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EFFECT ON HARDNESS & MICRO STRUCTURAL BEHAVIOUR OF TOOL STEEL AFTER HEAT TREATMENT PROCESS

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Abstract

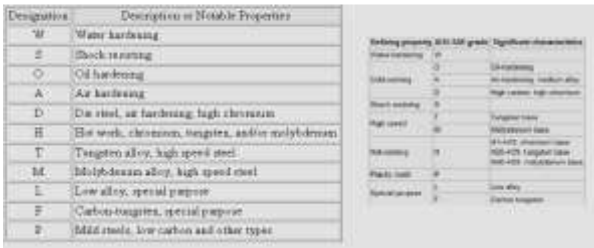
This study is conducted to analyze the effect on the Hardness & Micro Structural Behaviour of three Sample Grades of Tool Steel i.e. EN-31, EN-8, and D3 after Heat Treatment Processes Such As Annealing, Normalizing, and Hardening & Tempering. The purpose of Selecting Tool Steel is Because Tool Steel is Mostly Used in the Manufacturing Industry. This study is based upon the empirical study which means it is derived from experiment and observation rather than theory.

Keywords - *Heat Treatment, Annealing, Normalizing, Hardening & Tempering, Tool Steels, EN-31, EN-8, D-3 Hardness, Microstructure*

2. 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.

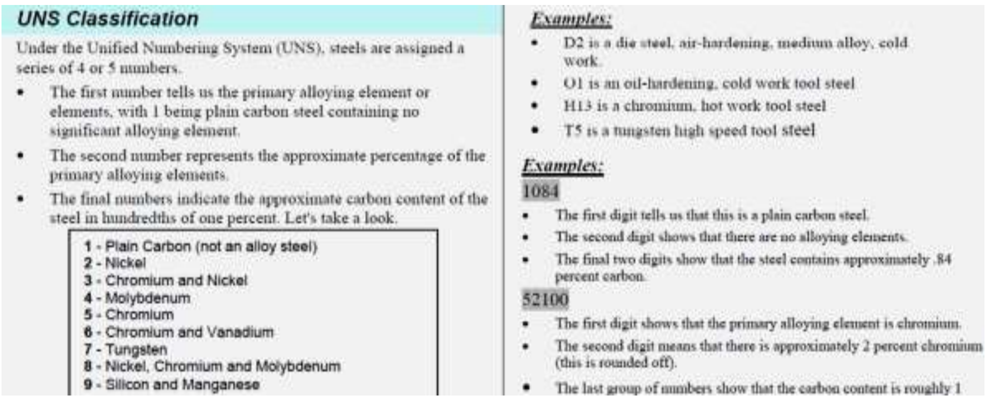
Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). Tool steel is generally used in a heat-treated state. With carbon content between 0.7% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality. The manganese content is often kept low to minimize the possibility of cracking during water quenching. However, proper heat treating of these steels is important for adequate performance, and there are many suppliers who provide tooling blanks intended for oil quenching.



Designation	Description or Notable Properties
W	Water hardening
S	Shock resisting
O	Oil hardening
A	Air hardening
D	Die steel, air hardening, high chromium
H	Hot work, chromium, tungsten, and/or molybdenum
T	Tungsten alloy, high speed steel
M	Molybdenum alloy, high speed steel
L	Low alloy, special purpose
F	Carbon-tungsten, special purpose
P	Mild steels, low carbon and other types

American Iron and Steel Institute (AISI) { in cooperation with Engineers (SAE) }	This system groups tool steels by their purpose or unique properties
Unified Numbering System (UNS)	This system classifies steels according to: a) their primary alloying element, b) the approximate content of the primary alloying element, c) The approximate carbon content in hundredths of one percent.

The AISI-SAE grades of tool steel are the most common scale used to identify various grades of tool steel. Individual alloys within a grade are given a number; for example: A2, O1, etc. The naming convention for steels can get quite confusing at times. Some are named with a series of letters and numbers; others are named with just numbers. The following are two of the methods used in the classification of steels.



UNS Classification

Under the Unified Numbering System (UNS), steels are assigned a series of 4 or 5 numbers.

- The first number tells us the primary alloying element or elements, with 1 being plain carbon steel containing no significant alloying element.
- The second number represents the approximate percentage of the primary alloying elements.
- The final numbers indicate the approximate carbon content of the steel in hundredths of one percent. Let's take a look.

1 - Plain Carbon (not an alloy steel)
2 - Nickel
3 - Chromium and Nickel
4 - Molybdenum
5 - Chromium
6 - Chromium and Vanadium
7 - Tungsten
8 - Nickel, Chromium and Molybdenum
9 - Silicon and Manganese

Examples:

- D2 is a die steel, air-hardening, medium alloy, cold work.
- O1 is an oil-hardening, cold work tool steel
- H13 is a chromium, hot work tool steel
- T5 is a tungsten high speed tool steel

Examples:

1084

- The first digit tells us that this is a plain carbon steel.
- The second digit shows that there are no alloying elements.
- The final two digits show that the steel contains approximately .84 percent carbon.

52100

- The first digit shows that the primary alloying element is chromium.
- The second digit means that there is approximately 2 percent chromium (this is rounded off).
- The last group of numbers show that the carbon content is roughly 1

Tool steels are made to a number of grades for different applications. Choice of grade depends on, among other things, whether a keen cutting edge is necessary, as in stamping dies, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, pickaxes, and quarrying implements. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools etc. Tool steels are also used for special applications like injection moulding because the resistance to abrasion is an important criterion for a mold that will be used to produce hundreds of thousands of parts.

- **Water-Hardening Grades**

WATER HARDENING COLD WORK TOOL STEELS [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
W1	T72301	0.60 1.40 (a)								
W2	T72302	0.06 1.40 (a)				0.25				
W5	T72305	1.10			0.50					

W-grade tool steel gets its name from its defining property of having to be water quenched. W grade steel is essentially high carbon plain-carbon steel. This type of tool steel is the most commonly used tool steel because of its low cost compared to other tool steels. They work well for small parts and applications where high temperatures are not encountered; above 150 °C it begins to soften to a noticeable degree. Hardenability is low so W-grade tool steels must be quenched in water. These steels can attain high hardness (above HRC 60) and are rather brittle compared to other tool steels. The toughness of W-grade tool steels is increased by alloying with manganese, silicon and molybdenum. Up to 0.20% of vanadium is used to retain fine grain sizes during heat treating.

