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Effect of the Cooling Condition and Corresponding Microstructure on Tensile and Impact Behaviour of Low Carbon Steel (EN8)

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Abstract

Steels benefit significantly from the heat treatment and quenching procedure because it modifies mechanical characteristics and affects phase change in the structure. To test EN8 steels, we execute this heat treatment procedure in a variety of quenching media. A few EN8 steel specimens were investigated and evaluated after being heated in the resistance furnace between 760°C and 950°C and then quenched in a different media. As diverse quenching mediums, oil, water, and air are employed. Mechanical characteristics such as hardness using Vickers hardness equipment and the quenched samples hardness were substantially more prominent than the base material. Followed by Charpy impact test is carried out on the samples according to ASTM E-23 and the Vickers hardness test according to ASTM-E92. In the present work, medium carbon steel (EN8) was used, and its composition is shown in the table below. The samples are prepared in 20mm cylindrical bars, which were then machined to final dimensions of 10x10x75 mm^3 on a lathe as per the ASTM-E23 and v - cut notch of 2 mm depth the center for impact testing. Tensile testing was conducted using an ASTM-E2 compliant servo-hydraulic machine with a 100 kN load cell. A clip-on extensometer and the result recorded for ultimate tensile strength, increase with fine grains.

Keywords: *Heat Treatment, Critical cooling Temperature, cooling medium, and Microstructure Examination.*

1.0 Introduction

The eternal towards science and technology, especially in material science, enhance the material's mechanical properties by changing the composition, heat treatment method, controlling the solidification rate, and using proper synthesis and processing technologies to improve the material quality[1]. One of the most intriguing parts of materials science is the study of a material's structure. The structure of materials significantly impacts many material characteristics[2], even if the overall composition does not change. In accordance with the World Steel Association, steel is an iron-carbon alloy[3] with a carbon-to-iron ratio of less than 2% and a manganese-to-iron ratio of less than 1%. Manganese and silicon are also present, along with smaller amounts of elements including sulphur and phosphorus. Steel has many practical applications in every aspect of life. Steel with favourable properties is the best among the goods[4].

Carbon levels in the steel were categorized into three distinct ranges. Due to their cheap cost and versatile qualities comparable to iron, low carbon steels (0.002-0.25%C) make for a considerable share of overall steel

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production[5]. Beams, channels, and angles made from structural steel, which has a C content of 0.15 to 0.25%, are utilized for automotive frames, furniture, refrigerator doors, and roofs[6,7]. Previous austenite grain size has been demonstrated to influence steel strength and hardness[8,9]. As grain size decreases, steel's strength and toughness increase, but the mechanism by which this happens is not well understood, especially for martensitic steels. It is possible to fortify steel in a number of ways[10]. In particular, the solid solution, dispersion, grain boundary dislocation, and textural strengthening processes[11] are all examples. Grain refining, or lowering the size of grains inside a material, is the sole strengthening technique that increases strength and ductility. To put it simply, grains are localized areas inside a substance where the atoms are aligned in a certain way[12].

This study was found useful in the iron and steel industries. It enables steelmakers to manufacture products with fine grains, good impact strength, and toughness. In addition, it presents a unique way of strengthening steel for improved stability in service.

Grain has been refined by heat treatment. Detailed instructions for heat treating low carbon steel are provided here. Because it can be done in any metallurgical department, the technology offers steel producers a highly effective and conveniently located option for modifying the microstructural makeup of their goods. In comparison with traditional diffusion controlled thermal treatment, this method is more cost-effective since it requires less time and energy to complete.

2.0 Methodology

2.1 Material and Process

The cylindrical raw material having a diameter of 30mm is procured from Perfect Metal Work Bangalore and its chemical composition analyzed by using Optical Emission Spectroscopy equipment by applying the method of JIS G 1253 (spark discharge atomic emission spectrometric analysis) in SSA Labs Bangalore and its chemical composition as shown in Table 1.

The raw material was then subjected to the secondary mechanical operation to obtain the diameter as per the standard required for tensile and impact tests, as shown in Figure 1. The samples are heated in a resistance furnace at 950°C. It was held for 30 minutes for a soaking period[13-14], followed by the furnace cooling and normalizing. The quenching was carried out in super multigrade 20W-40 oil, water at room temperature, and ice (0°C) to study the effect of cooling media on a microstructure and characterization of mechanical properties.

