Evaluation of Mechanical Properties of Medium Carbon Low Alloy Forged Steels by Polymer Quenching

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Abstract: Medium carbon low alloy forged steels were investigated (EN18, EN19, EN 24, and EN25) with respect to their mechanical properties by polymer quenching. The effect of polyethylene glycol (PEG) H−(O−CH2−CH2)n−OH as a quenchant was studied by varying polymer concentration (10% and 30%) to investigate the mechanical properties and their metallographic structures. The study was carried out on the medium carbon low alloy forged steels in heat treated condition by hardening in the polymer quenchant. 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 step tempering process of the specimen gives the high strength with high hardenability. The specimen quenched in the polymer solution exhibited the best mechanical properties, viz., as received samples. The mechanical properties are found increased in the polymer quenchant because of the slow and uniform cooling rate of the polymer. The microstructural examination of the specimens were found to have justified reason for the increment recorded in some of the mechanical properties, as it displayed a high proportion of the martensitic phase.

Keywords: EN Steels, Heat Treatment, Impact strength, Polymer Quenching.

1. INTRODUCTION

Medium carbon low alloy steels (MCLA) is used in the forged condition in the automobiles, aerospace and transportation industries. Reliability of critical components made of EN Series is directly based on the strength of the steel, which in turn is dependent on forging process. EN18 (AISI 5140), EN19 (AISI 4140), EN 24 (AISI 4340) and EN25 (3430) are medium carbon low alloy steels under HSLA categories. In some applications, there is need to increase the high strength along with the high ductility where the combination of these properties produces excellent products. In practice, heat treatment is the process by which change in mechanical
properties can be achieved. It is mainly depends on the microstructural transformation, the microstructural changes occur at different heat treatment condition with varying the holding time and with varying the tempering temperature. The heat treatment \[1\] of steels gives the improved mechanical properties. The final end structure of the heat treated components decides the applications where it can be used with the environmental conditions. The conventional quenching medium as water and oil are used for the quenching of the heat treated parts. The convention type quenchants have disadvantages as compare to the new generation synthetic quenchants such as PEG \[2\] results in less risk of cracking and less distortion in the parts which gives the good properties. The microstructure of the step tempered parts produces the fine tempered martensitic structure which yields the high strength. The effect of polyethylene glycol as quenchant was studied to investigate the mechanical properties and microstructural evaluation of steels.

2. Materials and Method

2.1 Materials and Equipment
Four steels, viz., EN 18, EN19, EN 24, and EN25 in the normalized condition were procured from Mumbai market. The chemical composition check of each steel given in the Table 1. Quenchant Polyethylene glycol \(H-(O-CH_2-CH_2)_n-OH\) [where \(n\) represent the average number of oxyethylene groups] was also procured to serve as the quenchant.

| 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  |

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

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

2.3 Heat Treatment/ Quenching and Step Tempering
The electrical furnace with maximum heating temperature of 1200\(^{\circ}\)C were heated at a certain predefined temperature and held at a period of 60 min (soaking period), where the homogeneous transformation phase takes place. The proportion of the polymer to water \[4\] used was 10% and
30% ratio of 1:9 and 3:7. The heated treated specimens were quenched in a polymer solution for the hardening and step tempering is carried out. Table 2 shows the temperature and soaking time of the steels.

Table 2. Temperature and soaking time of steels

| Process   | Temp °C | Soaking time |
|-----------|---------|--------------|
| Hardening | 855     | 60 Min       |
| Tempering I | 575     | 60 Min       |
| Tempering II | 220     | 60 Min       |

2.4 Mechanical Tests

A standard Brinell Hardness Tester was used for measurement of indentation hardness. The tests were conducted using a 10mm 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.