- **Cold-Working Grades**

These tool steels are used on larger parts or parts that require minimal distortion during hardening. The use of oil quenching and air hardening helps reducing distortion as opposed to higher stress caused by quicker water quenching. More alloying elements are used in these steels, as compared to water- hardening grades. These alloys increase the steels' hardenability and thus require a less severe quenching process. These steels are also less likely to crack and are often used to make knife blades.

- **Oil-Hardening Grades**

01 is an oil hardening carbon manganese tool steel, possessing excellent dimensional stability during heat treatment. Typical applications: Press Tools, Broaches, Clipping, Marking Punches, Gauges, Jigs, Deep Drawing Dies, Slitting Cutters, Taps & Screwing Tools

➢ Air-Hardening Grades

The first air hardening grade tool steel was mushet steel, which was known as air-hardening steel at the time. Modern air-hardening steels are characterized by low distortion during heat treatment because of their high-chromium content. They also harden in air because they have less alloyants than oil-hardening grades. Their machinability is good for tool steels and they have a balance of wear resistance and toughness. E.g. A1, A2, A3, A4, A5, A6, A7, A8, A9, A10.

➢ D-Grades

HIGH CARBON, HIGH CHROMIUM COLD WORK STEEL [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
D2	T30402	1.50			12.00	1.00		1.00		
D3	T30403	2.25			12.00					
D4	T30404	2.25			12.00			1.00		
D5	T30405	1.50			12.00			1.00	3.00	
D7	T30407	2.15 2.50	0.60 MAX	0.60 MAX	11.50 13.50	3.80 4.40		0.70 1.20		

D-grade tool steels contain between 10% and 18% chromium. These steels retain their hardness up to a temperature of 425 °C. Common applications for these grade of tool steel is forging dies, die-casting die blocks, and drawing dies. Due to high chromium content, certain D-grade tool steel grades are often considered stainless or semi-stainless tool steels. However their corrosion resistance was very limited due to the precipitation of major amount of chromium and carbon as carbides.

➢ Shock Resisting Grades

SHOCK RESISTING TOOL STEELS [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
S1	T41901	0.50			1.50		2.50			
S2	T41902	0.50		1.00				0.50		
S4	T41904	0.05 0.65	0.60 0.95	1.75 2.25	0.35 MAX	0.35 MAX				
S5	T41905	0.55	0.80	2.00				0.40		
S6	T41906	0.45	1.40	2.25	1.50			0.40		
S7	T41907	0.50			3.25			1.40		

S-grade tool steel is designed to resist shock at both low and high temperatures. Low carbon content is required for the necessary toughness (approximately 0.5% carbon). Carbide-forming alloys provide the necessary abrasion resistance, hardenability, and hot-working characteristics. This family of steels displays very high impact toughness and relatively low abrasion resistance; it can attain relatively high hardness (HRC 58/60). This type of steel is used in applications such as jackhammer bits.

- **Hot-Working Grades**

  H-grade tool steels were developed for strength and hardness during prolonged exposure to elevated temperatures. All of these tool steels use a substantial amount of carbide forming alloys. H11 to H19 are based on a chromium content of 5%; H20 to H39 are based on a tungsten content of 9-18% and a chromium content of 3–4%; H40 to H59 are molybdenum based.

CHROMIUM HOT WORK TOOL STEELS [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
H11	T20811	0.35			5.00	0.40		1.50		
H12	T20812	0.35			5.00	0.40	1.50	1.50		
H13	T20813	0.35			5.00	1.00		1.50		
H14	T20814	0.40			5.00		5.00			
H19	T20819	0.40			4.25	2.00	4.25		4.25	
TUNGSTEN HOT WORK TOOL STEELS [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
H21	T20821	0.35			3.50		9.00			
H22	T20822	0.35			2.00		11.00			
H23	T20823	0.30			12.00		12.00			
H24	T20824	0.45			3.00		15.00			
H25	T20825	0.25			4.00		15.00			
H26	T20826	0.50			4.00	1.00	18.00			
MOLYBDENUM HOT WORK TOOL STEEL [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
H42	T20842	0.60			4.00	2.00	6.00	5.00		
H43	T20843	0.50 .65	0.15 0.40	0.20 0.45	3.75 .50	1.80 2.20		7.75 8.50		

High Speed Grades

T-grade and M-grade tool steels are used for cutting tools where strength and hardness must be retained at temperatures up to or exceeding 760 °C. M-grade tool steels were developed to reduce the amount of tungsten and chromium required.T1 (also known as 18-4-1) is a common T-grade alloy. Its composition is 0.7% carbon, 18% tungsten, 4% chromium and

ULTRAHARD HIGH SPEED TOOL STEELS [UP]										
AISI	UNS. No.	C	Mn	Si	Cr	V	W	Mo	Co	Ni
M41	T11341	1.10			4.25	2.00	6.75	3.75	5.00	
M42	T11342	1.10			3.75	1.15	1.50	9.50	8.00	
M43	T11343	1.15 1.25			3.50 4.25	1.60	2.75	8.00	8.25	
M46	T11346	1.25			4.00	3.20	2.00	8.25	8.25	
M47	T11347	1.10			3.75	1.25	1.50	9.50	5.00	
M48	T11348	1.50			3.75	3.10	10.00	5.25	9.00	
M52	T11352	0.90			4.00	2.00	1.25	4.00		
M62	T11362	1.30			3.75	2.00	6.25	10.50		

1% vanadium. M2 is a common M-grade alloy.

Special Purpose Grades

P-grade tool steel is short for plastic mold steels. They are designed to meet the requirements of zinc die casting and plastic injection molding dies. L-grade tool steel is short for low alloy special purpose tool steel. L6 is extremely tough. F-grade tool steel is water hardened and substantially more wear resistant than W-grade tool steel.