Table 1: The received EN8 Chemical composition

	Elements	Composition %
1	Carbon (C)	0.4
2	Silicon (Si)	0.26
3	Manganese (Mn)	0.88
4	Phosphorous (P)	0.059
5	Sulphur (S)	0.024
6	Chromium (Cr)	0.23
7	Nickel (Ni)	0.015
8	Molybdenum (Mo)	<0.008

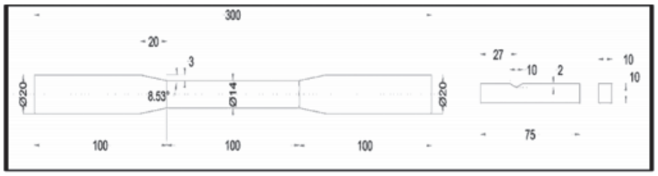


Figure 1: Tensile and impact specimen as per the standards

2.2 Microstructural Characterization

Metallographic samples were prepared from the heat-treated materials in both the transverse and longitudinal directions. Mechanically ground and polished as per ASTM E3[15], the samples were chemically etched with 2% nital. The microstructural examination was performed using a metallurgical microscope (metascope) as per the ASM handbook volume XI method[16].

2.3 Mechanical Tests

The microstructural examination was performed using a metallurgical microscope (metascope) per the ASM handbook volume XI method. Metallographic specimens were cut from heat-treated materials in both the transverse and longitudinal directions. Mechanically ground and polished as per ASTM E3[15], the samples were chemically etched with 2% nital. Metallographic specimens were cut from heat-treated materials in both the transverse and longitudinal directions. Mechanically ground and polished as per ASTM E3[17], the samples were chemically etched with 2% nital. The microstructural examination was performed using a metallurgical microscope (metascope) as per the ASM handbook volume XI method. Charpy impact specimens of 10×10×75 mm^3 were assessed with impact strength of 2mm V-notch. They were cut from the heat treatment samples perpendicularly to the V-notch. As per ASTM E-23[18], the impact tests were performed using an instrumented Charpy impact testing equipment to get information about load time, besides statistics on the energy absorbed and permits the assessment of contributions to the overall energy effect.

3.0 Results and Discussion

3.1 Microstructure

According to the low magnification metallurgical microscope photographs of the obtained material and it reveals, the grains are dispersed with pearlite and ferrite phases. Figure 2(a) shows the predominantly perlitic grains with roughly 30% ferrite grains spread uniformly. Figure 2(b) shows a pearlite matrix with approximately 45% per cent ferrite grains distributed uniformly. The white areas indicate the presence of the ferrite phase; however, the formation of the pearlite phase is characterized by black spots. Depending on the alloy composition, pearlite formation starts at temperatures ranging from 1150°C to 723°C[19]. The pearlite decomposition occurs below the eutectoid temperature as carbon comes out from the precipitate and combines with iron to form iron carbide.

The microstructure of normalizing and oil quenching samples are different cooling rates as compared to Figure 2(a) and 2(b) in normalizing pearlite around 50% with ferrite grains distributed evenly, as shown in Figure 2(c). Oil quenching led to predominately perlitic with ferrite grains around 30% distributed uniformly. The grain growth kinetics stagnation occurs as increase the rate of cooling because the nucleation rate is higher than the growth rate[20-21]. Thereby grain size decreases as indicated in Figures 3(a) and 3(b).

The critical cooling rate employing water and ice quenching, where the nucleation rate is very fast compared to the grain growth, led to forming the predominately low carbon tempered martensite structure (lathe martensite) during ice quenching, as shown in Figure 4(a). The water quenching

