

Study Of Effect Of Phases On Charpy Impact Energy Of Steels

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Abstract

In this investigation, we have taken mild steel and EN8 steel specimens and performed various heat treatments like annealing, normalizing and quenching. Austenitization was conducted at 850 °C and holding time was chosen 1 hour and 10 minutes. The 1st 2nd and 3rd stage tempering are carried out at 250 °C, 400 °C and 550 °C temperatures respectively for 3 hours and captured the microstructures for all heat treatment processes. The Charpy impact tests were conducted at room temperature and energy values were measured. The hardness before and after heat treatment processes for mild steel and EN8 steel specimens were measured. The highest Charpy impact energy 208 Joules was measured for mild steel after 3rd stage tempering and lowest charpy impact energy was found after quenching. The highest hardness value Rc 40 was measured after quenching treatment and lowest hardness value Rc 6 was observed after annealing heat treatment of mild steel specimens. Charpy impact energies of EN8 steel were measured after employing high temperature tempering heat treatment.

Keyword: Charpy impact energies, Furnace, Hardness, Martensite.

1. Introduction

The Charpy impact test is extensively used in the industries due to simplicity of test and results can be produced in small time of span. Thermo-mechanically treatments to low carbon steels with small alloying additions are conducted [1-4]. Thermo-mechanical treatments include forging and the heat treatments such as annealing, tempering after hardening. The optimization of strength, ductility, fracture strength, weldability and resistance to neutron irradiation is required to use for nuclear vessel.

Many low carbon steels have been designed to manufacture nuclear vessels. The steel alloys added with Mn, Ni and Mo are most widely used steels to manufacture nuclear vessel in heat treated conditions [5-7]. During the forging treatment, major transformation takes place to upper bainitic region. Hence to obtain good toughness is a challenge. As the Charpy energy decreases in service due to irradiation of neutron resulting increase in ductile to brittle transition temperature [8, 9]. The Charpy energy can be maintained in service by optimization of composition of steel. The aim of this work is to improve the Charpy energy levels. In order to enhance the Charpy energy levels, the microstructure, especially the nucleation of carbides, of the steels was modified by the heat treatment processes [10]. The pipe line steels are becoming stronger and tougher to increase the transportation capability and to meet the requirements for severe conditions in drilling operations in oil or gas companies such as cold or deep [11-13]. The fracture strength of these steels are determined by Charpy impact test. The results obtained by Charpy impact tests are assumed as the measure of the difficulty in v-notch propagation for the failure through ductile fracture [14-17]. The carbides of iron are identified as potential sites for cleavage fracture [18, 19].

2. Experimental Details

The experimental procedure for this investigation is as follows: Specimen preparation, heat treatment, impact energy measurement, microstructural analysis and hardness measurement.

Initially, as received were rods of square section 10 mm x 10 mm of mild steel and EN8 steel of 40 cm length. The specimens were cut into 14 pieces each of 5. 5 cm of each steel using cutting machine. After that specimens were polished and introduced a 45° V-notch, 2 mm deep with a 0. 25 mm root radius using a triangular file. The Charpy impact tests were carried out on the specimens of mild steel and EN8 steel in different state of heat treatment conditions. The specimen was supported as a beam in a horizontal position and loaded behind the notch by the impact of a heavy swinging pendulum (the impact velocity is approximate 5 m/s). The specimen is forced to bend and fracture at a high strain rate on the order of 10^3 per sec. For austenitizing of steels, the specimen were heated at 850 °C and soaked for 1hour and10 minutes and corresponding cooling processes were adopted. In 1st, 2nd and 3rd stage tempering, the heating temperatures were kept at 250 °C, 400 °C and 550 °C respectively and soaked for three hours. To analyze the microstructure, the specimens polished by using belt grinder, emery papers of grades (220, 400, 600, 1000 and 1200), and disk polishing. After the fine polishing, the specimens were washed and dried followed by etching with Nital (2% Nitric acid in ethanol or methanol). The microstructures of etched specimen were taken using Leica Optical Microscope. The hardness values are measured using Rockwell hardness testing machine on C-scale with a diamond cone indenter of angle 120 °applying minor and measure loads 10 Kg and 150 Kg respectively.

