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An experimental investigation on hardness and microstructure of heat treated EN 9 steel

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Abstract. In the modern engineering world, extensive research has led to the development of some special grades of steel, often suited for enhanced functions. EN 9 steel is one such grade, having major applications in power plants, automobile and aerospace industry. Different heat treatment processes are employed to achieve high hardness and high wear resistance, but machinability subsequently decreases. Existing literature is not sufficient to achieve a balance between hardness and machinability. The aim of this experimental work is to determine the hardness values and observe microstructural changes in EN9 steel, when it is subjected to annealing, normalizing and quenching. Finally, the effects of tempering after each of these heat treatments on hardness and microstructure have also been shown. It is seen that the tempering after normalizing the specimen achieved satisfactory results. The microstructure was also observed to be consisting of fine grains.

1. INTRODUCTION

EN 9 steel is a medium carbon steel grade having 0.5 to 0.6% carbon, commonly supplied in the as-rolled condition. Available in various forms- rounds, flats, hexagon etc., it is used in a number of engineering applications such as gears, sprockets and cams. It is sometimes flame or induction hardened to induce high surface hardness to resist wear for a carbon grade steel [1]. EN9 carbon steel is cheaper than EN19 alloy steel, another grade of steel, although chemical composition and mechanical properties differences exist [2].

Various heat treatment processes are commonly employed to induce certain mechanical properties and microstructure changes. Previous researchers have conducted various studies on the effect of heat treatment conditions on microstructure, mechanical properties (strength, hardness etc). Some of the studies have been reviewed as follows. The effect of different heat treatment on mechanical properties (yield strength and tensile strength) of medium carbon steel was investigated by Senthilkumar et al. [3]. It was seen that the hardened specimens had the highest tensile strength, followed by tempered, normalized and then annealed specimens. The strains produced followed a reverse order. It was concluded that cooling rate and heat treatment processes affect largely the mechanical properties. The effect of three heat treatment processes on the hardness of three different grades of steel (EN-31, EN-8, D-3) were studied and compared by Bhateja et al. [4]. Three processes (normalizing, annealing, and hardening with tempering) have been carried out. It was seen that hardness (BHN) increased in annealing of D-3 tool steel. Also, the maximum hardness was achieved during normalizing of D-3 steel. Another heat treatment study was carried out by Fadare et al. [5], on NST 37-2 steel which stated that normalization treatment produced higher hardness and tensile strength than annealed samples. The effects of austenizing temperature and time, along with tempering temperature on the microstructure, mechanical and corrosion properties of AISI420 steel were investigated by Nasery et al. [6[. It was seen that the mechanical properties are affected by austenizing temperature significantly. SEM images of the fractured surfaces indicated both brittle and ductile fracture mechanisms at 200°C and 700°C and brittle mechanism at 500°C. Another experimental investigation of effects of microstructure on mechanical properties of EN8 steel was conducted [7]. Four different types of heat treatment methods were used to obtain various microstructural changes.SEM images show that grain size and its distribution have a significant effect on plastic deformation. The grain size, in turn, is affected by annealing temperature and holding time.

To the best of the author's knowledge, few studies regarding effect of heat treatment methods on EN 9 steel have been reported. This experimental work is intended to compare the hardness values and microstructure images after three heat treatment processes. The effects of tempering after each heat treatment processes have also been shown.

2. EXPERIMENTAL DETAILS

The workpiece used was EN9 steel, obtained as round bars of 25mm diameter. Individual samples of 11mm length were cut from the bar to obtain six specimens. A muffle furnace was used for the heat treatment and hardness of the samples was measured using a Brinell Hardness Tester. The complete experimental and equipment details are given in Table 1.

Table 1. Details of equipment and experiments.

Workpiece	Material: EN 9 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
Response variables	(a) Hardness (b) Microstructure

2. 1 *Heat treatment*: The three heat treatment methods used in this experimental work is discussed as follows:

2.1.1 Annealing. Two specimens were taken and put it into the muffle furnace. Then the furnace was started and the temperature is set at 800^0C. At this temperature, the specimen was held for 2 hours for homogeneous transformation. After soaking for 2hours, the furnace was switched off so that the specimen temperature will decrease with the same rate as that of the furnace. The specimen was taken out of the furnace after 14 hours when the temperature reduced to room temperature.

