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Application of Polymeric Quenchants in Heat Treatment of Steels

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Abstract

Aqueous polymer quenchants are being used increasingly in steel heat treatment industries as a substitution for conventional quenchants. By adjusting the quench parameters of the polymeric media, it is possible to achieve desirable microstructure and mechanical properties in addition to reduction in distortion and cracking. In this work, Polyalkylene Glycol (PAG) aqueous solution was used as the quenching medium in the heat treatment of four grades of steels produced by Iran Alloy Steel Company including 1.7227, 1.6582, 1.1191 and 1.7765. In addition, the resultant mechanical properties of this procedure were compared with the properties of the specimens quenched in the conventional quenchants. The results showed that using polymer-based quenchants, the distortion and cracking can be minimized compared to water quenching. On the other hand, the mechanical properties which are not achievable by oil quenching can be obtained using polymeric quench medium.

Keywords: Steel, Heat Treatment, Quenching, Polymeric Solutions

1- Introduction

Success or failure of a quenching process is determined by selecting appropriate quenchants. However, there are many quenchants that are capable of providing a wide range of cooling rates. The suitable quenching medium must have enough quench severity to prevent diffusional phase transformations. Nevertheless, it should have lower cooling rates at lower temperatures to minimize the internal stresses occuring during martensitic phase transformations.

Water and oil are two conventional quenchants that have the most applications in heat treatment industries. While water quenching can result in the formation of hard martensitic microsturcture and subsequently provide high strength and toughness after tempering, it might also lead to some problems like distortion and cracking. On the other side, oil quenching does not involve these problems, but cannot provide suitable cooling rates to harden the part and to achieve acceptable mechanical properties, especially in large cross sections. Considering the disadvantages of water and oil quenching in steel heat treatment, and the need for a suitable quenchant to provide enough severity for hardening and in order to prevent distortion and cracking, polymeric solutions were introduced as the substitutions for conventional quenchants[1)]. There are several commercial polymer quenchants that are readily accepted and used today such as Polyvinyl Alcohol, Polyvinylpyrrolidone, Polyacrylates, and Polyalkylene Glycol (PAG), among which PAGs are the most common[2)].

High molecular weight PAG is completely soluble in water at room temperature and therefore has been used extensively in the quenching of hot metal. PAG also exhibits a unique property in which it has inverse solubility as temperature increases in the water[3)].

Three different stages of heat removal, when quenching in vaporizable liquids, are film boiling or vapor blanket cooling, nucleate boiling and convective cooling (Fig. 1). In film boiling, surface temperatures are sufficiently high to produce a stable vapor film around the part. Cooling rates during film boiling are characteristically low due to the slow heat transfer through the vapor barrier. The transition temperature from vapor blanket cooling to nucleate boiling is called the Leidenfrost temperature. As the surface temperature decreases, the vapor film collapses and nucleate boiling begins. During nucleate boiling, the liquid contacts the hot surface and evaporates, producing vapor bubbles. Nucleate boiling produces strong convective currents resulting in high heat transfer rates. When the surface temperature cools below the boiling point of the liquid, the surface is permanently wetted by the fluid

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resulting in convective cooling. Convective cooling rates are relatively low and are primarily a function of the viscosity of the fluid[4].

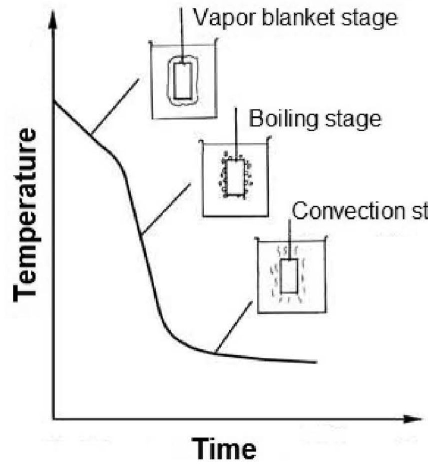

Fig. 1. Three stages of cooling during quenching process.

For water and oil quenching processes illustrated in Figs. 2 (a) and (b), all three cooling mechanisms may coexist on the cooling surface simultaneously[5-7]. This strongly affects the wetting processes; and surface heat transfer occurring during quenching and the resulting thermal gradients that can form contribute to an undesirable nonuniform quenching process.

