MECHANICAL CHARACTERISTICSEVALUATION OF CONVENTIONAL AND SPECIAL HARDENING TREATMENTS ON AISI 4340 STEEL

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Abstract- Application of steel demands propertiesto enhance durability, dimensional stability and flexibility to alter properties depending on application conditions. Generally to improve some of the propertiessteel is heat treated.The present work aims at experimentally investigate the effects of conventional heat treatments like annealing, normalizing and special hardening techniques like austempering and time quenching on AISI 4340 (EN24) steel. The test specimens are machined as per ASTM standards and then different tests like microstructure analysis, hardness test, tensile test, impact test were carried out after the heat treatment processes. Annealed steel is observed to be soft, normalized steel moderate hard, austempered is tough with balanced hardness while time quenched steel is hardest at the surface compared to inner core.The microstructure shows coarse grain structure in annealed, fine in normalized with finest in austemperedandmartensite structure at the surface of the time quenched specimen.An increase in brittleness was observed with the increase in hardness during time quenching displaying lesser impact strength compared to austempered one.

Keywords- Normalizing,annealing, austempering, microstructure, martensite.

I. INTRODUCTION

Heat treatment is a method of heating and cooling in different interval of time to improve the properties of the material [1-3]. During heat treatment of steel, type of phases, weight% of individual phases at lower temperature, grain size of the material may vary depending on time and cooling method. Some of the properties may vary so that desiredmechanical propertiessuch as hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation may be incorporated [4-6].The most important heat treatment methods like normalizing, annealing, austemperingand time quenching (hardening with self-tempering)are used to alter the properties.Today, among different engineering materials available steel is the most useful structuralmaterial for general applications.Annealing is the heat treatment wherein a material softened, causing coarser grain structure with enhanced creep property [7].The process involves heating of steel to super critical temperature followed by cooling slowly to yielddiffusion controlled coarseror medium pearlitic phase the process. Well distinguished lamellar colonies of ferrite-cementite (pearlite) microstructure is observed if the process variables are tailored suitably [8-10].It is used where maximum ductility and appreciable level of tensilestrength are required in engineering materials.In normalizing, the material is heated to theaustenitic temperature range and critically cooledin air. This treatment is usually carriedout to obtain finepearliticcolony followed by grain refinement, which results in better machinability due to the development of moderate strength and hardness levels[11-15].

The time quenching results in hardened deeper case with tougher core. It is the substitute for conventional case hardening or surface hardening techniques. The property variation is due to the formation of supersaturated harder martensitic phase in the case with diffusion controlled pearlitic phase inward i.e., towards the core of specimen. Austempering produces tough bainitic phase obtained by controlled diffusion of austenite into acicular bainite [16].

Properties and Application AISI 4340 Steel

Table 1 shows the Spectometric analysis of EN 24 steel. It is a low alloy medium carbon steel, containing different alloying elements such as chromium, nickel and molybdenum. Chromium and molybdenum serve as ferrite stabilizers or carbide formersto improve hardness and wear resistance of the steel with better strength. Nickel is the strong austenite stabilizer which improves strength, toughness and hardenability properties. It has high good impact resistance and strength when grainsare refined. The addition of molybdenum also prevents the steel from being susceptible to temper embrittlement. Nickel also improves the hot hardness value corrosion and wear resistance. Chromium also improves corrosion and wear resistance. The usages

clearly demands the different conditions where combinations of properties are required.

Table 1: Typical Chemical Composition of AISI 4340 Steel

Element	Wt.%
Carbon	0.40%
Silicon	0.25%
Manganese	0.70%
Nickel	1.85%
Chromium	0.80%
Molybdenum	0.25%
Iron	95.75%

AISI 4340 alloy steel is mainly used in power transmission system links and shafts, aircraft landing gears and other structural parts. It is also used in heavy-duty axles, spindles, pins, studs, collets, bolts, couplings, sprockets, torsion bars, connecting rods, crow bars, conveyor parts etc. EN24 steel is a high tensile strength alloy steel renowned for its wear resistance properties and exactly fits where high strength properties are required. EN24 is used in components subject to high stress environment and severe temperature fluctuation condition. It is also one of the most useable ferrous metalsin different applications in our day today life.