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2.1.2 Normalizing. After inserting another two specimens in the furnace, the furnace temperature was set to 800^{0}C. The specimen was heated to normalizing temperature of 800 ^{0}C. At 800^{0}C, the specimen was held for 2 hours. After soaking for 2hours, the furnace was switched off and the specimen was taken out and air cooled to room temperature.
2.1.3 Quenching. The third set of specimens is inserted into the muffle furnace. Then the furnace is started and the temperature is set at 800^{0}C. At 800^{0}C, the specimen was held for 2 hours. After soaking for 2hours, the furnace was switched off and the specimen was taken out and quenched in water for 30 minutes. After that the specimen was air cooled 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^{0}C 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.

2.3 HARDNESS TESTING

Hardness of the samples was measured by Brinell hardness tester. A steel ball indenter of 0.5 mm diameter steel was used. The specimen was kept on the support table and the load is set to 100 kgf. The indenter touched on the specimen surface. After applying the load for minimum 15sec, the load release liver is pulled. The specimen is taken out and placed under microscope to view the reading on the dial. A total of three hardness values are taken on the work piece surfaces at three different locations.

2.4 MICROSTRUCTURE STUDY

To observe the microstructure of the heat-treated samples, the specimen surface was ground with emery paper to remove any surface damage. Polishing was then done on dry cloth and fine Al_2O_3 slurry to achieve a mirror finish. After cleaning with alcohol, few drops of 2% nital solution were applied on the specimen surface. After 30 seconds, the etchant was rinsed with water and then quickly rinsed with alcohol. The sample was dried again. Finally, microscopic observation of the samples was done using an optical microscope.

3. RESULTS AND DISCUSSION

EN 9 steel was used for the present work. Hardness was determined for differently heat-treated steels. Table 2 shows the hardness values (BHN) of heat treated specimens.

Table 2. Hardness values of heat-treated samples.

Heat treatment method	Observation No.	Hardness (BHN)	Average hardness (BHN)
Quenching without tempering	1	508	507
	2	507	
	3	506	
Quenching with tempering	1	258	289
	2	352	
	3	258	
Annealing without tempering	1	155	153
	2	150	
	3	152	
Annealing with tempering	1	127	125
	2	125	
	3	127	
Normalizing without tempering	1	259	255
	2	251	
	3	253	
Normalizing with tempering	1	156	172
	2	197	
	3	165	

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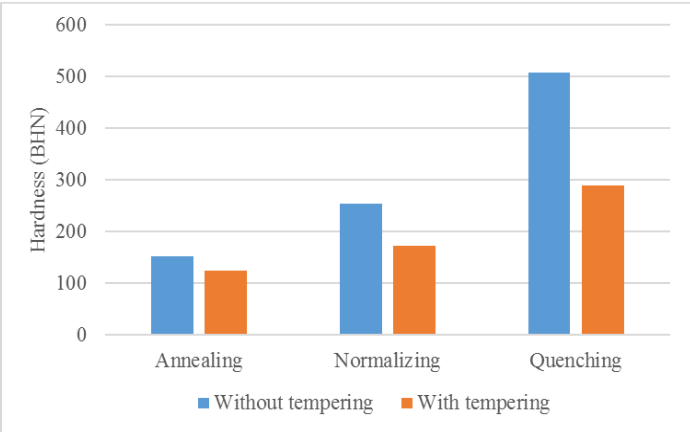

Figure 1. Comparison of hardness values of EN 9 steel for different heat treatments.

From figure 1, it is seen that the annealed specimen has the lowest hardness values, as the rate of cooling was very slow. Highest rate of cooling was applicable to quenched specimen; hence it reported the highest hardness values. It is also observed that effect of tempering on the hardness of EN 9 steel is the most in case of quenching, where a decrease in hardness of almost 43% is achieved. This is possibly due to formation of martensite and precipitation of carbide particles existing in the microstructure of the workpiece. The reduction in hardness in case of tempering after normalizing is 32.5%, while it is the least in case of tempering after annealing (18.3%). The changes in the microstructure on account of different heat treatments are shown later.

The samples are placed under optical microscope and their micro structures were observed. Figures 2(a) and 2(b) show the microstructure in case of annealed and tempered and annealed EN9 steel.

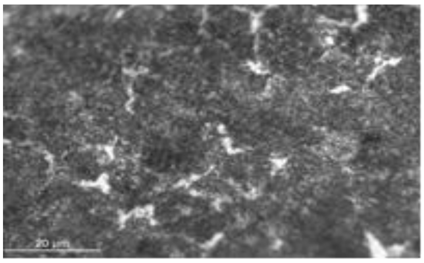

Figure 2(a): Annealed microstructure (1000x).