Tool Steel Equivalents

Even though the British EN (Emergency Number) designation scheme for steel is obsolete it is still widely used. The following table lists the EN grades commonly seen at NHTC and the closest AISI equivalents and the uses for the grade.

EN	AISI	Uses
EN1A	1213	A mild steel available in round, flat or hexagonal form
EN3A	1023	A mild steel suitable for general purpose use. Available hot rolled, cold drawn or turned in black round or square, bright round, square, flat or hexagonal.
EN8	1040	A medium strength steel suitable for stressed pins, shafts, studs, keys etc. Available in square, round or flat bar.
EN19	4140	An oil hardenable chromium molybdenum steel used for gears and high strength shafts etc with good resistance to shock loads.. Available as black round or square bar and bright round, square and hexagonal bar.
EN24	4340	An oil hardenable nickel chromium molybdenum steel with high strength and toughness. Used for gears, axles and high strength studs. Available as black round or square bar and bright round, square and hexagonal bar. (small sections can be vacuum hardened)
EN24T	4340	Same as EN24 but pre-hardened to 29-32HR_c
EN41A (905M31)		A chromium molybdenum steel with aluminium which makes it eminently suitable for nitriding. We have not seen this steel at the NHTC but we feel certain that it would be more suitable for nitriding than some of the steels we are asked to nitride.

Other tool steel equivalents are as follows:

Cold Work Tool Steels

AISI	DIN	Uddeholm	Bohler
O1	1.2510	Arne	K460
A2	1.2363	Rigor	K305
D2	1.2379	Sverker 21	K110
D6 (D3)	1.2436	Sverker 3	K107

Mould Steels

AISI	DIN	Uddeholm	Bohler
P20	1.2312	Impax Supreme	M200
420 (Stainless)	1.2083	Stavax	M310
H13	1.2344	Orvar Supreme	W302

3. Study Brief and Objectives

Main Objective of this project work to be carried out is to study the Effect on the Hardness & Micro Structural Behaviour 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.

For the fulfillment of this objective our first motive is selection of sample grades of tool steels based on the selected heat treatment process which is commonly used for steel for that purpose literature review and industrial survey is conducted. From literature survey we try to analyze that on which tool steel grades is type of study is not yet conducted for that purpose we refers many journals, Research papers, text books and by conducting industrial survey we aims to select the recommended tool steel which is most commonly used for industrial application i.e. type of tool steel grade most preferred for this study, type of tool steel grade most difficult for this aimed study to be carried out. Also in end aims to do market & cost analysis of the recommended tool steel grades from experts i.e. approximated cost & check out the market availability of material . This survey also helps to find out the place of the work to be carried out i.e. availability of set up, achiness and techniques used for such, estimated time & cost requires for such study to be carried out For the purpose of industrial survey to be carried out be designed a questioner for that. After literature review and industrial survey aims to preparing the heat treatment performance Indexing of HTPI 2012 is supposed to be very effective to defined objective function.

After the 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 in the end Also aims to study micro structural behavior of selected tool steel grades i.e. EN-31, EN-8, and D3 after Heat Treatment Processes . Apparatus selected for Microstructure Study is Metallurgical Microscope .These microstructures are analyzed with the help of metallurgical software‘s. So the properties can be varied as desired according to the use. Thus this study helps to find the worth of the heat treatment processes in varying the properties of the tool steel.

4 . Grades of Engineering Steels

The following grades of Engineering Steels:

En1A	**EN1A,** also known as 230M07. EN1A is low carbon mild steel. Properties: free cutting, suitable for machining using both automatic and CNC machines. Available in square, round, flat or hexagon form.
En1A Leaded	**EN1A Leaded,** also known as 230M07 Pb. A low carbon mild steel with added lead. Properties: free cutting, suitable for machining using both automatic and CNC machines. Available in square, round, flat or hexagon form.
En3B	**EN3B,** also known as 070m20, available in rounds, flats, squares & hexagons. En3b is mild steel suitable for welding and general machining.
En8	EN8 also known as 080M40. An Unalloyed medium carbon steel. EN8 is a medium strength steel, good tensile strength. Suitable for shafts, stressed pins, studs, keys etc. Available as normalized or rolled. EN8 is supplied as round drawn/turned, round hot rolled, hexagon, square, flats and plate.
En9	EN9, also known as 070m55, available in diameters, flats, squares and plates with a carbon content 0.50/0.60 this is a medium carbon steel which can develop a tensile strength of 700N/mm 45tsi. In the normalised condition EN9 can be used for gears, sprockets and cams.
En14	**EN14** also known as 150m19. Medium tensile strength carbon manganese steel suitable for welding. EN14 can be hardened and tempered to 550-850N/mm$^{2.}$ EN14 offers good ductility combined with excellent shock resistance.
En16, En16t	**EN16** also known as 605m36 comes as rolled or in the T condition it has good mechanical properties and has freedom from temper brittleness ideal for bolts, nuts, shafts and axles.
En19, EN19T	**EN19** also known as 708M40 / 709M40 comes treated in the annealed as rolled or even T condition. We can offer EN19 in diameters, squares, and flats from stock. It is renowned [The state of being well-known and much spoken about; the quality of being famous for] for its wear resistance properties and where high strength properties is
	required. Suitable for gears, shafts, spindles, etc.
En24, En24t	**EN24** also known as 817m40 comes treated in the T condition to 850/1000 N/mm^2 we can offer EN24 in plate from 10mm thick up to 300mm, diameters from 10mm up to 950mm, squares from 20mm to 300mm and flats 20 x 10 up to 3000 x 300mm from stock

En36	**En36** aka 655m13, is a nickel chromium case hardening steel which is suitable for deep hardening to develop a tough core is suitable for gears, cams rollers available in diameters only.