II. METHODOLOGY

2.1 Heat Treatment Procedure

2.1.1 Annealing

The prepared specimens are heated to a temperature of 900^{o} C held isothermally for 2 hours followed by furnace cooling.

2.1.2 Normalizing

The specimens are heated to900^{o} Csimilar to annealing holding the specimen for 2 hours in the furnace followed by air cooling.

2.1.3 Austempering

The prepared specimens are heated to a temperature of 900^{o} C for 2 hours followed by intermediate temperature isothermal holding by shifting the specimen to salt bath (60% NaNo3 and NaNo2) maintaining at 350^{o} Cfor 24 minutes followed by air cooling.

2.1.4 Time quenching

It is also known as hardening with self-tempering.Specimens are heated to a temperature of 900^{o} C for 2 hours followed by quenching in engine oil (SAE40) maintained at 100^{o} Cfor 5 minutes followed by air cooling.

2.2 Preparation of Specimens

2.2.1 Impact Specimen

Commercially available 16 mm diameter AISI4340 rod is procured from the market. First,materialis cut in to 60mm long pieces using band saw. Drilling is carried out to make the hole at one end in order to hold the work piece in tail stock. Turning is done in engine lathe to reduce the diameter to 14.14 mm and parting operation to reduce the size length 55mm.Shaping is carried out to obtain 10x10 mm square cross section. The ASTM standard Charpyspecimen used in this work is shown in figure 1.V notch is cut on the square work piece using shaper and V notch is blunt into 1mm radius as shown in figure 1.



Fig.1Dimensions of impact test specimen

2.2.2 Hardness Specimen

First, cylindrical specimen is cut in to 30mm length cylindrical pieces using band saw and turned to reduce the diameter 15mm. The ends are smoothened by facing operation and length reduced to 25mm.The hardened specimen prepared with respect to geometrical shape and dimension is shown in figure 2.

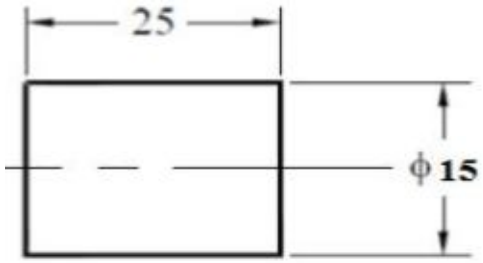


Fig.2 Hardness specimen (All dimensions in mm)

2.2.3 Tensile Specimen

The commercially available 10mmrod is cut into 30 mm length cylindrical pieces using band saw. Therequired length of the specimen is obtained by facing operation on engine lathe. Step truingis carried out as shown in figure 3. Fillets are rounded off to finish the job.

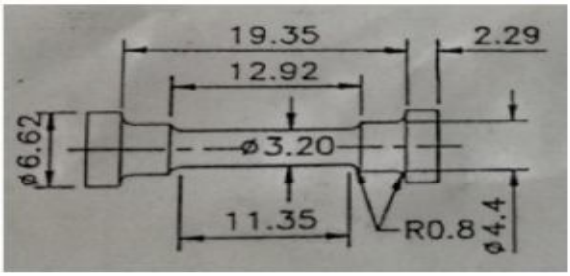


Fig.3 Tensile specimen (All dimensions in mm)

2.3Experimental Details

2.3.1 Impact Test

Impact tester is used to find the impact resistance of the specimen. The impact test is carried out under the maximum load conditionand the pendulum is released to strike the specimen with impact load. The energy absorbed before failure is noted. Totally3 trials are conducted.

2.3.2 Hardness Test

Vickers hardness tester is used to find the hardness of the component. The specimen is placed on the hardness testing fixture and magnification is set to 400X. Micro-indentation is made on the surface of the specimen by applying 100gf for 15 seconds. With the help of eye piece, the length of the diagonals of the indentation is noted. Using the lengths of the diagonals the machine generates the hardness value. Three trials are performed.

2.3.3. Tensile Test

Computer controlled tensometer is employed for tensile test. Specimen is clamped between jaws and then load is applied till it fails. The load verses elongation graphs are analyzed and corresponding values of the %elongation and ultimate strength are recorded. The averages of three trials are taken for recording.

