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# Study the Effect on the Hardness of three Sample Grades of Tool Steel i.e. EN-31, EN-8, and D3 after Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering

[1]Ashish Bhateja
*[1]Assistant Professor, Department of Mechanical Engineering,*
*Gulzar Institute of Engineering & Technology, Khanna, Punjab -141003, India*
[2]Aditya Varma, [3]Ashish Kashyap and [4]Bhupinder Singh
*[2, 3, 4] B.Tech Students, Department of Mechanical Engineering,*
*Gulzar Institute of Engineering & Technology, Khanna, Punjab -141003, India*

**Abstract**

This Study is based upon the empirical study which means it is derived from experiment and observation rather than theory. Main Objective is to Study the Effect on the Hardness of three Sample Grades of Tool Steel i.e. EN-31, EN-8, and D3 after Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering. This survey also helps to find out the place of the work to be carried out i.e. availability of set up, techniques used for such, estimated time & cost requires for such study to be carried out for such industrial survey to be carried out we designed a Survey questioner and selects various places who offers heat treatment services Ludhiana based. After literature review and industrial survey aims to prepare heat treatment performance Index HTPI 2012 which is supposed to be very effective tool for defining the objective function. After selection of material & heat treatment processes further aims to perform mechanical & chemical analysis i.e. composition testing of the three tool steel EN-31, EN-8, and D3 before treatment. After composition testing aims to do heat treatment processes i.e. Annealing, Normalizing, and Hardening & Tempering to be carried on such material & after treatment aims to perform harness testing on the treated and untreated work samples.

**Keywords -**Annealing, Hardening & Tempering, Heat Treatment, Normalizing, Tool Steels

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## I. Introduction

Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. Heat Treatment is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability, restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics.

The heat treatment operation can be defined as: heating a metal or alloy to various definite temperatures, holding these for various time durations and cooling at various rates. This combination of controlled heating and cooling determine not only nature and distribution of micro-constituents (which determine the properties of a metal or alloy), but also the grain size.

Thus, the main aim of heat treatment operations is to control the properties of a metal or alloy through the alternation of structure of metal or alloy. The purposes of the various heat treatment operations are as given below:

- To remove or relieve strains or stresses induced by cold working (drawing, bending etc.) or non-uniform cooling of hot metal (for example welding): Annealing
- To increase strength or hardness of the material for improved wear resistance: Hardening.
- To improve machinability : Annealing
- To soften the material: Annealing
- To decrease hardness and increase ductility and toughness to withstand high impact (Tempering)
- To improve the cutting properties of tools.
- To change or modify the physical properties of material such as electrical properties, magnetic
- Properties, corrosion resistance and heat resistance etc.
- Elimination of $H_2$ gas dissolved during pickling or electro-plating which causes brittleness.

## II. Research Background

Literature has been collected from various journals, books, papers etc. & has been reviewed as follows-

Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material. Steels are heat treated for one of the following reasons:

1. Softening
2. Hardening
3. Material Modification

**1. Softening:** Softening is done to reduce strength or hardness, remove residual stresses, improve toughness, restore ductility, refine grain size or change the electromagnetic properties of the steel. Restoring ductility or removing residual stresses is a necessary operation when a large amount of cold working is to be performed, such as in a cold-rolling operation or wiredrawing. Annealing — full Process, Spheroidizing, Normalizing and tempering — Austempering, Martempering are the principal ways by which steel is softened.

**2. Hardening:** Hardening of steels is done to increase the strength and wear properties. One of the pre-requisites for hardening is sufficient carbon and alloy content. If there is sufficient Carbon content then the steel can be directly hardened. Otherwise the surface of the part has to be Carbon enriched using some diffusion treatment hardening techniques.

**3. Material Modification:** Heat treatment is used to modify properties of materials in addition to hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., stress relieving, or strength properties, e.g., cryogenic treatment, or some other desirable properties, e.g., spring aging.

Heat treatment is a combination of timed heating and cooling applied to a particular metal or alloy in the solid state in such ways as to produce certain microstructure and desired mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation and percentage reduction). Annealing, normalising, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. Hardening is the most common heat treatment applied to tool steels. It consists of three operations:

1. Heating
2. Quenching
3. Tempering.

Heating is carried out by preheating the work piece until its temperature is equalized throughout, and then holding or soaking it at the processing temperature to dissolve its carbides (compounds of carbon and alloying elements) into the matrix (the surrounding material in which they are embedded). This makes the matrix richer in carbon and alloying elements, with the hardness finally achieved depending primarily on the amount of carbon dissolved. The alloying elements mostly determine the speed at which the steel must be quenched and the depth of hardness attained in it.