3. Results and Discussion

Charpy impact energy values of as received specimens of mild steel and EN8 steel are found observed 103 J and 92 J respectively.

Table 1. Hardness and Charpy impact energy after heat treatments of mild steel and EN8 steel.

Heat treatment process	Rockwell hardness values (R_C)		Applied Energy (Joules)	Energy absorbed (Joules)	
	Mild steel	EN8 steel		Mild steel	EN8 steel
Annealing	6	16	300	70	106
Normalizing	10	48	300	62	72
Quenching	42	59	300	40	38
1 st Stage-Tempering	23	45	300	72	46
2 nd Stage-Tempering	13	43	300	170	74
3 rd Stage-Tempering	9	32	300	208	174

3. 1. Microstructural Analysis

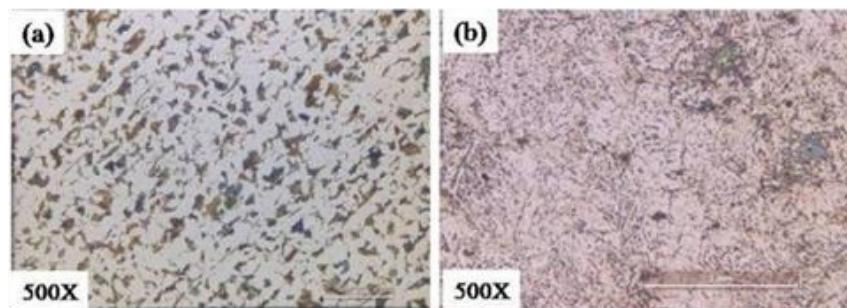


Fig. 1. Optical microstructure of mild steel, (a) Normalized, at 500X, (b) Quenched, at 500X.

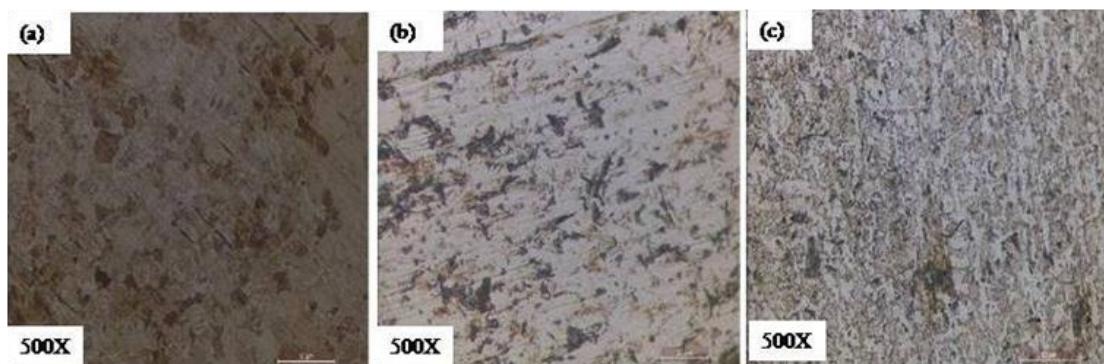


Fig. 2. Optical microstructure of tempered mild steel at 500X, (a) Tempered at 250 °C, (b) Tempered at 400 °C, (c) Tempered at 550 °C.

