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Effects of tempering process on microstructure and mechanical properties of ZG30Mn

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Abstract. Through microstructure analysis, hardness testing, tensile and impact tests, the effects of tempering process on the microstructure and mechanical properties of ZG30Mn were studied. The results show that the microstructure of ZG30Mn treated by different tempering processes is tempered sorbite. When the holding time is 60 min, with the increasing of the tempering temperature, the hardness and strength gradually decrease, and the elongation and impact energy gradually increase. When the tempering temperature is 600 °C, the hardness and strength of ZG30Mn gradually decrease with the prolongation of holding time, while the elongation and impact energy increase first and then decrease. According to the analysis, as the tempering temperature increases, the recovery and recrystallization of α-phase occurs and dispersed fine cementite gradually grows and spheroidizes, resulting in a decrease in hardness and strength, and an increase in elongation and impact energy. With the prolongation of holding time, the aggregation growth of alloy cementite results in the decrease of the elongation and the impact energy.

1. Introduction

ZG30Mn is a medium carbon manganese low alloy cast steel material, which is often used as large cast steel structural parts such as wheels, gears and wheels for excavators, cranes and mining machinery. The heat treatment process of ZG30Mn used in large cast steel structural parts is usually quenching and tempering process, which the steel castings can obtain excellent comprehensive mechanical properties [1, 2]. The quenching and tempering process includes quenching and high temperature tempering, high temperature tempering can eliminate the quenching stress, obtain the ideal microstructure, so that the strength, plasticity and toughness of the steel castings are optimally matched. The tempering temperature and tempering time are the most important parameters of high temperature tempering process. Reasonable choice of tempering temperature and tempering time can make ZG30Mn obtain the best comprehensive mechanical properties. Therefore, in the investigation, the effect of the tempering process on microstructure and mechanical properties of ZG30Mn was examnined to provide data support for the formulation of heat treatment process in actual production.

2. Experimental materials and methods

The ZG30Mn test rod with a diameter of 50mm was prepared by melting in an electrical resistance under the protection of a mixed gas atmosphere of SF_6 (1 vol.%) and CO_2 (99%). The chemical composition of the test cast steel is shown in Table 1.

Table 1. Chemical composition of the tested cast steel(wt%)

C	Si	Mn	P	S	Cr	Ni	Mo
0.31	0.32	1.45	0.010	0.009	0.38	0.20	0.16

The heat treatment test was carried out in a N41/H/P300 electric heating box furnace. The ZG30Mn test rod was first normalized at 880 °C × 90 min for the purpose of refining the crystal grains. The test sample was taken from the normalized ZG30Mn test rod and cut by a molybdenum wire electric discharge wire cutter. The surface of the sample is pre-coated with an anti-oxidation decarburization coating before heat treatment to prevent oxidative decarburization on the surface of the sample during heat treatment.

In this paper, two series of tempering process tests were designed. The samples were first austenitized at 880 °C for 30 min, and quenched in 8% PAG quenching liquid. A series of tempering process is to study the effect of tempering temperature on the mechanical properties of the test cast steel. The specimen was tempered at 560 °C, 580 °C, 600 °C, 620 °C, 640 °C, respectively, and the tempering time is 60min; Another series of tempering process is to study the influence of tempering time on mechanical properties of the test cast steel. The specimen was tempered at 600 °C, and the tempering time is 30min, 60min, 90min, 120min, respectively. In order to avoid the second type of temper brittleness of the alloy structural steel, the tempering specimen was rapidly cooled in the 8% PAG quenching liquid after being heated.

The 600DX-C4A-G7F universal testing machine was used to test the yield strength, tensile strength and elongation. The impact toughness was tested with a PTM2200 pendulum impact test machine at room temperature. The Brinell hardness was tested with a BBS-3000DB Brinell hardness testing instrument.

The cross section of the sample was cut by an automatic cutter, and after grinding, mechanical polishing, and 4% nitric acid solution etching, the microstructure was observed under a DMI5000M inverted metallurgical microscope.