2.2.4 Microstructure Study

Inverted metallurgical microscope is employed for recording the microstructure at 200X magnification. Specimen is polished using emery papers in the order of 1/0, 2/0, 3/0 and 4/0. The final polishing to mirror finish is performed on disc polisher with velvet cloth and alumina paste (Al2O3). Before mounting the specimen on holder, it is etched with 5% NITAL rinsed with cold water and dried.

III. RESULTS AND DISCUSSIONS

3.1 Charpy Impact Test

The impact energy values in Joules obtained in three trials are recorded and the bar chart is drawn as shown in figure 4. The impact energy absorbed is the measure of toughness of the specimen and shows highest for austempered and second highest for time quenched specimens. The excellent toughness of austempered one is due to the lower bainitic phase which is even recorded in the metallography. The well distributed fine ferrite and cementite phases surrounded by enormous dislocation density is responsible for the excellent toughness. Surprisingly time quenched also shows almost same toughness values as that of austempered one. This may be due to the harder martensite phase formed on the thicker case with medium or fine lamellar pearlite at the core.

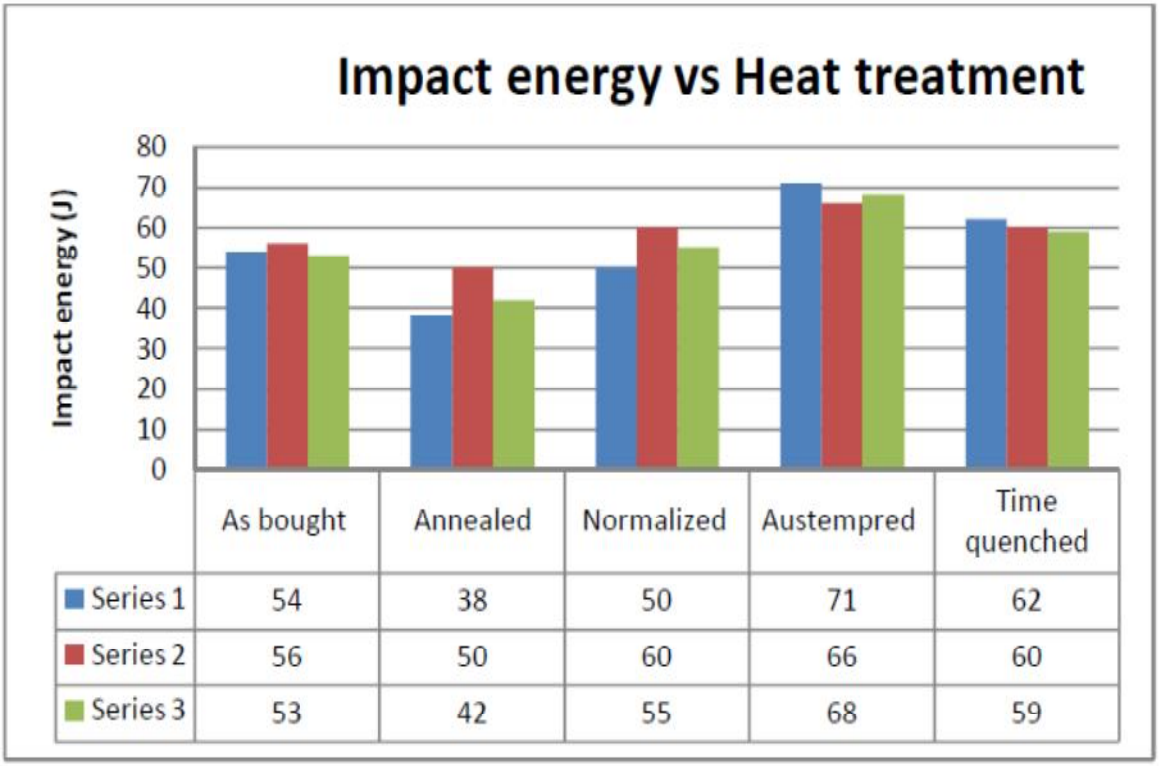


Figure 4: Impact energy versus heat treatments

As bought and normalized show similar toughness values and it justifies that the as bought steel is as cast. Annealed specimen shows slightly poor toughness may be due to the presence of more amount of softer coarser ferrite phases.