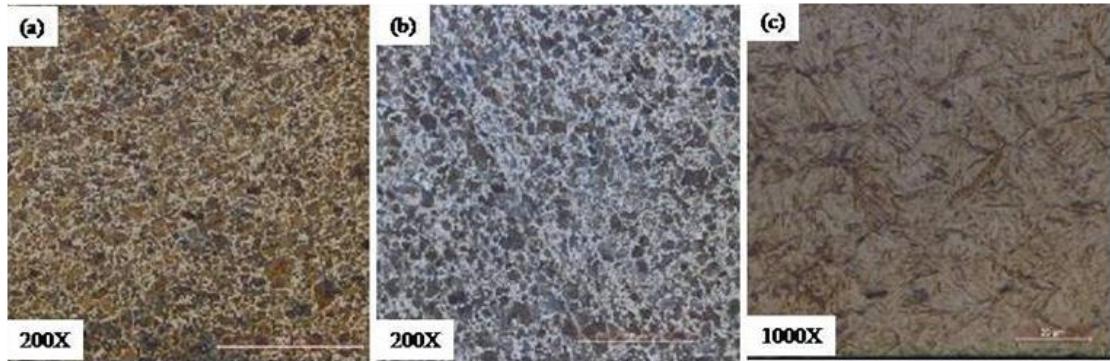


Fig. 3. Optical microstructure of EN8 steel, (a) Annealed, at 200X, (b) Normalized, at 200X, (c) Quenched, at 1000X.

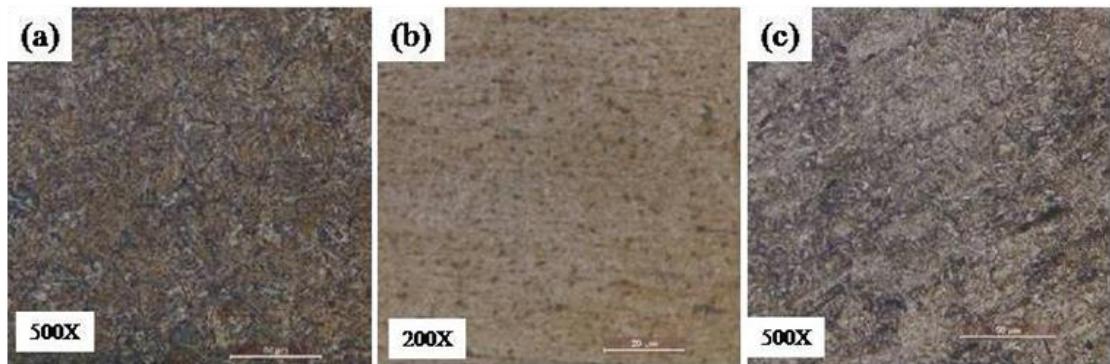


Fig. 4. Optical microstructure of tempered EN8 steel, (a) Tempered at 250 °C, at 200X, (b) Tempered at 400 °C, at 500X, (c) Tempered at 550 °C, at 500X.

3. 2 Plots of hardness, Charpy energy as a function of process and temperature.

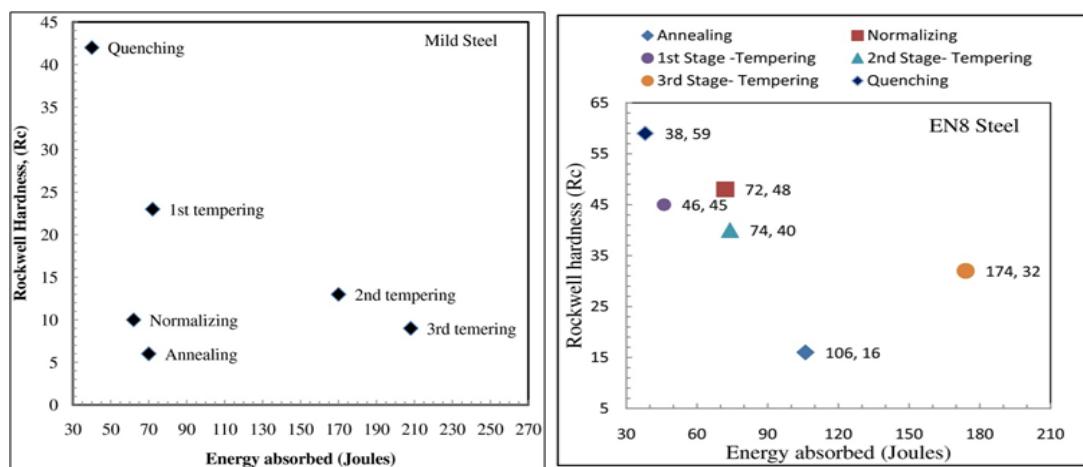


Fig. 5. Hardness vs. Charpy impact energy of mild steel and EN8 steel as function of heat treatment process.

