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Short Communication

Effects of Heat Treatment on Mechanical Properties and Corrosion Performance of 12MnNiVR Oil Tank Steel

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Two different heat treatments were conducted on 12MnNiVR steel, and the mechanical properties and corrosion performance were investigated. The results showed that, after quenching and tempering the 12MnNiVR steel showed much better mechanical properties and corrosion resistance compared with the quenched one. The hardness, tensile strength and the lower yield strength of the quenched and tempered 12MnNiVR steel were lower than those of the quenched one. However, the R_{el}/R_m was in an ideal range and the elongation also increased significantly after quenching and tempering. The corrosion rate of the 12MnNiVR steel came down nearly by half after quenching and tempering, which was probably attributed to the denser corrosion scale formed on the substrate.

Keywords: 12MnNiVR steel; Mechanical properties; Corrosion; Heat treatment

1. INTRODUCTION

The oil tank is the one of the basic equipment in the oil storage and transportations. Obviously, the larger volume of the oil tank can have the higher cost efficiency for the same amount of the oil [1]. Therefore, the development direction of the oil tank is toward large. However, with the oil tank becoming larger and larger, the mechanical properties of the steel used in the oil tank have to be much better. Changing the heat treatment is one of important methods to improve the mechanical properties of the steel. Therefore, the effect of heat treatment on the mechanical properties of 12MnNiVR oil tank steel was investigated in this work.

On the other hand, the corrosion property is also of vital importance to the life of the oil tank. In the corrosion of oil tanks, there are mainly two kinds of corrosion; the inner corrosion and the external corrosion [2]. The external corrosion is usually the atmospheric corrosion, which is light. The inner corrosion is much more severe than the external corrosion. Generally, the designed serving life of an oil tank is usually 20 to 30 years. However, much severe corrosion is often observed in a few years [3]. With the development of the oil industry, the oil tank construction is developing very quickly. During the construction of the oil tanks, the preloading filling test is an essential working procedure [4-7]. The fresh water is usually used as the medium during the preloading test. However, the preloading test of the oil tank often costs a large amount of water because of the large volume of the tank. This costs much and also wastes water. Therefore, the seawater becomes an important medium in the preloading test of the oil tank which is constructed in the coastal areas. This is much more economical and environmental friendly [8, 9]. However, the seawater is very corrosive as it contains a lot of corrosive ions, especially the chloride ion [10-13]. Moreover, there is some dissolved oxygen in the seawater, which can promote the oxygen reaction on the steel surface, and thus increasing the corrosion of the substrate [14-16]. During the preloading filling test, the oil tank is susceptible to inner corrosion. Once the corrosion occurs, the mechanical property and the lifetime of the tank will decline significantly. Therefore, the corrosion performance of the oil tank steel in the seawater environment must be studied before the preloading filling test with seawater.

In this work, we conducted two different heat treatments on 12MnNiVR steel, which is used in oil tank. Mechanical properties including hardness and tensile properties were measured, and the corrosion performance was investigated in the 3.5 wt% NaCl solution. The corrosion immersion tests were performed at room temperature and atmosphere. Oxygen can be free to enter the solution. The results showed that the quenched and tempered 12MnNiVR steel has much better mechanical properties and corrosion resistance than that of the quenched one.

2. MATERIALS AND METHODS

In this work, the 12MnNiVR steel used as oil tank steel was chosen as the experimental material. The main chemical composition of this steel was listed as follows in Table 1. In order to investigate the effect of heat treatment on the mechanical and corrosion performance of the 12MnNiVR steel, two different heat treatments were conducted in this work; one is quenching and the other is quenching and tempering.

Table 1. The chemical composition of 12MnNiVR steel, wt%

Element	C	Si	Mn	S	P	Cr	Mo	Ni	V	Fe
Measured result	0.14	0.31	1.43	0.003	0.012	0.04	0.21	0.25	0.039	Bal.