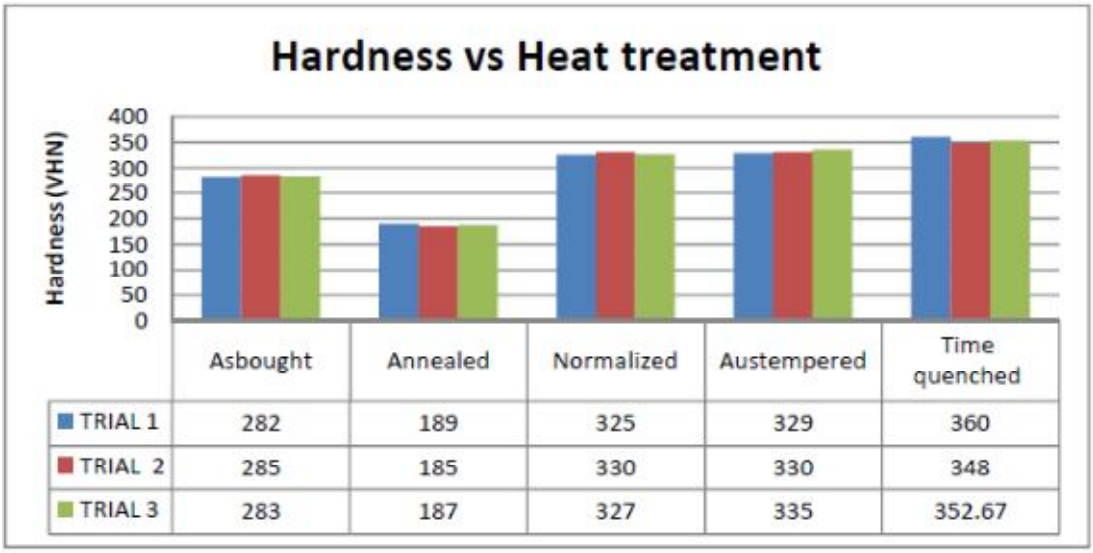


Figure 5: Hardness versus heat treatments

3.2 Hardness Test

Hardness of normalized and austempered are on par with each other. This may be due to the fineness of the diffusion controlled phases. As bought hardness is slightly poor than normalized one. It is due to the dendritic segregation present in the as cast structure leading to the composition inhomogeneity in the inner dendritic arms of the grains. Time quenched shows excellent surface hardness compared to other heat treatment conditions due to the formation of super saturated martensite phase coupled with anormous amount of crystal defects and is the hardest phase that one can observe in steel.

3.3 Tensile Property

The fracture strength of normalized, austempered and time quenched are comparable whereas annealed and as bought show very poor fracture strength as well as yield strength. UTS of annealed and as bought is0.3 to 0.4 times as that of normalized, austempered and time quenched conditions. Since hardness and strength go hand in hand the decrease in strength of as bought may be due to the dendritic segregation. Annealed and austempered shows good ductility values followed by time quenching and normalizing. As hardness and strength decrease ductility increases. It is clearly observed from the figure 6.