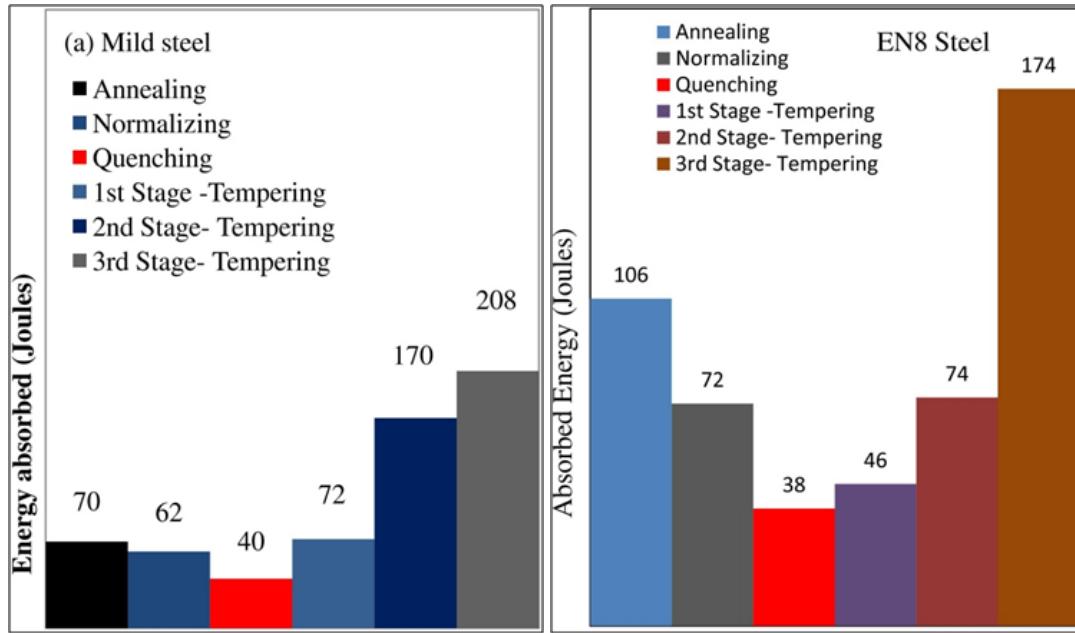


Fig. 6. Bar diagram of Charpy impact energy values of mild steel and EN8 steel as a function of heat treatment processes.