4.1 EN- 8 Tool Steel

EN8 is an unalloyed medium carbon steel with good tensile strength. It is normally supplied in cold drawn or as rolled. Tensile properties can vary but are usually between 500-800 N/mm2. EN8 is available from stock in bar and can be cut to your requirements. We also offer EN8 plate flame cut to your required sizes and normalised.

TYPICAL ANALYSIS				
C.	Si.	Mn.	S.	P.
0.40%	0.25%	0.80%	0.015%	0.015%

Hardening: Heat uniformly to 830/860°C until heated through. Quench in oil or water. Can also be induction or flame hardened.

Tempering: Heat uniformly and thoroughly at the selected tempering temperatures, between 550°C to 660°C and hold at heat for one hour per inch of total thickness.

Normalising: Normalise at 830-860°C, and cool in air.

Available sections

4.2 EN- 31 Tool Steel

EN31 is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance.

TYPICAL ANALYSIS			
C.	Mn.	Cr.	Si.
1.00%	0.50%	1.40%	0.20%

Forging: Forge at 1000°/1050°C. Heat slowly, allowing sufficient time at the forging temperature for the steel to be thoroughly soaked through. Re-heat as often as necessary to keep the temperature above 850°C. After forging cool very slowly, preferably in a furnace**.**

Annealing: Heat uniformly to 800°C, equalise, then furnace cool. (Hardness about 229 Brinell). **Stress Relieving:** If machining operations have been heavy or if the tool has an unbalanced section, remove stresses before hardening by heating up to 700°C, equalise, and then cool slowly. **Hardening:** Heat uniformly to 800/820°C until heated through. Allow 30 minutes per inch of ruling section and quench immediately in oil.

Tempering: Heat uniformly and thoroughly at the selected tempering temperatures and hold for at least one hour per inch of total thickness.

Tempering °C	100	150	200	250	300	350
HRC	64/63	63/62	62/61	60/59	57/56	54/53

Available sections

5. Tool Steel, High -speed Steels and Mould Steels

Following grades of tool steels and high speed steels

01 Tool Steel	**01** is an oil hardening carbon manganese tool steel, possessing excellent dimensional stability during heat treatment. **Typical applications**: Press Tools, Broaches, Clipping, Marking Punches, Gauges, Jigs, Deep Drawing Dies, Slitting Cutters, Taps & Screwing Tools
A2 Tool Steel	**A2** is an air hardening, cold work, tool steel. A 5% Chromium steel which provides high hardness after heat treatment with good dimensional stability. A2 delivers good toughness with medium wear resistance and is relatively easy to machine. Used in many applications which require good wear resistance as well as good toughness. Typical Applications: blanking tools, punch dies, trim dies, forming dies, gauges, shear, blades, stamping dies.
D2 Tool Steel	**D2** Steel is a high carbon, high chromium cold work tool steel. Recommended for use when greater toughness is required. It offers good wear resistance and high compressive strength. ***Typical applications***: Press Tools (inc. heavy duty), general purpose punches and dies, crushers, gauges, swaging dies, tools requiring resistance to abrasion, blanking tools, Thread rolling, Coining, General purpose
D2 Supreme ™	**D2 Supreme** is a close equivalent to **DC53** cold work die and mold steel. It has excellent machining characteristics coupled with excellent wear resistance, toughness and compressive strength. Highly recommended for use when greater toughness is required. ***Typical applications***: Moulds, punches, swaging dies, cold forging dies, forming dies, gauges, blades, shears, general purpose
D3 Tool Steel	**D3 Steel** is a high Carbon, high chromium cold work tool steel. D3 is similar to D2 but can attain a slightly higher hardness, it displays excellent abrasion/wear resistance and has good dimensional stability and high compressive strength. **TYPICAL APPLICATIONS:** Use for blanking and forming dies that require maximum resistance to abrasion. D3 is also used in forming rolls, press tools and punches.
H13 Tool Steel	**H13** is an air hardening chromium die steel - can be used for a range of applications. The higher vanadium content ensures increased resistance to heat checking and all round improvement to properties at elevated temperatures. Tools may be water cooled without risk of cracking. After normal heat treatment has been carried out it is suitable for nitriding 0.30mm (0.012") deep. ***Typical applications***: Hot forging and pressing dies,

	Extrusion dies, mandrels and punches, Hot chisels, Pressure pads, Extrusion stems and rams, Blanking and bending tools, Hot heading tools, Backer blocks.
M2 High Speed Steel	**M2** is a medium alloyed high speed steel which has good machinability. The composition of M2 gives a good combination of toughness and hardness. Widely used for cutting tools such as twist drills, taps, milling cutters, saws, knives etc. Also suitable for cold work applications in tools for punching, forming and pressing
M42 High Speed Steel	M42 is highly cobalt alloyed. It's composition makes for a good combination of toughness and hardness. M42 is a steel to be used in conditions where the demand for hot hardness is greatly important. Due to it's well balanced properties M42 has come into wide use for all cutting tools
P20 Tool Steel	**P20** (1.2311) Pre hardened to approximately 300 B.H (65 t.s.i) P20 requires no further heat treatment therefore avoiding risk of distortion or cracking. Although pre-hardened P20 is still capable of being machined and of giving a good polished finish. ***Typical applications***:Plastic moulds, backers, bolsters, die holders. Also suitable for other applications such as rails, shafts and wear strips **P20S** (1.2312) Delivered pre-hardened this material is ready for use at approximately 280/325 H.B. Similar to P20 (1.2311) but with a higher sulpher content which provides much improved machinability. This grade is not suitable for polishing or other applications requiring a fine finish. ***Typical applications***: Suitable for large mould frames and bolsters **P20N** (1.2738) Delivered pre hardened ready for use at 280/325 H.B. With added Nickel to ensure consistent hardness through large sections. Easy to polish and readyily machinable. ***Typical applications***: Used for quality for pressing and injection moulding tools. If the section exceeds 400mm P20 (1.2311) won't provide a consistent through hardness. Suitable for hard chrome plating and for nitriding

5.1 D3 Tool Steel

D3 steel, also know as 1.2080 (Werkstoff), is an air hardening, high-carbon, high-chromium tool steel. It displays excellent abrasion/wear resistance and has good dimensional stability and high compressive strength. It is heat treatable and will offer hardness in the range 58-64 HRC. Due to its abrasion resistance in the hardened condition, D3 machining should be limited to finished grinding. Typical applications for D3 Steel:

1. Blanking and forming dies
2. Forming rolls
3. Press tools
4. Punches
5. Bushes

C	SI	Cr	Mn	Ni
2.10%	0.30%	11.50%	0.40%	0.31%

Typical chemical composition of AISI D3 Steel

Annealing: Heat uniformly to 850-870°C, soak thoroughly, then slow furnace cool at a rate of not more than 25°C per hour to 650°C. The parts may then be air cooled. This should result in a maximum hardness of brinell 248.