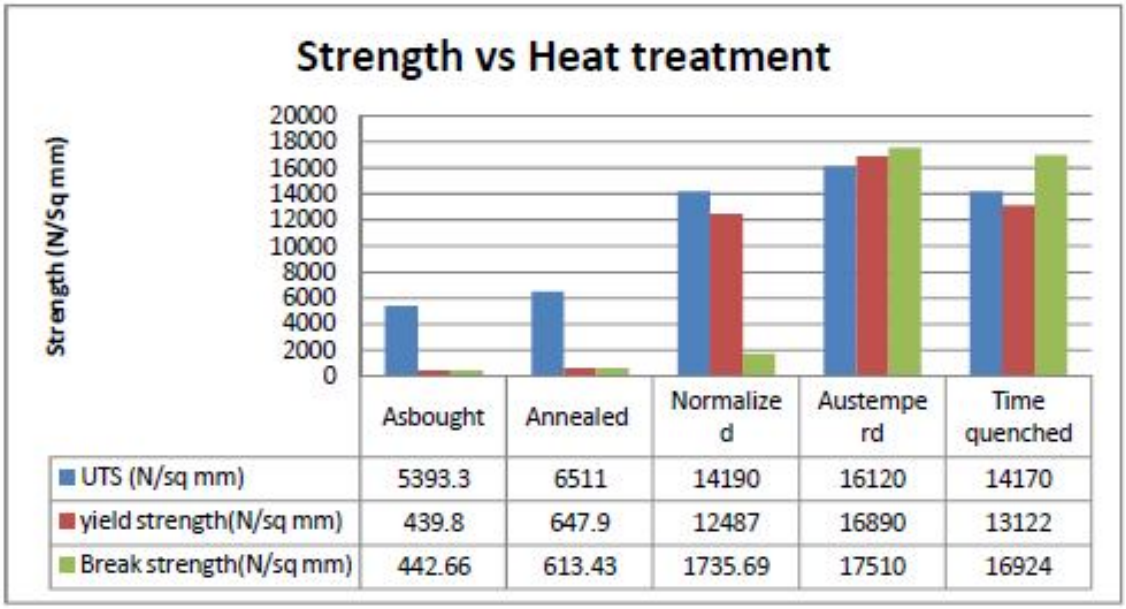


Figure 6: Tensile strength versus heat treatments

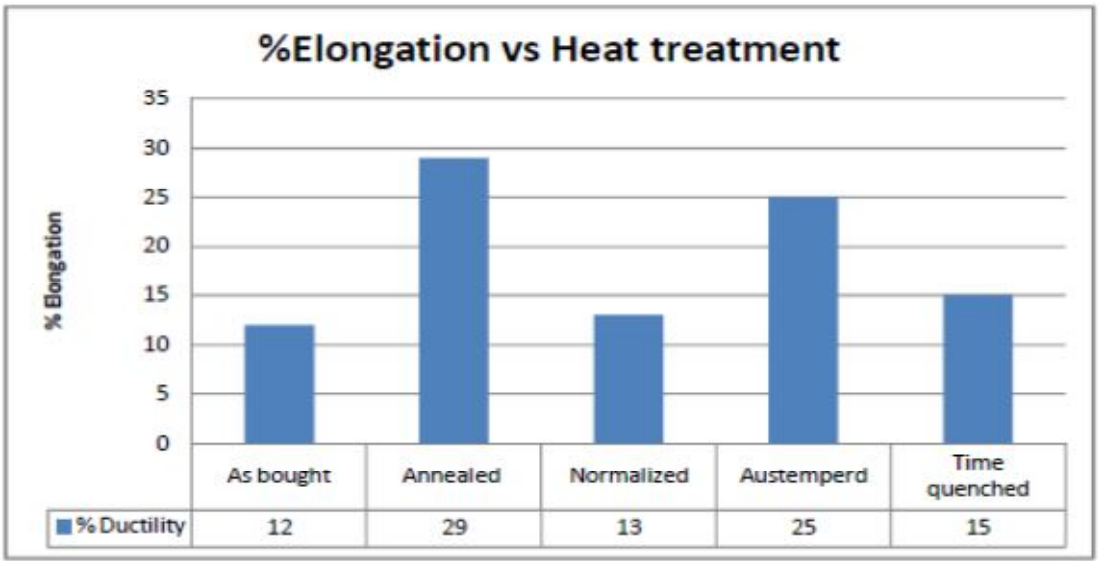


Figure 7: % Elongation versus heat treatments

3.4 Microstructure Study

Microstructure of as bought, normalized and annealed specimens at 200X magnification are shown in figures 8(a), (b) and (c) respectively. The microstructures show pearlite colonies and proeutectoid ferrite phases as shown in the figures. The phases are coarser in annealed compared to normalized one. Critical eye judgement shows that amount of pearlitic phases is more in as bought and normalized conditions as compared to annealed. Figures 8(d) and (e) show microstructure of austempered and time quench specimens respectively. Austempered shows well dispersed finer ferrite and cementite phases with crisscross orientation. There is no appearance of proeutectoid phases. This may be due to the insufficient time available at higher temperature ranges for proeutectoid precipitation. The time quenching reports martensite bands (plate martensite) with well distributed fine pearlite phases.