The mechanical properties of 12MnNiVR steel were investigated including the hardness and the tensile properties. The hardness test was conducted on the 10 mm * 10 mm * 3mm specimen. All tests details were according to the standard of CN-GB/T 2654-2008. The hardness was measured by using the DOHR-150c vickers hardness tester. The tensile properties were measured according to the standard of CN-GB/T 2651-2008. The specimen used in the tensile test was the plate specimen with the dimension of 120 mm * 18 mm * 3mm. The length direction of the tensile samples was the same with that of the rolling direction of the steel plate.

The corrosion rates were studied by the immersion tests combined with the weight loss method. The corrosion immersion tests were performed in a 5-L beaker. There were three parallel samples in each experiment. The two kinds of steels with different heat treatments were separated into two beakers so that to avoid the interaction effect between these two different steels. All immersion tests were conducted at room temperature and atmosphere. The solution used in the immersion tests was the 3.5 wt% NaCl solution. Before each test, the specimen was polished to 1200 grit surface. After that, the samples were cleaned with acetone, absolute ethyl alcohol and then dried with cold air to prevent the pre-oxidation in the air. Each sample was weighed by an analytical balance before immersed into the solution. After the immersion of 30 d, the samples were removed from the beakers, and rinsed with absolute ethyl alcohol quickly, so that to prevent the oxidation in the air. After that, the corrosion products on the samples were removed according to the standard of ASTM G1-03. The derusting solution used in this work was the 500 Ml hydrochloric acid and 3.5 g hexamethylene tetramine reagent water to make 1000 mL. The derusting period was 10 min. Long time may be required in some certain instances. The samples after removed the corrosion products were reweighed to get the weight loss in the immersion tests. The corrosion rate was obtained by the following equation:

$$V_{corr} = \frac{8.76 \times 10^7 \times (W_0 - W_1)}{St\rho} \quad (1)$$

where V_{corr} is the corrosion rate, mm/y; W_0 is the original weight of the sample, g; W_1 is the final weight of the sample, g; S is the total exposed surface area, cm^2; t is the corrosion period, h; ρ is the density of the steel, kg/m^3.

In order to investigate the corrosion performance of the 12MnNiVR steel, the polarization tests were performed in this work. The electrochemical tests were conducted using the traditional three-electrode system. The reference electrode was a saturated calomel electrode, which was connected to the cell via a Luggin capillary through a porous Vycor frit. The counter electrode was a platinum plate, which had an exposed surface of 20mm * 20 mm. The working electrode was made from the 12MnNiVR steel. Before tests, the working electrode was sealed by silica gel, so that the surface area of the working electrode was only 1 cm^2. After that, the working electrode was polished by silicon carbide sand paper to 1500 grit surface. The open circuit potential (OCP) was measured for 10 min prior each polarization test. For the polarization tests, the polarization scanning rate was 0.2 mV/s. All electrochemical tests were performed at room temperature and atmosphere.

3. RESULTS AND DISCUSSION

3.1 Mechanical properties

In the course of service, the oil tank steels are usually subjected to random loadings. Therefore, it is easy to cause the degradation of the mechanical properties of the steel. To prolong the service life of the oil tank, the steel must have a good mechanical properties. In this section, the 12MnNiVR steel used as oil tank steel was treated by two kinds of heat treatments including quenching and quenching and tempering. After that, the main mechanical properties, including hardness and tensile properties, were measured. All tests were repeated three times using three parallel specimens.

Figure 1 shows the hardness values of the 12MnNiVR steel with two different heat treatments. For quenched 12MnNiVR steel, the hardness was approximately 275 HV10 in average, which was higher than that of the quenched and tempered steel. That is, the 12MnNiVR steel got a slight hardness loss after quenching and tempering compared with the quenched one. However, the most important mechanical property for the 12MnNiVR steel is the tensile property. Table 2 gives the tensile properties of the 12MnNiVR steels with two kinds of heat treatment. As shown in Table 2, the average lower yield strength (R_{el}) of the quenched 12MnNiVR steel reached 626 MPa, which was nearly 50 MPa higher than that of the quenched and tempered one.