Hardening: D3 tool steel is extremely sensitive to overheating during hardening – do not overheat. Pre heat slowly to 800-850°C, the raise rapidly to 950-970°C and soak until completely equalised. Quench in oil.

Stress Relieving: Heat to 650-700ºC. Soak for 2-4 hours then furnace cool.

Tempering: Heat uniformly and thoroughly to the desired temperature and hold for 25 minutes per cm of thickness. D3 can be double tempered after intermediate cooling to room temperature.

Tempering °C	150	200	250	300	350	400
HRC	64/63	63/61	62/60	61/60	60/59	59/58

Tempering D3 Steel

D3 steel is available from stock in flats and squares, hot rolled rounds, bright drawn rounds in imperial and metric sizes.

6. 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

Literature Gap analysis has been collected by referring various conferences, journals, books, papers etc. for the purpose of the selection of material on which lesser work done for such objective of contribution of relevant output for industrial point of view. For the objective of to get information about Selection of Material from the industrial point of view, Market availability of the recommended tool steel & their Cost Analysis, Time Analysis to complete the experiment , and Place where to Perform Experiment .

For the objective of study to be carried out we prepared Heat Treatment Performance Index HTPI 2012.

Step 2 Composition testing of Untreated Tool Steel i.e. EN-31, EN-8, and D3

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 **Step 3 Cutting and Grinding of Specimens**:- Place of Experiment: Central Tool Room, Ludhiana 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

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

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, and 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

Step 6 Micro Structural Analysis of 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, and D3 Instrument Used: Microscope (Olympus)

Observation: Process [A], Process [N], Process [H&T] At 100 & 500 x 3 % natal etch

7. Experimental Procedure

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

We Select the Tool Steel Grades for Project . Tool Steel Grades like EN-8, EN-31 and D-3 is selected for project. These 3 Materials were suggested to be the best during Survey by Various Industries also. The Carbon Composition is different from each other in these materials .So we can easily differentiate b\w selected Parameters after Heat Treatment. These 3 Materials are brought From Material Shop of

C.T.R Ludhiana. For the objective of study to be carried out we prepared Heat Treatment Performance Index HTPI 2012.

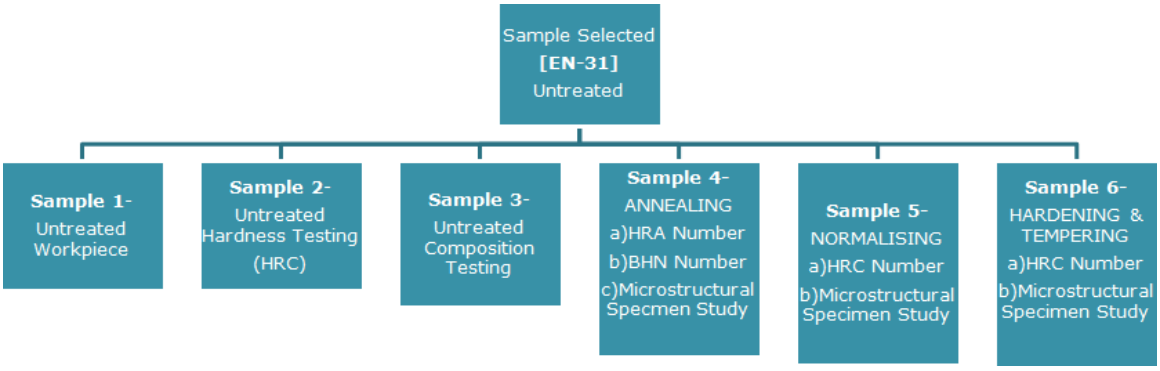
Overview of raw material section at work station

Step 2 Cutting and Grinding of Specimens:-

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"mm in length. Chamfering was done using Bench Grinder.

En-8 En-31 D-3

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 3 Material undergoing Spark testing.



Block diagram of Illustration of cutting of specimen of EN-31 Tool Steel for Experimental Work

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

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.

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.

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

After the Chemical Composition Testing various other Heat Treatments Processes can be performed on the Samples for evaluating further parameters.

We Selected the following Heat Treatment Processes:-

I. Annealing
II. Normalizing
III. Hardening and Tempering

There is Requirement of Three Samples of EN-8 for Annealing, Normalizing and for Hardening & Tempering. Same is to be done for EN-31 and D-3.

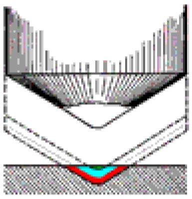
Step 5 Hardness Testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3

To know the Effect of Heat Treatment Process on Treated Samples we decided to evaluate the Hardness of the Material. Hardness of these Treated Samples is compared with Hardness of Untreated Samples. The Following Methods which can be used for Hardness Testing are:-

I. Rockwell Hardness Testing
II. Brinell Hardness Testing
III. Vickers Hardness Testing

We used Rockwell Hardness Testing for Tool Steel Category. The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting down the depth of penetration hardness value directly from a dial.

