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Evaluation of Mechanical Properties of Medium Carbon Low Alloy Forged Steels Quenched in Water, Oil and Polymer

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Abstract

Medium carbon low alloy forged steels (EN 18, EN19, EN 24, and EN25) have been investigated with respect to their mechanical properties after heat treatment. For heat treatment solutionizing temperature of 855°C with a soaking period of 60 min was used. Thereafter quenching was carried out in three media, viz., Step water, oil and polymer (polyethylene glycol) separately. The quenched samples were step tempered at 575°C and at 220°C sequentially for 60 min each. Hardness, tensile strength, Charpy impact strength and metallographic were carried out on the untreated and heat treated specimens. The heat treated specimens showed higher hardness (10-30%), higher strength (20-100%) and higher impact energy (20-160%). The specimens quenched in poly ethylene glycol exhibited the best mechanical properties. The heat treated specimens had a structure of fine tempered martensite with small amount of bainite.

Keywords: EN steels; Heat treatment; Polymer quenching; Forged steels; Impact energy

Introduction

Medium carbon steels are similar to low-carbon steels except that the carbon ranges from 0.30 to 0.50% and manganese from 0.60 to 1.65%. The uses of medium carbon steels include shafts, axles, gears, crankshafts, couplings and forgings. Steels of 0.40 to 0.60% C ranges are used for rails, railway wheels and rail axles. Therefore medium carbon low Alloy steels (MCLA) are commonly used for engineering applications in automobiles, aircraft and transportation industries. They are readily hot forged usually at temperatures ranging from 1065°C to 1230°C [1]. In industry, quenching in oil or polymers is resorted to especially for heavy sections to avoid quench crack commonly observed during water quenching. Choice of quenching medium for the MCLA forged steels depends on the composition of the steel in addition to the size and shape of the parts. Of the conventional quenching media, (water, oil and polymer), water quenching and in some cases even oil quenching may result in quench cracks in thick sections. Further though mineral oils exhibit good cooling capacity for the majority of alloy steels, they are relatively expensive and toxic. The synthetic polymer quenchant, polyethylene glycol (PEG) [2] has the advantages of lesser risk of cracking and less distortion, resulting in better mechanical properties compared to water, oil and brine solutions.

Microalloyed steels, are designed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels. They are not considered to be alloy steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition (steels have yield strengths greater than 275 MPa, or 40 ksi). The chemical composition of a specific steel may vary for different product thicknesses to meet mechanical property requirements. The steels in sheet or plate form have low carbon content (0.05 to-0.25% C) in order to produce adequate formability and weldability, and they have manganese content up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium are used in various combinations [3]. The mechanical properties of microalloyed steel result, however, from more than just the mere presence of microalloying elements. Austenite conditioning, which depends on the complex effects of alloy design and rolling techniques, is also an important factor in the grain refinement of hot-rolled steels [4]. Grain refinement by austenite conditioning with controlled rolling methods has resulted in improved toughness and high yield strengths in the range of 345 to 620 MPa (50 to 90 ksi). The present study is aimed at determining a comparative evaluation of mechanical properties achieved in MCLA steels (EN steels) with different quenching media with standard step tempering procedure [5-8].

Materials and Methods

Four steels, viz., EN 18, EN19, EN 24, and EN25 in the normalized condition were procured from Mumbai market. The compositions were analysed for confirmation and Table 1 gives the results of the composition check.

Mineral oil (SAE 320 gear oil) and polymer {Polyethylene glycol, $H\text{-}(O\text{-}CH_2\text{-}CH_2)n\text{-}OH$ [where n represent the average number of oxyethylene groups]} from Bangalore market to serve as quenchant.

Test specimen preparation

A set of specimens was prepared for Tensile, Impact, Hardness and Microstructural analyses. The standards used for samples to carry out the various tests are listed out in Table 2.

Heat treatment/quenching and step tempering

An electric furnace with maximum temperature of 1200°C was used for both solutionizing and step tempering. The heat treat temperatures were kept same for all four steels studied, as shown in Table 3. After solutionizing, the samples were directly quenched in water, oil [9] or

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Element	EN18	EN19	EN24	EN25
C	0.380	0.393	0.431	0.350
Mn	0.700	0.660	0.605	0.700
P	0.012	0.014	0.023	0.04
S	0.012	0.019	0.030	0.04
Si	0.192	0.253	0.283	0.40
Ni	--	--	1.395	2.80
Cr	0.70	1.043	0.978	0.80
Mo	--	0.202	0.207	0.65
Fe	bal	bal	bal	bal

Table 1: Chemical Composition of steels studied.

