IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 5, May 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

Investigating the Heat Treatment Parameters of En-31 Using Taguchi Method

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ABSTRACT

Investigating the effect of heat treatment in industry, more focus was found on the use of optimization technique. The main aim of this process is to maximize of Hardness in of Steel material using Heat Treatment & Taguchi Method. EN31 is a manganese spring steel with high carbon content. EN31 is used widely in the motor vehicle industry for heavy duty gear, shaft, pinion, camshafts, gudgeon pins and machining components and many general engineering applications. The Experiment was conducted with a view to refer and research on Hardness and improving machinability. Heat treatment process done in various stages after selecting the material. For removing internal stresses from material process done. Value of hardness and strength will increase after the experiment. Rate of hitting, rate of cooling, socking time, loading & unloading temperature are different types of parameters for the heat treatment process. Considering the short product life cycle, maximum Hardness is always desirable. Therefore parameters affecting the Hardness should be recognized and optimized for desired results. The experiments conducted based on the Heat Treatment and results were optimized. Experiment was carried out using three input parameters Austenizing Temperature, Quenching Media and Tempering Temperature with three different levels. The effects of different input parameters and effect of their combination on Hardness was determined using Taguchi and ANOVA table. Hardness of material increase due to the percentage of carbon increases. Due to that strength of the material will increases. Strength of material will check on the load tester. Values coming out from the experiment will provide us proper information about the steel material.

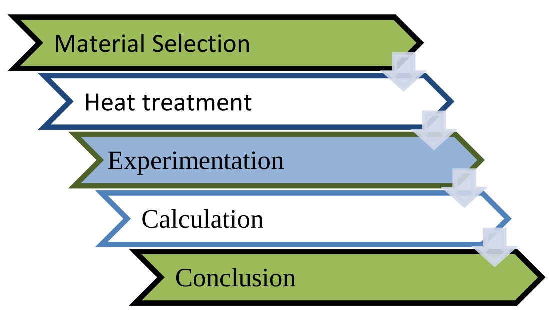
KEYWORD :- *Heat Treatment, Alloy Steel, EN-31, Taguchi Method, ANOVA*

1. INTRODUCTION

As Steelworkers, we are interested in the heat treatment of metals, because we have to know what effects the heat produced by welding or cutting has on metal. We also need to know the methods used to restore metal to its original condition. The purpose of heat treating is to make a metal more useful by changing or restoring its mechanical properties. Through heat treating, we can make a metal harder, stronger, and more resistant to impact 3 Stages Of Heat Treatment is carried out for heat treatment. (1) Heating (2) Socking (3) Cooling. Taguchi & ANOVA is used to find the perfect parameters for Heat Treatment Water, Oil & Air are used as quenching media. Some properties are improved at the expense of others; for example, hardening a metal may make it brittle.

2. METHODOLOGY

Table 2.1 Methodology



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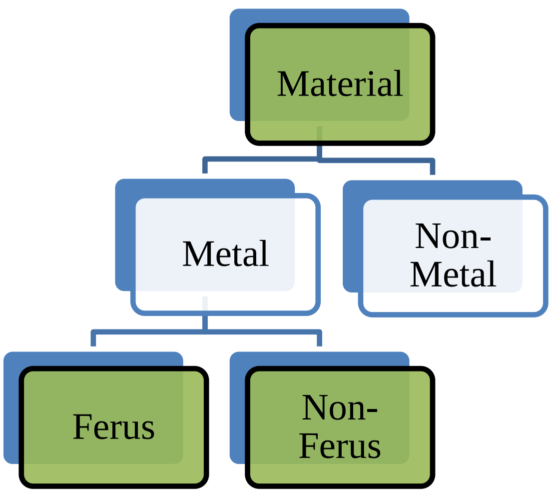
2.1 Material Selection

Various materials are available in the market. This might include metals, non-metals, ceramics etc.

