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Development of wear resistant carbidic austempered ductile iron (CADI)

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Abstract

The abrasion wear resistance of irons may be improved by the incorporation of an extra phase to the matrix, typically consistent of carbides. Nevertheless, the improvement in wear resistance is generally accompanied by a decrease in the impact toughness. The aim of this work is to study the methodology to obtain a controlled precipitation of carbides in a ductile cast iron that is subsequently austempered, obtaining the so-called carbidic austempered ductile iron (CADI). This material is expected to offer high abrasion resistance but still retaining higher impact toughness than other reinforced irons, thanks to the particular characteristics of the matrix. A plate model with a copper chill allowed to evaluate both, the influence of a high cooling rate and the effect of alloying elements on carbide precipitation. Four different alloys with equivalent carbon close to the eutectic composition were used in order to evaluate the effect of chromium contents ranging from 1 to 2.5%. A detailed microstructural characterisation of the material was made, studying particularly carbide content and composition, besides their stability during the heat treatment. The abrasion wear resistance was evaluated by testing under the ASTM G 65 standard, obtaining relative wear resistance values ranging between 1.02 and 1.95 with respect to conventional ADI samples taken as reference material. The impact toughness decreased from about 138–101 J for ADI to about 26–7 J for CADI.

Keywords: Carbidic austempered ductile iron; Microstructure; Carbides; Abrasion; Impact toughness

1. Introduction

Austempered Ductile Iron (ADI) has been long recognised for its high tensile strength and toughness (over 1600 MPa and over 100 J for grades 5 and 1, respectively, according to the ASTM A 834-95), making possible to replace forged steels in many applications. It is also well known the ability of this material to perform very well under different wear mechanisms such as rolling contact fatigue, adhesion and abrasion [1–3].

ADI has proved to behave in a different manner under abrasive conditions, depending on the tribosystem (low or high stress abrasion), but being always possible to obtain a good performance in service if the heat treating parameters are properly selected [2].

A new type of ADI, containing carbides immersed in the typical ausferritic matrix, called carbidic ADI or CADI has been recently introduced in the market. Nevertheless, the literature available only show application examples and data about the response to abrasive wear but not the procedure to produce CADI.

The presence of carbides is expected to promote an increase in the abrasion wear resistance, but on the other hand toughness is expected to decrease. Therefore, the challenge related to the development of this material is to be able to control the microstructure in order to obtain the optimum balance between abrasion resistance and toughness, taking into account the tribosystem and the operating conditions.

One of the methodologies commonly used to obtain a microstructure with as-cast carbides is to reduce the quantity of graphitising elements (in particular Si), in order to promote the precipitation of ledeburitic carbides during solidification due to a closer interval between the stable and metastable diagrams. This methodology may be combined with a second option given by the high undercooling promoted by the use of a chill in the mould. A third option is to alloy the melt with carbide stabilising elements, such as chromium, molybdenum or titanium [4,5], which strongly reduce the interval between stable and metastable eutectic temperatures and promote total or partial solidification

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according to the metastable diagram [6]. It must be taken into account that an undercooling also affects the size and count of the solidification units, and therefore, the microsegregation. The lower the cooling rate, the greater the microsegregation effect increasing the probability for carbide precipitation at the last to freeze zones, and therefore, the formation of alloyed carbides. Then, the size and composition of carbides may vary, from typical unalloyed ledeburitic to thin plate shaped high-alloyed carbides, depending on the chemical composition and cooling rate [6–9].

It was demonstrated [10] that ledeburitic carbides produced either by controlling the cooling rate or the silicon level (non-alloyed carbides) have a high tendency to dissolve during the austenitizing stage and are less stable than alloyed carbides. Therefore, carbide dissolution during heat treatment should be evaluated.

The objectives of this work is to produce different variants of CADI, studying its microstructural characteristics and evaluating some mechanical properties, particularly the abrasion resistance and the impact toughness.

