Influence of Cooling Rate on the Microstructure and Properties of a New CADI

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Abstract:

Carbidic austempered ductile iron is a family of ductile cast irons produced with carbides that are subsequently austempered to exhibit excellent wear resistance, which is a new type of austempered ductile iron recently introduced in the market. Heat treatment parameters affect the microstructure of the carbidic austempered ductile iron. Among heat treatment parameters, cooling rate from homogenization temperatures to salt bath temperatures is the most effective, and is often easy to be neglected. Therefore, the effect of cooling rate on the microstructure and mechanical properties of carbidic austempered ductile iron was investigated. The experimental results indicate that with the increase of the cooling rate, the size of acicular ferrite became fine acicular ferrite gradually, the austenite content was retained, the impact toughness decreases and the hardness of the samples increases.

Keywords:-Cooling Rate, Microstructure, CADI.

1. Introduction

Austempered ductile iron (ADI) has been used for a wide variety of applications in automotive, rail, and heavy engineering industry because of its excellent mechanical properties such as high strength with good ductility, good wear resistance, and good fatigue properties [1–4]. Furthermore, the density of ADI is lower than steel. Thus, ADI has the advantage of higher specific strength than steel [5]. Carbidic austempered ductile iron (CADI) is a new wear-resistant material, which has recently been introduced in the market [6–8]. The use of CADI is increasing because of its excellent combination of high abrasion resistance and good impact toughness compared to other materials with similar wear resistance [9]. It is more wearresistant than Grade 5 ADI and less expensive and tougher than 18%chrome white iron, and it can replace Mn steel at an equal or lower cost [10]. Most of the studies have focused on the experimental work for abrasive wear behavior of CADI, but very little attention was paid to the effect of the cooling rate on the microstructure and properties of CADI. The aim of this study was to investigate the influences of cooling rate, achieved by adding water to the salt-bath, on the microstructure and mechanical properties of CADI.

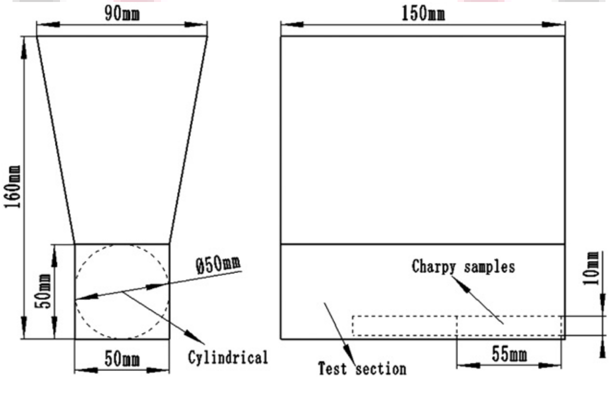

Fig. 1 – Dimensions of Y-blocks

2. Experimental Procedure

2.1. Material Preparations

The carbidic ductile iron was melted in a 30-kg medium frequency coreless induction furnace with siliceous lining, with charge materials of steel scrap, Fe–Cr, Fe–Mn and Fe–Si master alloys. In all cases, the melt was nodulized with Fe–Si–Mg6–Re2 (6 wt.% Mg) and inoculation processing with Fe–Si–Ba (72 wt.% Si). The melt was superheated to 1550 °C. After holding the melt at this temperature for 5 min, the melt was poured into a tundish-covered ladle for nodularizing treatment, and the melt was then poured into Y-shape molds with approximate size of 50 mm.

