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Effect of heat treatment on microstructure behavior and hardness of EN 8 steel

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Abstract. EN 8 steel is an important grade of steel, used for manufacture of axles and shafts, bolts, gears, studs etc. Heat treatment is an important step in achieving desired mechanical properties and microstructure, for different applications. However, with the increase in hardness and wear resistance, machinability decreases consequently. Literature review of past works failed to achieve a good balance between hardness and machinability. In this experimental work, heat treatment methods, namely, annealing, normalizing and quenching is done on EN 8 steel, a grade of medium carbon steel. Hardness and microstructure is studied and compared. Furthermore, tempering is also conducted after each heat treatment to study its effects on hardness and microstructure. Results show that tempering after normalizing of EN 8 steel gives satisfactory hardness values. The microstructure is also found to consist of fine grains of pearlite.

1. INTRODUCTION

In industrial sectors, EN 8 steel is a widely used grade of medium carbon steel, usually unalloyed. For applications that are not subjected to high strength, EN 8 steel is an excellent choice, suitable for manufacturing parts such as general-purpose automobile axles and crankshafts, bolts, gears and studs. It is possible to further enhance the surface hardness of this material to 50-55 HRC, commonly by induction processes. This results in parts produced with high wear resistance. However, the machining capability or machinability tends to decrease subsequently. To avoid this, suitable heat treatment methods are required. EN 8 steel is generally tempered from 550°C to 660°C, heated for one hour for every inch of thickness, then cooled in water or oil. Normalizing of EN 8 steel is carried out at 830-860°C, then it is cooled in still air [1].

The industrial and scientific application of any metal or alloy is determined by its properties. Heat treatment methods are used to alter the microstructure and mechanical properties of steel. Literature survey has revealed various aspects of heat treatment. Moleejane et al. [2] investigated the effects of microstructural evolution on mechanical properties of unalloyed EN 8 steel. Special emphasis was given on the effects of various grain sizes, prepared by different heat treatment processes. SEM and OEM were used to study the microstructural changes and mechanical properties were studied by tensile and hardness tests. Results showed that structural parameter directly controlling the yield strength and elongation at failure severely affects the material formability. Khatirkar et.al [3] studied the structural and wear characterization of heat treated features of EN 24 steels using hardening and tempering temperature in relation to microstructure and hardness. Another study on ODS steels was

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conducted by Noh et al. [4]. Heat treatments processes such as hot rolling-tempering and normalizing-tempering were carried out. It was seen that grain size and oxide distributions of the ODS steels can be altered by heat treatment, which significantly affected the strength of steel at high temperature. The effect of heat treatment methods on compressive properties of steel foams was investigated by Bekoz et al. [5]. Reductions in compressive yield strength and Young's modulus were obtained. Heat treatment processes were carried out on EN8 steel to study microstructure and mechanical properties. Results showed increase in mechanical properties with suitable heat treatment cycles [6]. Htun et al. [7] studied the effect of quench and temper heat treatments by microstructural observation and hardness testing of heavy duty spring steel. It was seen that by increasing tempering time and temperature, ultimate tensile strength gradually decreased and ductility improved. Hu et al. [8] investigated effects of normalizing and tempering temperatures on microstructure and mechanical properties of steel casting. Results showed that tensile strength increased with the increase in normalizing temperature. The steel should be normalized at 970°C and tempered in the range 500 °C-550°C which will result in optimum mechanical properties. MATLAB software was used to achieve the relationship of mechanical properties with temperature.

Past researchers have mainly focused on the effect of different heat treatment methods on the mechanical and/or microstructures of steel. However, to the best knowledge of the author, EN 8 steel, though having wide applications, is rarely used. This experimental work is aimed to compare the microstructure and mechanical properties (hardness) of EN 8 steel after annealing, normalizing and quenching. Moreover, tempering after each heat treatment process is also studied.

2. EXPERIMENTAL DETAILS

Medium carbon steel designated as EN 8 steel is used in this study. The chemical composition of the steel is given in Table 1.

Table 1. Chemical composition of EN 8 steel

Element	C	Mn	P	S	Si	Fe
Wt (%)	0.36-0.44	0.6-1.00	0.05	0.005	0.10-0.40	Rest

The specimen was obtained as 25 mm round bars, out of which samples of 11 mmm length were cut. A muffle furnace is used for heat treatments and surface hardness is measured in a Brinell hardness testing machine. Details of experiments and equipment are given in Table 2.