Aqueous polymer quenchants mediate heat transfer by the formation of a film around the hot metal surface (Fig. 2(c)), which provides uniform heat transfer relative to the moving vapor front observable for oil and water[5-7]. Upon initial immersion, the polymer film encapsulates the vapor formed around the hot metal. At approximately the Leidenfrost temperature, the vapor blanket explosively ruptures, resulting in a pseudo-nucleate boiling process. The thickness of this insulating film is dependent on the concentration of the polymer quenchant[8], as well as the quenchant fluid temperature. Typically, quench severity decreases with increasing polymer quenchant concentration (increased film thickness), increasing quenchant temperature and decreasing flow rate[4].

The PAG aqueous polymer was employed as the quenching medium in this study and some of the most important grades of the steels produced by Iran Alloy Steel Company were heat treated using this quenchant. Furthermore, similar specimens were also heat treated using water and oil quenchants and the resultant mechanical properties were compared with the results obtained from polymer quenching.

2- Materials and Experiments

In order to study the efficiency of the various quenchants, the heat treatment process of four grades of the most important and sensitive products of Iran Alloy Steel Company including 1.7227, 1.6582, 1.1191, and 1.7765 steels was investigated.

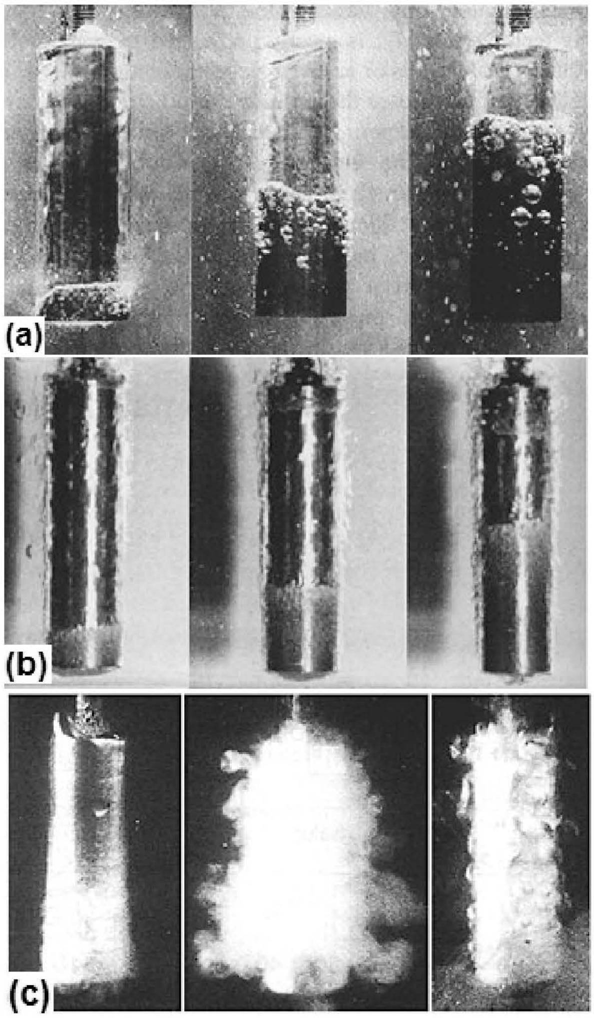

Fig. 2. Wetting process of a cylindrical probe quenched in (a) water, (b) oil, and (c) 10% polymer solution[4].

The chemical composition of the steels studied in this work is shown in Table 1. Furthermore, the size, austenitizing, and tempering conditions used for heat treatment of the specimens are presented in Table 2. The length of the cylindrical specimens was designed to be up to 200 mm so that the heat transfer which occurs at the bases of the blocks can be ignored. A uniform heating condition was applied to austenitize the specimens and three different liquids including water, oil, and polymeric solution were considered as the quenching media. To prepare the polymeric solution, a PAG type polymer with the commercial name "AVA Aqua Quench" was used. The ratio of the polymer to water was considered to be 1:8. Moreover, the concentration of the bath was constantly controlled and adjusted using a calibrated refractometer to provide a uniform condition during the experiments. After quenching, the lateral surface of the specimens was ground and hardness tests were carried out on the surface points located in the middle of the specimens. Afterwards, all specimens with similar chemical composition, quenched in different media, were tempered using a similar procedure. After tempering, the lateral surface of the specimens was slightly ground and hardness tests conducted in at the middle of the blocks. Then, the tensile and impact specimens were produced from the heat treated specimens and the relevant tests were conducted on them.

3- Results and Discussion

Fig. 3 illustrates the resulting mechanical properties including as-quenched hardness, as-tempered hardness, yield strength, ultimate tensile strength, elongation, and impact strength for different steel grades quenched in various media.