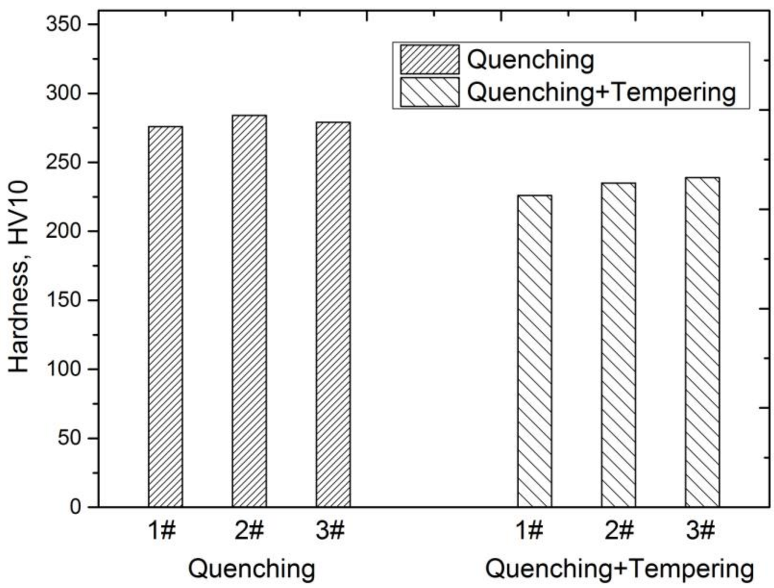


Figure 1. Hardness of the 12MnNiVR steel with two different heat treatments

Table 2. Tensile properties of 12MnNiVR steels with two different heat treatments

Heat treatment	No.	Lower yield strength R_{el}/MPa	Tnesile strength Rm/MPa	R_{el}/R_m	Elongation A_f/%
Quenching	1#	625	688	0.91	19.5
	2#	618	672	0.92	20.2
	3#	634	692	0.92	19.0
	Average	626	684	0.92	19.6
Quenching & Tempering	1#	576	652	0.88	24.3
	2#	558	640	0.87	25.0
	3#	584	671	0.87	24.0
	Average	573	654	0.87	24.4

The tensile strength (R_m) showed the similar change. However, the R_{el}/R_m of the quenched 12MnNiVR steel reaches 0.92. This was too high for the mechanical material. After quenching and tempering, the R_{el}/R_m fell into an ideal range, which was between 0.85 and 0.9. On the other hand, the elongation of the 12MnNiVR steel also showed a significant increase after quenching and tempering. This was good to the toughness of the steel. In summary, the quenched and tempered 12MnNiVR steel can provide the better comprehensive mechanical properties compared with the quenching one.

3.2 Corrosion resistance

The corrosion rate of the 12MnNiVR steel was obtained by the weight loss method after the immersion of 30 days. Figure 2 shows the comparison of the corrosion rates between the quenched and quenched and tempered 12MnNiVR steels. Obviously, all the corrosion rates of three parallel quenched 12MnNiVR samples were much higher than those of the quenched and tempered one. The corrosion rate of the quenched and tempered 12MnNiVR steel was approximately 0.16mm/y, which was nearly half of that of the quenched one. This indicates that the quenching and tempering can significantly improve the corrosion resistance of the 12MnNiVR steel.