Table 2. Details of equipment and experiments

Workpiece	Material: EN 8 steel, Dimensions: 11mm length with 25 mm diameter
Muffle Furnace	Make: United Nations Scientific Co., Serial No.: JIS/ME/MT.LAB/011
Brinell Hardness Testing Machine	Make: Saroj, Model No.: RAB-250, Load: 100 kgs, Indenter: 0.5 mm diameter, steel ball
Microscope	Make: Leica Microsystems, Model No.: Leica DM2700 M
Heat Treatment Conditions	(a) Annealing, (b) Normalizing (c) Quenching (d) Tempering

2. 1 Heat treatment methods

EN 8 steel samples were subjected to the following heat treatment methods, as described:

2.1.1 Annealing. Two samples are preheated slowly, in the muffle furnace, to 820ºC and held for 45 minutes. Then furnace is shut off and samples are left inside the furnace until the temperature dropped down to 480 ºC. Then furnace door is opened and the samples are cooled to room temperature.

2.1.2 Normalizing. Two samples are taken and inserted in the muffle furnace. After closing the furnace door, temperature is set to a normalizing temperature of 850 ºC. The samples were held for 2 hours for homogeneous transformation. After soaking for 2 hours, the furnace was switched off and samples were taken out to cool to room temperature.
2.1.3 Quenching. Two samples are heated to 850 ºC in the muffle furnace and held for 30 minutes for homogeneous transformation. After holding for 30 minutes, furnace is shut off and the furnace door is opened to allow the samples to cool inside, till the red heat is gone. The samples are then cooled rapidly by submerging them in an oil bath, and quenched to room temperature.
2.1.4 Tempering. One heat-treated sample from each set (i.e. annealed, normalized and quenched) were then tempered to compare the microstructure and hardness of the samples. In tempering, the samples were reheated to 300^0C in the muffle furnace and then soaked for 1hour. Then, the furnace was switched off and samples were taken out to air cool to room temperature.

After heat treating the samples, surface hardness is measured using a Brinell hardness tester. A steel ball indenter of 0.5 mm diameter steel is used. The load given is 100 kgf and the indenter is made to just touch the sample surface. After the load is applied for 15 seconds' minimum, the load release lever is pulled. The hardness readings are taken from the dial. Three hardness values are taken on the sample surface at three different locations, for each heat-treated sample. Microscopic observation of heat treated samples is done using an optical microscope. For this, polishing was done using Al_2O_3 slurry. Few drops of 2% nital solution were applied on the specimen surface, after cleaning with alcohol.

3. RESULTS AND DISCUSSION

In the present work, EN 8 steel was used as the specimen. Hardness was measured for three different locations on the specimen surface, for each heat-treatment condition. The hardness values and the average hardness is given in Table 3, while the hardness is compared for each condition in figure 1.

Table 3. Hardness values of heat-treated samples

Heat treatment method	Observation No.	Hardness (BHN)	Average hardness (BHN)
Annealing without tempering	1	192	187
	2	186	
	3	183	
Annealing with tempering	1	155	155
	2	162	
	3	148	
Normalizing without tempering	1	458	446
	2	444	
	3	436	
Normalizing with tempering	1	222	234
	2	236	
	3	244	
Quenching without tempering	1	672	685
	2	680	
	3	700	
Quenching with tempering	1	402	392
	2	390	
	3	384	

