International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-3, February 2019

Study of Mechanical Properties and Change in Microstructure of Alloy Steel EN24 under various Heat Treatment Process.

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Abstract*: *The alloy steel EN24 as a base metal before heat treatment has limited applications because of its low values of tensile properties. In order to enhanced its mechanical properties, hardness, its machinability up to such an extent that it can be used as: gears, connecting rods, swivel arms, transmission parts, machine tool parts, dies, cylinders, cropping blades , aero planes & aerospace systems the alloy steel EN24 have to be heat treated with different processes. The above problems of alloy steel En24 is improved in this project by applying three heat treatment processes i.e. stress relieving, normalizing and hardened & tempered for each specimens and testing each specimens for their tensile properties, chemical composition, hardness & microstructures. The graphs and their comparative analysis are done in the end.

***Keywords*: *Chemical composition, EN24, Hardness Testing, Heat Treatment, Mechanical Properties & Microstructure study*.**

I. INTRODUCTION

In physical metallurgy, the study of mechanical properties and influence of heat treatment on microstructures is always been a topic of research [1-3]. To find newer steel with enhanced mechanical properties, hardness within the cost range is always remain in Industrial demand with widespread application zones. EN24 comes in the family of alloy steels which inherently have high tensile properties, is of high quality & is very popular that can be machined without difficulty in the "T" condition. For the manufacturing of heavy duty axles and shafts and stud EN24T is very much appropriate. Its wear resistance can further be increased by induction or nitride processes which raise its surface hardness in the range of 58-60 HRC. EN24T is very useful in offshore applications as it retain very good impact values at low temperatures. The larger cross section of part manufactured by EN24T can exposed to future treatment by quenching and tempering, but this result in fall out of mechanical properties from surface to core. To overcome this we annealed and later perform quenching/cooling that helps us to strengthen mechanical properties towards the core.

II. OBJECTIVE OF WORK

The objective of this work is to determine the mechanical properties, chemical composition, hardness & microstructures analysis of alloy steel EN24 before & after heat treatment processes.

Manuscript published on 28 February 2019.
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After that compare these properties with different treatment conditions, the treatment conditions are mainly stress relieving, normalizing and hardened & tempered.

- **Mechanical properties are** :
  - Tensile strength (U.T.S)
  - % Elongation
  - Yield load
  - Breaking load
  - Yield stress
- Chemical composition test is done for base metal EN24 (before heat treatment) and hardened & tempered specimens of EN24 to depict the variations in the % of Carbon (c), Chromium (Cr), Copper (Cu), Iron (Fe), & Manganese (Mn).
- Hardness test is done for before and after heat treated specimens of EN24.
- Microstructure test result is done for before and after heat treated specimens of EN24.

Then these mechanical properties, chemical composition elements variations, hardness variations are plotted graphically & microstructure`s test results are analyzed.

III. METHODOLOGY/EXPERIMENTAL PROCEDURE

To analyze the effect of heat treatment on the alloy steel EN24, the exploration was done out in the following steps:-

- Preparation of the specimen from 0.36% carbon ingot.
- Heat treating the specimens.
- Color detection in the specimen after heat treatment.
- Mechanical properties and chemical properties study.
- Microstructure study.

3.1 Specimen Preparation

Specimen is prepared by as per American Society for Testing and Materials (ASTM) standards and has the following specification:-

(i) Gauge length-55 mm
(ii)Gauge diameter- 10 mm
(iii)Total length- 175 mm
(iv) Diameter of Grip - 18 mm

This specimen is subjected to testing for mechanical properties and heat treatment.

3.2 Heat Treatment

Heat treatment is a process in which we controlled heating and cooling of materials to yield changes in their microstructures, strength, machinability.

Alloy steels EN24 are primarily heat treated to improve its mechanical properties like tensile strength, percentage elongation and improving its hardness.

It basically had a ferrite and bainite type of microstructures, but by using different heat treatment processes the structure changes from ferrite, bainite to tempered martensite. The process adopted in this study is as follows:-

3.2.1 Normalizing: In this process the specimen was heated in a coal based furnace up to temperature of 900°C, then it is held at that temperature for 2 hours and in the last it is taken out, air cooled in the ordinary environment.