3. RESULTS AND DISCUSSIONS

Table 4 shows the mechanical properties of the as-received and heat treated steel samples with the varying polymer concentration. Figs. 1-4 are plots of variations of mechanical properties with polymer concentrations. Fig. 1 shows the variation of hardness for the EN steels of as-received and varying polymer concentration. It is observed that the maximum hardness value of 315 BHN is obtained in EN 25 for 30% polymer. 30% polymer quenching has the maximum impact on hardness followed by 10% as-received as the least defect. Fig. 2 depicts the defect of varying the quenchant on the UTS of EN steels. It is observed again that the highest UTS value is obtained in 30% polymer for EN 25 steel (1240 Mpa) which is more than the as-received and 10% polymer quenched sample. Figure 3 depicts the change of impact energy of the four EN steels. It is evident that step tempering after quenching improves the toughness of steels, also while elongation is reduced by maximum 20% only.

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

| EN Series | Sample quenching medium | Tempering Temperature (°C) | BHN | Tensile strength (MPa) | Impact Energy, J | % El |
|-----------|--------------------------|-----------------------------|-----|------------------------|------------------|------|
| EN 18     | As-received              | 188                         | 580 | 42                     | 32               |
| EN 18     | 10% Polymer 575,220      | 232                         | 1020| 60                     | 26               |
| EN 18     | 30% Polymer 575,220      | 272                         | 1050| 78                     | 27               |
| EN 19     | As-received              | 252                         | 900 | 56                     | 31               |
| EN 19     | 10% Polymer 575,220      | 276                         | 1102| 71                     | 25               |
| EN 19     | 30% Polymer 575,220      | 282                         | 1135| 88                     | 26               |
| EN 24     | As-received              | 265                         | 920 | 55                     | 29               |
| EN 24     | 10% Polymer 575,220      | 267                         | 1025| 82                     | 24               |
| EN 24     | 30% Polymer 575,220      | 270                         | 1198| 100                    | 25               |
| EN 25     | As-received              | 280                         | 1020| 45                     | 26               |
| EN 25     | 10% Polymer 575,220      | 295                         | 1210| 102                    | 27               |
| EN 25     | 30% Polymer 575,220      | 315                         | 1240| 112                    | 28               |
3.1 Effects of variations of Mechanical Properties with varying Polymer concentrations.

Figure 1: Variation of BHN of EN steels with the different proportion of polymer

Figure 2: Variation of UTS of EN steels with the different proportion of polymer
3.2 Effects of Polymer Quenching on the Microstructure of Medium Carbon Low Alloy Forged Steels

The microstructural investigation of samples quenched in 10% and 30% polymer solution were performed using a Carl Zeiss optical microscope. In sequence, the steps include sectioning, mounting, coarse grinding, fine grinding, polishing, etching and 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 1000µm - 1500µm. The samples were etched with nitric solution, 100 ml ethanol and 1-10 ml nitric acid for about 10 – 20 seconds before observation in the optical microscope. Figs. 5-12 are the photomicrographs of EN18 and EN19, EN 24 and EN 25 respectively.
Figure 5: Microstructure of EN18 steel quenched in 10% Polymer solution.

Figure 6: Microstructure of EN18 steel quenched in 30% Polymer solution

Figure 7: Microstructure of EN19 steel quenched in 10% Polymer solution
Figure 8: Microstructure of EN19 steel quenched in 30% Polymer solution.

Figure 9: Microstructure of EN24 steel quenched in 10% Polymer solution.

Figure 10: Microstructure of EN24 steel quenched in 30% Polymer solution.

Figure 11: Microstructure of EN25 steel quenched in 10% Polymer solution.
Observation: 10% and 30% polymer quenched samples result with fine tempered martensite structure with small amount of ferrite due to steels are subjected to step tempering process. Thus polymer quenching would improve ductility, toughness and impact strength values.

4. CONCLUSION
1. It has been investigated that polymer can also be used as quenching medium for MCLA steels.
2. The study has shown that using of polymer as quenchants improves the mechanical properties when compared to the as received samples.
3. The mechanical properties increases with increase in polymer concentration, 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.

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