment. Punches in Batch-2 were not tempered. The treatment cycles followed for the samples are indicated in Table. 2.

2.2.3 Cryogenic treatment

The D3 type cold work tool steel piercing punches in Batch-2 and Batch-3 were cryotreated in a cryogenic chamber after hardening. The punches were brought to -196°C in 1 hour from room temperature gradually and soaked at -196°C for 10 hours. Then the punch samples were brought back to room temperature in 1 hour gradually. The punches in Batch-4 were cryotreated following the same procedure after double tempering.

2.3 Hardness measurement

The microhardness values of the samples were obtained by Vickers Micro hardness tester and the Vickers micro hardness values were measured at a load of 0.2 kg and the test was carried out several times to obtain a reliable value.

2.4 Microstructural examination

For the metallographic studies, the samples were prepared as per standard guidelines. The microstructural studies were carriedout on images taken by Scanning Electron Microscope (SEM) (Make: Jeol, Model: JSM-6390) and Optical Microscope (Make: CARL ZEISS) at different magnifications. The samples were etched using three different etchents to understand the microstructure in each case.

The etchants used are i) 2% Nital, ii) Peric acid, Soap oil and Water and iii) Viella's reagent (1gm picric acid, 5 ml Hcl and 100ml ethanol). Among the three etchants used the Viella's reagent revealed the tempered martensitic microstructure better when compared to other two etchants.

3 Results and discussion

3.1 Chemical Composition

The chemical composition of all the 4 sample category was analysed for the conformance of material selected for the analysis using Spectroscopy and the results are listed below in Table 3.

Table 3 Chemical Composition of the D3 samples tested

Sample Category	%C	%Mn	%P	%Al	%Ni	%Si	%V	%Cr	%Mo
Batch-1 (HT)	2.034	0.2709	0.0154	-	0.0681	0.27094	0.07553	12.150	0.02004
Batch-2 (HC)	2.096	0.2632	0.0206	0.0028	0.1881	0.21768	0.07222	12.635	0.04217
Batch-3 (HCT)	2.064	0.2423	0.0192	-	0.1729	0.18926	0.05969	12.836	0.03033
Batch-4 (HTC)	2.165	0.2632	0.0206	0.0028	0.1881	0.21768	0.06369	12.635	0.26327

The chemical composition of the samples tested confirms to D3 Grade steel as per ASTM A681 Standards.

3.2 Hardness tests

The Vickers Micro hardness values were measured at a load of 0.2 kg using Vickers Micro hardness tester and the values are converted into equivalent HRC values as listed in Table 4 below.

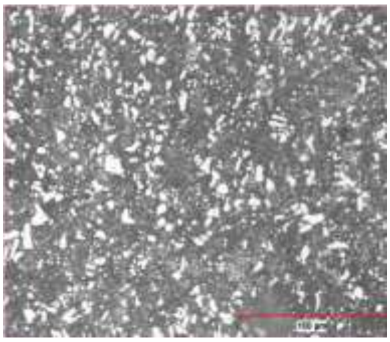
Table 4. Vickers Micro hardness values of the D3 samples tested

Sample Category	Batch-1 (HT)	Batch-2 (HC)	Batch-3 (HCT)	Batch-4 (HTC)
Hardness Value (HRC)	58	62	60	59

The results showed that the cryotreatment increases hardness value considerably than conventional heat treated samples in Batch-1 (HT). Samples in Batch-2 (HC) achieved the highest hardness by cryogenic treatment immediately after hardening due to the conversion of retained austenite into martensite structure during cryogenic cooling. While comparing the hardness value of the Specimens in Batch-3 (HCT) is 2HRC less than Batch-2 (HC) samples due to precipitation of carbides and reduction in tetragonality of martensite during tempering. The hardness value of the Batch-4 (HTC) samples is less than Batch-3 (HCT) samples. The reason might be that the tempering followed by hardening stabilizes the retained austenite, making it more difficult to transform during cryogenic treatment.

3.3 Microstructural analysis

Microstructural analysis was carried out to ascertain the effects of Cryogenic treatment on the properties of D3 tools steel. Figure 3 shows the optical microscope images of the D3 steel specimens subjected to various treatments as per the schedule in Table 2. Figure 3 (a) depicits the microstructure of Batch-1 (HT) specimen in which elliptical Globular shape carbides are observed in matrix of tempered martensite. Globular and nodular shaped carbides uniformly distributed in the martensite matrix. Retained austenite seen in the matrix. Figure 3 (b) exhibhits the microstructure of Batch-2 (HC) specimen in which globular and erratic shape carbides are observed in matrix of tempered martensite. The size of the globular carbides are very small compared to that of Batch-1 (HT) specimen. Untempered martensite observed. Carbides uniformly distributed in the austenite matrix. Figure 3 (c) exhibits the microstructure of Batch-3 (HCT) specimen in which reduction of carbide size is visible compared to Batch-1 (HT). Globular and nodular carbides uniformly distributed in the tempered matrix. Retained austenite not seen. Figure 3 (d) depicits the microstructure of Batch-4 (HTC)specimen. Globular and erratic shape carbide is observed in matrix of tempered martensite. Carbides uniformly distributed in the tempered martensite matrix. Untempered martensite observed.



