Effect of heat treatment on Alloy EN24 study behaviour of mechanical properties and change in microstructure

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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 effect of heat treatment on microstructures and study of mechanical properties is always been a study properties [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 58-62 HRC. Heat treatment is used to improve the mechanical properties of the given specimen. The different heat treatment techniques include normalizing, annealing, quenching and tempering. On performing these tests, we aim to improve the strength and hardness of the specimens. Heat treatment also results in a change in the microstructure of the specimen. This change in microstructure can be observed under a microscope. The specimen for the tensile test is in the form of a bone structure with dimensions of 75X12.5mm. The impact test specimen has dimensions of 50X10X10mm with a groove of depth 5mm in the center

Table 1. Composition of EN24 Steel Alloy

chemical composition	Weight
Carbon	**0.36-0.44**
Silicon	**0.10-0.40**
Manganese	**0.45-0.70**
Sulphur	**0.040 Max**
Phosphorous	**0.035 Max**
Chromium	**0.90-1.40**
Molybdenum	**0.20-0.35**
Nickel	**1.30-1.70**

- **Mechanical properties are studied below** :
- 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.

Objective of work

- The objective of this work is to determine the mechanical properties hardness & microstructures analysis of alloy steel EN24 before & after heat treatment processes. After that compare these properties with different treatment conditions, the treatment conditions are mainly annealing, normalizing and hardened & tempered.
- The main objective is to simultaneously enhance the strength and ductility of the steel alloy by heat treatment. Therefore to improve the strength and ductility, the specimen is quenched. Increases the hardness, the specimen becomes very brittle on quenching. In order to reduce the brittleness and improve toughness, tempering is done on the quenched specimens

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.

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 the test doing college lab

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:-

- **Normalizing:** In this process the specimen was heated in a coal based furnace up to temperature of 800-900°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 muffle furnace to refine grain structure

- **Annealing** - 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 700-800^{0}C for a soaking time span of 1 - 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 muffle furnace.

- **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.[1-3]

Color detection in the specimen after heat treatment-

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.[

Mechanical properties and chemical composition

Specimen`s analysis for mechanical properties, hardness and chemical composition was carried out in Sadhana NDT Services lab situated in Pune

- **Hardness Testing:** The heat treated specimens hardness was measured by means of Rockwell hardness tester.
- **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.
- **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.
- **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 80-2500 grade 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).[4-5]

RESULTS & DISCUSSIONS

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.[5]

Process	Diameter (mm)	Area (mm^2)	Gauge length (mm)	B.L (N)	Y.L (N)
BHT	10	78.50	50	52250	36000
Annealing	10	78.50	50	54000	400000
Normalizing	10	78.50	50	94256	------
Hardening & tempering	9.90	77.56	50.00	111500	------

Process	Elongated length(mm)	Tensile strength(N/mm^2)	Y S (N/mm^2)	Elongnation %
BHT	61.26	660.1	460.2	22.50
Annealing	62.10	690.5	518.6	24.40
normalizing	51.40	1200.65	------	2.80
Hardening &tempering	50.32	1447.74	------	0.63

- B H T – Before heat treatment
- H & T - Hardened & Tempered

- B L - Breaking load
- Y L - Yield load
- T S - Tensile strength
- Y S - Yield stress
- R A- Reduction area

Hardness measurement-

The measure hardness on Rockwell hardness test (HRC scale) before and after heat treatment sample 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. [6-7]

Table: Rockwell Hardness Test Result EN24 (HRC)

Process	HRC Scale
Before heat treatment	31.5 HRC
Annealing	20.8 HRC
Normalizing	41 HRC
Hardening & Tempering	52.7 HRC

Chemical composition- 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 : Chemical composition test result for before & after heat treated EN24

Process	C	Si	Mn	Cr	Ni	Mo	V
BHT	0.365	0.295	0.551	1.040	1.440	0.208	0.018
AHT	0.400	0.298	0.583	1.100	1.410	0.217	0.019

Process	Cu	Al	S	P	B	Pb	Fe
BHT	0.102	0.033	0.030	0.035	0.001	0.005	95.8
AHT	0.148	0.008	0.023	0.026	0.001	0.005	95.6

Microstructure Test result

In Microstructure test we basically defined the structures of the specimens of alloy steel EN24 before & after heat treatment.[5-6]

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Microstructure :

Microstructure found ferrite and bainite
500x with etched 2% nital

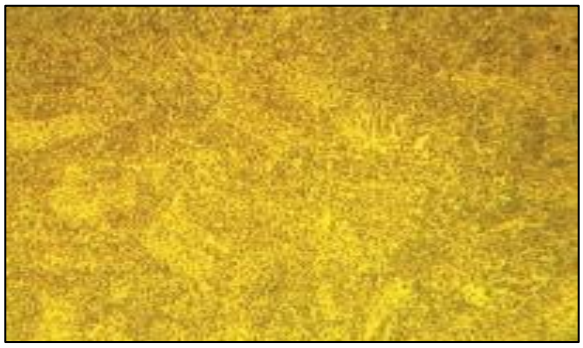


Figure 1 : Microstructure EN24 of before heat treatment

Microstructure :
Microstructure found ferrite and bainite
500X Magnification with etched 2% nital