Quenching consists of cooling the heated work piece rapidly by immersing it in a liquid (oil, water, and molten salt), surrounding it with gas or air, or submerging it in a fluidized bed to keep the carbon in solid solution in the steel.

Tempering consists of reheating the quenched steel one or more times to a lower temperature, 150 to 650 °C., and cooling it again to develop the desired levels of ductility and toughness.

- ❖ Steel in the annealed condition is soft and ductile and has low tensile strength. Status: Ferrite + Pearlite + Carbides of various compositions.
- ❖ At hardening temperature the steel is very soft and has very low tensile strength. Structure: Austenite + residual Carbides
- ❖ After quenching the steel is hard and brittle. Structure: Martensite (highly stressed) + other transformation products + soft retained Austenite + residual Carbides.
- ❖ After Temper 1 the steel is hard but tougher (better impact strength). Structure: Tempered (less stressed) Martensite, + highly stressed untempered. Martensite or other transformation products + small quantity of retained Austenite + residual carbides
- ❖ After Temper 2 the toughness is further increased (best impact strength) Structure: tempered Martensite and other transformation products + residual Carbons.

## III. Materials and Methods

### 3.1 Empirical Approach

Empirical Approach means derived from experiment and observation rather than theory.

**Step 1** Literature Gap analysis & Conducting Industrial Survey for the selection of Tool Steel Grades for experiment & Index preparation of objective function

**Step 2** Cutting and Grinding of Specimens

**Step 3** Composition testing of Untreated Tool Steel i.e. EN-31, EN-8, and D3

**Step 4** Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering of Tool Steels i.e. EN-31, EN-8, and D3

**Step 5** Hardness Testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3

### 3.2 Experimental Procedure

<u>Step 1 Literature Gap analysis & Conducting Industrial Survey for the selection of Tool Steel Grades for experiment & Index preparation of objective function</u>

Literature Gap analysis has been collected by referring various journals, books, papers etc. for the purpose of the

Selection of tool steels grades material on and work piece material on which lesser study will be carried out. Another objective selection of Place where to Perform Experiment, Market availability of the recommended tool steel & their Cost Analysis, Time Analysis to complete the experiment etc. The purpose of Selecting Tool Steel is that they are Mostly Used in the Manufacturing Industry. Tool Steel Grades like EN-8, EN-31 and D-3 is selected for project. These steel grades were suggested to be the best during Surveying Various Industries for that objective we designed an industrial based questioner. The Carbon Composition is different from each other in these materials. So we can easily differentiate between selected Parameters after Heat Treatment. These three Materials are purchased From Material Shop of C.T.R Ludhiana. For defining the objective of study to be carried out more effectively and specific we designed Heat Treatment Performance Index **HTPI 2012**.

**<u>Step 2 Cutting and Grinding of Specimens</u>**

**Sample Mark**: EN-31, EN-8, and D3
**Instrument Used**: Power Hack saw & Grinding Machine
**Units of Sample Prepared**: Six for each material for different objectives

There was a Requirement for 6 Samples of Each Material for the Treatment and Testing Purpose. So we cut the Samples Using Power Hack-Saw .All the Samples are 20mm in Diameter and 2.5" to 3.5" in length. Chamfering was done using Bench Grinder. During Chamfering we also Performed Spark Testing of the material which is commonly used in the Industries to analyze Different Material on the basis of the Intensity of Spark Produced and Flowers evolved during Spark Testing. Figure Below shows the three Material undergoing Spark testing.

**EN-8** **EN-31** **D-3**

Fig 1. Pictorial View of Spark Testing for Various Materials

<u>Step 3 Composition testing of Untreated Tool Steel i.e. EN-31, EN-8, and D3</u>

Chemical Composition is Important Testing for making sure that the Chemical Composition of the Purchased Material Matches with that of the International Standards of Materials. This Testing is done By Using the Glow Discharge Spectrometer. Surface finishing of Single Sample of Each material is done on the Belt Grinding Machine of 100Grit Belt. After Grinding and giving the material a good Surface finish Sample EN-8 is inserted in the Machine. The Machine Holds the Material by Vacuum Holder of the machine .Then the Door is closed for further Operation to be performed on the material and command is given to the Specific Software on the Computer. This is done by using the glow discharge method, sample material is uniformly sputtered [Spit up in an explosive manner] from the surface.

