Effect of tempering process on microstructure and mechanical properties of G18NiMoCr3-6 cast steel

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Abstract. The effect of tempering process on the microstructure and mechanical properties of G18NiMoCr3-6 cast steel was investigated. The results show that the microstructure of G18NiMoCr3-6 cast steel is granular bainite after normalizing at 900°C, which consists of bainitic ferrite and isolated grain or strips (M/A) islands. (M/A) island decomposes, and carbide precipitates when the tempering temperature is 200-400°C. When the tempering temperature rises to 500-600°C, the (M/A) islands completely decompose, and the carbides aggregate and gradually spheroidize. With the increasing of tempering temperature, the hardness and yield strength and tensile strength gradually decrease, and elongation and impact energy show a trend of decreasing at first and then increasing. The tempering brittleness occurs at 200-400°C.

1. Introduction
G18NiMoCr3-6 is a structural cast steel that belongs to Cr-Ni-Mo series high strength low alloy cast steel and has good weldability. Due to the addition of alloying elements such as Cr, Ni, Mo, etc., G18NiMoCr3-6 cast steel has good hardenability and low temperature toughness. Granular bainite can be obtained by normalizing G18NiMoCr3-6 cast steel, which is composed of bainitic ferrite matrix and island-shaped or strip-shaped retained austenite (abbreviated as (M/A) island) distributed thereon. It has been shown that an appropriate tempering process can improve the strength and toughness of the bainite steel and make the bainite steel obtain the best comprehensive performances [1, 2, 3]. However, most of the researches on bainite tempering process are based on steel rolling. There are few researches on cast steel. Therefore, it is of great significance to study the influence of tempering process on the microstructure and mechanical properties of bainite cast steel and to develop an appropriate tempering process.

2. Experimental materials and methods
According to the SEW520 standard, the G18NiMoCr3-6 cast steel was melted in a vacuum induction furnace and cast in a metal mold to obtain a 45mm thick plate. The chemical composition is given in Table 1. The cast steel plate was cut into several pieces, which were normalized in N41/H/P300 type of resistance furnace at 900°C for 90 minutes. At last they were tempered at 200, 300, 400, 500, and 600°C respectively for 120 minutes, and air-cooled to room temperature.
According to the GB/T 2975 standard, molybdenum wire electric discharge wire cutting was used to cut impact specimens and tensile specimens. Impact test was performed on a PTM2200 pendulum impact tester, and the tensile test was conducted at room temperature with an AG-100kNXPLUS electronic universal testing machine. The Brinell hardness of the samples after tempering at different temperatures was measured with a THBS-3000DB Brookfield hardness tester. The metallographic sample was taken from a section parallel to the impact fracture. After cutting, grinding, polishing, and etching with a 4% nitric acid alcohol solution, the microstructure was observed by a DMI5000M inverted metallographic microscope.

3. Results and discussion

3.1. Effect of tempering temperature on microstructure

Figure 1 exhibits the microstructure of G18NiMoCr3-6 cast steel under different heat treatment conditions. Figure 1(a) shows the microstructure of a normalized condition. The microstructure is granular bainite, which is mainly characterized by bainitic ferrite matrix and isolated grain or strips (M/A) islands [4, 5]. The microstructures of G18NiMoCr3-6 cast steel tempered at different temperatures are present in Figure 1(b) to Figure 1(f). It can be seen that when the tempering temperature is 200°C, 300°C and 400°C, the (M/A) islands decompose and strip carbides precipitate. As the tempering temperature rises to 500-600°C, the (M/A) islands are completely decomposed, carbides are dispersed on the ferrite matrix. Carbides aggregate and grow and gradually spheroidize with the increase of tempering temperature.

### Table 1. Composition of the tested steel (mass fraction, %)

|   | C   | Si  | Mn  | P   | S   | Cr  | Ni  | Mo  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
|   | 0.20| 0.30| 0.85| 0.012| 0.007| 0.51| 0.59| 0.47|
Figure 1. Microstructure of G18NiMoCr3-6 cast steel after normalizing and tempering
(a) as-normalizing; (b) tempering at 200°C; (c) tempering at 300°C; (d) tempering at 400°C; (e) tempering at 500°C; (f) tempering at 600°C

3.2. Effect of tempering temperature on hardness
Figure 2 exhibits the variation of Brinell hardness of G18NiMoCr3-6 cast steel after tempering at various temperatures. As can be seen from Figure 2, with the tempering temperature increasing, the hardness gradually decreases. The tempering temperature is lower than 400°C, the hardness decreases slowly, while the tempering temperature exceeded 400°C, the hardness decreases sharply.

