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Effects of tempering process on microstructure and mechanical properties of G18NiMoCr3-6

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Abstract. In this article the effects of tempering temperature and tempering time on microstructure and mechanical properties of G18NiMoCr3-6 cast steel were studied. The results show that: the microstructure of G18NiMoCr3-6 treated by different tempering processes is tempered sorbite. When tempering temperature is within 510°C ~630°C, the hardness and strength gradually decrease; the elongation and impact energy gradually increase with the increasing of the tempering temperature. The reason is that the tempering temperature increases the dislocation density decreases gradually, the martensite decomposes and the carbide precipitates, aggregates and grows. When G18NiMoCr3-6 is tempered at 600 °C for 60min~120min, the microstructure is tempered sorbite. With the prolongation of holding time, the mechanical properties of G18NiMoCr3-6 changed little.

1. Introduction

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G18NiMoCr3-6 is a kind of low carbon low alloy cast steel. It has the advantages of good hardenability, high strength and good toughness. It is used as steel castings with complex structure in engineering machinery. Different microstructure and mechanical properties can be obtained by adjusting the heat treatment process to meet the requirements of material performance under different working conditions. The application state of G18NiMoCr3-6 in structural parts is usually quenched and tempered. In this paper, the effects of different tempering temperature and tempering time on the microstructure and mechanical properties of G18NiMoCr3-6 cast steel were studied. The purpose is to find out the best heat treatment process for G18NiMoCr3-6 cast steel, in order to guide the actual production in the future.

2. Material and Experimental Procedures

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The object of study is 40mm thick G18NiMoCr3-6 cast steel plate. The chemical composition of the steel was analyzed by direct reading spectrometer. The results are shown in Table 1.

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Si	Mn	Р	S	Cr	Ni

0.009

0.65

0.70

 Table 1. Chemical composition of G18NiMoCr3-6 cast steel(wt%)

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Put G18NiMoCr3-6 cast steel plate in box type furnace for heating. The steel was pretreated at 900°C \times 60min for normalizing. The aim is to refine the grain and improve the microstructure of the steel castings, so as to prepare for the next quenching process. The pretreated samples were austenitizing at 880°C for 50min, and then quenched in 8%PAG quenching liquid.

Temperature is the main factor that determines the properties of materials. In the process of tempering G18NiMoCr3-6 cast steel, the effect of tempering temperature on material properties is first considered. In this paper, the first series of tempering processes are 510°C, 540°C, 570°C, 600°C and 630°C respectively, and the holding time is 60 min. According to the performance requirements of the parts, a suitable tempering temperature is selected for the next test. The tempering temperature of the second series test is 600°C, and the tempering holding time is 60 min, 90 min and 120 min respectively. The influence of different tempering holding time on the microstructure and properties of G18NiMoCr3-6 cast steel is further studied, which provides a basis for the reasonable selection of tempering process for G18NiMoCr3-6 cast steel [1].

The heat treated specimens were cut into $(10 \times 10 \times 20)$ mm metallographic specimens, $(55 \times 10 \times 10)$ mm impact specimens and tensile specimens with a standard distance of 50 mm by a wire cutting. 600kN universal testing machine was used for tensile test. PTM2200 pendulum impact testing machine was used to carry out impact test. The Brinell hardness was tested with a THBS-3000DB Brinell hardness testing instrument. The test result is the average of 3 experimental values. The microstructure was observed by DMI 5000M inverted metallographic microscope.

3. Results and discussion

3.1. Effect of tempering process on microstructure

Fig. 1(a) is G18NiMoCr3-6 quenched structure of cast steel at 880°C. Fig. 1 (b)~ Fig. 1 (f) is the microstructure at different tempering temperatures. It can be seen from Fig. 1(a) that the quenched microstructure is lath martensite. The low carbon content of lath martensite can cause "self-tempering". The distribution of carbides is uniform and this kind of martensite has higher toughness [2].

Martensite is an unstable metastable phase. During high-temperature tempering, quenched martensite gradually decomposes. At the same time, carbide precipitates aggregates and grows. From Fig. 1(b) ~ Fig. 1(f), it can be seen that the microstructure of tempered sorbite retains martensite orientation at 510°C. Because the tempering temperature is low, the recovery and recrystallization of the alloy are not enough. The supersaturated C in martensite is preferentially precipitated, and the martensite lath interface is unevenly distributed, and the microstructure maintains the original martensite lath morphology to a great extent. When the tempering temperature is at $540^{\circ}C$ ~ $630^{\circ}C$, martensite transforms into small tempered sorbite. The lath shape of martensite in the microstructure is no longer obvious, but more or less retained the lath marks. The tempering temperature rises continuously, and the carbide continues to precipitate evenly distributed on the ferrite matrix [3].