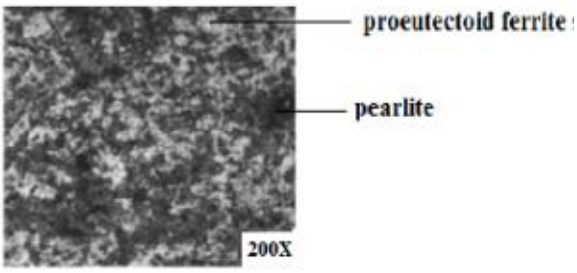


Fig.8(a) Microstructure of As Bought Specimen

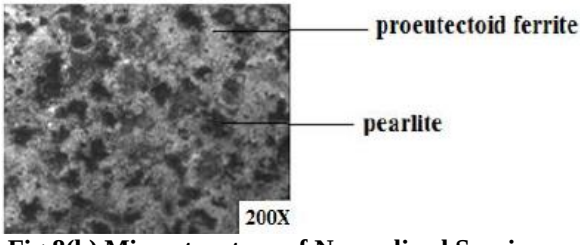


Fig.8(b) Microstructure of Normalized Specimen

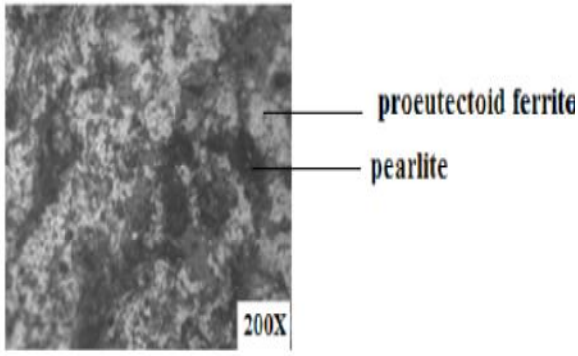


Fig.8 (c) Microstructure of Annealed Specimen

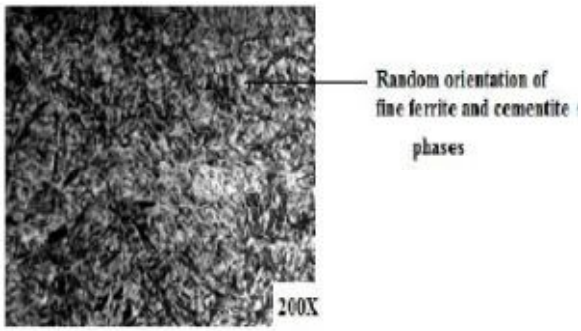


Fig.8 (d) Microstructure of Austempered Specimen

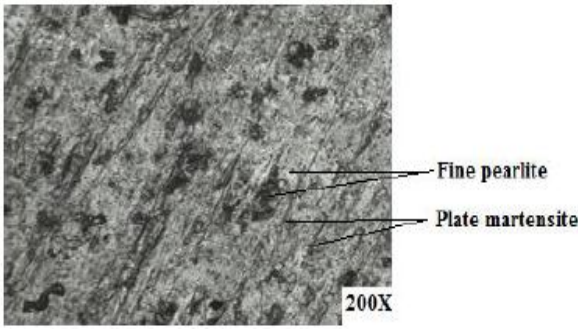


Fig.8 (e) Microstructure of Time quenched Specimen

CONCLUSION

The steel is successfully heat treated with considerable alterations in properties. The following conclusions are arrived from the experiments.

- The austempered specimen shows excellent toughness due to bainitic phase and as bought, normalized and time quenched slightly lesser but similar moderate values, whereas annealed shows minimum.
- The hardness of the as bought steel is similar to normalized specimen. It implies that as bought steel is as cast one.
- The hardness of the annealed steel is lesser than that of as bought and normalized due to the coarser grains.
- The austempered hardness is on par with normalized butless than time quenched.
- The fracture strength of normalized, austempered and time quenched are comparable whereas annealed and as bought show very poor fracture strength as well as yield strength.
- Annealed and austempered show good ductility values followed by time quenching and normalizing. As hardness and strength decrease ductility increases.
- Microstructure of as bought, normalized and annealed specimens shows pearlite colonies and proeutectoid ferrite phases.
- The phases are coarser in annealed compared to normalized one.
- Austempered shows well dispersed finer ferrite and cementite phases with crisscross orientations.
- There is no appearance of proeutectoid phases in austempered microstructure.
- The time quenchedmicrostructure reports martensite bands (plate martensite) with well distributed fine pearlite phases.

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