The change in hardness during the tempering process is closely related to the (M/A) island transition. The (M/A) island is an unstable mixed microstructure. According to thermodynamic conditions, it has a tendency to shift to equilibrium state during the tempering process. When tempering at 200-400°C, the (M/A) island in the granular bainite occurs to decompose. The retained austenite transforms into martensite, which results in an increase in hardness, while carbon segregation and carbide precipitation occur in martensite, resulting in a decrease in hardness. The combination of two transformations leads to a slow decrease in hardness [6]. When the tempering temperature rises to 500-600°C, the (M/A) island is completely decomposed, at this time, dispersion strengthening of carbides plays a leading role in hardness. Therefore, as the tempering temperature increases, the reason for the further decrease in hardness is the growth and spheroidization of carbides.

Figure 2. Variation of hardness of G18NiMoCr3-6 cast steel with tempering temperature

3.3. Effect of tempering temperature on tensile properties
The effect of different tempering temperatures on the tensile properties of G18NiMoCr3-6 cast steel is shown in Figure 3. As can be seen from Figure 3, with the tempering temperature increasing, the
tensile strength and yield strength slowly decrease at first, when the tempering temperature is higher than 400°C, they rapidly decrease, the tensile strength decreases from 1106MPa to 886MPa, and the yield strength decreased from 880 MPa to 800 MPa. The elongation shows a tendency of decreasing at first and then increasing. At the tempering temperature of 400°C, the elongation is the lowest.

According to the microstructure analysis, when the tempering temperature of G18NiMoCr3-6 cast steel is lower than 400 °C, the (M/A) islands in the granular bainite structure decompose and transform into ferrite and strip carbide. When the tempering temperature rises to 500-600°C, the strip carbides aggregate and grow and spheroidize. Therefore, with the increase of tempering temperature, the matrix gradually softens, and the tensile strength and yield strength tend to decrease as a whole.

The retained austenite stability in (M/A) islands deteriorates with increasing the tempering temperature. During the stretching process, due to stress and strain, martensite transformation is induced and plasticity is reduced [7]. When the tempering temperature is 500-600°C, as (M/A) islands are completely decomposed, which the stress-strain-induced martensite-induced plasticity reduction disappeared, and the strips of carbides aggregated and grew and spheroidized, which the splitting of the matrix weakened, plasticity increases and elongation increases.

Figure 3. Variation of tensile properties of G18NiMoCr3-6 cast steel with tempering temperature

3.4. Effect of tempering temperature on impact toughness

Figure 4 shows the trend of the room temperature impact energy value of G18NiMoCr3-6 cast steel at different tempering temperatures. From Figure 4, it can be seen that as the tempering temperature increases, the impact energy decreases at first and then increases. At the tempering temperature of 400°C, the impact energy is the lowest.

When the tempering temperature is 200–400°C, the stability of retained austenite in (M/A) islands deteriorates, and the retained austenite decomposes to precipitate brittle carbide which distributed along prior austenitic grain boundaries [8]. In addition, the presence of (M/A) islands disrupts the continuity of the matrix, and more or less of the lattice distortion occurs around the (M/A) islands. Under the action of the impact load, stress concentration is easily generated at the interface between the ferrite and the cementite and the lattice distortion, as a result, the impact energy of the G18NiMoCr3-6 cast steel is reduced and tempering brittleness occurs. When the tempering temperature is 500-600° C, the (M/A) island transformation is completed, carbide aggregates and spheroidizes, and the toughness of the cast steel increases.
In this paper, the effect of tempering temperature on microstructure and mechanical properties of G18NiMoCr3-6 cast steel was investigated. The following conclusions can be drawn:

1) The normalized microstructure of G18NiMoCr3-6 cast steel is granular bainite, which consists of bainitic ferrite and some isolated grain or strips (M/A) islands. With increasing the tempering temperature, the (M/A) islands gradually decompose and carbides precipitate. When the tempering temperature rises to 500-600 °C, the (M/A) islands are completely decomposed, and carbides aggregate and spheroidize.

2) When the tempering temperature is 200-400 °C, due to the decomposition of (M/A) islands and precipitation of carbides, hardness, yield strength, and tensile strength show a slowly decreasing trend. When the tempering temperature is higher than 400 °C, the hardness, yield strength, and tensile strength are significantly reduced. The elongation decreased at first and then increased. At the tempering temperature of 400°C, the elongation is the lowest.

3) When the tempering temperature is 200-400 °C, the impact energy of G18NiMoCr3-6 cast steel gradually decreases, and tempering brittleness occurs. When the tempering temperature is higher than 400 °C, the impact energy is significantly improved and the toughness is enhanced.

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