ROCKWELL HARDNESS TESTING: - Principal of the Rockwell Test



- The indenter moves down into position on the part surface
- A minor load is applied and a zero reference position is established
- The major load is applied for a specified time period (dwell time) beyond zero
- The major load is released leaving the minor load applied

The resulting Rockwell number represents the difference in depth from the zero reference position as a result of the application of the major load. In this Apparatus Diamond of 120^o is used as an Indenter in this Machine. The Values of Hardness is given by 3 Scales are as follows:-

- H.R.A -60 kg
- H.R.B – 100 kg
- H.R.C – 150 kg

is most commonly used scale in Rockwell Hardness Testing. In H.R.C Scale Load is used 150kgf. In this Testing 3 Untreated and 9 untreated samples are Tested . Only for Annealed Samples we use the H.R.A Scale because on H.R.C scale its gives Value Zero

Step 6 Micro Structural Analysis of Treated Tool Steel i.e. EN-31, EN-8, and D3

Most Important Testing which give the reason why the Properties of material changed after Heat Treatment .For Microstructure Testing there are following Steps are done:-

Cutting of Sample: - We cut the small piece of each treated material in semicircular shape up to some depth.

Fixing in Tablets:- This Semicircular shape samples are fixed in B\w the Compound So we can easily Handling on the Surface finishing of the Small samples .We take small 40mm dia. fixture in which we apply a grease on all sides .Small semicircular sample is placed at centre of this fixture. We put a Liquid and solid compound in ratio. Fixture Fill with compound. After 15 minutes it become hard there is exothermic reaction take place. This tablet is removed from fixture. Same is done for other 8 treated materials.

Finishing of Surface: - This is done by using the Emblem or Sand Paper of Different Grits .Starting with 200 up to 1200 Grit papers are used. After finishing by the paper we used the Double disc polishing machine. This whole Process is done for each sample

Etching: - It is Reagent which used for separation the grains from each other so we can differentiate during Observation on microscope. For Tool steel grades we used Etchant of 3% Nitric Acid and 97% of Alcohol. We put a single drop of Reagent on face each sample for 10 to 15 sec.

Observation on Microscope: - There is Special type of Microscope which is known as Metallurgical Microscope. We used Inverted type. The Etchant Sample is placed and after Positioning of material on the Light we can see the Microstructure of sample. In this we can used 100x and 500x lens for the Observation to differentiate between the treated materials. Microstructure observation from eye lens is attached with standard microstructure Pictures.

8. Results and Discussion

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

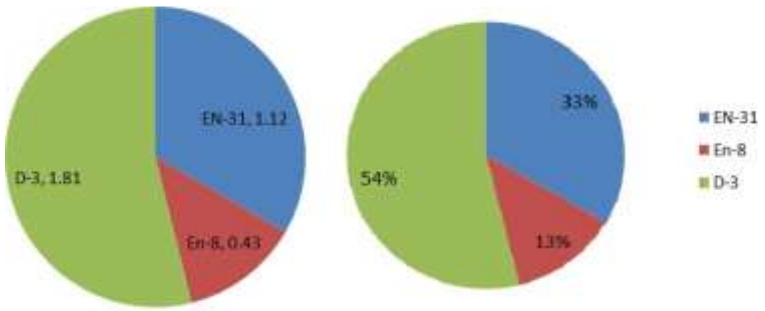
Mark	C%	Si%	MN%	P%	S%	Cr%	MO%
EN-31	1.12	0.22	0.45	0.022	0.025	1.12	-
En-8	0.43	0.31	0.6	0.04	0.04	-	-
D-3	1.81	0.65	0.45	0.017	0.03	11.12	0.21

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



Carbon % of Tool steels

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

1. Annealing

It is done to increase Machinability Properties of Material. Temperature of annealing is not directly increase .It is Steps increase With the Time .In EN-8 and EN-31 Annealing Process is same. In this Process these materials are Heated up to 650oc and then Soaking Time is Half an Hour .Then Material is Again heated up to 800oc then Soaking Time is 2 Hours .After this time Furnace Power will off and Sample remain in Furnace for Furnace Cooling . This type of annealing is also known as Isothermal Annealing. In D-3 these sample is Heated up to 650 ^{o}c and then Soaking Time is 1 Hour .Then s step wise heating is done. Temperature of Furnace is increase 20 ^{o}c in 1 hour then again 20 ^{o}c for 1 Hour .Temperature is increased up to 820oc in steps at 820 ^{o}c soaking time is 2 Hour. Then Step Down Temperature Decrease 10 ^{o}c for an hour up to 650 ^{o}c At This temperature Furnace Power will off and Sample remain in Furnace for Furnace Cooling.

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

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

2. Normalizing

Normalizing is only used for low Carbon tool Steel .If we done on High Carbon Steels then Grain will never dissolved uniformly.EN-8 Only Give fine Grain size after Normalizing .

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

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

3. **Hardening and Tempering:-**

Hardening and Tempering Process consist of four Steps:-

- Pre Heating Temperature 550 ^{o}c up to 1 Hour
- Hardening
- Quenching in Oil medium at 60 ^{o}c .Oil is known as quenching oil
- Tempering 200 ^{o}c for 1hour Medium for Tempering is Furnace .Only to maintain temperature of Furnace to 200 ^{o}c .

Stresses produce in Quenching Due to Large change in Temperature so the stresses produced in material. To remove these stresses tempering of material is Done Hardening and Tempering is used to increase the Wear and Tear Resistance of Material after Quenching Martensite Produce then after Tempering Martensite changes To Tempered Martensite. In D-3 Tempering is 3 Time Recommended at International Level. In EN-31 Tempering is 2 Time Recommended at International Level. In EN- 8Tempering is 1 Time Recommended at International Level.