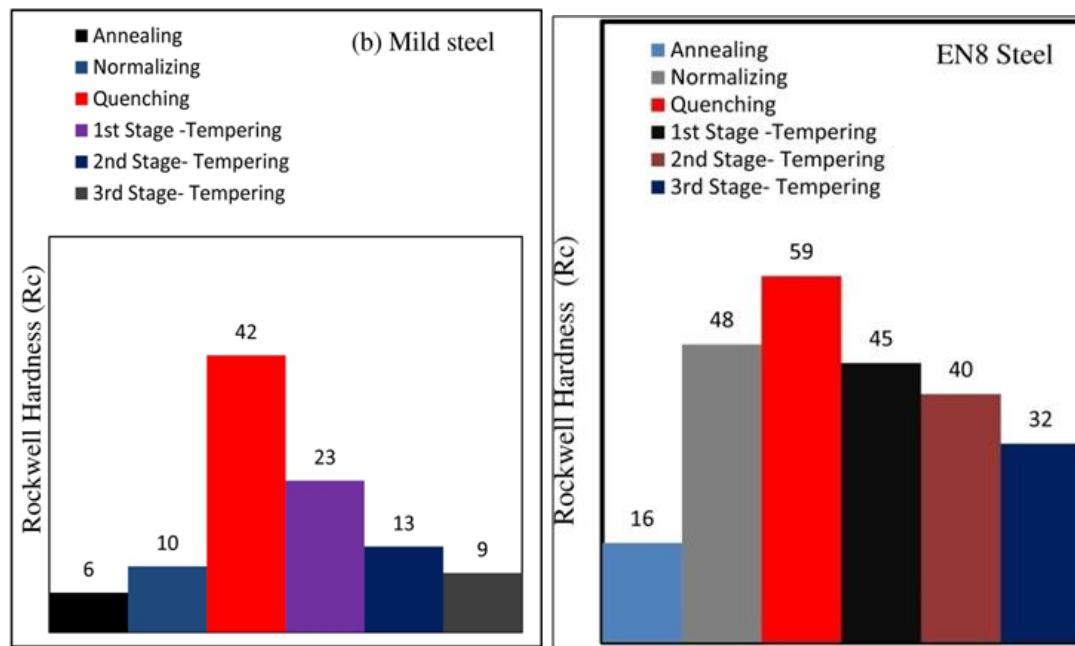


Fig. 7. Bar diagram of Rockwell hardness (Rc) of mild steel and EN8 steel as a function of heat treatment processes.

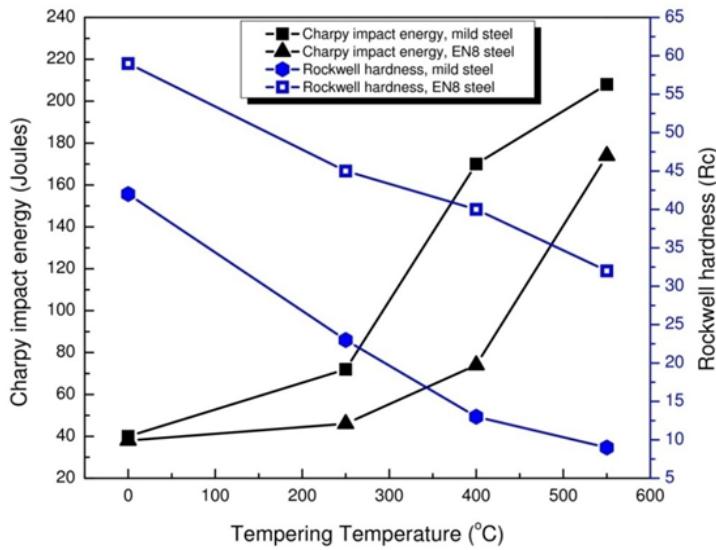


Fig. 8. Charpy impact energy, Rockwell hardness (Rc) vs tempering temperature of mild steel and EN8 steel.

3.3. Discussion

The study of Charpy impact energy values of two types of steels in various heat treated conditions such as annealing, normalizing, quenching and tempering has been done. The austenitizing temperature was chosen 850 °C and held at this temperature for 1 hour 10 minutes. The 1st, 2nd and 3rd stage tempering are carried out at 250 °C, 400 °C and 550 °C respectively for 3 hours. The optical microstructures were obtained after metallographic preparation for different heat treatment processes. Fig. 1 (a & b) show normalized [course paerlite (dark) and ferrite (bright)] and quenched [martensite (dark) in the ferritic matrix] microstructure of mild steel. This martensite consists of lath type structure and found in the form of packets. The high dislocation density is found in the form of cells associated in the lath martensite with average width 2500 Å [20, 21]. Fig. 2 (a, b, c) represent the tempered microstructures which show as the tempering temperature increases the values of toughness also increase. The optical microstrucutres of EN8 steel shown in Fig. 3 (a, b, c) are obtained in annealed [course paerlite (dark) and ferrite (bright)], normalized [fine paerlite (dark) and ferrite (bright)] and quenched [retained austenite, martensite (dark) in the ferrite matrix] conditions respectively. The martensite shown in Fig. 3 (c) is of mixed type of structure. It is composed of lath as well as plate martensitic structures. The microstructure shown in Fig. 3 (a) exhibits least Rockwell hardness but higher impact toughness compared to the microstructures shown in Fig. 3 (b & c).