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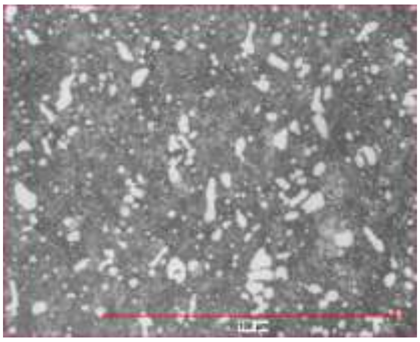

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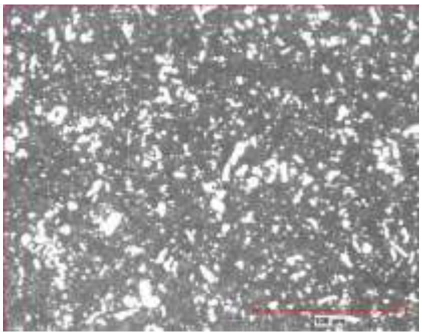
(a) Batch-1 (HT)



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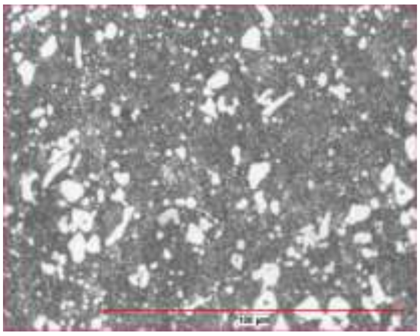

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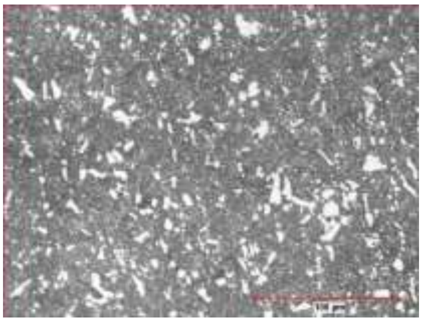
(b) Batch-2 (HC)



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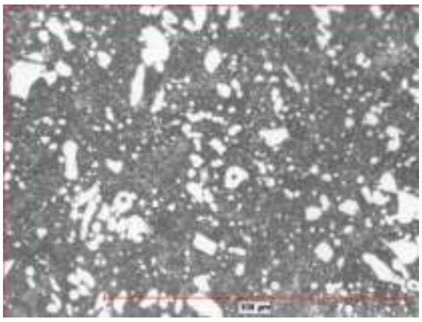

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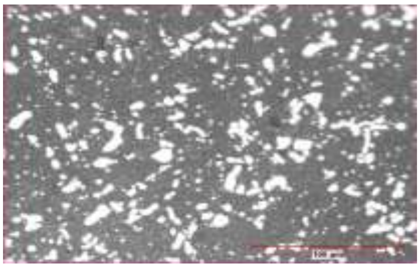
(c) Batch-3 (HCT)



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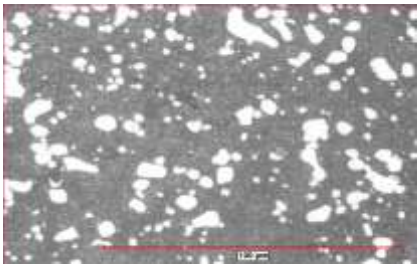

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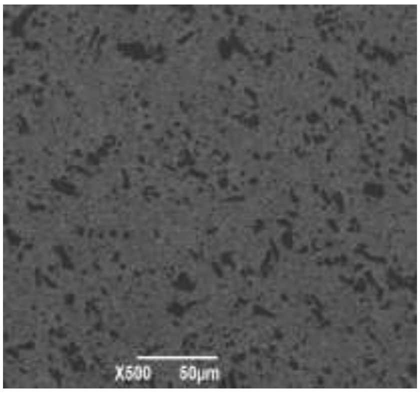
(d) Batch-4 (HTC)

Fig. 3 Microstructure of D3 specimens: (a) Batch-1; (b) Batch-2; (c) Batch-3; (d) Batch-4

To ascertain the presence of fine carbides SEM images with high magnification (@3500X) were taken. Figure 4 shows the SEM images of the D3 steel specimens subjected to various treatments as per the schedule in Table 2. Figure 4 (a) shows the microstructure of the Batch-1 (HT) conventionally heat treated D3 specimen in which the primary carbides and secondary carbides were uniformly distributed in the tempered martensitic matrix with undissolved carbides seen. Figure 4 (b) shows the microstructure of the Batch-2 (HC) specimen which consists of martensite matrix with undissolved carbides and fine carbides. Untempered martensites are also visibly present. Figure 4 (c) shows the microstructure of Batch-3 (HCT) specimen which consists of tempered martensite matrix with undissolved carbides. Undissolved carbides considered as primary carbides as they became unprecipitated. Hence no presence of retained austenites in the structure. Particularly the size of the secondary carbides are refined. Also the carbide population is increased. Figure 4 (d) shows the microstructure of Batch-4 (HTC) specimen which exhibits the tempered martensite matrix, undissolved carbides and fine carbide precipitates.