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

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

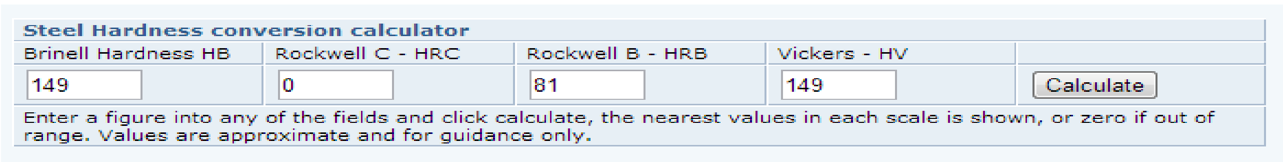
8.3 Hardness Testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3

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

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

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

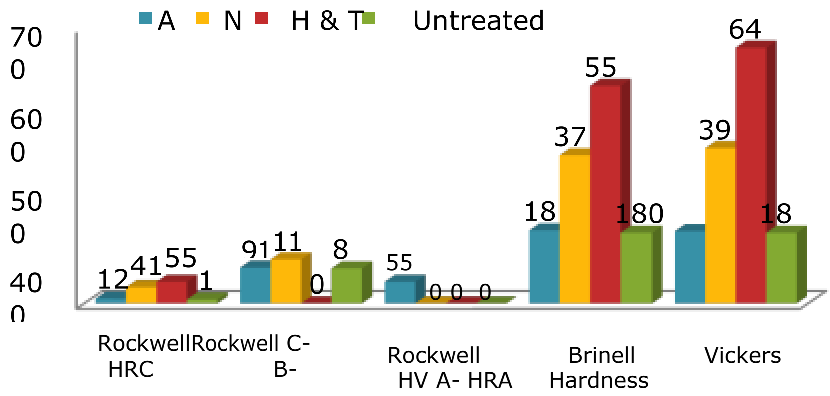
Tool Steel Material	Sample Mark	Rockwell C-HRC	Rockwell B-HRB	Rockwell A- HRA	Brinell Hardness HB	Vickers HV
D-3	A	23	100	----------	240	247
	N	55	0	----------	552	649
	H & T	56	0	----------	572	694



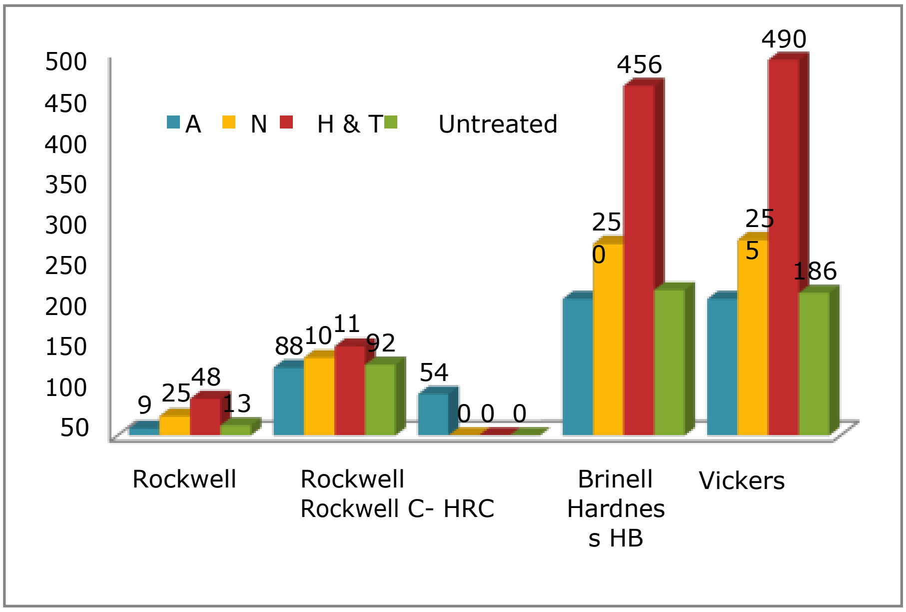
Reference table: Steel Hardness conversion chart. Since the various types of hardness tests do not all measure the same combination of material properties, conversion from one hardness scale to another is only an approximate process. Because of the wide range of variation among different materials, it is not possible to state confidence limits for the errors in using a conversion chart. This table shows approximate hardness of steel using Brinell, Rockwell B and C and Vickers scales. These conversion charts are provided for guidance only as each scale uses different methods of measuring hardness. The right hand columns show an approximate equivalent tensile strength.

Hardness ranges for heat treated steel

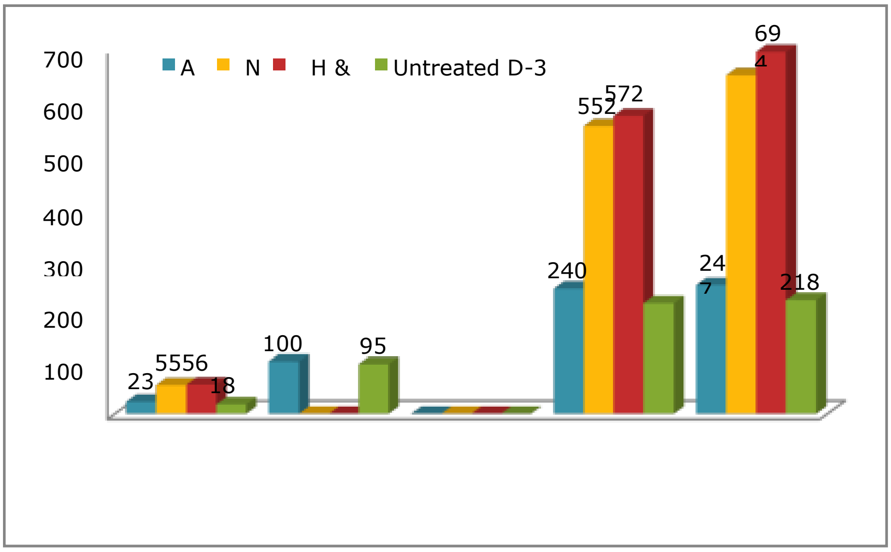
Heat Treated Condition	Q	R	S	T	U	V	W	X	Z
Tensile Strength	625-775 n/mm²	700-850 n/mm²	775-925 n/mm²	850-1000 n/mm²	925-1075 n/mm²	1000-1150 n/mm²	1075-1225 n/mm²	1150-1300 n/mm²	1550 n/mm²
Hardness Brinell	179-229	201-225	223-277	248-302	269-331	293-352	311-375	345-401	444



Hardness Comparison of En-31 Treated & Untreated



Hardness Comparison of En-8 Treated & Untreated



	0 0	0 0 0 0		
0				
Rockwell	Rockwell	Rockwell	Brinell	Vickers HV
C- HRC	B- HRB	A- HRA	dness HB	

Hardness Comparison of D-3 Treated & Untreated

En-31

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

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 more 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.