3.2.2 Hardening & Tempering Process : Hardening and Tempering process is also called hardening process in which the specimen is heated up to a temperature of 900°C, then it is held at that temperature for 2 hours, after that it is oil quenched so that the temperature drops up to range of 50-65 °C.

After the above process, tempering is done, in which specimen is heated at a temperature of 600 °C, then their it is held for 1 hour, soaking time is ½ hour and in the last the specimen is cool in a natural air at a rate of 100 °C / hour.

3.2.3 Stress Relieving Process: It is a process that helps to reduce undesirable residual stresses that results from processes such as hot forging, cold forming **[1].** For EN24 specimen, the recommended temperature range was 650-670°C for a soaking time span of 2 hours, after this the furnace was switched off and the specimen was cooled inside the furnace itself. The furnace used in this process was electric furnace.

3.3 Color detection in the specimen after heat treatment.

Process	Elongated Length (mm)	T S (N/mm^2)	Y S (N/mm^2)	Elongation (%)	RA (%)
B H T	61.26	665.61	458.60	22.52	64
S R	62.10	687.90	509.55	24.20	66.9
Normal-izing	51.40	1200.64	------	2.80	----
H & T	50.32	1447.50	------	0.64	-----

After using various heat treatment processes, the color of the specimen goes on changing. The EN24 before heat treatment slightly has a silver like color, it changes into bluish color when it is normalized, when it is hardened & tempered it changes into black color, and by stress relieving process it becomes slightly reddish.

3.4 Mechanical properties and chemical composition study.

Specimen`s analysis for mechanical properties, hardness and chemical composition was carried out in Bhartiya testing lab situated in Faridabad.

3.4.1 Hardness Testing: The heat treated specimens hardness was measured by means of Rockwell hardness tester.

3.4.2 Ultimate Tensile Strength Testing: Specimens gone through different heat treatment processes were then tested on Universal Testing Machine to get comparative analysis of different mechanical properties like % elongation, Ultimate Tensile Strength, yield Strength, breaking load etc.

3.4.3 Chemical Composition Testing: In this process the specimen was cut into small pieces and then put inside the spectrometer, the holding of the specimen inside it is done by creating a vacuum & then the specimen is press by the hydraulic driven arm.

3.5 Microstructure study.

Microstructure is basically used to describe the appearance of the material or we can say that positioning of phases and defects. Analysis of microstructure is divided into following sequential steps. Firstly a layer of approximate 4 mm is sliced then it is further prepared by using Bakelite powder then polished by SiC paper (emery paper) and then by 1 µm cloth coated with diamond paste and lastly the samples were etched by using 2% natal (2% conc. Nitric acid in methanol solution).

IV. Results & Discussions

4.1 Mechanical Properties:

The mechanical properties measured by using Universal testing machine of alloy steel EN24 before and after heat treatment processes are given in Table 1 lists the mechanical properties viz. Breaking load, Tensile strength, % Elongation, Hardness etc. of EN24 respectively.

Table 1: Mechanical properties of EN24

Process	Dia (mm)	Area (mm^2)	Gauge length (mm)	B L (N)	Y L (N)
B H T	10	78.50	50	52250	36000
S R	10	78.50	50	54000	40000
Normalizing	10	78.50	50	94250	-----
H & T	9.95	77.72	50.00	112500	------

* B H T – Before heat treatment
* S R - stress relieving process
* H & T - Hardened & Tempered
* B L - Breaking load
* Y L - Yield load
* T S - Tensile strength
* Y S - Yield stress

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NOTE: From the above table we are seeing that for normalizing and hardened & tempering process the column of yield load, yield stress & reduction in area are vacant; it is basically because the samples broke at the gauge mark.

4.2 Hardness measurement:

Table 2 shows the results of hardness test in (Rockwell Hardness 'B' & 'C' scale) for before & after heat treated samples of EN24.

The hardness increases as it goes from stress relieving process to normalizing & then to hardened & tempered process. It happens due to microstructure transformation of ferrite & bainite to martensite & then to tempered martensite.