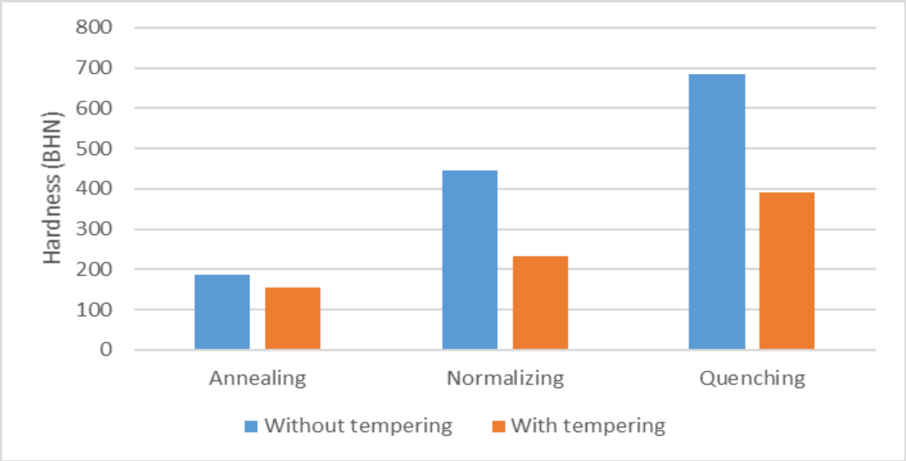

Figure 1. Comparison of hardness values of EN 8 steel for different heat treatments.

It is evident from figure 1 that the annealing achieves the lowest hardness, amongst the three heat treatment methods used in this study. Annealing has the lowest rate of cooling, while quenching experiences the highest rate of cooling. Quenching leads to the highest hardness values, as expected. This is due to the formation of huge amounts of martensite, from austenite, as observed in the microstructure. Tempering after heat treatment of EN 8 steel always leads to a reduction in hardness. The reduction in surface hardness is the most in normalizing (almost 48%), while it is the least in annealing (17%). Tempering after quenching is a necessity, used to induce a balance between hardness, strength and toughness.

Microstructure observation is achieved by observing the samples under a microscope. Figures 2 and 3 show the annealed microstructure, and tempered after annealing microstructure, of EN 8 steel, respectively.

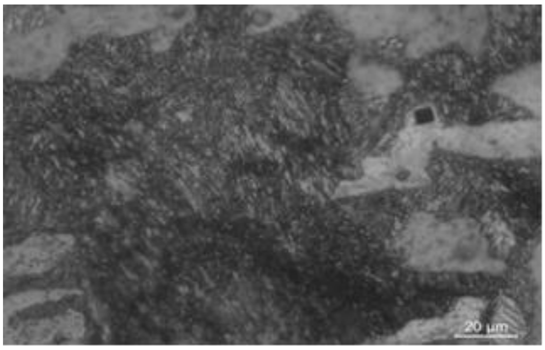

Figure 2. Annealed microstructure of EN 8 steel (1000x).

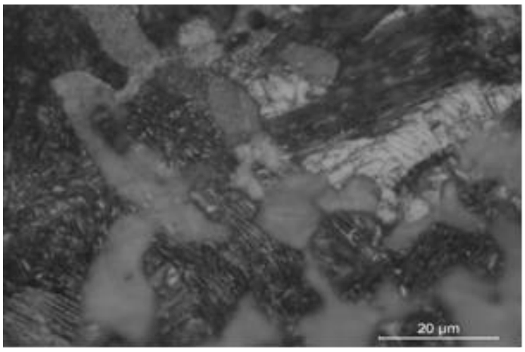

Figure 3. Tempered after annealing microstructure of EN 8 steel (1000x).

White patches indicate formation of ferrite and black patches indicate pearlite formation. Fine grains, observed in figure 2 are transformed into coarsened grains in figure 3. This indicates voids are decreased and grain size diameter is increased. The dark grey areas are more in the annealed microstructure, than the tempered after annealed microstructure, as evident from figure 3. Grey areas signify graphite flakes, consequently, the hardness of the tempered EN 8 steel is reduced. Actually, excess carbon trapped in the martensite is relieved by tempering [9].

Figures 4 and 5 depict the microstructures of EN 8 steel when it is normalized and tempered after normalizing, respectively.

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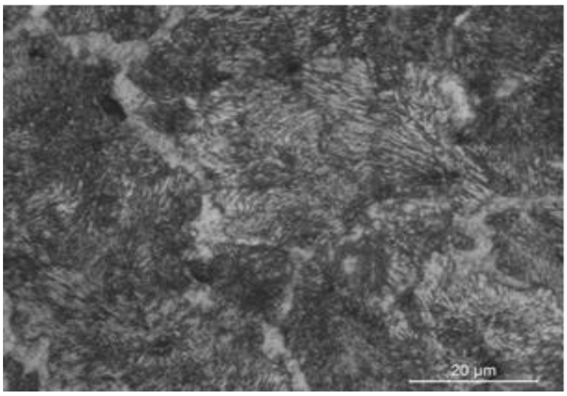

Figure 4. Normalized microstructure of EN 8 steel (1000x).