En-8

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 more harder then annealing specimen .this is due to formation of pearlite is more as compared to ferrite.

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.

D-3

Before treatment D-3hardness 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.

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 is hardest then other three specimens also having a good corrosion resistance.

8.4 Micro Structural Analysis of 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, and D3 Instrument Used: Microscope (Olympus)

Observation: Process [A], Process [N], Process [H&T] At 100 & 500 x 3 % natal etch

Tool Steel Grade	Micro Structural Observation		
	Process (Annealing)	Process (Normalizing)	ss (Hardening and Tempering)
For EN-8	Microstructure consists of Pearlite and Ferrite Grains. Grain Size 5-6 ASTM [American Society for Testing and Materials]	Microstructure consists of Pearlite (dark area) and Ferrite Grains. Sample is normalized	Microstructure consist of fine Tempered Martensite with few Patches of Ferrite
For EN-31	Microstructure consist of Blocky Ferrite and fine to coarse lamellar parlite	Microstructure consist of intermediate product of Bainite and Martensite (EN-31 cannot be normalized) because of air hardening steel	Microstructure consist of Tempered Martensite
For D-3	Microstructure consist a dispersion of massive carbide particle and small spheroidal Carbide in matrix of pearlite and Ferrite	Microstructure consist of greater number un dissolved carbide particle	Microstructure consist of carbide particle in matrix of tempered Martensite

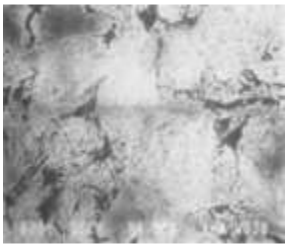
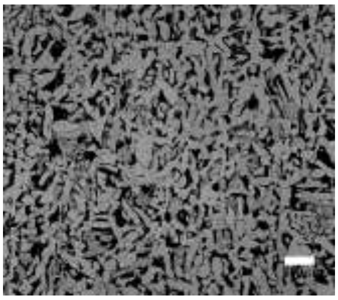
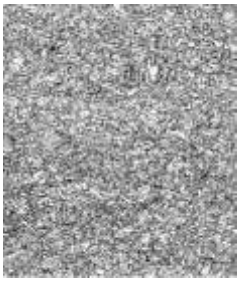
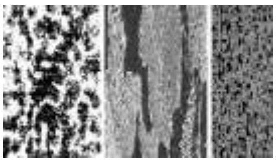
Annealing:-After Annealing EN-8 consist pearlite and ferrite only But in case of EN-31 and D-3 consist of Massive and small carbide in matrix pearlite and ferrite. So there is same microstructure formed for EN-31 and D-3 after the annealing Process .These Carbides are formed due to Chrome and Carbon Elements. By Annealing EN-31 and D-3 can be used Surface Treatment .It Prevents the Surface from Corrosion.

Normalizing:- In the Normalizing En-8 consist of Pearlite and Ferrite . EN-31 consist Bainite and Martensite which means we can't do normalizing of the EN-31.In air Cooling EN-31 forms Martensite. D-3 Consists Un-dissolved Carbide so it means Normalizing can be used for only En-8.

Hardening and Tempering:- In EN-8 Martensite with few patches is formed so it is not more brittle and not More Soft.EN-31 Produce only Martensite so it makes the material Brittle .In D-3 Consist of Martensite with Carbide particle .Martensite is less in EN-8 and D-

3.Hardening and Tempering is Suitable for En-8 and D-3.

This table purely belongs to the Illustration of the appearance of micro Structural outcomes after treatment .This helps to describe the changes of stages in the standard format as per the study of change in behavior only the illustrated sketches in the tabulated format are not purely the as per the observation for selected tool steels.

Tool Steel Grade	**Illustration of the appearance of Micro Structural Observation**		
	Process (Annealing)	**Process (Normalizing)**	**Process (Hardening and Tempering)**
For EN-8	 Pearlite & Ferrite Grains. Garin Size 6 ASTM	 ite (dark area) & Ferrite Grains (Light grey).	 Fine Tempered Martensite with few Patches of Ferrite
For EN- 31	 Blocky Ferrite & fine to coarse lamellar parlite	 Bainite and Martensite	 Tempered Martensite
For D-3	 Massive carbide particle and small spheroidal Carbide in matrix of pearlite and Ferrite	 Un dissolved carbide particle	 Carbide particle in x of tempered Martensite

9. Conclusions

After Hardness testing of Untreated & Treated Tool Steel i.e. EN-31, EN-8, and D3 we compare the effect on mechanical properties before and after treatment. 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 is hardest then other three specimens also having a good corrosion resistance.

After Micro Structural Analysis of Treated Tool Steel i.e. EN-31, EN-8, and D3 very significant results carried out. It is found that the After Annealing EN-8 consist pearlite and ferrite only But in case of EN-31 and D-3 consist of Massive and small carbide in matrix pearlite and ferrite. So there is same microstructure formed for EN-31 and D-3 after the annealing Process .These Carbides are formed due to Chrome and Carbon Elements. By Annealing EN-31 and D-3 can be used Surface Treatment. It Prevents the Surface from Corrosion.

In the Normalizing En-8 consist of Pearlite and Ferrite. EN-31 consist Bainite and Martensite which means we can't do normalizing of the EN-31.In air Cooling EN-31 forms Martensite. D-3 Consists Un-dissolved Carbide so it means Normalizing can be used for only En-8.

In the Hardening and Tempering EN-8 Martensite with few patches is formed so it is not more brittle and not More Soft.EN-31 Produce only Martensite so it makes the material Brittle .In D-3 Consist of Martensite with Carbide particle .Martensite is less in EN-8 and D-3.Hardening and Tempering is Suitable for En-8 and D-3.

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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