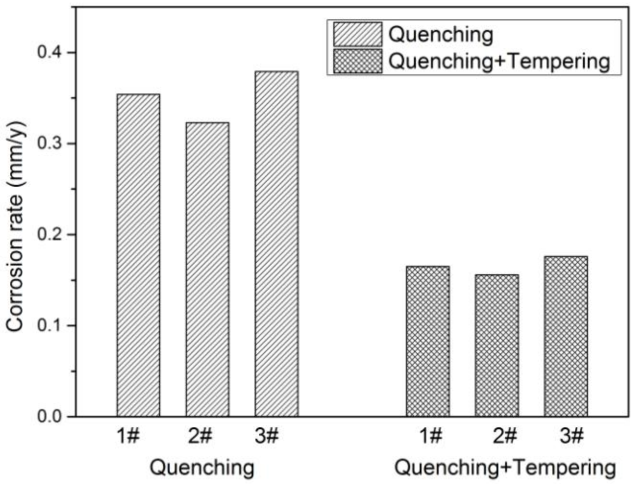
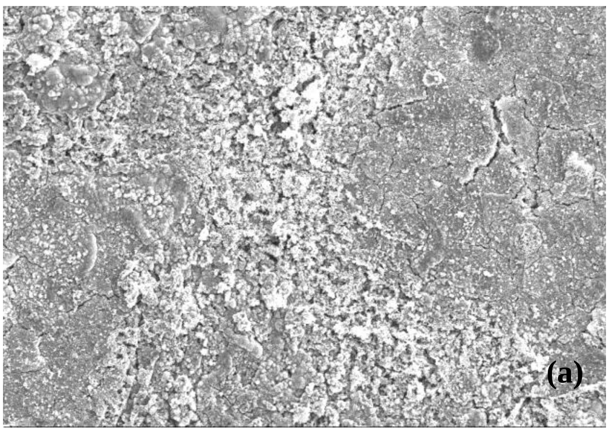


Figure 2. Corrosion rates of the 12MnNiVR steel with two different heat treatments



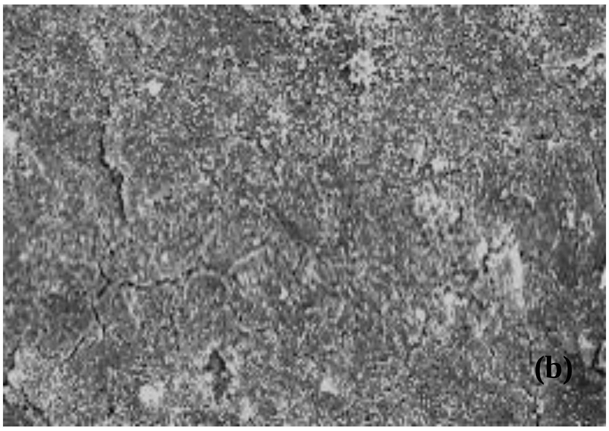


Figure 3. SEM images showing the corrosion scales that formed on the 12MnNiVR steel with two different heat treatments: (a) Quenching; (b) Quenching + Tempering

This was probably related to the difference of the corrosion scales that formed on these two steels with different heat treatments [17, 18]. Figure 3 shows the SEM images showing the corrosion scales that formed on the 12MnNiVR steel with two different heat treatments. Compared with Figure 3(a) and Figure 3(b), the corrosion scale that formed on the quenched and tempered 12MnNiVR steel was much denser than that formed on the quenched one. There were a lot of porous areas on the corrosion scale of the quenched steel as shown in Figure 3a. For the quenched and tempered one, the corrosion scale was continuous and dense with few cracks which were probably caused by the dehydration after the removal of the specimen from the solution. Therefore, the corrosion scale became much denser and more protective after quenching and tempering compared with that of the quenched one, and thus the corrosion rate was much lower than that of the quenched one [19, 20].

3.3 Polarization curves

To investigate the influence of heat treatment on the electrochemical corrosion behavior of the 12MnNiVR steel, the polarization tests were performed in this section. Figure 4 shows the comparison of the polarization curves between the quenched and quenched and tempered 12MnNiVR steels. As shown in Figure 4, the corrosion potential of the quenched steel was about – 0.75 V, while that of the quenched and tempered one was about – 0.7 V. That is, the corrosion potential of the 12MnNiVR steel moved to negative after quenching and tempering. On the other hand, the cathodic and anodic tafel slopes of the 12MnNiVR steel also changed significantly after quenching and tempering, especially the anodic tafel slope. The anodic tafel slope of the quenched and tempered 12MnNiVR steel was much higher than that of the quenched one, indicating that the quenched and tempered 12MnNiVR steel was much more stable than the quenched one. Moreover, the corrosion current of these two steels were obtained from the polarization curves, as listed in Table 3. Regarding the corrosion current of these two steels, the corrosion current density of the quenched steel was about 1.2×10^{-5} A/cm^2 while that of the quenched and tempered one was about 1.0×10^{-6} A/cm^2. It can be seen that the corrosion current density decreased by an order of magnitude after quenching and tempering. Therefore, the corrosion rate of the quenched and tempered 12MnNiVR steel was much lower than that of the quenched one. This is consistent with the result of the corrosion rates obtained in the immersion tests.