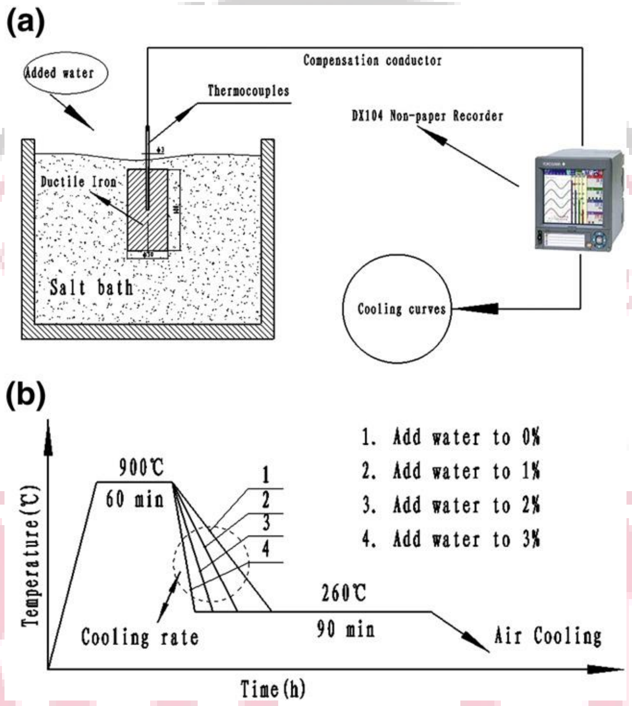

Fig. 2 – Schematic description of the salt bath while obtaining the different cooling rates. (a) Schematic description of the designed salt bath cooling ability. (b) Schematic description of austempering.

To observe the effect of cooling rate on the micro structure and properties of CADI, all Charpy specimens taken from the bottom of the Y-shape molds (Fig. 1) were austenitized at 900°C for 60 min in a tubular furnace. This process was performed to ensure that the matrix was transformed to austenite and acquired certain volume carbides. At the completion of the 60 min austenitization, the specimens were transferred into a salt bath at 260 °C for 90 min followed by air cooling at room temperature. In order to reflect the difference in cooling rates of the salt bath, the thermocouple was embedded in the center of the cylindrical sample that was taken from the center of the test zone The tap water was simply poured into the salt bath, with gas stirring at the bottom of the salt bath.

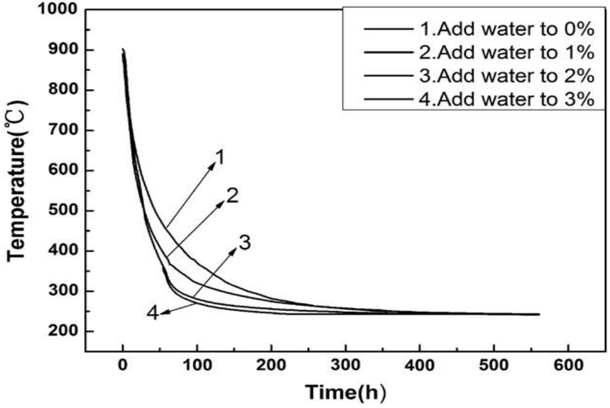

Fig. 3 – Cooling curves obtained from thermocouples

3. Microstructural Characterizations

Metallographic sample preparation for optical microscopy examination was carried out using standard techniques for cutting and polishing before etching with 4% Nital. The microstructures of the samples were examined under an MDS-DM20 metal-lurgical microscope and scanning electron microscopy (SEM) (LEO1530VP).The retained austenite content was determined by an X-ray diffraction technique [11]. The volume fractions of retained austenite were determined by X-ray diffraction(XRD) (D8 ADVANCE, Bruker/AKS, Germany) with Cu-Ka radiation using a D/magi-2550 X-ray diffract meter based on a direct comparison method of the integrated intensity of the austenite The samples were scanned for angles between 30°and 110°. In order to obtain experimental diffraction profiles with low statistical errors, the scan step used was 0.02°.

4. Mechanical Properties

The samples were designated for impact, and hardness tests were cut from the bottom of the Y-block and machined to 10 mm×10 mm×55 mm. At the completion of the heat treatments, the impact tests were performed using a 150-J capacity machine at room temperature. The reported values are the average of three determinations. Hardness was tested on a HR-150A Rockwell hardness machine. Five hardness tests were carried out in each location.