Fig. 4 represents the optical microstructures of tempered EN8 steel. Tempering of EN8 steel is driven by diffusion of carbon from supersaturated martensite to the lattice defects and formation of carbide particles in the ferrite matrix. And also some more reactions take place during tempering heat treatment such as disintegration of untransformed austenite, restoration and recrystallization of martensitic phase.

Generally, these reactions overlap and found occurring on the fine range. The tempering at 250 °C involves formation of low carbon martensite and carbide of α -iron from supersaturated state. The decomposition of supersaturated martensite progresses through nucleation and growth process and this growth continues till the carbon in the martesite reaches to 0.30 pct. The carbide formed at this tempering temperature is not cementite, it is termed as epsilon carbide. These structural changes in the microstructure lead to increase in ductility and Charpy impact energy. During the tempering at 400 °C, the transformation of retained austenite to bainite takes place but this bainite is the mixture of ferrite and epsilon carbide [22]. These changes in the microstructure lead to restoration of maximum elasticity, increased ductility and better impact toughness. The high temperature tempering (at 550 °C) changes epsilon carbide to spheroidized cementite and also martensite transforms into ferrite (bcc) by rejecting carbon form martensitic (bct) structure. The specific combination of ferrite and cementite is the reason behind the high Charpy impact toughness. The annealed microstructures have better impact toughness values than normalized structures for both of the mild steel and EN8 steel as shown in Table 1. The Rockwell hardness values are found more for normalized structures than the annealed structures for both of the steels. The least impact energy among the annealing, normalizing and quenching is observed after quenching due to formation of martensitic structure which is hard and brittle distorted body centered tetragonal structure.

The variation of Rockwell hardness values after various heat treatment has been shown in the Fig. 7. These figures represent the maximum hardness Rc 42 and Rc 59 after quenching for mild steel and EN8 steel and also represent the continuous drop in hardness values after successive stages of tempering heat treatments due to reduced carbon content in martensitic phase and precipitation of carbide particles. The hardness values are found decreasing after tempering due to dissolution of the martensitic phase while the impact energies are found increasing due to more tough structure after successive stages of tempering treatments as shown in Fig. 5. Fig. 6 represents the variation of impact energy with change in heat treatment process for mild steel and EN8 steel. The lowest energy (40 Joules) is observed (red color-bar) and the highest Charpy impact energy 208 Joules was measured after 3rd stage tempering due to tempered martensite and transformed retained austenite in the matrix of ferrite (the tallest grey color-bar) in case of mild steel. Fig. 6 shows the similar trend of variation of impact energies for mild steel and EN8 steel with values 106 Joules, 38 Joules and 174 Joules after annealing, quenching and 3rd stage tempering respectively in case of EN8 steel. This variation of impact energies is attributed due to presence of coarse pearlite (annealing), fine pearlite and small amount of martensite (normalizing) and tempered martensite (3rd stage tempering). The lowest Charpy impact energy is measured in quenched condition in both types of steels. The variations of charpy impact energies and Rockwell hardnesses with the tempering temperatures have been shown in Fig. 8. It is clear from Fig. 8 that the hardness decreases with increase in tempering temperature while impact energy increases with rise in tempering temperature.

4. Conclusion

1. The Charpy impact energy values are found better after tempering treatments. The presence of pearlite, spheroidized cementite, tempered martensite and transformed retained austenite play very important role in the improvement of impact toughness.
2. For mild steel specimen, the highest Charpy impact energy value after 3rd stage tempering is observed 208 Joules for mild steel specimen and the lowest Charpy impact energy value 40 Joules is found after quenching.
3. The Rockwell hardness of quenched and annealed mild steel specimens are found Rc 40 and Rc 6 respectively.
4. For EN8 steel specimen, the charpy impact energy after annealing, quenching and 3rd stage tempering are obtained 106 Joules, 40 Joules and 174 Joules repectively.
5. The hardness values for quenched and annealed specimens are observed 59 Rc and 16 Rc respectively for EN8 steel.

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