Figure 2 : Microstructure of Annealing EN24

Microstructure :

Microstructure found bainite ferrite and martensite
500X Magnification with etched 2% nital

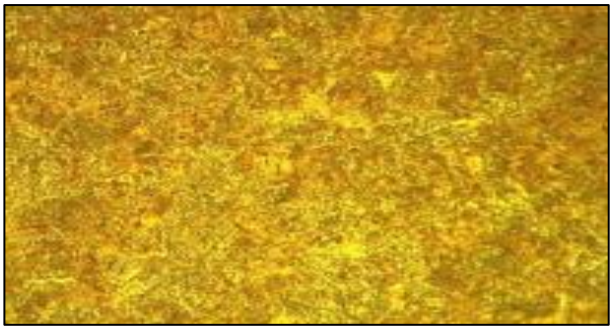


Figure 3 : Microstructure of normalizing EN24

Microstructure :

Microstructure found temper martensite
500X Magnification with etched 2% nital

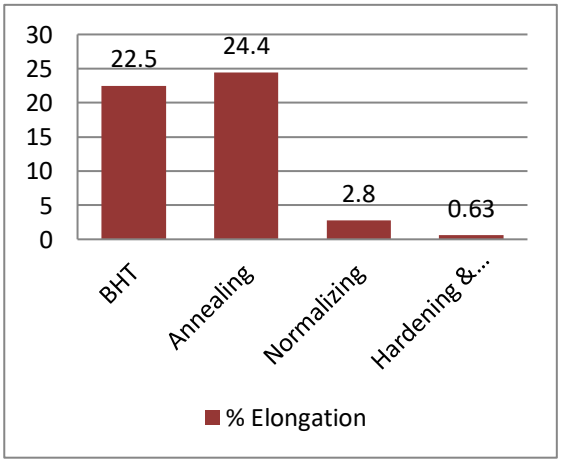
Figure 4 : Microstructure of hardening & tempering EN24

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 annealing 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 [7]

Graphs-



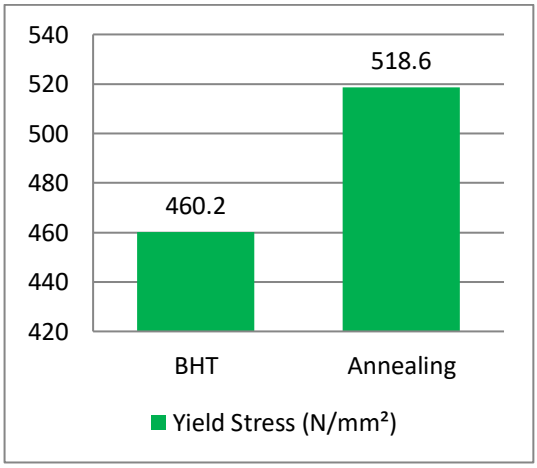


Fig 5 (a & b). % elongation variation and Yield stress variation due to different heat treatment process

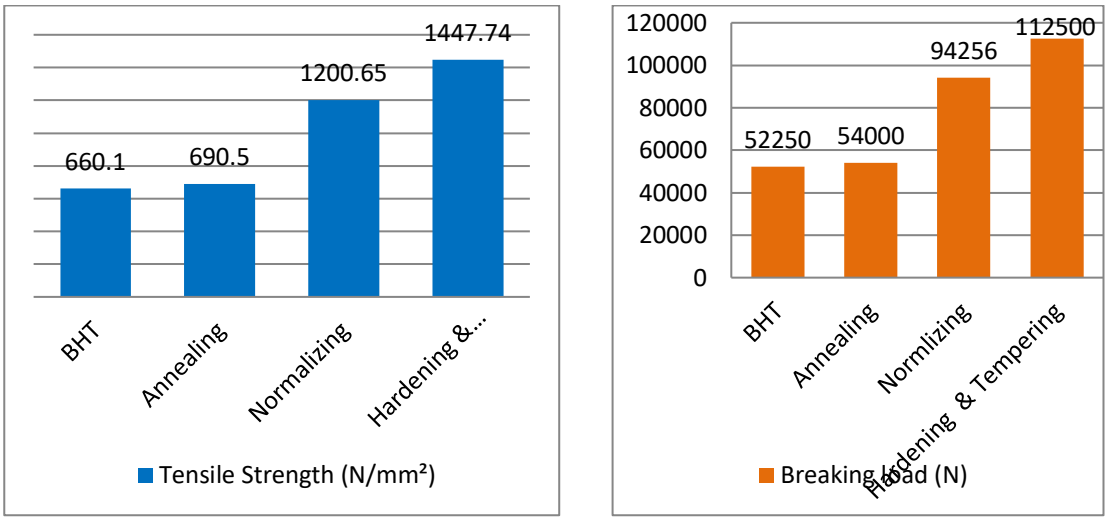


Fig 6 (a & b). Tensile strength and Breaking load variation due to different heat treatment processes