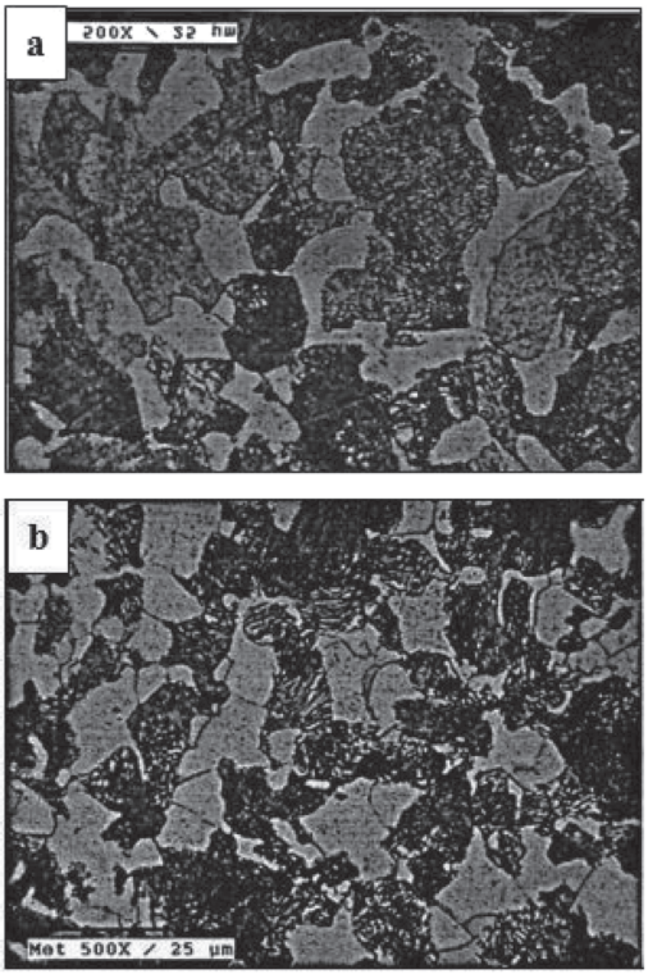


Figure 2: Low magnification metallurgical microscope showing the microstructure coarse grains 2(a) as received EN8 material and 2(b) annealing

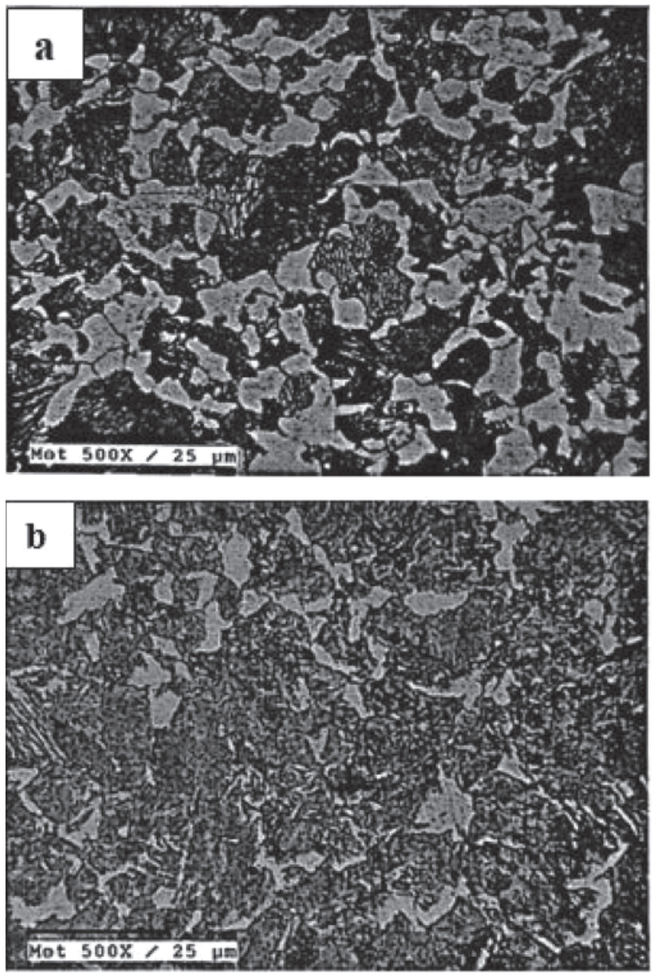
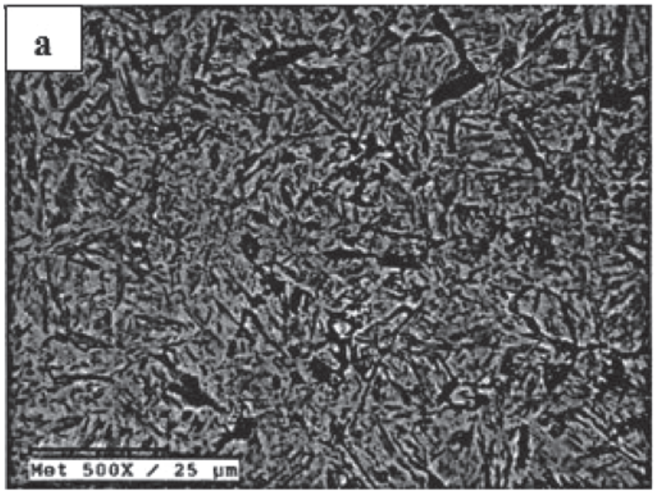


