Effect of Tempering on ADI Microstructure and Properties

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Abstract: The transformation of mechanical properties occurs in ADI at different tempering temperatures and times. The microstructure of ADI is analyzed using the univariate comparison method, which involved observing metallography, scanning electron microscopy (SEM), and backscattering electron diffraction technique (EBSD) methods after the material is treated with different tempering temperatures and times. The mechanical properties of the material were also examined. The tensile test and Charpy impact test are employed to examine the mechanical properties of the material, namely strength, plasticity, and toughness. The results indicated that the transformation temperature of the ADI is in the range of 310 to 330°C. When the tempering time is certain, the strength increases with an increase in tempering temperature, while hardness remains almost unchanged. And plasticity is reduced by 45%, and impact toughness is reduced by 67%. These changes affect the normal use of the material. The reason for the transformation is that the structure of the residual austenite transformed into ferrite and carbide, reducing the plasticity and toughness of the material. When the tempering temperature is certain and higher than the transformation temperature, the tempering time will only reduce the plasticity, strength, hardness, and impact toughness to a negligible extent, while the matrix structure remains largely unaltered.

Keywords: ADI; ausferrite; temper; residual austenite

1 Introduction

Austempered ductile iron (ADI) is a novel type of ductile iron material that has been developed over the past four decades. It is produced by isothermal quenching of ductile iron through austenitization. ADI exhibits enhanced tensile strength, fatigue strength, fracture toughness, and superior wear resistance compared to conventional ductile iron[1]. The structure of austenite in ADI materials remains stable at room temperature. If the material is subjected to prolonged stress or elevated temperatures, the matrix structure may undergo a transformation[2], resulting in a significant decline in the conventional mechanical properties and limiting the applicability of ADI components. In this study, tempering tests were conducted at varying temperatures or times to observe the tissue changes and detect the mechanical property alterations, thereby determining the tempering transformation temperature and transformation time.

2 Experimental procedure

The experiment employs QTD1050-6 grade ADI material. The raw materials employed in this experiment are pig iron, scrap, and furnace material. The casting temperature is 1340℃~1360 ℃, with the flow of pregnancy. The final composition is C: 3.3 ~ 3.8% , Si: 2.2 ~ 2.9%, Mn: 0.4-0.9%, P: <0.03%, S: <0.02, Mo: <0.2%, Cu: 0.4- 0.9%, Mg: 0.03-0.05%. Molten iron is poured into a 25-millimeter-thick Y-shaped test piece. Rectangular blocks measuring 25 mm × 25 mm × 220 mm should be extracted from the Y-shaped test block below for use as an isothermal quenching test object. The equal quenching process is as follows: the austenite temperature is 900°C, the austenitization time is 2.5 hs, and the isothermal quenching temperature is set at 345°C, with a quenching time of 2.5 hours. The bars should be cut into 20 mm × 220 mm pieces..

3 Result and discussion

3.1 Effect of tempering temperature on properties and microstructure

6 specimens were prepared. Heat each specimen by 5℃ per minute from room temperature to 310℃, 330℃, 350℃, 370℃ and 390℃. After being insulated for 5 hs, the specimens were removed using a sample clamp and air-cooled to room temperature.

From the metallographic test results, it was observed that the base structure consisted of ausferrite, with carbides appearing after tempering at 330°C. In terms of mechanical properties, both tensile strength and yield strength exhibited a decreasing trend with increasing environmental temperature. However, there was no significant change in hardness. The post-fracture elongation and impact performance drastically decreased when tempered at 330°C. The post-fracture elongation decreased from 11% to 6%, representing a reduction of 45%. And the impact performance dropped from12 J to 4 J, with the decrease of 67%.