Table 2.2 Material Selection



According to the World Steel Association, there are over 3,500 different grades of steel, encompassing unique physical, chemical, and environmental properties.

In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determine the properties of each steel grade.

The carbon content in steel can range from 0.1-1.5%, but the most widely used grades of steel contain only 0.1-0.25% carbon.

Elements such as manganese, phosphorus, and sulfur are found in all grades of steel, but, whereas manganese provides beneficial effects, phosphorus and sulfur are deleterious to steel's strength and durability.

Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties. According to the American Iron and Steel Institute (AISI), steel can be broadly categorized into four groups based on their chemical compositions:

1. Carbon Steels
2. Alloy Steels
3. Stainless Steels
4. Tool Steels

Carbon Steels

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorized into three groups depending on their carbon content:

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon

Alloy Steels

Alloy steel contain alloying elimentseg (silicon, nickel, titanium, copper, chromium, and aluminum) in varying proportions in order to manipulate the steel's properties, such as its hardenability, corrosion resistance, strength, formability, weldability or ductility.
Applications for alloys steel include pipelines, auto parts, transformers, power generators and electric motors.

Stainless Steels

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. With over 11% chromium, steel is about 200 times more resistant to corrosion than mild steel. These steels can be divided into three groups based on their crystalline structure:

- Austenitic: Austenitic steels are non-magnetic and non heat-treatable, and generally contain 18% chromium, 8% nickel and less than 0.8% carbon. Austenitic steels form the largest portion of the global stainless steel market and are often used in food processing equipment, kitchen utensils, and piping.

- Ferrite: Ferrite steels contain trace amounts of nickel, 12-17% chromium, less than 0.1% carbon, along with other alloying elements, such as molybdenum, aluminum or titanium. These magnetic steels cannot be hardened by heat treatment but can be strengthened by cold working.

- Martensitic: Martensitic steels contain 11-17% chromium, less than 0.4% nickel, and up to 1.2% carbon. These magnetic and heat-treatable steels are used in knives, cutting tools, as well as dental and surgical equipment.

Tool Steels

- Tool steels contain tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment.
- Steel products can also be divided by their shapes and related applications:
- Long/Tubular Products include bars and rods, rails, wires, angles, pipes, and shapes and sections. These products are commonly used in the automotive and construction sectors.
- Flat Products include plates, sheets, coils, and strips. These materials are mainly used in automotive parts, appliances, packaging, shipbuilding, and construction.
- Other Products include valves, fittings, and flanges and are mainly used as piping materials.

2.3 Different types of steel and their application

- EN-8. Crank shafts, automobile axle beams, connecting rods, lightly stressed gears. Generally used for moderately stressed parts of Motor Vehicles and general engineering works.
- EN-9. Crank shafts, Cylinders, Gears, Sprockets. Mainly used in machine parts which require moderate wear resistance
- EN-19. Axle shafts, Crank shafts, Gears, Connecting rods, Studs, Bolts, Propeller shaft joint. Suitable for heat treated parts where high tensile and impacts are required along with high endurance bending strength.
- EN-24. Aircraft and heavy vehicle crank shafts, Connecting rods, Gear shafts, Chain parts, Clutches, Propeller shafts, Cam shafts, Spindles, Screws, Studs, Pinions, Tappets, Boring bars. Preferred to be applied for heat treated components having large sections and subject to exacting requirements.
- EN-30. B Application similar to EN-24 Steel. More Suitable for extra ordinary high toughness purposes.
- EN-31. Ball and Roller Bearings, Spinning tools, Beading Rolls, Punches and Dies. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading.
- EN-36. Disc wheels, Grooved shafts, Cams, Gears, Heavy duty gears for air craft, Heavy vehicle and automobile transmission parts, General engineering works, Universal joints. Mainly used for highly stressed machine parts which are intended for cementation with high strength and core toughness.
- SPRING STEEL
- EN-45. Leaf and volute springs, Road and railway vehicle springs including helical and plate springs. This steel is capable of taking up a good hardness and possesses an increased stability in tempering.
- EN-47. High duty volute and leaf springs, Heavy engine valve springs, Helical and torsional bar springs. It has a high ratio of yield point to tensile strength and high torsional fatigue strength.