Table 2: Hardness test results of EN24

TREATMENT	HARDNESS
Before Heat treatment (B H T)	91.5 HRB
Stress Relieving	93.0 HRB
Normalizing	39.2 HRC
Hardened & Tempered	49.2 HRC

4.3 Chemical composition test result.

Chemical composition test was done on spectrometer for base metal EN24 (before Heat treatment) and for Hardened & tempered EN24 to detect the variation in the composition elements before and after heat Treatment. Table 3 shows the variation of the composition elements for both the tested specimens.

Table 3: Chemical composition test result for before & after heat treated EN24.

Process	Elements (All in %)						
	C	Si	Mn	Cr	Ni	Mo	V
B H T	0.365	0.295	0.551	1.040	1.440	0.208	0.018
H & T	0.400	0.298	0.583	1.100	1.410	0.217	0.019

Process	Elements (All in %)						
	Cu	Al	S	P	B	Pb	Fe
B H T	0.102	0.033	0.030	0.035	0.001	0.005	95.8
H & T	0.148	0.008	0.023	0.026	0.001	0.005	95.7

***** B H T- Before Heat treatment
* H & T- Hardened & tempered

4.4 Microstructure Test result

In Microstructure test we basically defined the structures of the specimens of alloy steel EN24 before & after heat treatment.

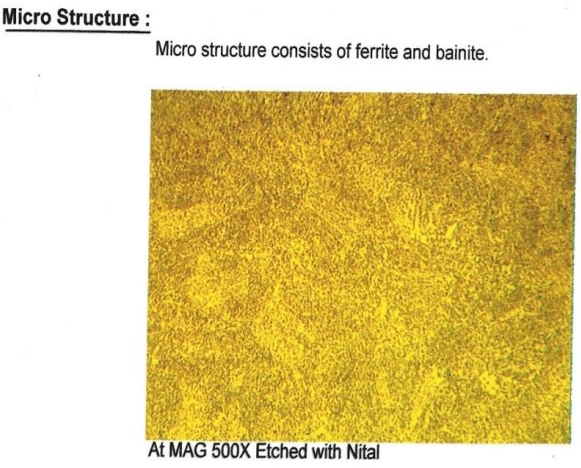

Fig 1. Microstructure of base metal EN24 (before heat treatment)