In 1.7227 steel, while the resulting as-quenched hardness after quenching in water and polymeric solution are similar, the as-quenched hardness achieved by oil quenching is significantly lower. After tempering, the difference between the specimens quenched in different media decreases. However, the as-tempered hardness of the water-quenched and PAG-quenched specimens is still higher in comparison to the oil-quenched specimens. Similarly, the yield strength and ultimate tensile strength of the water-quenched and PAG-quenched specimens are comparable and higher than oil-quenched specimens. The elongation and impact strength were similar in all specimens. It should be noted that while circular cracks were observed at the bases of the specimens quenched in water, no crack was detected in the specimens quenched in oil and polymeric solution.

As can be seen, the as-quenched hardness decreases in 1.6582 specimens as the quench severity decreases from water to polymeric solution and oil. There is not a big difference between the as-quenched hardness of the specimens quenched in water and PAG solution. Since the hardenability of the 1.6582 steel is higher than 1.7227 steel, a smaller difference was observed in 1.6582 specimens quenched in oil compared to those quenched in water and PAG solution. However, owing to the presence of alloying elements and subsequently high hardenability of this steel, the as-tempered hardness and the other mechanical properties obtained by quenching in various media are comparable.

Since the 1.1191 steel is a plain-carbon, low-hardenable grade, the difference between the hardness values of the specimens quenched in different media is considerable. It is obvious that as the quench severity decreases from water to PAG solution and oil, the as-quenched hardness decreases significantly. After tempering, the difference between the hardness of the water-quenched and the PAG-quenched specimens decreases, but the hardness of the oil-quenched specimens is still considerably lower than the others. This is due to the fact that oil does not have enough severity to provide sufficient cooling rates for the formation of martensitic microstructure and hardening 1.1191 steel. This trend is also obvious in the case of yield strength and ultimate tensile stress so that the yield stress and ultimate tensile stress of the specimens quenched in water and polymeric solution are high and comparable but the resulting strength in the oil-quenched specimens is low. Other investigated mechanical properties including elongation and impact strength were similar in all specimens.

As-quenched hardness of the 1.7765 specimens also decreases with a decrease in the quench severity from water to polymeric solution and oil. Due to high contents of alloying elements, this steel has an excellent hardenability, and martensitic transformation can occur even in slow cooling rates. Therefore, the as-quenched hardness in all specimens made of this steel is high. Since all specimens quenched in different media hardened completely, the mechanical properties of all specimens were similar after tempering.

Table 1. Chemical composition of steels studied in this work

Grade	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo	%Al
1.7227	0.43	0.74	0.26	0.011	0.034	1.11	0.077	0.17	0.024
1.6582	0.353	0.62	0.274	0.0076	0.0078	1.49	1.51	0.1644	0.0335
1.1191	0.451	0.613	0.227	0.023	0.0199	0.21	0.224	0.0515	0.0168
1.7765	0.325	0.563	0.313	0.0083	0.0085	2.98	0.094	0.965	0.052

Table 2. Size and heat treating parameters applied to the specimens

Steel Grade	**1.7227**	**1.6582**	**1.1191**	**1.7765**
Diameter (mm)	63	65	60	38
Austenitizing Temperature (˚C)	850	845	845	910
Austenitizing Time (hr)	1	1	1	1
Tempering Temperature (˚C)	620	610	570	680
Tempering Time (hr)	3.5	2.5	2.5	2.5