5. Microstructure of CADI

CADI was produced by austempering ductile cast iron that contains carbides, and the microstructures are shown in Fig. 4(a)–(b). The number of the nodular graphite was approximately 220/mm^2, the percentage of spheroidization was approximately 91% and the carbide content was approximately 17%. The microstructures under high magnification are shown in Fig. 4(c)–(d). The graphite nodules and carbides were present in a fine pearlite matrix. After austempering heat treatment, the matrix of CADI was changed from a fine pearlite matrix to a typical ausferritic matrix, and the microstructure consists of graphite nodules, a certain volume of carbides within an ausferrite matrix. It can be seen from Fig. 5 that the acicular ferrite matrix content continuously decreased as the water content increased. When the water content was 3%, fewer amounts of acicular ferrite matrix and more white-bright zones in CADI were observed. This should be related with the diffusion rate of carbon from ferrite to austenite [13]. Retained austenite content plays effective role in the microstructure and properties of CADI [14]. Strain-induced martensitic transformation occurs locally in the plastic zone ahead of the crack so as to relax the stress concentration. The accompanying volume change also encourages plastically induced crack closure to occur, reduces fatigue crack growth rate and increases fracture toughness. However, too much retained austenite could decrease wear-resistance of materials [15,16]. Hence, determination of retained austenite content is an important task in materials research [15].The low carbon retained austenite was transformed into brittle martensite phase easily during the cooling process from austempering temperature to room temperature. This may be the reason for high hardness and low impact toughness at the higher cooling rate (cooling rate at 4.333 °C/s), because the retained austenite content decreased by XRD analysis, and the white-bright zones in CADI increased by observing the microstructures examination. The samples of each condition were analyzed by XRD in order to determine the weight percentages of the retained austenite [17]. The influence of the water content on the retained austenite content of CADI is shown in Fig. 6.As the water content increased, the retained austenite content of the samples decreased. The results show that there exists a relation between retained austenite content and impact toughness. It is known that the retained austenite can effectively block micro crack propagation [18], so proper retained austenite content is important for CADI. The morphology of ausferrite depends on the diffusion ability of ferrous and carbon atoms and nucleation driving force of ferrite. The cooling rate which influences the nucleating ability of the acicular ferrite is an important factor. When the cooling rate is high, the driving force for austenite transformed into acicular ferrite is larger. As the cooling rate decreased, the driving force of acicular ferrite nucleation became weaker and weaker. According to this reason, the acicular ferrite should be fine and dense at the higher cooling rate, but the result raises an interesting question: why acicular ferrite had not been fine and dense under high cooling rate. Authors of the paper consider that a severe undercooling may lead to the martensite transformation resulting in the stop of the growth of the acicular ferrite. With the aid of microstructure observation and hardness measurement, the martensite microstructure of CADI was observed under a severe undercooling, and fewer amounts of acicular ferrite matrix and more white-bright zones in CADI were observed. The micro hardness of the matrix attains to HV936 under a severe undercooling (cooling rate at 4.333 °C/s) much more than that of the matrix under other case (cooling rate at 1.625 °C/s). Phase transition drive force increased greatly and the diffusion of Fe and C atoms reduced greatly resulting to a severe undercooling, which might cause martensitic transformation. The other reason was that severe undercooling was likely to increase the martensite transformation temperature, and therefore the microstructure of CADI might be transformed into martensite. It had been established that adding water to salt bath changes the acicular ferrite growth rate remarkably. The experimental results show that adding water to the salt bath pot could change the microstructure of CADI. Generally speaking, salt bath is an important factor for ADI and ADI production; therefore, adding water to the salt bath is a very important way to change the microstructure of CADI. If the microstructure of CADI is adjusted accurately according to the client's request, it will obtain widely industrial application in wear-resisting region.