Figure 3: Low magnification metallurgical microscope showing the microstructure fine grains in 3(a) n normalizing and 3(b) oil quenching



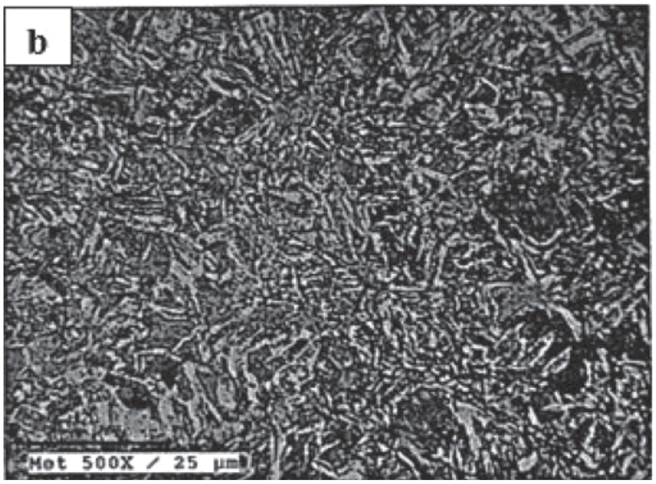


Figure 4: Low magnification metallurgical microscope showing the microstructure of 4(a) tempered martensite, cooling rate creates surrounded and, 4(b) lathe martensite

at room temperature leads to a predominate martensite structure with some retained pearlite present, as shown in Figure 4(b).

The proportion of elements present in the heat-treated EN8 steel samples were summarized in Table 2. Table 3 shows that an increase in cooling rate results in finer grain size and more brittle phases, which increase the hardness and ultimate tensile strength but lower the impact strength.

3.2 Hardness Test

The results of hardness in EN8 steel samples, as received material, annealing, normalizing, and oil quenching increases (131-219 VHN) with increases in the volume fraction of pearlite as shown in Figures 1 and 2, and it indicates the presence of higher volume fraction of pearlite and with low ferrite. The water and ice quenching steel sample's hardness again increases (243-263 VHN) because of martensite and acicular ferrite, as shown in Figure 3. According to the previously indicated microstructural elements, the increasing cooling rate substantially enhances the hardness and ultimate tensile strength. On the contrary, the presence of martensite lowers the impact strength[3,8].

Table 2: Volume fraction of constituents of heat-treated EN8 steel

Cooling Method	Pearlite (%)	Ferrite (%)	Martensite (%)
Received material	70	30	-
Annealing	55	45	-
Normalizing	50	50	-
Oil quenching	70	30	
Water quenching	20	10	70
Ice quenching	10	10	90

Table 3

Cooling Method	Hardness (VHN)	Tensile strength (MPa)	Impact strength (MPa)
Annealing	131	401	656
Normalizing	197	456	625
Oil quenching	219	518	586
Water quenching	243	551	502
Ice quenching	263	577	451

