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Short Communication

Characteristics of tempering response of austempered ductile iron

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ABSTRACT

Austempered ductile iron (ADI) is produced by an isothermal heat treatment. Tempering is an effective method to increase the toughness and decrease the hardness of ADI. In the present research, the transformation of ADI was investigated after applying various tempering temperatures. The hardness of ADI samples with and without tempering was measured and the microstructure of ADI samples was analyzed by using metallographic optical microscopy. It was found that the ausferrite decomposed into dispersive cementite particles above a tempering temperature of 538 °C. Thus, the tempering process for ADI must be carefully selected so that the excellent properties of ADI are not degraded.

1. Introduction

Austempered ductile iron (ADI) is ductile iron which undergoes an isothermal heat treatment. The optimal microstructure of ADI consists of graphite nodules surrounded by acicular ferrite and high carbon content austenite, which is called ausferrite [1–3]. The excellent mechanical properties of ADI have led it to becoming a good alternative to steel castings and forgings and even aluminum in diverse applications, especially in the automotive area [4–6]. The production of ADI requires stringent control because the final ausferritic morphology can be influenced by chemical composition, holding time of heat treatment, cooling rate, etc. [7,8]. Standard ADI grades have been specified in terms of material properties [9].

The ADI heat treatment is comprised of two controlled steps: austenitizing and austempering. The austempering step can be subdivided into two continuous reaction stages depending on holding time. The unique ausferritic matrix can be achieved only within the first stage. In the second stage, the high carbon content austenite will be decomposed into ferrite and carbon will be precipitated in the form of carbide. In this case, some of the mechanical properties of ADI will be degraded with the formation of bainite in the matrix [2,8].

In industry, tempering has been utilized as an effective heat treatment to reduce brittleness and relieve the internal stress of quenched and normalized materials [10–12]. The ductility and toughness of materials can be improved by tempering along with a decrease in hardness. The resulting material properties are dependent on the tempering temperature and time and alloying elements and their percentages. However,

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the hardness may not be changed by the tempering process for some materials containing Mo and S, and high speed steel after tempering is also an exception, which becomes harder due to completed martensite formation [13].

Kshemendranath et al. [14] reported that the hardness of austempered low carbon equivalent ductile iron decreased with increasing tempering temperature. Putatunda et al. [15] found that the microstructure of austempered ductile cast iron had an austenite-free ferritic matrix after being tempered at 484 °C for 2 h. The hardness of tempered ADI samples could be increased or decreased, dependent on the original microstructure of non-tempered ADI.

Even though the metallurgy and material properties of ADI have been studied extensively, there is a lack of information with respect to how the morphology of the ADI matrix responds after applying various tempering temperatures. It is desirable to confirm if the ausferritic structure will remain in the matrix or will transform into some other phases during tempering. This is also important in the understanding of microstructural changes which may occur in case hardening processes such as nitriding and nitrocarburizing. Hence, the objective of this research was to explore ausferritic transformation of ADI material processed using various tempering temperatures.

This objective was carried out by performing heat treatment on samples including austenitizing, austempering and tempering processes. Then, hardness tests and observation using metallographic optical microscopy were carried out to analyze the characteristics of tempered ADI samples.

2. Experimental procedure

2.1. Chemical composition

The chemical composition of the experimental ductile iron was 3.87% C, 0.49% Mn, 0.023% P, 0.007% S, 2.17% Si, 0.04% Cr, 0.02% Ni, 0.02% Mo, 0.73% Cu, 0.007% Al, 0.005% V, 0.015% Nb, 0.01% Ti, 0.003% Co, 0.028% Sn, 0.052% Mg and 0.001% W.

2.2. Heat treatment procedure

The original samples were cut from bars into a 60 degree sector shape with a diameter of 50 mm and thickness of 8 mm. The original microstructure of the as-cast ductile iron has graphite nodules uniformly surrounded by pearlite (see Fig. 1). An austenitizing temperature of 900 °C was selected based on previous research [16]. The ductile iron samples were austenitized in a salt bath furnace for 25 min. Then, samples were rapidly transferred to another pre-heated salt bath furnace for an austempering process at 276 °C, 321 °C or 373 °C for 30 min, and then cooled in air to room temperature. The ADI samples were then subjected to a tempering process at various temperatures for 60 min in an electric furnace and cooled by water quenching to room temperature. A schematic of the heat treatment processes utilized in this research is shown in Fig. 2.

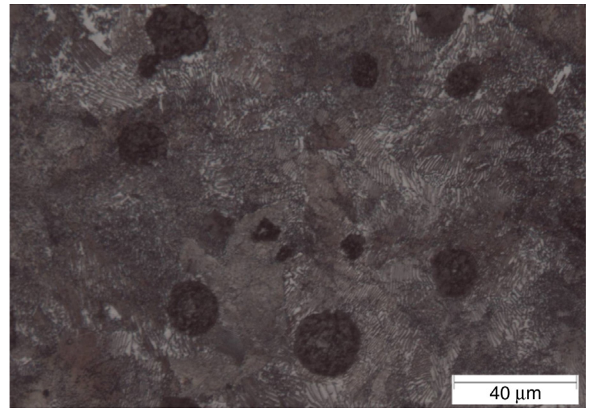

Fig. 1 – Original microstructure of as-cast ductile iron (500×).

3. Results

3.1. Hardness measurement (Rockwell C)

A Rockwell hardness tester was used to measure the hardness of the ADI samples. In Fig. 3, it can be seen that the hardness of the ADI samples decreases with increasing austempering temperature at the same holding time. This may be due to a decrease in martensite in the matrix and more austenite being transformed into ausferrite. In addition, the hardness also decreases with increasing tempering temperature for each austempering condition.

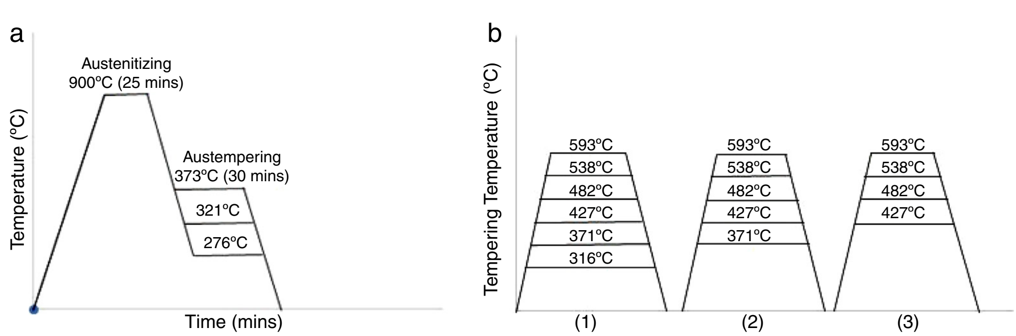

Fig. 2 – (a) Austenitizing and austempering processes. (b) Tempering processes carried out for 60 min on ADI samples: (1) austempering (276 °C), (2) austempering (321 °C), (3) austempering (373 °C).

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