**Type of Sample**: Cut Pieces of Steel
**Sample Mark**: EN-31, EN-8, and D3
**Instrument Used**: Glow Discharge Spectrometer

Fig 2. Marks of Argon Gas after Composition Testing

It takes about 5-6 minutes for the chemical composition testing of a single material. The readings of the test are shown on the Display of Computer in Tabulated Form. It

Shows the Percentage Composition of Each Element .After Testing Chemical Composition of the material, the values Compared with that of Values as per International Standards. The Testing of a Single Sample is done 2-4 times from Different point on the smooth surface of the sample. The same Procedure for chemical testing is also done for EN-31 and D-3 also. The figure below show the Specimen where the Chemical Composition Testing is done leaving behind the impact of Argon Gas used at the time of testing. We can see three marks which states that Testing is Performed 3 times on the Material.

<u>Step 4 Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering of Tool Steels i.e. EN-31, EN-8, and D3</u>

**Place of Experiment**: Central Tool Room, Ludhiana

**Heat treatment process**: Annealing [A], Normalizing [N] and Hardening & Tempering [H&T].
**Sample Mark**: EN-31, EN-8, and D3
**Instrument Used**: Muffle Furnace [for EN-8] & Fulmina Furnace [for EN-31 & D-3]

Step 5 Hardness Testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3

**Place of Experiment**: Central Tool Room, Ludhiana

**Type of Sample**: Round Piece, Material EN-31, EN-8, D3
**Sample mark 1**: Untreated Material EN-31, EN-8, and D3

**Type of Sample:** Round Piece, Material EN-31
**Sample Mark 2**: Annealing [A], Normalizing [N] and Hardening & Tempering [H&T].

**Type of Sample**: Round Piece, Material EN-8
**Sample Mark 2**: Annealing [A], Normalizing [N] and Hardening & Tempering [H&T].

**Type of Sample**: Round Piece, Material D-3
**Sample Mark 2**: Annealing [A], Normalizing [N] and Hardening & Tempering [H&T].

**Instrument Used**: Rockwell hardness tester

Steel Hardness Calculator Used for Conversion of Values. Using that we calculated HRB value & Brinell Hardness HB, Vickers HV.

## IV. Results & Discussion

1. Composition Testing of Untreated Tool Steel i.e. EN-31, EN-8, and D3

Table 1. Composition of Tool Steel as per AISI Standard

| * Mark | C% | Si% | Mn% | P% | S% | Cr% | Mo% |
|---|---|---|---|---|---|---|---|
| EN-31 | 1.30 | 0.30 | 0.50 | 0.024 | 0.025 | 1.40 | - |
| En-8 | 0.45 | 0.32 | 0.8 | 0.05 | 0.05 | - | - |
| D-3 | 2.10 | 0.65 | 0.45 | 0.021 | 0.03 | 11.50 | 0.22 |

* Composed With the Help of Literature Survey.

Table 2 Composition of Tool Steel after Composition Testing using Glow Discharge Spectrometer

| **Mark | C% | Si% | Mn% | P% | S% | Cr% | Mo% |
|---|---|---|---|---|---|---|---|
| EN-31 | 1.12 | 0.22 | 0.45 | 0.022 | 0.025 | 1.12 | - |
| En-8 | 0.43 | 0.31 | 0.6 | 0.04 | 0.04 | - | - |
| D-3 | 1.81 | 0.65 | 0.45 | 0.017 | 0.03 | 11.12 | 0.21 |

** **Place of Experiment**: Central Tool Room, Ludhiana
**Type of Sample**: Cut Pieces of Steel, Sample Mark: EN-31, EN-8, and D3

**Instrument Used**: Glow Discharge Spectrometer

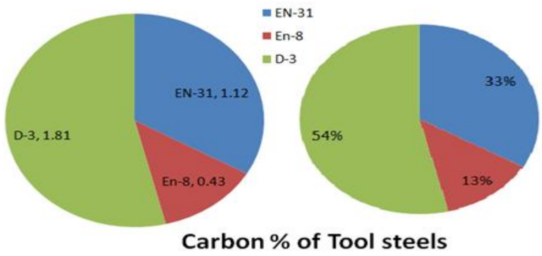


Fig 3. Carbon % of Tool Material Used

**Conclusion:** In Comparison All the values Match-able as per AISI Standard .Shows the originality of Material used for testing leads to validity of performances outcomes that carried out further.

2. Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering of Tool Steels i.e. EN-31, EN-8, and D3

Table 3 Heat Treatment Conditions for Annealing Process for Tool Steel i.e. EN-31, EN-8, and D3

| Material | Annealing Temp. | Soaking Time |
|---|---|---|
| EN-8 | 800 | 2 Hour |
| EN-31 | 800 | 2 Hour |
| D-3 | 820 | 2 Hour |

Table 4 Heat Treatment Conditions for Normalizing Process for Tool Steel i.e. EN-31, EN-8, and D-3

| Material | Normalizing Temp. | Soaking Time | Cooling Medium |
|---|---|---|---|
| EN-8 | 880 | 1/2 Hour | Air |
| EN-31 | 930 | 1/2 Hour | Air |
| D-3 | 900 | 1/2 Hour | Air |

Table 5 Heat Treatment Conditions for Hardening and Tempering Process for Tool Steel i.e. EN-31, EN-8, and D3

| Material | Pre Heating Temp. | Soaking Time | Hardening Temp | Soaking Time | Quenching Temp. | Quenching Medium | Tempering Temp. | Soaking time |
|---|---|---|---|---|---|---|---|---|
| D-3 | 550°C | 1 Hour | 960°C | ½ Hour | 60-80°C | Quenching Oil | 200°C | 1 Hour |
| EN-8 | 550°C | 1 Hour | 860°C | ½ Hour | 50-60°C | Quenching Oil | 200°C | 1 Hour |
| EN-31 | 550°C | 1 Hour | 850°C | ½ Hour | 60-70°C | Quenching Oil | 200°C | 1 Hour |

3. Hardness Testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3

Table 6. Hardness of Untreated Tool Steel Material EN-31, EN-8, and D3

| Untreated material Sample Mark | Rockwell C- HRC | Rockwell B- HRB | Rockwell A- HRA | Brinell Hardness HB | Vickers HV |
|---|---|---|---|---|---|
| EN-31 | 10 | 89 | ---------- | 180 | 180 |
| EN-8 | 13 | 92 | ---------- | 190 | 186 |
| D-3 | 18 | 95 | ---------- | 212 | 218 |

Table 7. Hardness of Treated Tool Steel EN-31

| Tool Steel Material | Sample Mark | Rockwell C- HRC | Rockwell B- HRB | Rockwell A- HRA | Brinell Hardness HB | Vickers HV |
|---|---|---|---|---|---|---|
| EN-31 | A | 12 | 91 | 55 | 186 | 184 |
| | N | 41 | 112 | ---------- | 375 | 393 |
| | H & T | 55 | 0 | ---------- | 552 | 649 |

Table 8. Hardness of Treated Tool Steel EN-8

| Tool Steel Material | Sample Mark | Rockwell C- HRC | Rockwell B- HRB | Rockwell A- HRA | Brinell Hardness HB | Vickers HV |
|---|---|---|---|---|---|---|
| EN-8 | A | 9 | 88 | 54 | 178 | 178 |
| | N | 25 | 101 | ---------- | 250 | 255 |
| | H & T | 48 | 116 | ---------- | 456 | 490 |

Table 9. Hardness of Treated Tool Steel D-3

| Tool Steel Material | Sample Mark | Rockwell C- HRC | Rockwell B- HRB | Rockwell A- HRA | Brinell Hardness HB | Vickers HV |
|---|---|---|---|---|---|---|
| D-3 | A | 23 | 100 | ---------- | 240 | 247 |
| | N | 55 | 0 | ---------- | 552 | 649 |
| | H & T | 56 | 0 | ---------- | 572 | 694 |

<u>Conclusion for EN-31</u>

Before treatment EN-31 hardness is 18 HRC hardness of untreated material is less. After done three treatments

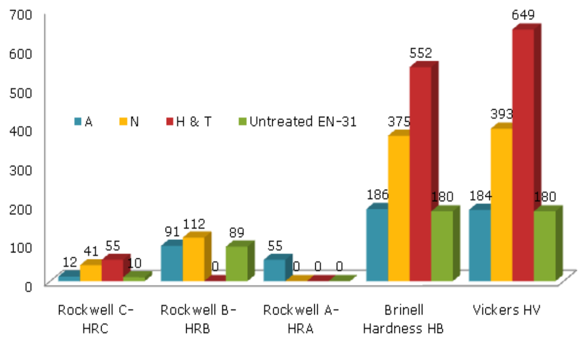


Fig 4. Hardness Comparison of EN-31 Treated & Untreated

**Annealing:** After annealing value of hardness of specimen is 55 HRC as compared to untreated specimen annealed specimen becomes softer. Therefore specimen machine-ability properties increase. We used HRA scale because after annealing EN-31 becomes soft and below 20 HRC value HRC scale is not gives the accurate value and also value is not valid.

