The effect of polymeric quenching media on mechanical properties of medium carbon steel

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Abstract. Water and oil are the most commonly used as quenching media in heat treatment processes to harden steel alloy. However, because of the water quenched steel requires to extra treatment (tempering) to yield the preferred properties, and with arising the environmental, disposal, safety and toxicological concerns, there are increased interests in the potential use of alternative quenching technologies. One of the most commonly considered alternatives to quench water or oils are polymer solutions. In this work, a polymer solution of Polyvinyl pyrrolidone (PVP) with different concentrations (15, 20 and 25%) in water was used to quenching samples of medium carbon steel alloy. Also, three bath temperatures (40, 50 and 60°C) were utilized for this investigation. The mechanical properties (tensile, hardness and toughness) in addition to microstructure examination were evaluated for quenched samples and compared to those of water quenched samples. The results show that the best combination of properties can be achieve with 20% PVP quenched samples at 40°C. This treatment (20% PVP at 40°C) can be used instead of water quenching and tempering treatment for medium carbon steel samples and consequently reduce the overall cost of heat treatment process.

Keywords: polymer quenching media; PVP quenching media; mechanical properties; medium carbon steel

1. Introduction

Medium carbon steel often the most commonly used in almost component of structures in different industries, due to their cheap, simple fabrication and easy forming [1]. However, it always does not meet the requirements for many industrial applications where high mechanical properties are desired. Therefore, several techniques of heat treatment were used to extend its scope of applications [2]. Quenching treatment are usually used for improving the properties of steel alloys, especially for medium carbon steel. The sound quenching process can be achieved by choosing the proper quenchants [3]. The proper quenching media must be minimizing the formation of residual stresses during the phase transformation. Water and oil are conventionally the most commonly used quenching media in the heat treatment processes because they are readily quenchable [4]. However, although the using water as quenchant lead to formation the hard martensite structure, but it still need to extra treatment (tempering) to yield the preferred properties that means additional operation and production cost. In addition to, it may be lead to distortion and cracking the quenched component [5]. On other hand, the using oil as quenchant can lead to provide insufficient cooling rates and consequently obtain
undesired mechanical properties [6]. Considering the limitations of water and oil there are increasing interests in using the polymeric solutions as quenchant in industry instead of conventional quenchants. There are many polymeric solutions that are used as quenchant like polyvinyl Alcohol, polyacrylates, polyalkylene Glycol (PAG), and polyvinyl pyrrolidone (PVP). Many papers about the using of the polymeric solutions as quenchant in heat treatments were published [7-11]. However, there are still little work has been done for evaluation the effect of bath temperature on properties and behavior of polymer quenched components. In current investigation, the polyvinyl pyrrolidone (PVP) was used as polymer quenchant. Three concentrations (15, 20 and 25) % of PVP with three bath temperatures (40, 50 and 60°C) were used to quenching the medium carbon steel samples. The properties of tensile, hardness, impact strength and microstructure of quenched samples were investigated. The experimental results of polymer quenched samples were compared with traditional quenching samples in water with tempering. the optimal conditions of heat treatment that obtain the best combination of studied properties of quenched samples was determined.

2. Materials and Experimental Procedure
A medium carbon steel (CK45) was used in current work. The martensite start temperature and TTT diagram were measured by using of MUCG-73 program [14] to select a temperature range of quenching as shown in figure 1. The mechanical tests used were tensile, impact and hardness. Microstructural observation was done in this research with (40x) of magnification. A water-soluble polymer of Polyvinylpyrrolidone (PVP) with three percentages is utilized as a quenching media at three bath temperatures. The conditions of this study are illustrated in table 1.

![Figure 1. Time-Temperature-Transformation of material used in this research](image-url)
Table 1. Classification of all samples.

| Sample code | Heating temperature | Bath temperature | Condition |
|-------------|---------------------|------------------|-----------|
| A           | ---                 | ---              | As received |
| B           | ---                 | Room temperature | Water Quenching |
| BB          | ---                 | Room temperature | Water Quenching + Tempering at 550°C |
| C1          | 840° C for 15 min.  | 40°C             | (15% PVP) in water |
| C2          | 50°C                | 60°C             |           |
| C3          | 60°C                |                  |           |
| D1          | 40°C                | 50°C             | (20% PVP) in water |
| D2          | 50°C                | 60°C             |           |
| D3          | 60°C                |                  |           |
| E1          | 40°C                | 50°C             | (25% PVP) in water |
| E2          | 50°C                | 60°C             |           |
| E3          | 60°C                |                  |           |

3. Results and Discussions
Hardness and impact results for all conditions are given in table 2. In general, hardness value is decreased in polymer quenched as compared with water quenched, while 20%PVP sample at 40°C gave the highest hardness value. It can be noted that whenever polymer percentage is increased in water, the hardness is dropped. Hardness of polymer quenched is improved as compared with condition of water quenching with tempering. Impact results have confirmed these drops in hardness, since; 25%PVP has the highest values. Polymer quenching media provides more ductility than conventional quenching which brittleness is formed, similar approach discussed in [7,15].

Table 2. Hardness and Impact results

| Sample code | A   | B   | BB  | C1  | C2  | C3  | D1  | D2  | D3  | E1  | E2  | E3  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Hardness (HV) | 209 | 530 | 221 | 366 | 370 | 368 | 397 | 353 | 359 | 310 | 317 | 344 |
| Impact Strength (J) | 29  | 31  | 27  | 36.5| 38.5| 37  | 36  | 41  | 37.5| 41  | 39.5| 39.5|

Figure 2. Tensile strength of 15%PVP at three bath temperatures
Tensile strength for all conditions is illustrated in figures 2, 3 and 4. It has the same behavior in hardness and impact, since, tensile strength of polymer quenched is lower than water quenched in general but higher than water quenched with tempering. Also, the elongation which represents ductility is increased when polymer in water is increased but it stills higher than water quenched, and water quenched with tempering.

Figure 3. Tensile strength of 20%PVP at three bath temperatures

These results are leading that using of PVP in water as a quenching media is better than using of water only and with tempering. These enhancing in strength as increasing of bath temperatures are concerned with ref. [6, 7].

Figure 4. Tensile strength of 25%PVP at three bath temperatures

Figure 5 (a – l) illustrates the microstructure that carried out in this investigation. As received sample is revealed the pearlite (dark) in ferrite (white) matrix which has characterized the low strength and high ductility [3, 15], this is confirmed in tensile strength and hardness. When the steel quenched rapidly, martensite (dark) is formed with retained austenite (white) [3, 15], this is appeared in fig. 7b. Martensite, bainite and retained austenite are formed for all bath temperatures and PVP percentages but with various ratios and softness of martensite, this is due to that PVP has lower H-value than water [16, 17].
4. Conclusions
It can be concluded from the experimental obtaining that the quenching treatment at 20 % PVP with bath temperature of 40°C for medium carbon steel samples yields the best combination of mechanical properties (hardness, toughness, tensile strength and elongation). The overall results of quenched samples in this solution exhibit higher mechanical properties as compared with those samples which quenching in water and tempered. Therefore, it can be used this treatment to enhance the properties of medium carbon steel instead of quenching in water and tempering and consequently reduces the time and cost of hardening treatment.

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