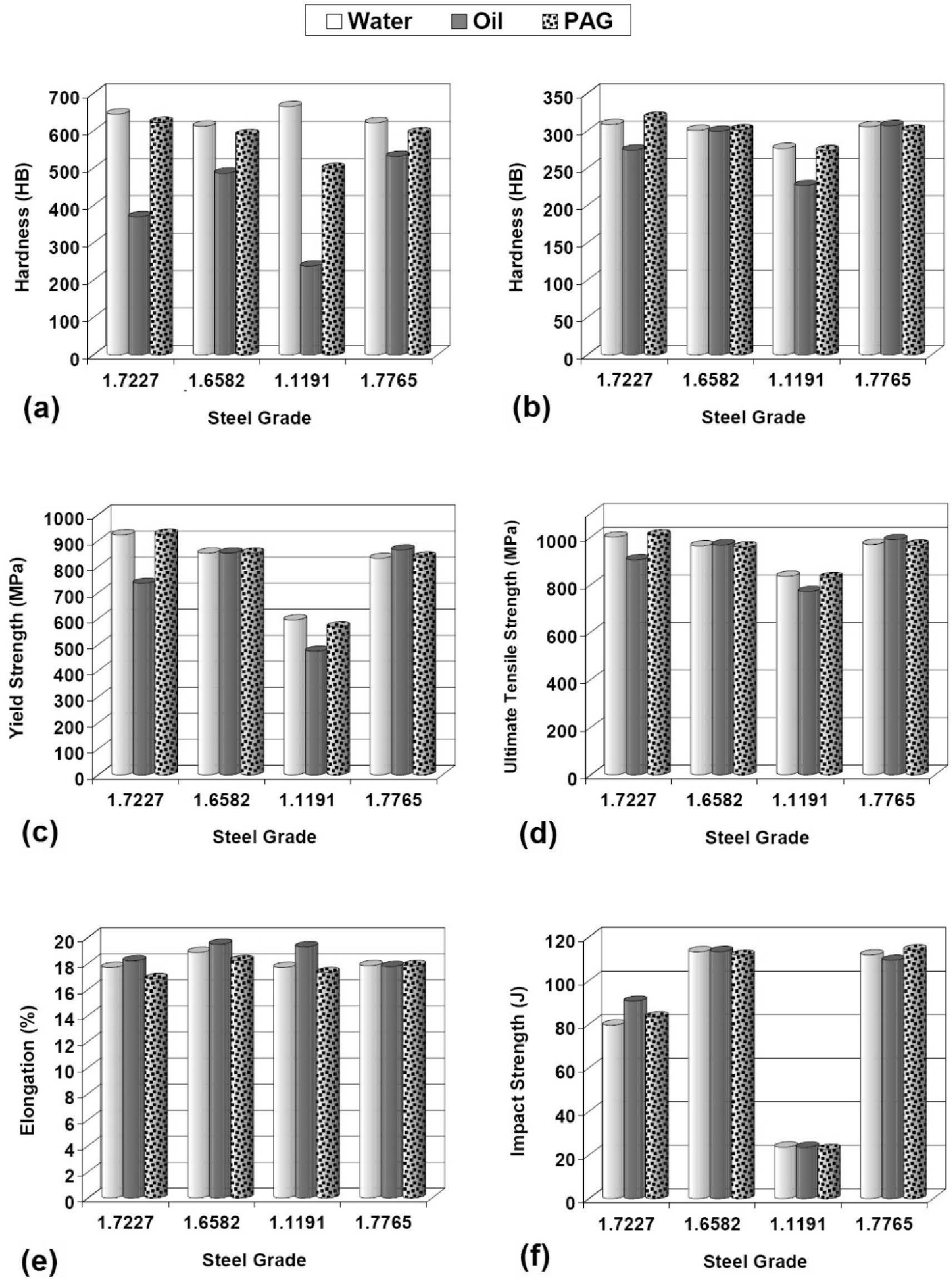

Fig. 3. The resulting mechanical properties in 1.7227, 1.6582, 1.1191, and 1.7765 steels by quenching in water, oil and PAG solution; (a) as-quenched hardness, (b) as-tempered hardness, (c) yield strength, (d) ultimate tensile strength, (e) elongation, and (f) impact strength.

4- Conclusion

This study showed that the use of PAG solution, with respect to its unique cooling mechanism, permits the heat treatment of a wide variety of steel hardenabilities and cross-section sizes with significantly improved mechanical properties and uniformity.

In the case of low hardenable steels, e.g. 1.1191, or in the parts with large cross-sections that oil-quenching cannot provide the sufficient cooling rates to harden the parts and meet the required properties, using PAG solution can result in desired mechanical properties

as well as reduction in distortion and crack probability.
In the medium hardenable steels, e.g. 1.7227, quenching in polymeric solution resulted in enhanced mechanical properties compared to oil quenching and, on the other hand, eliminated the quench cracking compared to water quenching.
In the case of high hardenable steels, e.g. 1.6582 and 1.7765, which are commonly quenched in oil, the results showed that the usage of polymeric solutions instead of oil can improve the resultant mechanical properties, especially in large cross-sections.
Aqueous polymer quenchants are recognized as more fire-resistant, biodegradable alternatives to oil in the steel heat treatment industry. It has been shown that in properly designed quenching systems, it is possible to achieve distortion and cracking reduction and enhanced mechanical properties that are significantly superior to conventional quenchants.

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