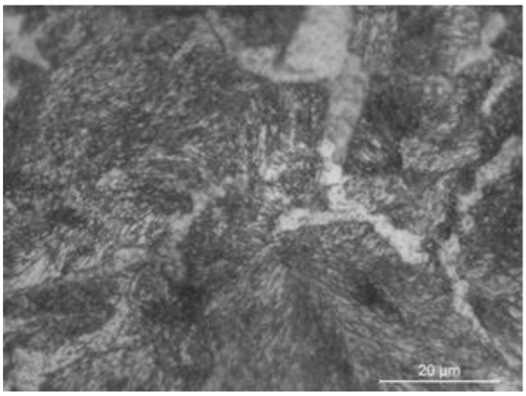

Figure 5. Tempered microstructure of EN 8 steel, after normalizing (1000x).

It is evident from figure 4 that normalized microstructure is almost fully pearlite, as indicated by the black regions. Some austenite grains are also seen. The difference in microstructure is attributed to a higher rate of cooling in normalizing, as compared to annealing. Tempering the normalized specimen at 580ºC leads to a reduction in hardness. This is due to the formation of smaller grains, which are finer. Tempering always relieves some quenching stress and simultaneously, reduces hardness and brittleness.

Figures 6 and 7 show the microstructure in case of quenched and tempered after quenching samples of EN9 steel.

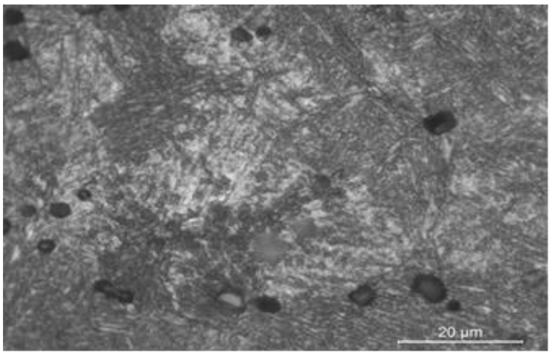

Figure 6. Quenched microstructure (1000x).

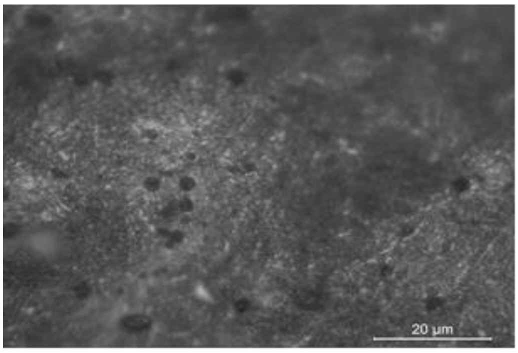

Figure 7. Tempered microstructure after quenching (1000x).

In figure 6, the microstructure is seen to consist of huge amount of fine, needle like structures. This structure is called martensite, which is hard, but brittle too. In quenching, the steel specimen experienced a very rapid rate of cooling. As such, the austenitic structure transformed into martensite. Figure 7 shows a recrystallized ferritic structure, with some secondary graphite sites observable. Tempering of the prevalent unstable martensite precipitates out the carbide particles into the ferrite matrix solution. As a result, microstructural modifications occur, resulting in reduced hardness levels and increased ductility. When martensite is reheated during tempering, it transforms into sorbite or troostite, which is indicated in figure 7.

4. CONCLUSION

In this experimental work, effect of heat treatment methods on hardness and microstructure of EN 8 steel is compared and discussed. Moreover, tempering was done after each heat treatment methods to observed the effects of tempering. It is seen that tempering leads to a decrease in hardness. This is actually desirable, as low hardness and good toughness will be beneficial for machining purposes, as cutting forces and specific energy required will be less. However, sometimes, reduced hardness leads to accelerated wear, in some applications, which is not desired. So, it is recommended that EN 8 steel should be tempered after normalizing. The microstructure consists of finer grains and hardness decreases, but not by much, which ensures good machinability.

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