Test	Standard used
Hardness Test	ASTM 92
Tensile Test	ASTM E-8
Charpy Test	IS: 1499

Table 2: Standards used [3].

Process	Temp °C	Soaking time
Hardening	855	60 min
Tempering I	575	60 min
Tempering II	220	60 min

Table 3: Temperature and soaking ftime [4].

polymer solution. The quenched samples were thereafter tested for their mechanical properties.

Mechanical tests

A standard Brinell Hardness Tester was used for measurement of indentation hardness. The tests were conducted using a 10 mm diameter steel ball and 3000-kg load. The tensile tests were carried out using an electrically powered Hounsfield tensometer with a capacity of 20 KN. Impact energy to failure was found using a Charpy impact tester.

Results and Discussions

Table 4 shows the mechanical properties of the as–received and heat treated steel samples with the three quenchants. Figures 1-4 are plots of variations of mechanical properties when different quenchants are used. Figure 1 shows the variation of hardness for the four EN steels when the quenchant is changed from water to oil and then polymer. It is observed that the maximum hardness value of 362 BHN is obtained in EN 25 with water quenching in general, water quenching has the maximum impact on hardness followed by oil quenching and polymer quenching as the least defect [10-12]. However, in case of EN 19 polymer quenching resulted in highest hardness of 286 BHN. Figure 2 depicts the defect of varying the quenchant on the UTS of EN steels. The variation of the UTS generally follows the same behaviour as the variation of hardness. It is observed that once again the highest UTS value is obtained in water quenched EN 25 steel (1280 MPa) which is more than twice the value (580 MPa) for the as received steel. Figure 3 depicts the change of impact energy of the four EN steels considered. Once again it is evident that step tempering after quenching for hardening has improved impact energy of steels except in case of water quenching of EN18 and EN19. This may appear as in congruent with Figure 4 where the percentage of elongation of the forged steels is highest in the as received condition in the lower in the heat treated conditions (except for oil quenching).

The explanation for higher impact energy (and therefore higher toughness) of the heat treated steels lies in 20-50% increase strength values while the elongation is reduced by maximum 20% only.

Effect of quenching in different media on the microstructure of EN steels

The microstructural investigation was performed using a Carl Zeiss optical microscope. In sequence, the steps include sectioning, mounting, coarse grinding, fine grinding, polishing, etching and

EN Series	Sample uenching medium	Tempering Temperature (°C)	BHN	Tensile strength MPa)	Impact Energy, J	% El
EN 18	As-received	-	188	580	42	32
	Water	575,220	270	1050.2	35	28
	Oil	575,220	232	1020.7	68	34
	Polymer	575,220	238	952.8	78	27
EN 19	As-received	-	252	900	56	31
	Water	575,220	280	1201.8	37	27
	Oil	575,220	252	1150.3	55	33
	Polymer	575,220	286	1135.9	88	26
EN 24	As-received	-	270	920	55	29
	Water	575,220	362	1220.4	60	26
	Oil	575,220	340	1060.2	75	31
	Polymer	575,220	260	1198.3	100	25
EN 25	As-received	-	290	1020	45	26
	Water	575,220	375	1280.3	60	25
	Oil	575,220	352	1240.2	80	29
	Polymer	575,220	315	1239.9	112	28

Table 4: Shows the Mechanical properties of as-received and quenched steel samples.

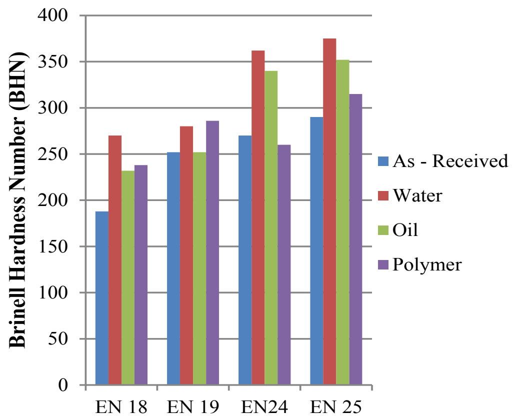

Figure 1: Variation of BHN of EN steels with as-received, quenched in water, oil and polymer.