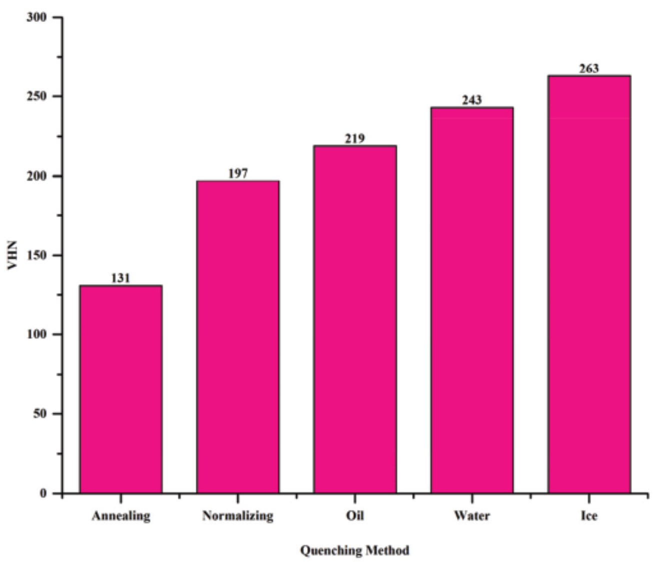


Fig.5

3.3 Tensile Strength

The tensile strength of the annealing, normalizing, and oil quenching samples (401-518 MPa) increases with increases in rate cooling, as clearly indicates the presence of high volume fraction of pearlite matrix surround with ferrite as shown in Figures 1, 2 and 3 indicates the presence of tempered and lathe martensite in water and ice quenching steel samples respectively (551-577 MPa). The degree of cooling decides the material's microstructure[10] because, at the slow cooling rate, the number of nuclei formed less than grain growth rate leads to developing the fine grains[22]. At the critical cooling rate, the number of nuclei formed more than the grain growth rate creates the martensite structure[23].

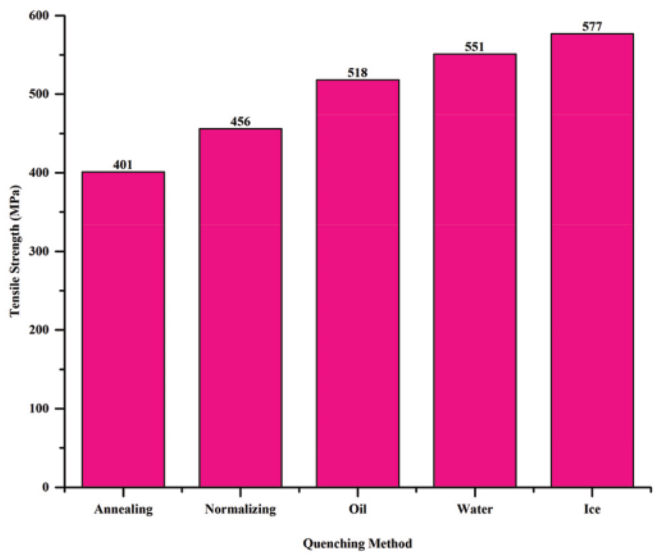


Fig.6

3.4 Impact Test

The impact strength of the annealing, normalizing, and oil quenching samples (656-586 MPa) are increased with increased in rate cooling, as clearly indicates the presence of high volume fraction of pearlite matrix surrounded by ferrite led to high ductility, as shown in Figures 1 and 2. Figure 3 indicates the presence of tempered and lathe martensite (502-401MPa) in water and ice quenching steel samples, respectively. As the cooling rate increases, grains become finer, leading to less energy[23]. The degree of cooling decides the material's microstructure because, at the slow cooling rate, the number of nuclei formed less than grain growth rate leads to including the fine grains. In critical cooling rate, the number of nuclei formed more than grain growth rate leads to the martensite structure.

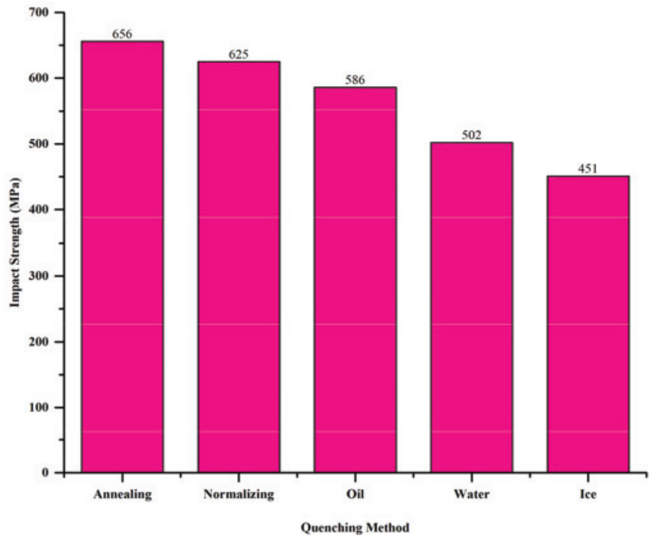


Fig.7

4.0 Conclusion

The present work studied the cooling rate's influence on low carbon steel's final microstructure and mechanical characteristics. The annealing and normalizing cooling rates result in a bigger preceding austenite grain size and a final mixed microstructure of pearlite and pro-eutectoid ferrite with good elongation-to-failure. Still, low impact toughness and cooling rates of oil, water, and ice quenching samples, on the other hand, reduced the previous austenite grain size and promoted the creation of a mixed microstructure of acicular ferrite plus martensite with higher tensile strength and lower elongation, as well as higher impact toughness.

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