3. Results and discussion

3.1. Effect of tempering process on microstructure

The microstructure of ZG30Mn in different tempering process is shown in Fig. 1 and Fig. 2. It can be seen from Fig. 1(a) that the microstructure of ZG30Mn quenched at 880°C is a martensite , that is, α-Fe of supersaturated carbon. The martensite is uniform and fine. It can be seen from Fig. 1(b) to Fig. 1(f) and Fig. 2(a) to Fig. 2(d) that after tempering with different tempering temperatures and tempering time, the martensite is decomposed and converted into tempered sorbite, the cementite is dispersed on the ferrite matrix. As the tempering temperature increases and the tempering time prolongs, the fine granular cementite gradually aggregates growth and spheroidizes.

Martensite is α-Fe with supersaturated carbon, which is an unstable metastable phase. According to thermodynamic conditions, the metastable phase has a tendency to transition to a stable phase. When tempered at high temperature, supersaturated carbon atoms in martensite precipitate from α-Fe in the form of cementite, and the original martensite phase is retained. With the increasing of tempering temperature, the precipitated cementite gradually aggregates growth and spheroidizes. Meanwhile, the α phase recovers and recrystallizes, and the equiaxed new α grain gradually replaces the strip-like α structure [3], the original martensite phase disappears slowly.

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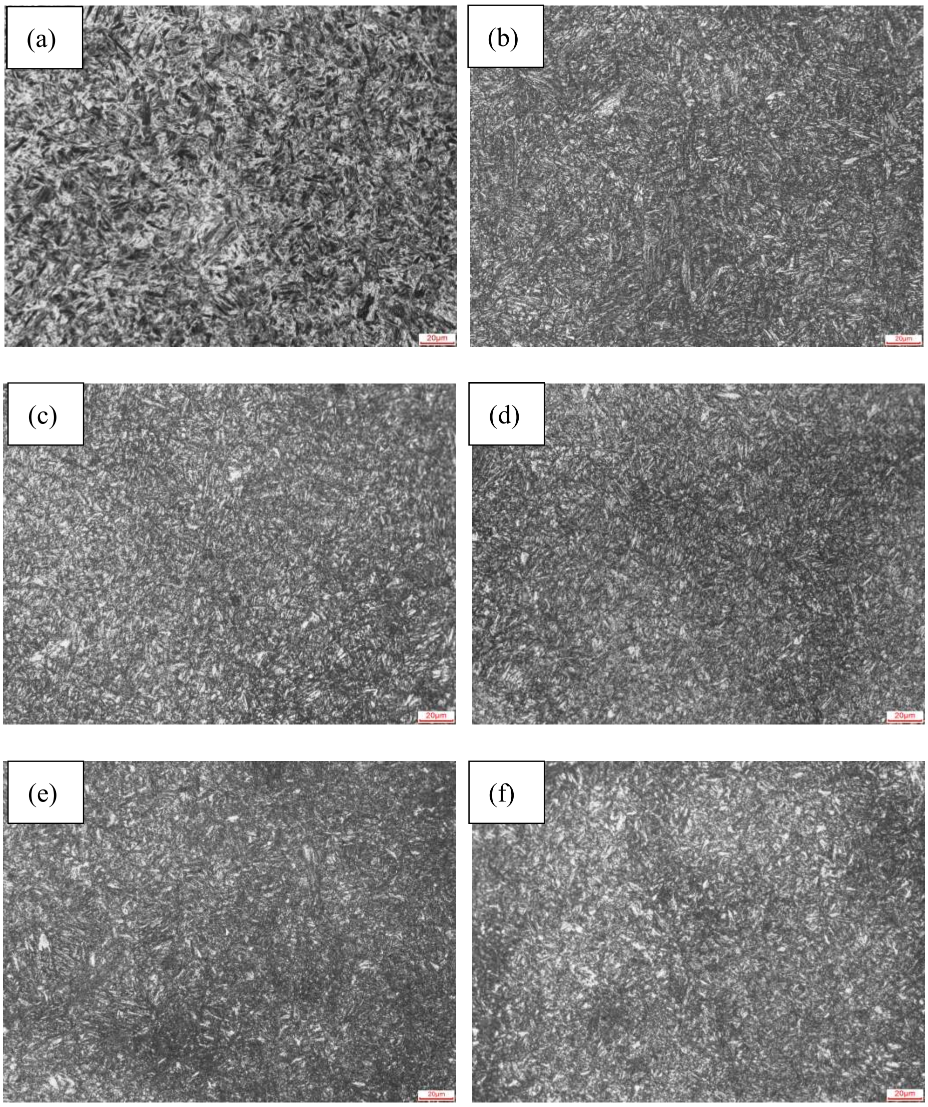
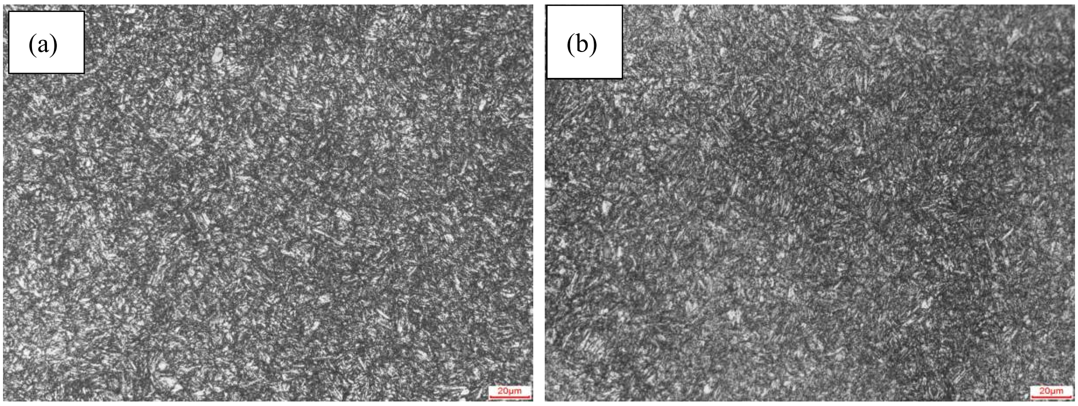