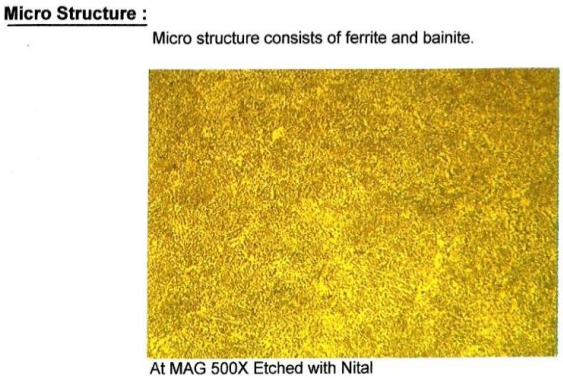

Fig 2. Microstructure of stress relieved EN24

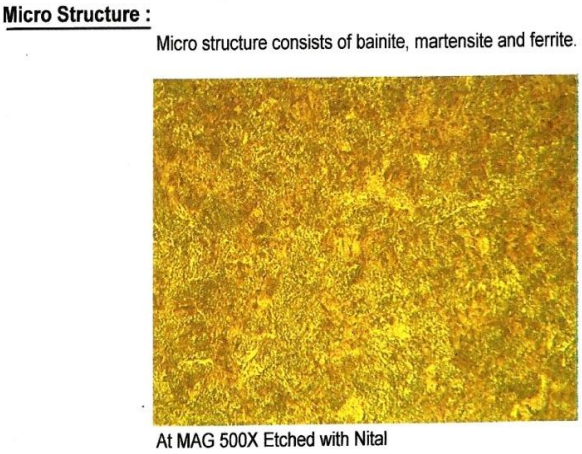

Fig 3. Microstructure of normalized EN24

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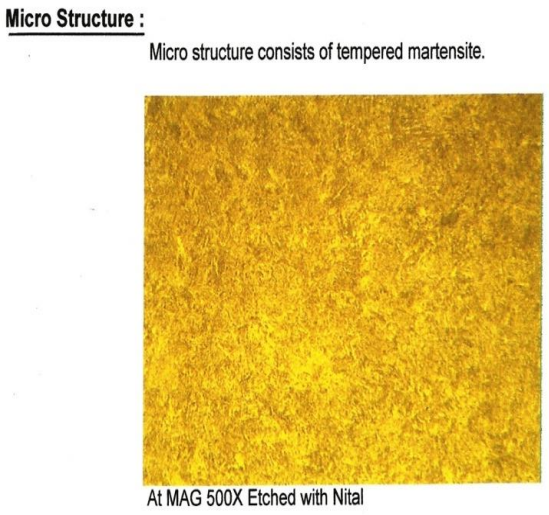


Fig 4. Microstructure of hardened & tempered EN24

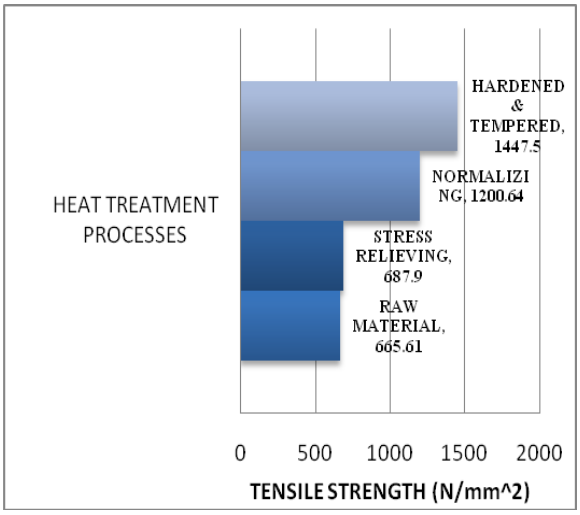
The microstructure of EN24 before heat treatment is basically consists of ferrite & bainite. After different treatments there is a change in matrix/phase structure. These cause changes in the mechanical properties of alloy steel EN24. The microstructures after different types of treatments of EN24 are shown in figure 1, 2, 3 & 4.

After stress relieving treatment, the microstructure of EN24 is quite similar to the before one specimen because it consists of ferrite & bainite, but tensile strength, yield stress, % elongation & hardness properties are improved.

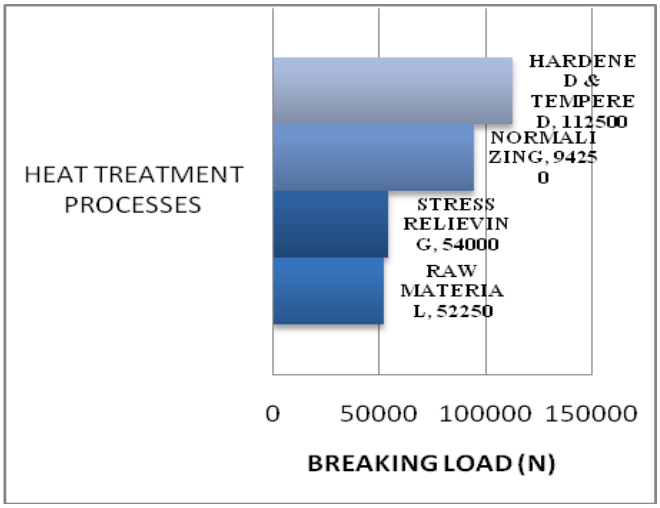
But after air cooling or normalizing, the microstructures gets envelope of martensite with bainite & little bit of ferrite, which results in the high increase in hardness value with tensile strength. In pearlite matrix graphite nodules and ferritic molecules have their fixed position and after tempering and hardening this phase modified to martensite so results in increase in strength and ductility caused by internal stress relieving [15].