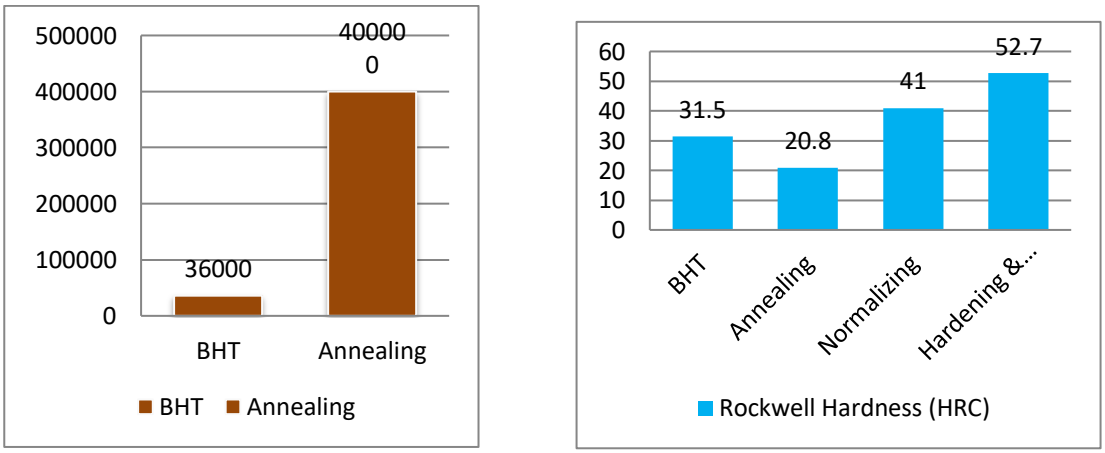


Fig 7 (a & b). Variation of hardness and Yield load variation due to different heat treatment Processes

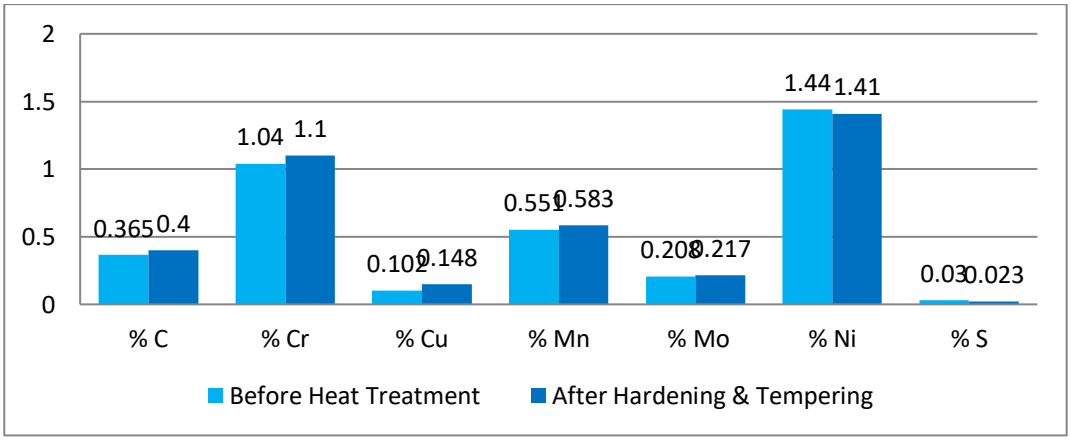


Fig .8 Variation of chemical composition percentage for before and Hardened & Tempering specimens.

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.

Hardness variation with different treatment conditions: Fig 6 shows the results of hardness test in (Rockwell Hardness 'C' scale) for before & after heat treated samples of EN24.The hardness increases as it goes from annealing 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 So say that hardness of tempered martensite is lesser than quenched martensite..[3][6]

Conclusion

The relation between the microstructures, hardness and mechanical properties of alloy steel EN24 were studied for three different heat treatment processes – annealing normalizing, hardened & tempered process & compared heat treated specimens with the base metal EN24 (before heat treatment). The properties depend on each other microstructures, hardness and mechanical properties of alloy steel EN24
For, annealing, normalizing, hardened & tempered, we observed the following:

- The annealing process was found good for relieving the stresses from the specimens & making it suitable for different manufacture 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 high for the hardened & tempered specimens but its % elongation was found less as compare heat treatment processes.
- The breaking load and tensile strength of the en24 specimen after normalizing were found greater than base metal (before heat treatment) and stress relieved samples but less than hardened and tempering specimen .
- The microstructure of EN24 before heat treatment is found of ferrite & bainite and some pearlite . After different treatments there is a change in phase structure. That reason changes in the mechanical properties of alloy steel EN24. After annealing treatment, the microstructure of EN24 is same because it found of ferrite & bainite, but tensile strength, yield stress, % elongation & hardness properties are improved.
- But after air cooling or normalizing, the microstructures gets found martensite with bainite & some of ferrite, which results in the high increase in hardness value and tensile strength.

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