Fig. 2.1 Different types of steel

2.4 EN 31

EN31 material is one of such ferrous metal that is generally used in manufacturing bearing component such as Ball and Roller Bearings, Spinning tools , Bedding Rolls, Punches and dies. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to serve abrasion, wear and high surface loading.

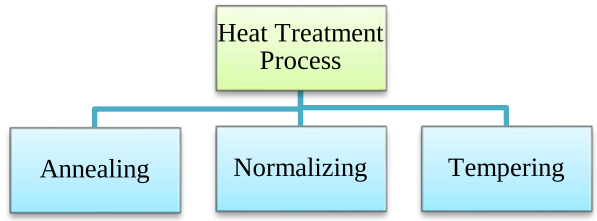
-Chemical Composition of EN31

Table 2.3 Chemical Composition

Element	C	Cr	Mn	P	S	Si
%	0.9-1.20	1-1.60	0.3-0.75	0.02-0.06	0.015-0.030	0.1-0.35

Fig. 2.2 EN31 Steel Specimen

2.5 Heat Treatment Process:



Annealing: Annealing process is heating a metal to a specific temperature and then cooling it slowly. Cooling at a rate that will produce a refined microstructure, either fully or partially separating the constituents.

Normalizing: The normalizing process is heating process and then cooling the material at normal room temperature. It is used to get uniformity in grain structure.

Tempering: Tempering consists of heating steel below the lower critical temperature, (often from 170 to 270 ˚C, depending on the desired results), to impart some toughness. Higher tempering temperatures (may be up to 700 ˚C, depending on the alloy and application) are sometimes used to impart further ductility, although some yield strength is lost.

From above-mentioned process, we have selected Annealing Heat Treatment process. EN31 is usually supplied in the annealed and machine able condition. To anneal, heat the EN31 steel slowly to 800-870°C, soak well and allow cooling in the furnace.

3. Experimentation

Work piece :The experiment on which Heat Treatment was carried outwash EN31 (unhardened) material. 25mm × 160 mm.

Furnace Specification :-

Working Size:-	500mm × 300mm × 500mm

Working temp:-	11000c (max)
Maximum temp	:-12000c
Operation:-	415v Three Phase
Insulation:-	Fiber wool insulation
Construction:-	CRC sheet-powder coated

Fig. 3.1 Furnace

3.1 Experimental Procedure:-

The entire experiment was carried on Heat Treatment Process. The experiment was performed individually for one material. First, all the initial hardness was measured before carrying out the Heat Treatment Process and chemical testing of material also done in laboratory. After that heat treatment process was done, final hardness of water quench, air quench and oil quench was compared with each other and the difference of hardness by the Heat treatment of EN material. After that tensile test was done on that material and difference between all quenched material was carried out.

The experiment was carried out according to the design of experiment table generated by Taguchi design of experiments. The software used was Minitab 17. Each work piece was hardened by full hardening process. After that hardness of material was measured. After hardening of material each work piece was quenched in different quenching media. After that each work piece was get socked and cooled in different tempering temperature. Tensile test was done on 2 work piece which has maximum hardness among all work pieces. After getting result water quench material is brittle and having less strength compare to oil quench material.