4.5 Graphs

4.5.1 Variation of mechanical properties with respect to different heat treatment processes.

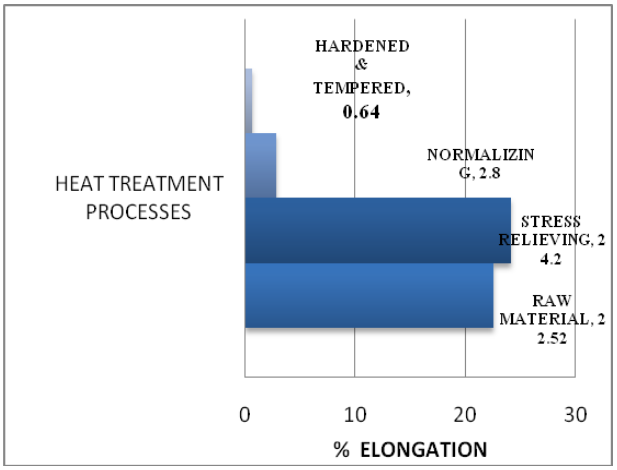


(a)

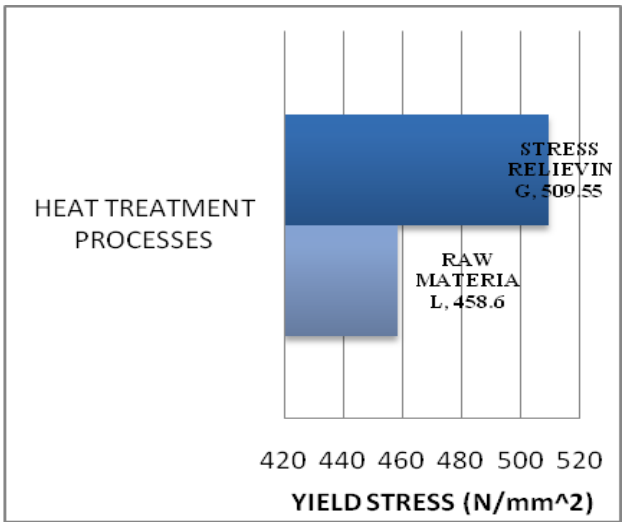


(b)

Fig 5 (a & b). Tensile strength and Breaking load variation due to different heat treatment processes



(a)



(b)

Fig 6 (a & b). % elongation variation and Yield stress variation due to different heat treatment processes.

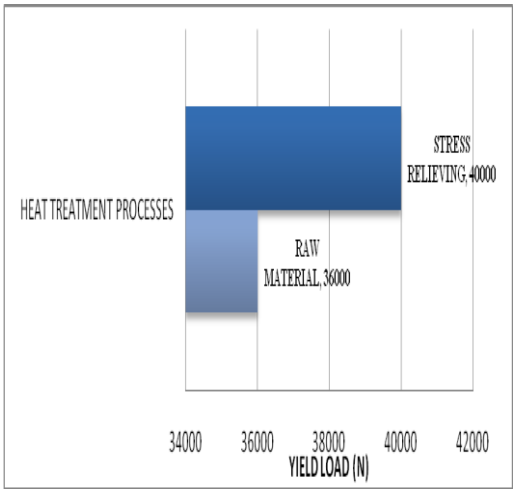
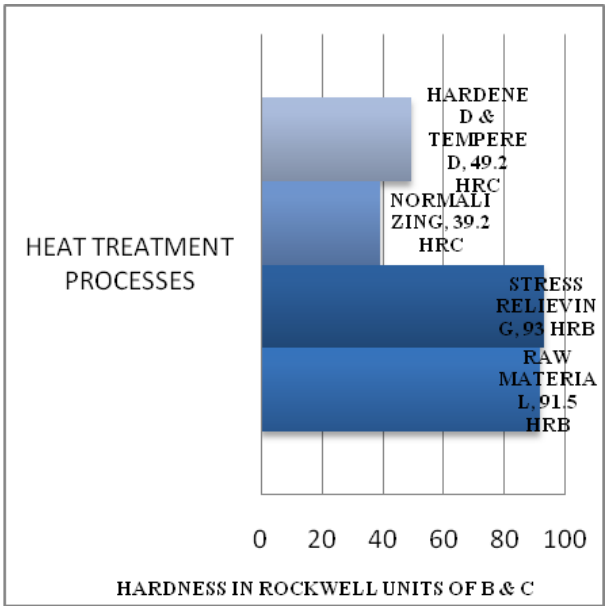
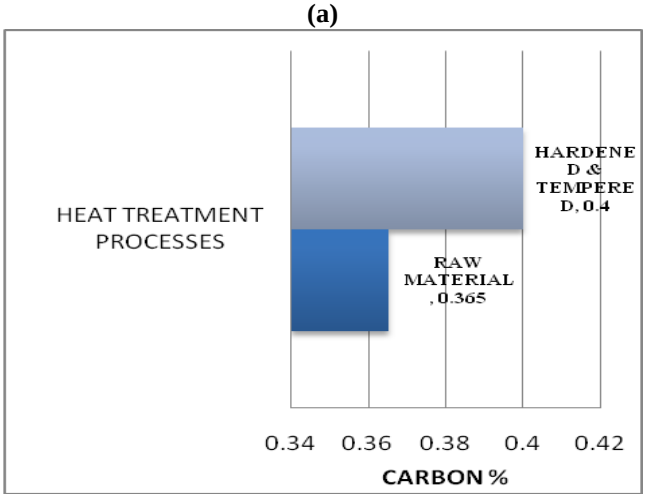