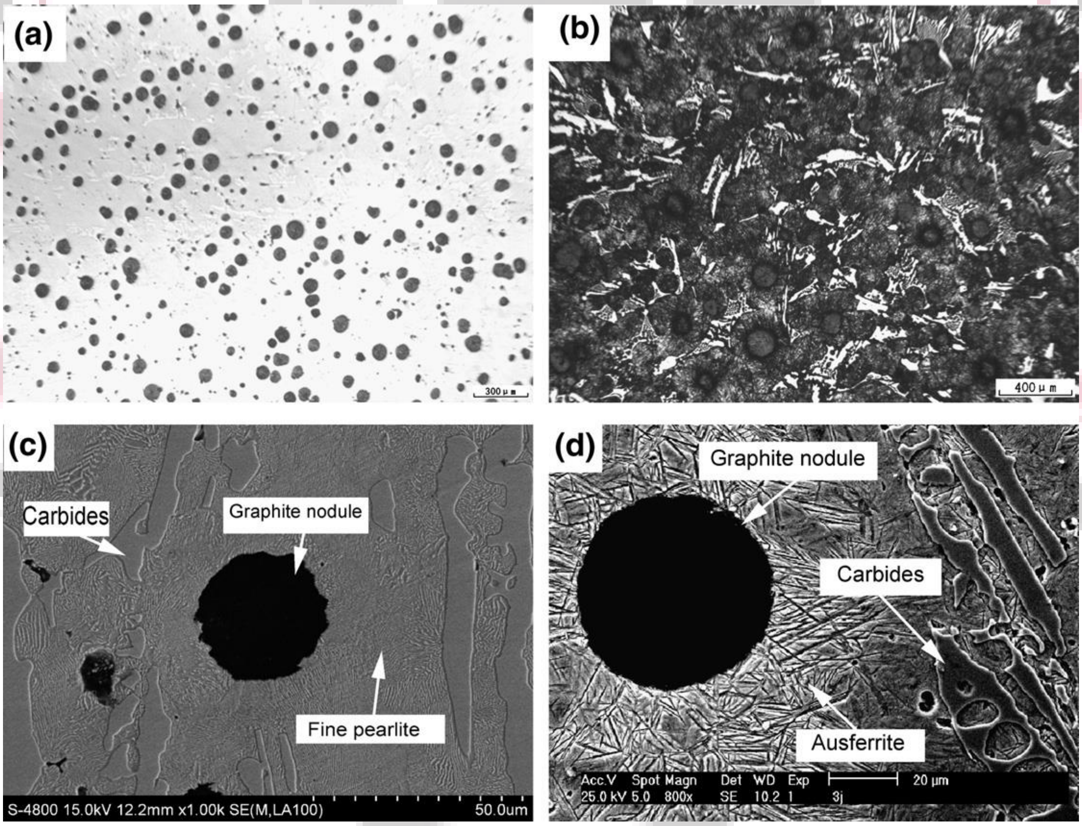

Fig. 4 – Microstructures before and after austempering. (a) The as-cast microstructure of a sample (100 ×). (b) Typical microstructure of the CADI (100 ×). (c) The as-cast microstructure of a sample (1000 ×). (d) Typical microstructure of the CADI (800 ×).

6 Effect of Water Content on the Mechanical Properties of CADI

The microstructural changes were reflected as change in most of the mechanical properties [19]. The influences of the water content on the hardness and impact toughness of CADI are shown in Table 2. It was evident from this table that as the water content increase, the hardness of the samples increase, and the impact toughness decrease. It may be depended on the growth of ferrite, carbon diffuses to austenite and forms carbon enriched austenite [20].