**Normalizing:** After normalizing hardness is 40 HRC given on Rockwell testing machine. It shows after the normalizing the specimen becomes harder then annealing specimen .this is due to formation of Bainite & Martensite.

**Hardening and Tempering:** After H&T treatment specimen hardness is 55 HRC it shows H&T treatment makes hardest then other two treatments.

This means material has more wear and tear as compared two other two heat treatments.

**Comparison:** After annealing specimen becomes more softer then untreated specimen as hardness value shown.

After normalizing hardness is more as compared to untreated specimen. After hardening and tempering specimen are hardest then other three specimens.

<u>Conclusion for EN-8</u>

Before treatment EN-8 hardness value is 10 HRC .Hardness of untreated material is less due to low carbon % in EN-8. After done three treatments

**Annealing:** After annealing value of hardness of specimen is 55 HRA as compared to untreated specimen annealed specimen becomes softer. So machine-ability properties of specimen increase due to annealing we used HRA scale because after annealing EN-8 becomes soft and below 20 HRC. Value HRC scale is not gives the accurate value and also value is not valid.

**Normalizing:** After normalizing hardness is 25 HRC given on Rockwell testing machine.It shows after the normalizing the specimen becomes harder then annealing specimen .this is due to formation of pearlite is more as compared to ferrite.

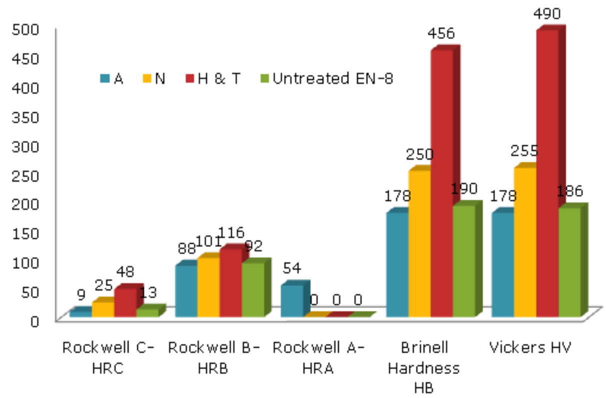


Fig 5. Hardness Comparison of EN-8 Treated & Untreated

**Hardening and Tempering:** After H&T treatment specimen hardness is 48 HRC it shows H&T treatment makes hardest then other two treatments. This means material has more wear and tear as compared two other two heat treatments.

**Comparison:** After annealing specimen becomes more softer then untreated specimen as hardness value shown. After normalizing hardness is more as compared to untreated specimen. After hardening and tempering specimen are hardest then other three specimens due to formation of fine tempered martensite.

Conclusion for D-3

Before treatment D-3 hardness value is 13 HRC hardness of untreated material is less. After done three treatments

**Annealing:** After annealing value of hardness of specimen is 23 HRC.

As compared to untreated specimen annealed specimen becomes harder. This is due to formation of carbide particles.

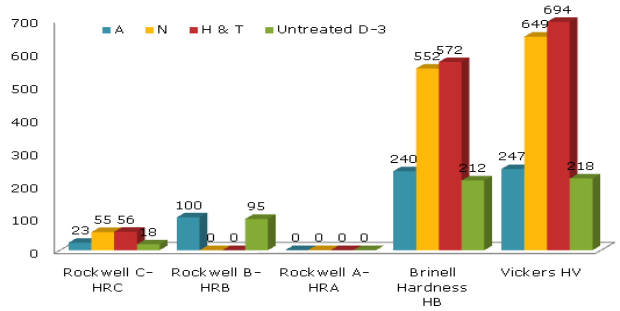


Fig 6. Hardness Comparison of D-3 Treated & Untreated

**Normalizing:** After normalizing hardness is 55 HRC given on Rockwell testing machine. It shows after the normalizing the specimen becomes harder then annealing specimen .This is due to formation of greater no. of Un-dissolved carbide particles so specimen becomes brittle.