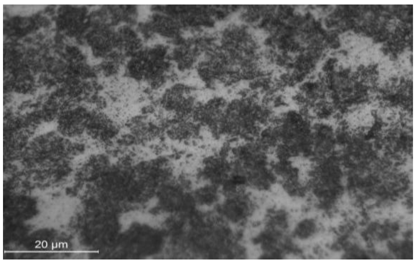

Figure 2(b): Tempered after annealing microstructure (1000x).

The white patches signify formation of ferrite and the dark grey signify pearlite formation. Amount of ferrite is less than the amount of pearlite which signifies large martensite formation. When the annealed steel was tempered, the microstructure shows the formation of coarse pearlite grains, as indicated by black patches in figure 2(b). Graphite flakes are also observed, as shown by grey areas. This accounts for the hardness reduction at the surface of the workpiece.

Figures 3(a) and 3(b) show the microstructure in case of normalized and tempered after normalizing EN9 steel respectively.

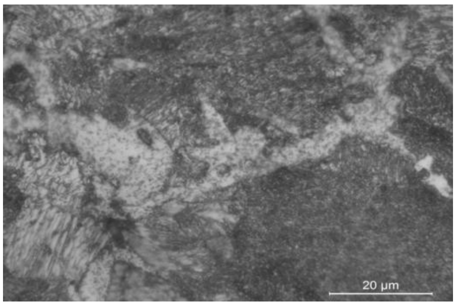

Figure 3(a): Normalized microstructure (1000x).

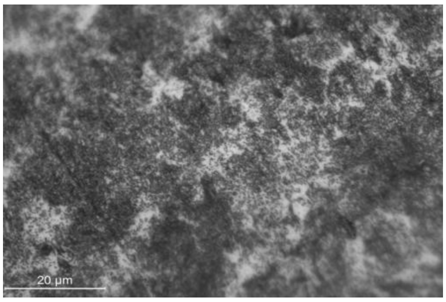

Figure 3(b): Tempered after normalizing microstructure (1000x).

From the above figure 3(a), it can be seen that fine pearlite grains are formed in the microstructure as a result of normalizing and the whole microstructure is almost pearlite. Austenite grains are also seen. The difference in microstructure is seen as the samples were cooled in still air, and so the cooling rate was faster than in annealing. When normalized steel is reheated at a temperature of 300^0C (tempering), formation of coarse pearlite, as seen by bigger grains, occurs, as evident from figure 3(b). This leads to a reduction in hardness of the normalized steel after tempering.

Figures 4(a) and (b) show the microstructure in case of quenched and tempered after quenching samples of EN9 steel.

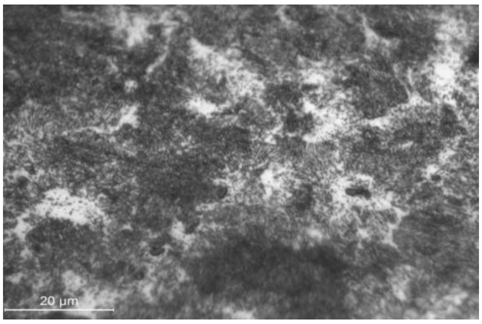

Figure 4(a): Quenched microstructure (1000x).

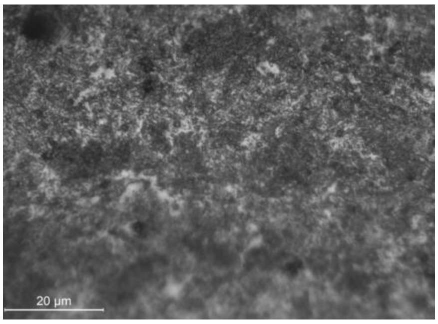

Figure 4(b): Tempered microstructure after quenching (1000x).

It is quite evident, from figure 4(a), that huge martensite formation takes place due to quenching in water. Rapid cooling takes place, due to which the austenite becomes unstable and breaks down to form martensite, which is a very hard structure. In figure 4(b), highly recrystallized ferrite grains with some secondary graphite site was observed. This micrograph revealed that the microstructure of tempered specimen consisted of appreciable carbide particles precipitated out from the matrix, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix. By this process the hardness of the steel is decreased and the material is also stress-relieved.

4. CONCLUSION

The experimental work in this paper compares the microstructure and the hardness of EN 9 steel under three different heat treatment methods. Also, hardness values and microstructure were compared under heat treatment methods with and without tempering. It is seen that tempering after heat treatment always led to a reduction in hardness. This is usually beneficial for machining, as low cutting forces and energy will be required. However, reduced hardness will lead to accelerated wear, in certain applications. So, it is observed that EN 9 steel should be tempered after normalizing, as hardness will decrease, but not by a large extent, ensuring good machinability.

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