Because the ferrite (low-carbon phase) transformation makes more carbon atoms diffuse into austenite and makes austenite contain more carbon content. If the sample was held at the austempering temperature for too short time, low-carbon austenite can be transformed into brittle martensite. Whether low-carbon austenite can be transformed into brittle martensite depends on austempering time. In this case, as the structure contains martensite,

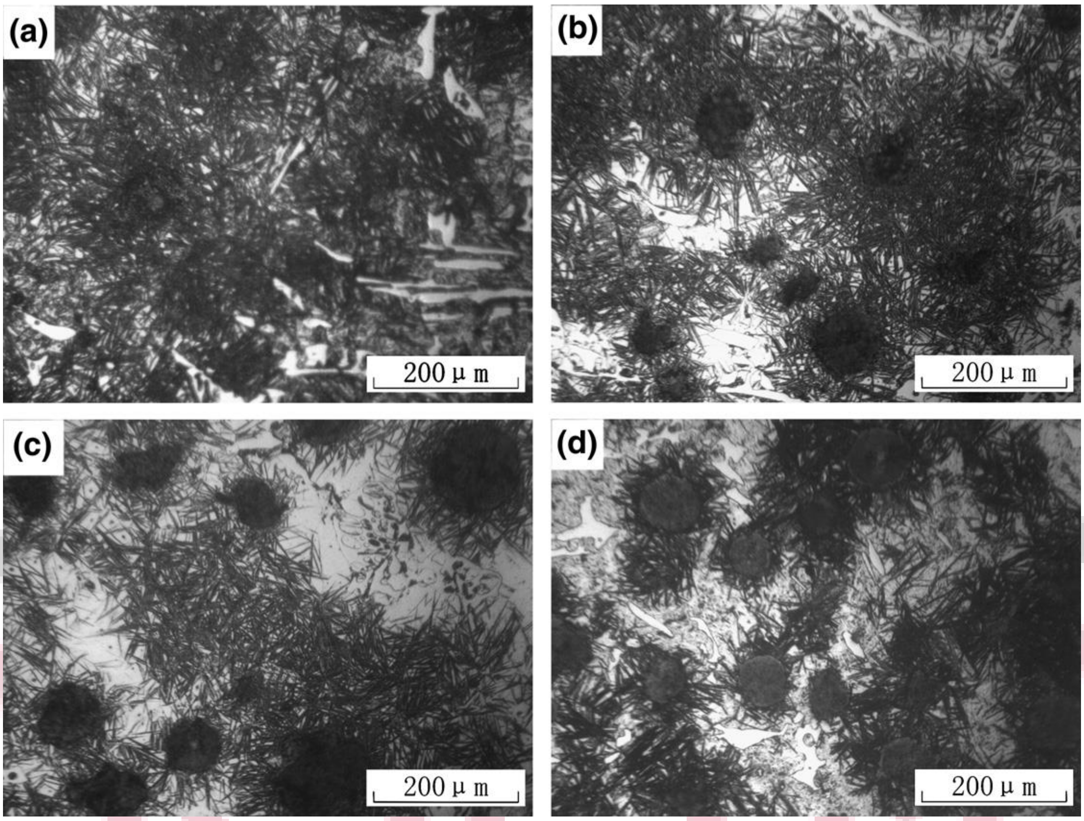

Fig. 5 – Microstructure of the CADI with various water contents (wt%) (etched) (200 ×): (a) 0% water, (b) 1% water, (c) 2% water and (d) 3% water.

7. Conclusions

Based on the results of this study, the following conclusions may be drawn:

1. Different cooling rates of salt-bath furnace were obtained by adding different water contents, which affects the microstructure and mechanical properties of CADI.
2. It was found that the higher the water volume added to the salt bath, the higher the hardness of CADI. The highest hardness of the sample was obtained when the water content is approximately 3%. However, the impact toughness decreased gradually as the water increased.
3. The percentage content of retained austenite was altered by different cooling rates, and the cooling rate had a great impact on the microstructure of CADI.
4. Adding water to the salt-bath furnace plays an effective role in the formation of ausferrite structure thus influencing mechanical properties.

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