Fig 7. Yield load variation due to different heat treatment processes.

NOTE:- In the above figures 6 & 7, the normalized and hardened & tempered specimens are not being plotted on the basis of yield stress & yield load because the specimens broke at the gauge mark due to high hardness.

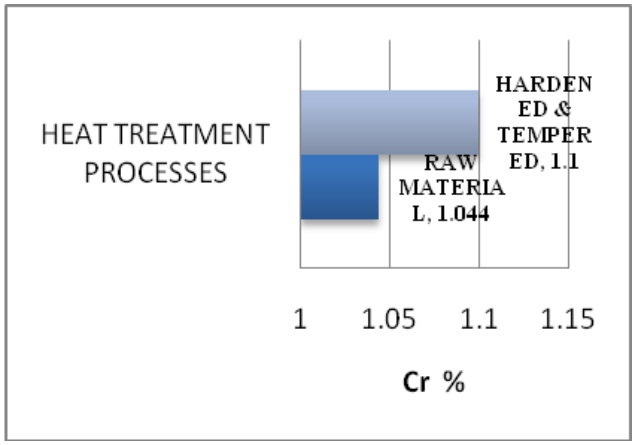


(a)

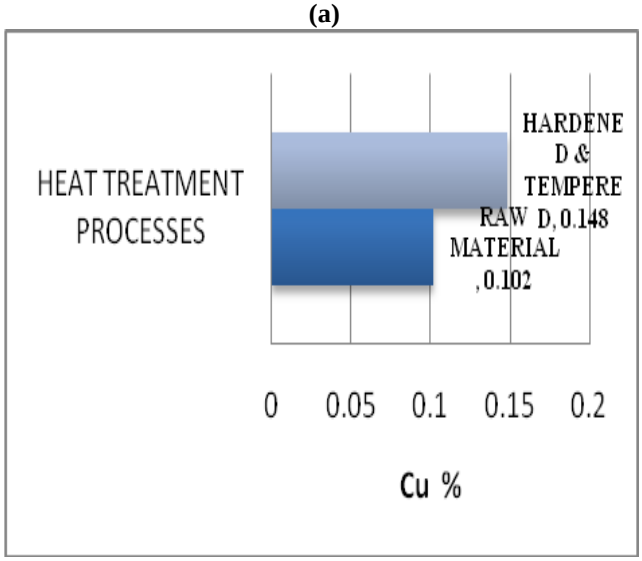


(b)

Fig 8 (a & b). Variation of hardness and Carbon % with respect to different heat treatment processes.