**Hardening and Tempering:** After H&T treatment specimen hardness is 56 HRC. It shows H&T treatment and normalizing have same hardness value. But we cannot use normalizing due improper microstructure. But in case of H&T hardness value is same but specimen consists of dissolved carbide particles. This means material has more corrosion resistance and hardness as compared two other two heat treatments.

**Comparison:** After annealing specimen becomes more harder then untreated specimen. After annealing hardness is more as compared to untreated specimen. But specimen has not obtained good microstructure. After hardening and tempering specimen are hardest then other three specimens also having a good corrosion resistance.

Fig 7. Overview of all specimens related with the study

## V. Conclusion of Study

Literature gap analysis & industrial survey conduction are found to be very useful approach for selection of tool steel grade which will more beneficial for industrial point of view. From the literature review, it is observed that less research work has been seen for Tool Steel i.e. EN-31, EN-8, and D3 after Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering. Also very less work has been reported for AISI D3 Die Steel. It is observed that the effect of hardness of work piece material after treatment of Tool Steel i.e. EN-31, EN-8, and D3 have not been explored yet, so it‘s interesting to Study the Effect on the Hardness of three Sample Grades of Tool Steel i.e. EN-31, EN-8, and D3 after Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering. All these aspects will be addressed in research work. Indexing of HTPI 2012 is found to be very effective to defined objective function.

After annealing specimen of EN-31 becomes more softer then untreated specimen as hardness value shown. After normalizing hardness is more as compared to untreated specimen. After hardening and tempering specimen are hardest then other three specimens.

After annealing specimen of EN-8 becomes more softer then untreated specimen as hardness value shown. After normalizing hardness is more as compared to untreated specimen. After hardening and tempering specimen are hardest then other three specimens due to formation of fine tempered martensite. After annealing specimen of D-3 becomes more harder then untreated specimen. After annealing hardness is more as compared to untreated specimen. But specimen has not obtained good microstructure. After hardening and tempering specimen are hardest then other three specimens also having a good corrosion resistance.

Future Aspects of this study to carry out further is very wide. Selecting of different tool steel material and compare them the effects on their mechanical properties. Recommended material for further work done to be carried out for similar study D-2, mild steel, HC HCR cold working tool steel grades as so many. HSS found to be very tool steel grade difficult for such study as per investigation form industrial survey. Using Different analytical approaches is also making an effective outcome which is also recommended.

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**Biographies**

1.  ***Ashish Bhateja,*** M.Tech regular pass out Student from NIT Jalandhar, June 2009 and my area of specialization is manufacturing technology. Presently working as an assistant professor in mechanical department at Gulzar group of institutes, Khanna (Punjab) AICET Approved & affiliated by Punjab technical university, Jalandhar (Punjab). Having 1.5 years of total Teaching & Research experience .My area of research topic is Production Engineering & Management. Already published two research papers Internationally on Green Supply Chain Management and further plans to contribute more in the field of Production Engineering & Management. This is Very Exciting for me to be appointed as a supervisor of such outstanding students Grouped Name [G4].

2.  ***Aditya Varma,*** B.Tech Final Year Student of Department of Mechanical Engineering at Gulzar Institute of Engineering & Technology, Khanna, and Punjab .Young, Dynamic & Creative By Nature . This Contribution of Research work is part of my Major Project carried out recently in the month of Dec 2012 under the guidance of Professor Ashish Bhateja. It tock's period of three months to complete that & we all worked together as a team.

3.  ***Ashish Kashyap,*** B.Tech Final Year Student of Department of Mechanical Engineering at Gulzar Institute of Engineering & Technology, Khanna, and Punjab .Promising Personality In terms of technical Aspects are concerned. This Contribution of Research work is part of my Major Project carried out recently in the month of Dec 2012 under the guidance of Professor Ashish Bhateja. It tock's period of three months to complete that & we all worked together as a team.

4.  ***Bhupinder Singh***, B.Tech Final Year Student of Department of Mechanical Engineering at Gulzar Institute of Engineering & Technology, Khanna, and Punjab .Efficient, Hardworking & Dedicated Personality. This Contribution of Research work is part of my Major Project carried out recently in the month of Dec 2012 under the guidance of Professor Ashish Bhateja. It tock's period of three months to complete that & we all worked together as a team.