Table 3.1 Hardness Result after Heat Treatment

Sr.No	**Austenizing Temp.**	**Quenching Medium**	**Tempering Temp.**	**Hardness (HRC)**
1	770	Water	170	58
2	770	Oil	220	47
3	770	Air	270	22
4	820	Water	220	59
5	820	Oil	270	49
6	820	Air	170	25
7	870	Water	270	65
8	870	Oil	170	60
9	870	Air	220	27

Table 3.2 Result of Tensile Strength

Sr	**Austenizing**	**Quen -**	**Temp-**	**Yield Tensile**	**Ultimate Tensile**

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No	Temp.	ching Medium	ering Temp.	strength N/mm2	strength N/mm2
1	870	Water	270	690.88	1296.17
2	870	Oil	170	730.69	1407.84

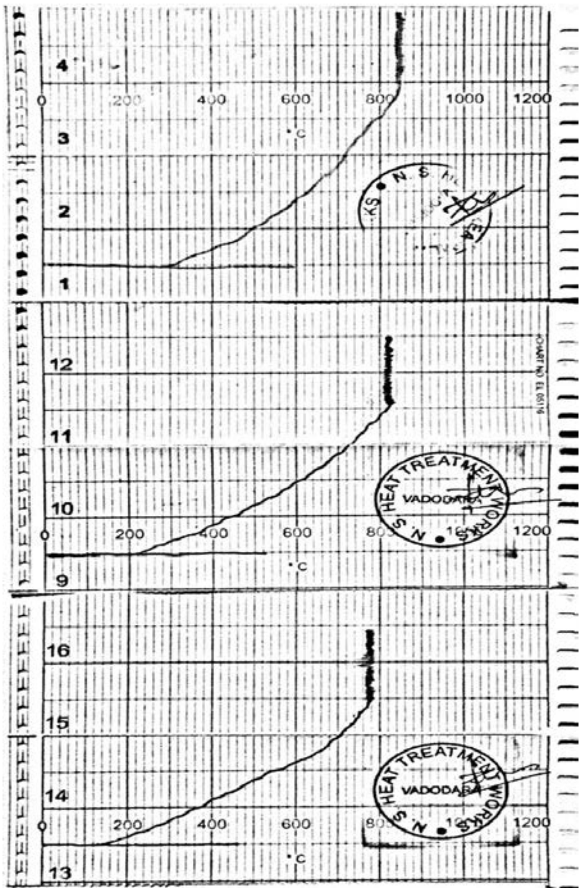

Fig. 3.2 Resulted Graph of Heat Treatment

3.2 Calculation

3.2.1 Calculation of S/N ratio for each trial

The hardened material hardness obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. For better strength , hardness should be high. Therefore, the S/N ratio is calculated for larger the better. For calculating S/N ratio for this case of lower the better Taguchi has outlined an equation. The equation to obtain the values of S/N ratio is shown below

S/N = -10 log10 (MSD)

For larger is better

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{i=n}\frac{1}{y_i^2}$$

MSD = Mean Square Deviation

y = hardness of material

n= No. repetition.

Example for trial no. 1

$n = 1$ and $y_1 = 58$

Therefore,

$$S/_N \text{ Ratio} = -10\log_{10}\frac{1}{1}[(\frac{1}{58^2})]$$

S/N = 35.2686

Similarly, S/N ratio for other trials is obtained and shown in Table3.3

Table 3.6 S/N Ratio of each trail for Heat Treated Material

Sr. No	Austenizing Temp.	Quenching Medium	Tempering Temp.	Hardness (HRC)	S/N Ratio
1	770	Water	170	58	35.2686
2	770	Oil	220	47	33.4420
3	770	Air	270	22	26.8485
4	820	Water	220	59	35.4170
5	820	Oil	270	49	33.8039
6	820	Air	170	25	27.9588
7	870	Water	270	65	36.2583
8	870	Oil	170	60	35.5630
9	870	Air	220	27	28.6273

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3.2.2 Calculation of S/N ration for Each Level of Each Factor

S/N ratio of level 1 for Austenizing Temperature is obtained as follows

For Level 1

$$=\frac{(35.2686)+(33.4420)+(26.8485)}{3}= 31.85$$

Similarly, the S/N ratio for each level of each factor is obtained, and the results of S/N ratio for each level are shown in table 3.4