Figure 1. Microstructure of the ZG30Mn after quenching and tempering at different temperature. (a)as-quenched at 880℃; (b)tempered at 560℃; (c)tempered at 580℃; (d)tempered at t 600℃; (e)tempered at 620℃; (f)tempered at 640℃



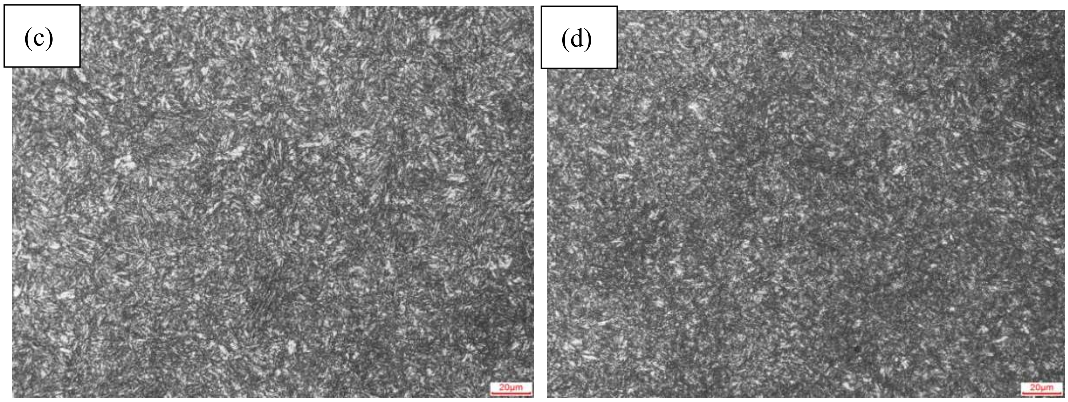


Figure 2. Microstructure of the ZG30Mn after quenching and tempering at different holding time. (a)30min; (b)60min; (c)90min; (d)120min

3.2. Effect of tempering process on mechanical properties

The effect of tempering temperature and tempering time on the mechanical properties of ZG30Mn is shown in Fig. 3. With the increasing of tempering temperature and tempering time, the strength (yield strength and tensile strength) and hardness of ZG30Mn gradually decrease. With the increase of tempering temperature, the elongation and impact energy of ZG30Mn increased gradually. With the increasing of tempering time, the elongation and impact energy of ZG30Mn increased first and then decreased. When the tempering time was 60min, the elongation and impact energy were the maximum.