The morphology of specimens 310℃,330℃ and 390℃ is observed under the scanning electron microscope. The tempering temperature of 310℃ is associated with a matrix structure of ausferrite (AF) that is arranged in an orderly manner. The ferrite needles are fine and uniform. Additionally, islands of residual austenite (RA) are observed between the ausferrite grains. At a tempering temperature of 330 ℃, the residual austenite in the matrix structure has undergone transformation into ferrite and carbides, accompanied by an increase in the thickness and length of the ferrite needles in the ausferrite. At a tempering temperature of 390 ℃, the ferrite needle coarsening and elongation is significant, and the grain direction is no longer ordered.

Residual austenite is an unstable phase that transforms at higher temperatures. In order to measure the specific content of residual austenite in the specimens, EBSD (electron backscatter diffraction) tests are performed on specimens 310℃, 330℃ and 390℃. The volume fractions of residual austenite are 27.3%, 13.5%, and 0%, respectively. The data indicates that when the tempering temperature is higher than the tissue transformation temperature, the residual austenite in the ADI material transforms into ferrite and carbide. The higher the tempering temperature, the more the residual austenite transformed until it is completely transformed.

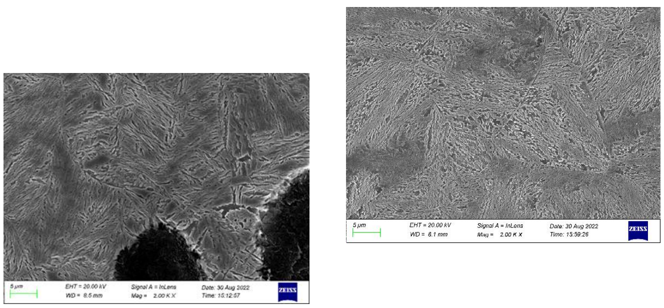

Fig 1 SEM morphology of specimen in 310℃ & 390℃

The aforementioned results demonstrate that in the tempering process, the ADI material microstructure transformation temperature is between 310℃ and 330℃. When the tempering temperature is below this range, the microstructure and properties of the material remain largely unaltered. Island-shaped residual austenite plasticity exerts a second-phase plasticizing effect. High-carbon austenite in ausferrite can also enhance the plastic deformation resistance. However, when the tempering temperature exceeds 330 ℃, the microstructure begins to transform. Residual austenite into ferrite, which no longer serves the role of a second-phase plasticizing agent. The ferrite needle becomes longer and coarser, and the grain transitions from an ordered to a disordered state, resulting in a sharp decline in plasticity and toughness, ultimately leading to material failure.

3.2 Effect of tempering time on properties and microstructure

The tempering process involves the preparation of five specimens. Each specimen is heated at a rate of 5 ℃/min from room temperature to 330 ℃, held for 0.5hs, 1h, 2hs, 3hs, or 4hs. Cool them to room temperature by air.

The metallographic test results indicated that the matrix structure is predominantly ausferrite, with no discernible differences. The mechanical properties demonstrated a tendency for the post-break elongation to decrease with the extension of the tempering time, while there is no significant change in tensile strength, yield strength, hardness and impact toughness. The post-break elongation exhibits a notable decline, decreasing from 12% to 5.5%, representing a 54% reduction.

To assess the microstructure of the specimens, EBSD tests conducts directly on specimens of 0.5hs, 2hs and 4hs, resulting in residual austenite volume fractions of 33.7%, 31.8%, and 35.1%, respectively. The results indicate that when the tempering temperature is higher than the tissue transformation temperature, the residual austenite in the ADI material doesn't decompose with the extension of tempering time, and the morphology of ferrite needles neither change. This implies that as long as the tempering temperature is higher than the transformation temperature, the tempering time only affects the plasticity of the material, and the strength, toughness, and microstructure don't transform significantly. In comparison to time, temperature exerts a more pronounced influence on the microstructure and properties of ADI materials.

4 Conclusion

(1)The transformation temperature of the ADI is in the range of 310 to 330°C.

(2)When the tempering time is certain, the strength increases with an increase in tempering temperature, hardness remains, and plasticity and impact toughness reduced.

(3) When the tempering temperature is certain and higher than the transformation temperature, the tempering time will only reduce the plasticity, strength, hardness, and impact toughness to a negligible extent.

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