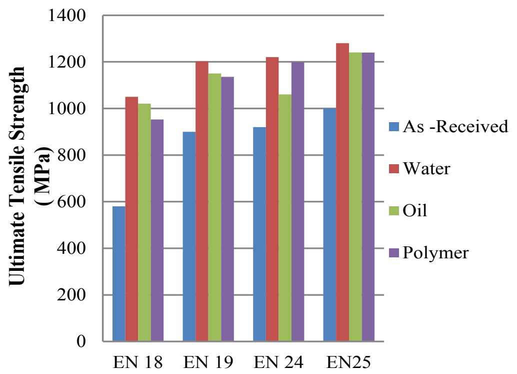

Figure 2: Variation of UTS of EN steels with as-received, quenched in water, oil and polymer.

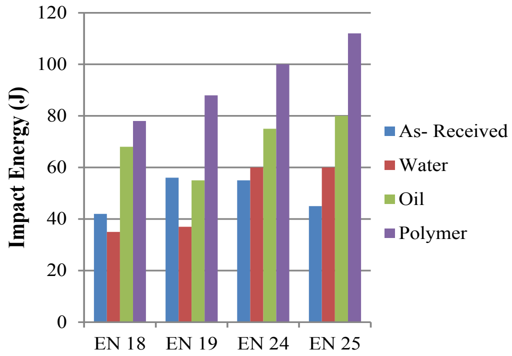

Figure 3: Variation of Impact Energy of EN steels with as-received, quenched in water, oil and polymer.

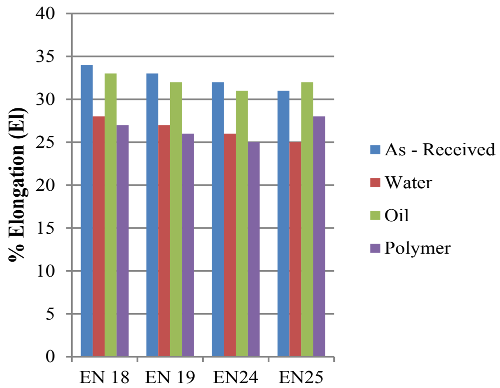

Figure 4: Variation of Elongation in Area of EN steels with as-received, quenched in water, oil and polymer.

microscopic examination, and the general procedure followed by earlier investigators was employed [6]. The samples were polished using a series of emery papers of grit size varying from 1000 μm to 1500 μm. The samples were etched with nital solution, 100 mL ethanol and 1-10 mL nitric acid for about 10-20 seconds before observation in the optical microscope [13-17].

The mechanical properties of microalloyed steels result, however, from more than just the mere presence of microalloying elements. Austenite conditioning, which depends on the complex effects of alloy design and rolling techniques, is also an important factor in the grain refinement of hot-rolled steels. Grain refinement by austenite conditioning with controlled rolling methods has resulted in improved toughness and high yield strengths in the range of 345 to 620 MPa (50 to 90 ksi).

Figures 5-8 are the photomicrographs of EN18 and EN19, EN 24 and EN 25, respectively. Figure 5a-5c shows the microstructures of EN 18 in the water quenched, oil quenched and polymer quenched conditions respectively. Similarly, Figures 6a-6c, 7a-7c and 8a-8c depict the microstructures for EN 19, EN24 and EN25 in different conditions.

Observations

The microstructure of water-quenched specimens appears to be a mixture of martensite and lower bainite. For oil-quenched specimens, a mixture of upper bainite, lower bainite and some martensite is obtained. In case of polymer quenched steels, the microstructure consists of fine tempered martensite with a small amount of ferrite.

Figure 5a: EN 18 water quenched.

Figure 5b: EN 18 Oil quenched.

Figure 5c: EN 18 Polymer quenched.

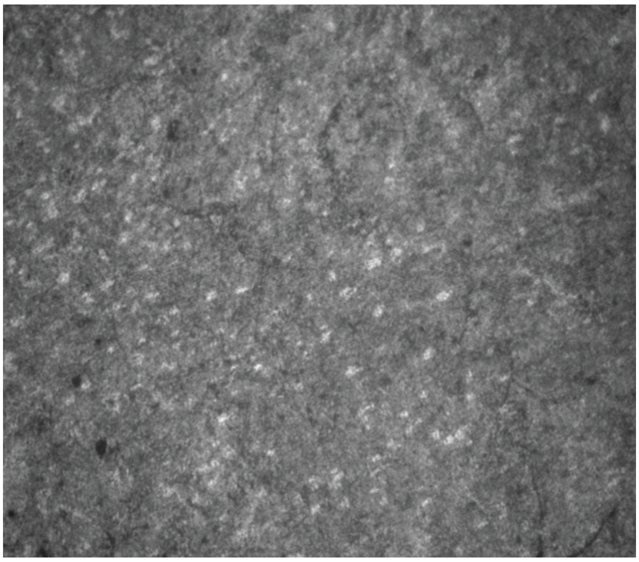

Figure 6a: EN 19 water quenched.