Table 3.4 Response table of S/N Ratio for each level of each factor

Levels	Factors		
	Austenizing Temp.	Quenching Medium	Tempering Temp.
1	31.85	35.64	32.93
2	32.39	34.26	32.49
3	33.48	27.81	32.30
Max. Difference	1.63	7.83	0.63

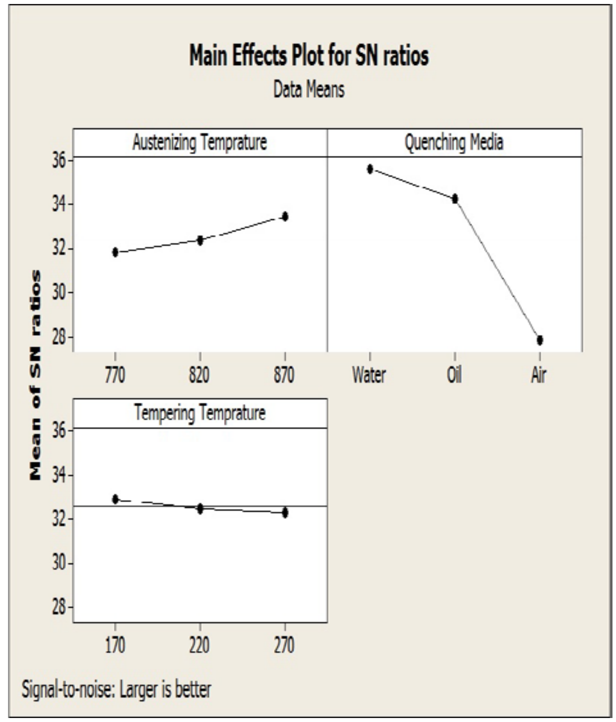

Fig 3.3 S/N ratio graph for Heat Treated Material

From the S/N ratio response as shown in Figure the best combination of parameters is Austenizing Temperature followed by Quenching media and Tempering Temperature. Hence optimum condition can be represented by A3B1C3 Table 3.7 shows the summary of best combinations of parameters setting.

Table 3.5 Best parameter setting for Heat Treated Material

Factors	Values
Austenizing Temperature	870^0c
Quenching media	water
Tempering Temperature	270^0c

3.3 ANOVA Calculations

ANOVA calculation is required because by using Taguchi method we get the only best combination of parameters but we don't get any information about the significance of parameters. By using ANOVA method we can get most significant parameter as well as percentage contribution of that parameter on output variables.

Table 3.9 ANOVA of Hardness For Heat Treated Material

Souce	DF	Seq SS	Adj SS	Adj MS	F	P	P(%)
Austenizing Temp.	2	113.56	113.56	56.78	13.81	0.068	3.76%
Quenching Medium	2	2118.22	2118.22	1059.11	257.62	0.004	95.66 %
Tempering Temp.	2	17.56	17.56	8.78	2.14	0.319	0.56
Error	2	8.22	8.22	4.11			
Total	8	2257.56					

TOTAL DEGREE OF FREEDOM

$f_T = N - 1$

Where N= no. of trials

$f_T = 9 - 1 = 8$

For factor A

$f_A = k_A - 1$

Where k_A = No. of levels for factor A

Therefore, $f_A = 3 - 1 = 2$

Similarly $f_B = 2$ and $f_C = 2$.

For Error, $fe = f_T - (f_A + f_B + f_C)$

$f_e = 8 - (2+2+2) = 2$

TOTAL SUM OF SQUARES

$$S_T = \left(T_{S_1}^2 + T_{S_2}^2 + \cdots + T_{S_N}^2\right) - \frac{(T_{S_1} + T_{S_2} + \cdots + T_{S_N})^2}{N}$$

$$S_T = [(35.2686)^2 + (33.4420)^2 + (26.8485)^2 + .. + (28.6237)^2] - \frac{(35.2686 + 33.4420 + 26.8485 + .. + 28.6273)^2}{9}$$