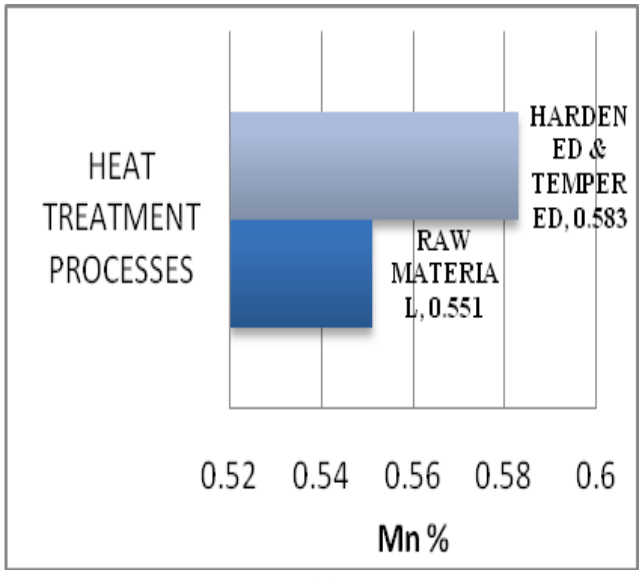


(a)



(b)

Fig 9 (a & b). Variation of Cr and Cu percentages for before and Hardened & Tempered specimens.



(a)

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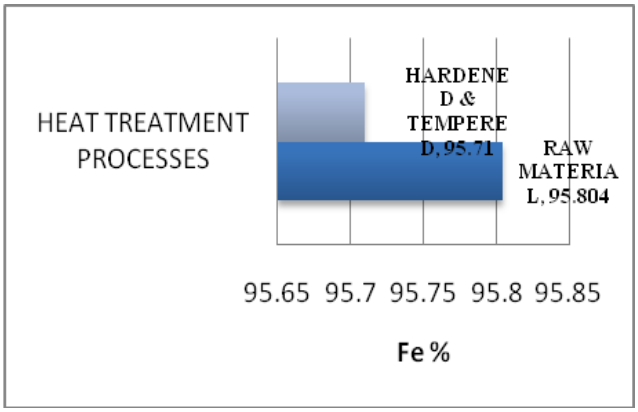

(b)

Fig 10 (a & b). Variation Mn & Fe percentage for before and Hardened & Tempered specimens.

4.5.2 Mechanical properties variation with different treatment conditions: When comparing the tensile strength of alloy steel EN24 specimen under the influence of various heat treatment, small changes were observed. The Load at failure and ultimate tensile strength of normalized sample were found more than the specimen without heat treatment and it was also observed that U.T.S and failure point is less than those samples which were hardened and tempered. From Fig 3, 4 & 5, we can conclude that tempered samples has higher U.T.S but less ductility. Fig 4 shows that stress relieving samples has high elongation when compared to normalized samples and it is caused by the formation of martensite.

4.5.3 Hardness variation with different treatment conditions: Fig 6 shows the results of hardness test in (Rockwell Hardness 'B' & 'C' scale) for before & after heat treated samples of EN24.The hardness increases as it goes from stress relieving process to normalizing & then to hardened & tempered process. When ferrite and bainite converted to martensite and later converted into tempered martensite it effects the hardness of the specimen. When martensite gets tempered its tetragonality gets reduced due to diffusion of carbon molecules from its structure. So we can say that hardness of tempered martensite is lesser than quenched martensite.

V. CONCLUSION

The correlation between the microstructures, hardness and mechanical properties of alloy steel EN24 were studied for three different heat treatment processes - stress relieving, normalizing, hardened & tempered process & compared heat treated specimens with the base metal EN24 (before heat treatment).

For stress relieving, normalizing, hardened & tempered, we observed the following:

- The stress relieving process was found good for relieving the stresses from the specimens & making it suitable for different welding processes with slightly increase in tensile strength, hardness, yield load, breaking load in compared with the base metal EN24.
- The tensile strength and hardness values were more for the hardened & tempered specimens but its % elongation was found least in compare with other heat treatment processes.
- The failure load and tensile strength of the specimen after normalizing were found greater than base metal (before heat treatment) and stress relieved samples but less than hardened and tempered samples.
- The microstructure of EN24 before heat treatment is basically consists of ferrite & bainite. After different treatments there is a change in matrix/phase structure. These cause changes in the mechanical properties of alloy steel EN24. After stress relieving treatment, the microstructure of EN24 is quite similar to the before one specimen because it consists of ferrite & bainite, but tensile strength, yield stress, % elongation & hardness properties are improved.

  But after air cooling or normalizing, the microstructures gets envelope of martensite with bainite & little bit of ferrite, which results in the high increase in hardness value with tensile strength.

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