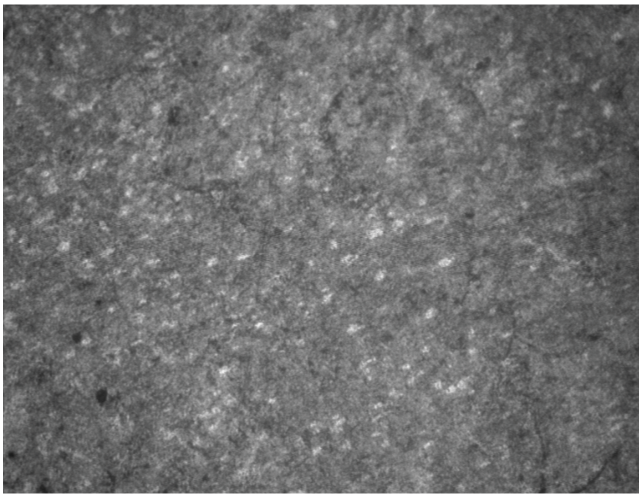

Figure 6b: EN 19 Oil quenched.

Figure 6c: EN 19 polymer quenched.

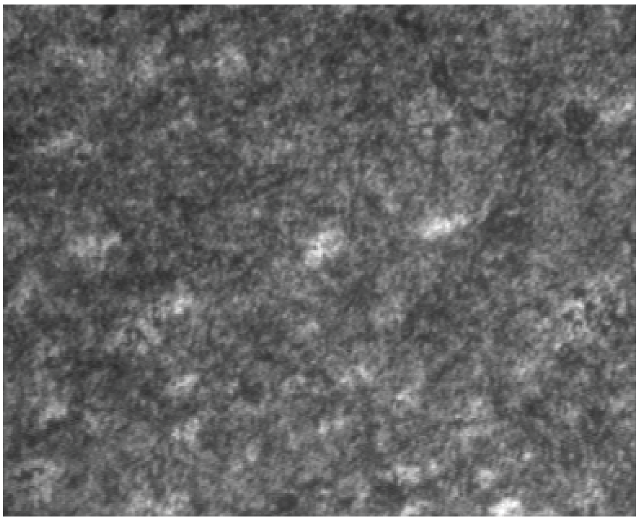

Figure 7a: EN 24 water quenched.

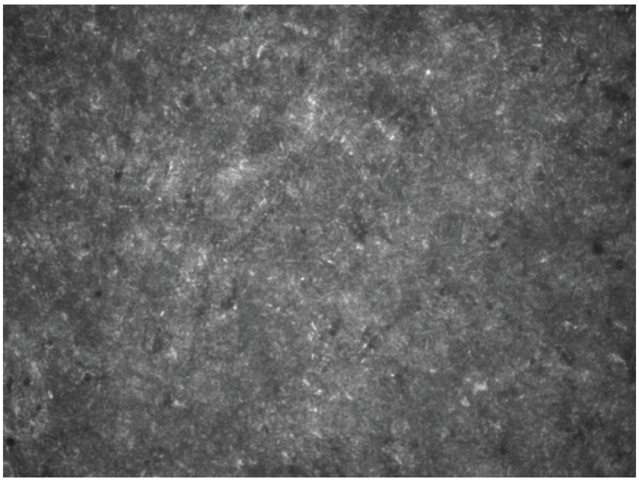

Figure 7b: EN 24 oil quenched.