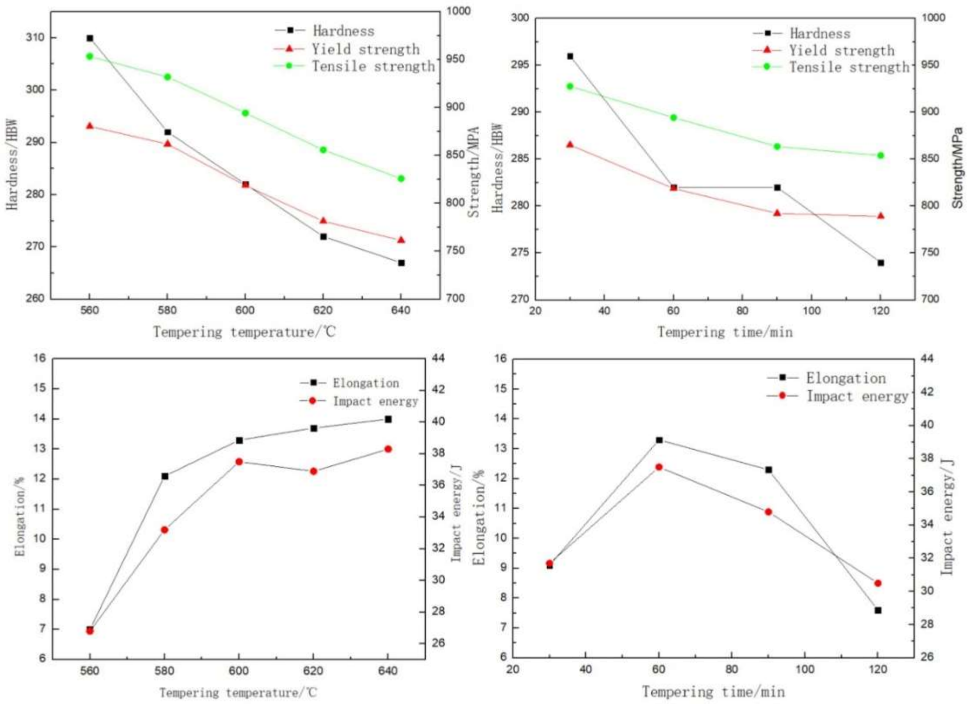


Figure 3. Effect of tempering process on mechanical properties of the ZG30Mn.

The microstructure of ZG30Mn tempered at high temperature is tempered sorbite, that is, cementite is dispersed on the ferrite matrix. Since carbon atoms are precipitated from α-Fe in the form of cementite, solid solution strengthening of carbon atom is weakened, and the dispersion strengthening of cementite is the main strengthening mechanism. The reasons for the hanrdenss and strength decrease with the increasing of tempering temperature and tempering time, one is the aggregation growth and spheroidization of cementite particles and the other is that the hindrance of cementite to dislocation motion is gradually weakened. The precipitated cementite is generally in the form of a sheet, which is in a coherent relationship with the matrix [4], which increases the stress in the matrix, resulting in low plasticity and toughness. As the tempering temperature increases, the sheet cementite gradually aggregates growth and spheroidizes, cementite and matrix are out of coherent relationship, the stress in the matrix is reduced [5, 6], combined with the recovery and recrystallization of the α phase, the granular carbide is evenly distributed on the equiaxed ferrite matrix, resulting in the increasing of plasticity and toughness. However, with the increasing of the tempering time, the alloy elements are redistributed between α-Fe and cementite, and the carbide forming elements are transferred to cementite, and some alloy cementites aggregation growth, resulting in the decrease of plasticity and toughness [7-9].

4. Conclusion

In this paper,the effects of tempering process on microstructure and mechanical properties of ZG30Mn were investigated. The following conclusions can be drawn.

1) With the increasing of tempering temperature, the hardness and strength of ZG30Mn gradually decrease, while the elongation and impact energy gradually increase.

2) With the increasing of tempering holding time, the hardness and strength of ZG30Mn are gradually decreased, and the elongation and impact energy increase first and then decrease. When the tempering holding time is 60 min, the elongation and impact energy have the maximum value.

3) The microstructure of ZG30Mn tempered at high temperature is tempered sorbite, and the cementite is dispersed on the ferrite matrix. With the increasing of tempering temperature, the α phase occurs to recovery and recrystallization, meanwhile, the fine granular shape cementite gradually aggregates growth and spheroidizes, resulting in the decrease of the hardness and strength, and the increase of the elongation and impact energy. With the increasing of tempering holding time, the aggregation growth of alloy cementite results in the decrease in elongation and impact energy after fracture.

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