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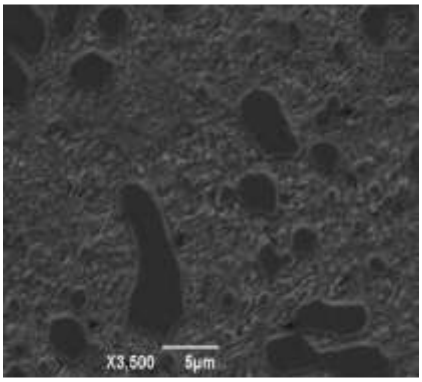

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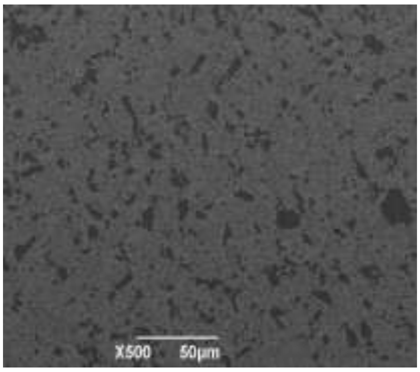
(a) Batch-1 (HT)



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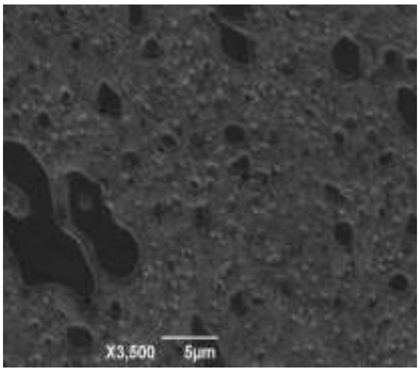

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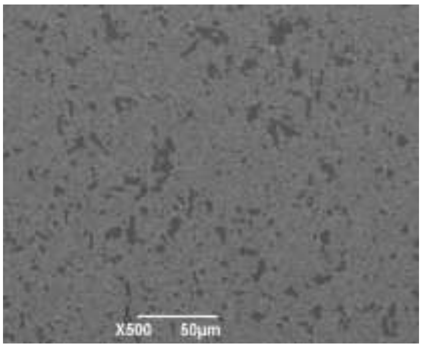
(b) Batch-2 (HC)



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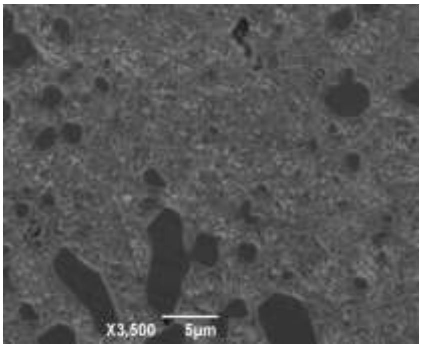

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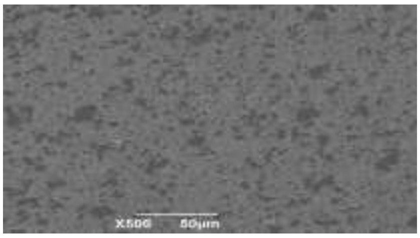
(c) Batch-3 (HCT)



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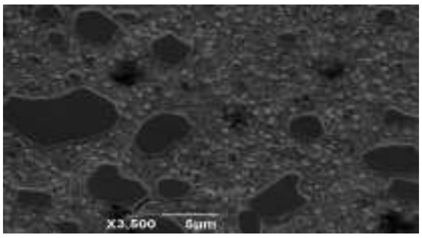

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(d) Batch-4 (HTC)

Fig. 4 SEM Micrographs of D3 specimens: (a) Batch-1; (b) Batch-2; (c) Batch-3; (d) Batch-4

4. Conclusion

Cryogenic treatment is an additional process to conventional heat treatment process of tool steel which improves the microstructure of metal by transforming retained austenite present after conventional heat treatment process into martensite, which on tempering results in the precipitation of carbide particles due to which both toughness and wear resistance increases consequently. Cryogenic treatment of D3 type cold work tool steel proved to be effective in increasing the hardness of specimens compared to the conventionally heat treated steel (HT). The hardness value gradually increased in the order of Conventionally Heat Treated Specimen (HT), Hardened + Tempered + Cryotreated (HTC), Hardened + Cryotreated + Tempered (HCT) and Hardened +Cryotreated (HC). From microstructural studies of Optical Microscopic images and SEM images it is evident that the retained austenite present in the conventionally heat treated specimen is converted in to Martensite and on tempering carbide precipitation occured. This conversion of retained austenite into martensite and precipitation of fine carbide will enhance the wear resistance and toughness of the steel. Hence the cryogenic treatment will augment the wear resistance and toughness properties of the punch material which will ensure the long life of the punches.

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