Fig. 2 is the microstructure after tempering at 600°C for different holding time. They are all compact tempered sorbite. There was no significant difference in the prolonging of tempering time under the metallographic microscope. In this condition, the ferrite has few carbon supersaturations. carbide is also stable carbide and at room temperature it is a balanced microstructure.

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Figure 1. Microstructure of G18NiMoCr3-6 with different heat treatment. (a) as-quenched at 880°C;(b) tempered at 510°C;(c) tempered at 540°C; (d) tempered at 570°C;(e) tempered at 600°C;(f) tempered at 630°C



Figure 2. Microstructure of G18NiMoCr3-6 with different tempering time. (a) 60min;(b) 90min;(c) 120min

3.2. Effect of tempering process on mechanical properties

Fig. 3 is a curve describing the variation of mechanical properties of G18NiMoCr3-6 cast steel with tempering temperature and tempering time. It can be seen that the yield strength, tensile strength and hardness of G18NiMoCr3-6 decrease gradually with the increase of tempering temperature. The elongation and impact energy increased gradually, indicating that the plasticity and toughness of the material increased.

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This is due to the thermodynamically unstable state of quenched martensite. During tempering, dislocations have enough thermal activation to migrate gradually. Carbon atoms precipitate from a-Fe in the form of cementite, and the solid solution strengthening effect of carbon atoms is weakened. When tempering at 510°C, the structure of martensite is retained to a great extent. Hindering dislocation movement, the material has higher strength and hardness. With the increase of tempering temperature, the dislocation density decreases gradually, the carbide precipitates ceaselessly, the alpha phase recovers and the martensite tempers fully gradually. After tempering at 600°C, the elongation at break of steel reaches the requirement of performance (elongation after failure is equal to 12%). It is due to the gradual disappearance of the malposition and the weakening effect of dislocation. When tempered at 630°C, the eliminated. The recovery and recrystallization of the alpha phase softens the matrix. Meanwhile, the carbon and alloy elements are continuously desolved, the content of interstitial solid solution atom C decreases, and the cementite gradually aggregates and grows, which leads to the strength and strength of the material. Hardness decreases, plasticity and toughness increase [4,5,6].



Figure 3. Effect of tempering process on mechanical properties of the G18NiMoCr3-6.

With the increase of tempering time, the yield strength, tensile strength and hardness gradually decrease, while the elongation and impact energy after fracture decrease, but the change is not significant. This is because the diffusion of carbon atoms is active in the high tempering stage. After the start of heat preservation, the carbide continuously precipitates. More fine dispersed carbide will be precipitated by prolonging the tempering time. The martensite recovered fully and continued to heat preservation, and the dislocation density decreased little. Therefore, the mechanical properties of materials change little. At 600°C 60min~120min, the residual stress is basically eliminated. The strength, plasticity and toughness of cast steel are properly matched and have good comprehensive mechanical properties. In contrast, tempering time has little effect on the properties of G18NiMoCr3-6 cast steel [1,7,8].

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4. Conclusion

In this paper, the effects of tempering process on microstructure and mechanical properties of G18NiMoCr3-6 were investigated. The following conclusions can be drawn.

(1) Tempering at 510° C~ 630° C, the morphology of the matrix and precipitates is slightly different, but all of them are tempered Soxhlet. There was no significant difference in microstructure between 60min~120min at 600° C.

(2) With the increase of tempering temperature, the hardness and strength of G18NiMoCr3-6 decrease gradually, and the elongation and impact energy increase gradually after fracture. When tempering at 600 $^{\circ}$ C, the comprehensive mechanical properties of steel can meet the technical requirements.

(3) The hardness and strength of G18NiMoCr3-6 decrease with the increase of tempering time. Elongation and impact energy increased after breaking. Tempering time has little effect on the mechanical properties of G18NiMoCr3-6. The material has good comprehensive mechanical properties at $60\min\sim120\min$ under 600 °C.

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