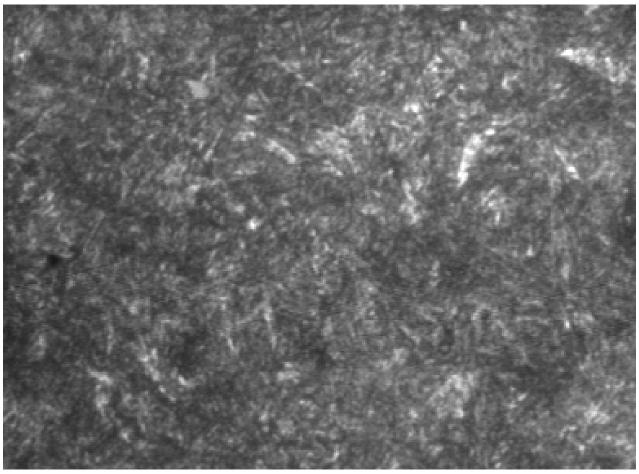

Figure 7c: EN 24 polymer quenched.

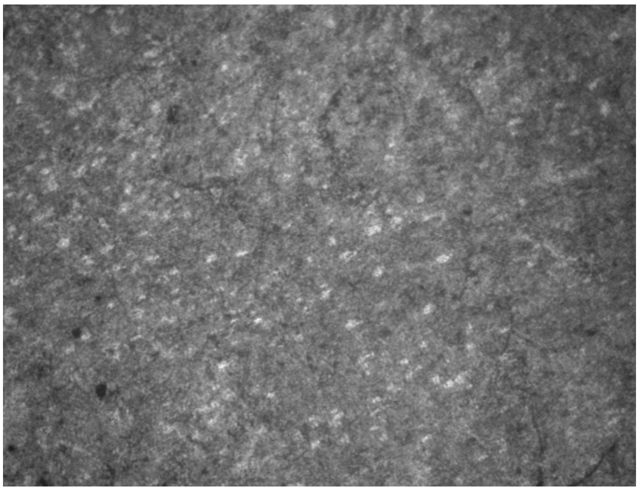

Figure 8a: EN 25 water quenched.

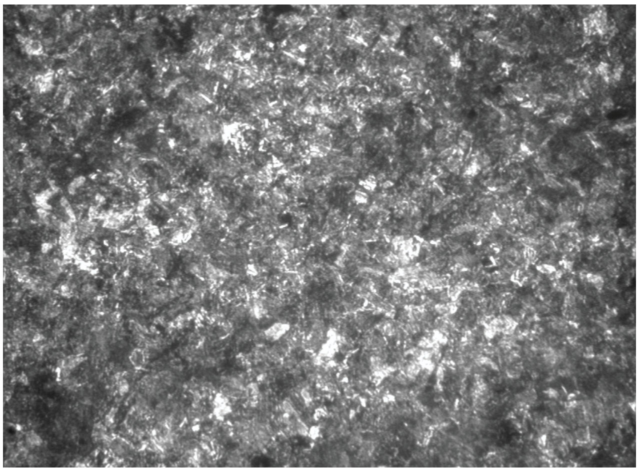

Figure 8b: EN 25 oil quenched.

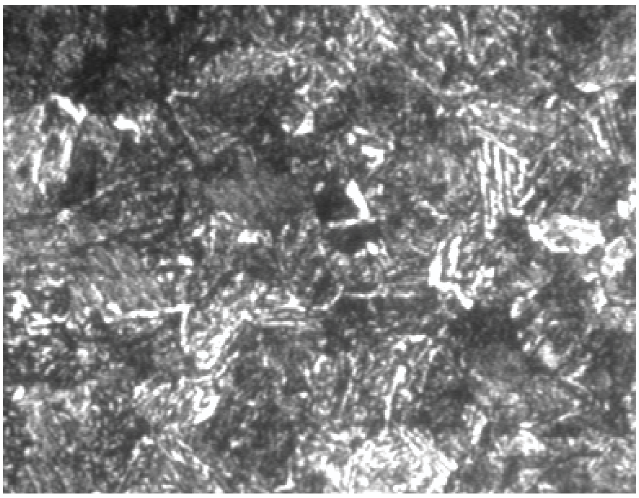

Figure 8c: EN 25 Polymer quenched.

Thus polymer quenching would improve ductility, toughness and impact strength values.

Conclusions

1. It has been established that polymer can also be used as a quenching medium for MCLA forged steels.
2. The study has shown that using of water, oil and polymer as quenchants improves the mechanical properties when compared to the untreated steels.
3. Polymer quenching improves the ductility of the steel because of its lower and uniform cooling rate compared with water and oil; also there is lesser risk of cracking and distortion in the parts. The uniform low cooling rates also result in better mechanical properties for the polymer quenched steels.
4. Microstructural analysis corroborates the changes in mechanical properties observed.

Acknowledgements

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