$S_T = 109.7755$

For factor A

$$S_A = \left(\frac{(\sum A_1)^2}{k_{A_1}} + \ldots + \frac{(\sum A_9)^2}{k_{A_9}}\right) - \frac{\left(T_{S_1} + T_{S_2} + \cdots + T_{S_N}\right)^2}{N}$$

$$S_A = \frac{(35.2686 + 33.4420 + 26.8485)^2}{3} + \frac{(35.4170 + 33.8039 + 27.9588)^2}{3} + \frac{(36.2583 + 35.5630 + 28.6273)^2}{3} - \frac{(35.2686 + 33.4420 + 26.8485 \ldots + 28.6273\ )^2}{9}$$

$S_A = 4.135473$

Similarly,

$$S_B = \left(\frac{(\sum B_1)^2}{k_{B_1}} + \ldots + \frac{(\sum B_9)^2}{k_{B_9}}\right) - \frac{\left(T_{S_1} + T_{S_2} + \cdots + T_{S_N}\right)^2}{N}$$

$S_B = 105.016545$and

$$S_C = \left(\frac{(\sum C_1)^2}{k_{C_1}} + \dots + \frac{(\sum C_9)^2}{k_{C_9}}\right) - \frac{(T_{S_1} + T_{S_2} + \cdots + T_{S_N})^2}{N}$$

Sc= 0.618363

For Error

$S_e = S_T - (S_A + S_B + S_C)$

$$S_e = 109.7755949 - (4.135473 + 105.016545 + 0.618363)$$

$S_e = 0.0052139$

VALUES OF VARIANCE FOR ALL FACTORS

For factor A

$$V_A = \frac{S_A}{f_A}$$

$$V_A = \frac{4.135473}{2}$$

$V_A = 2.0677365$

For factor B

$$V_B = \frac{S_B}{f_B}$$

$V_B = 52.5082725$

For factor C

$$V_C = \frac{S_C}{f_C}$$

$V_C = 0.3091$

For variance error

$$V_e = \frac{S_e}{f_e}$$

$$V_e = \frac{0.0052139}{2} = 0.00260695$$

F- RATIO FOR ALL FACTORS

For factor A

$$F_A = \frac{V_A}{V_e}$$

$$F_A = \frac{2.0677365}{0.00260695}$$

$F_A = 793.16308$

For factor B

$$F_B = \frac{V_B}{V_e}$$

$F_B = 20141.64925$

For factor C

$$F_C = \frac{V_C}{V_e}$$

$F_C = 118.567674$

PERCENTAGE CONTRIBUTION (P %)

For factor A

$$P_A = \left(\frac{S_A}{S_T}\right) \times 100$$

$P_A = 3.76\ \%$

For factor B

$$P_B = \left(\frac{S_B}{S_T}\right) \times 100$$

$P_B = 95.66\ \%$

For factor C

$$P_C = \left(\frac{S_C}{S_T}\right) \times 100$$

$$P_C = 0.56\%$$

Conclusion

In this study, the Taguchi method & Heat Treatment were used to obtain optimal control parameters combination with their level in Hardness of EN31 material. Experimental results were evaluated using ANOVA & Heat Treatment method. The results can be drawn as follows:

- The optimum levels of the control factors to obtain better Hardness by using Taguchi method are: Austenizing Temperature = 870^0, Quenching Media = Water, and Tempering Temperature = 270^0.
- By Heat Treatment Process highest Hardness is 65 at 870^0 austenizing temperature, water as a quenching media & 270^0 tempering temperature. But Water absorbs large quantities of atmospheric gases, and when a hot piece of metal is quenched, these gases have a tendency to form bubbles on the surface of the metal. These bubbles tend to collect in holes or recesses and can cause soft spots that later lead to cracking or warping. So, Oil Quenching is better for EN31 is Proved by Tensile Test.
- By ANOVA analysis for Heat Treatment rate, it was found that the Quenching Media is the most significant factor affecting the Heat Treatment with a percentage contribution of 95.66%.

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