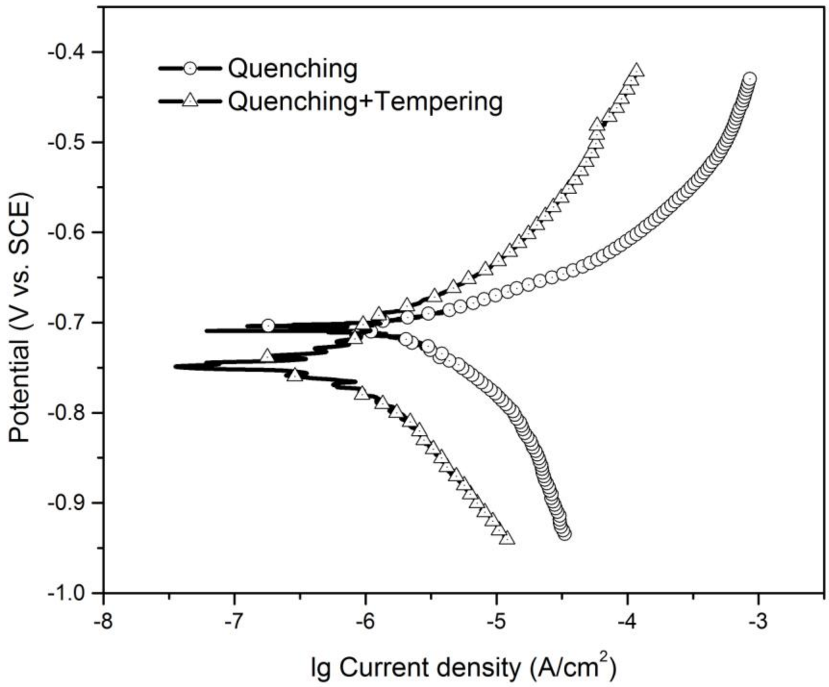


Figure 4. Polarization curves of the 12MnNiVR steel with two kinds of heat treatments in 3.5 wt% NaCl solution. The polarization scanning rate was 0.2 mV/s. All tests were performed at room temperature and atmosphere.

. **Table 3** Corrosion parameters of 12MnNiVR steels with two different heat treatments

Heat treatment	E_{corr} / (V vs. SCE)	I_{corr} / (A/cm^2)
Quenching	- 0.7	1.2×10^{-5}
Quenching & Tempering	- 0.75	1.0×10^{-6}

4. CONCLUSION

After quenching and tempering, the 12MnNiVR steel showed much better mechanical properties and corrosion resistance compared with the quenched one. The detailed conclusions showed as the followings:

(1) The hardness, tensile strength and the lower yield strength of the quenched and tempered 12MnNiVR steel were lower than those of the quenchd one. However, the R_{el}/R_m was in an ideal range and the elongation also increased significantly after quenching and tempering.

(2) The quenching and tempering can significantly improve the corrosion resistance of the 12MnNiVR steel. After quenching and tempering, the corrosion rate of the 12MnNiVR steel came down nearly by half. This is probably attributed to the denser corrosion scale that formed on the quenched and tempered 12MnNiVR steel compared with the quenched one.

(3) After quenching and tempering, the corrosion current density of the 12MnNiVR steel decreased by an order of magnitude. This is consistent with the corrosion rate results obtained by the weight loss method.

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