2. Experimental procedure

2.1. Sample preparation

The material used in this study was obtained in a metal casting laboratory, using a 55 kg capacity 3 kHz induction furnace. Steel scrap and foundry returns were used as charge materials. In all cases the melts were nodulized with FeSiMg (9 wt.% Mg) and inoculated with FeSi (75 wt.% Si). Five alloys of ductile iron were obtained, with approximately 0, 1.0, 1.5, 2.0 and 2.5 wt.% Cr.

The shape and dimensions of the model used [11,12] is shown in Fig. 1. A copper chill of 38 mm × 38 mm × 200 mm was positioned at the end of the plate in order to promote a chilling effect in its vicinity introducing a cooling rate gradient along the plate.

A numerical simulation of the feeding and solidification processes was carried out by using the software Nova Flow & Solids®. The simulation was used to evaluate the variation of the cooling rate with the distance to the chill and to determine the distance at which the chill is no longer effective.

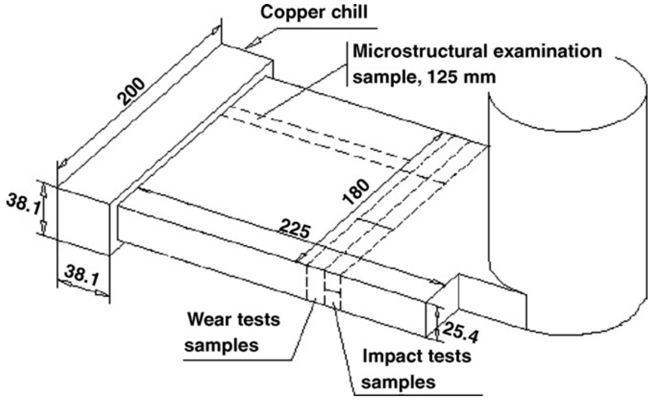

Fig. 1. Plate model with copper chill at one end showing the location where test samples were obtained.

Table 1
Sample identification, in both the as-cast and treated conditions

Identification	Heat (% Cr)	Condition	Austempering temperature (°C)
C1	1 (2.5)	As-cast	–
A1-280	1 (2.5)	Austempered	280
A1-360	1 (2.5)	Austempered	360
C2	2 (2.0)	As-cast	–
A2-280	2 (2.0)	Austempered	280
A2-360	2 (2.0)	Austempered	360
C3	3 (1.5)	As-cast	–
A3-280	3 (1.5)	Austempered	280
A3-360	3 (1.5)	Austempered	360
C4	4 (1.0)	As-cast	–
A4-280	4 (1.0)	Austempered	280
A4-360	4 (1.0)	Austempered	360
C5	5 (0)	As-cast	–
ADI 280	5 (0)	Austempered	280
ADI 360	5 (0)	Austempered	360

Austenitizing temperature 900 °C in all samples.

The plates were cut as shown in Fig. 1, with a longitudinal slice ∼125 mm long obtained for the microstructural characterisation, carbide quantification and dissolution studies. At distances between 125 and 150 mm (zone not affected by the chill), two slices ∼11 mm thick were cut (Fig. 1), from which impact and wear test samples were obtained. Hardness measurements were also performed on all samples.

The samples obtained from the five alloys were then heat treated by austenitizing 1 h at 900 °C in a muffle followed by an austempering step in a salt bath for 2 h, at two different temperatures, 280 and 360 °C. The unalloyed samples without carbides (conventional ADI) were used as reference material for wear and impact tests together with the CADI variants (having different carbide contents). Sample identification in both the as-cast and heat treated conditions is listed in Table 1.

2.2. Chemical and microstructural examination

The chemical composition of the alloys was determined by means of a Baird Spark Emission Optic Spectrometer with a DV6 excitation source. The chemical composition of the carbides was evaluated by using a Philips Scanning Electron Microscope with an EDX module, in order to analyse the microsegregation effects and its influence on the carbide dissolution during heat treatment. The values reported are the average of three determinations.

Metallographic sample preparation for optical microscopy examination was carried out by using standard techniques for cutting and polishing before etching with 2% Nital. In order to quantify the amount of carbides, they were revealed by etching with 10% ammonium persulfate in aqueous solution and its content (in percent) was measured in zones located every 2 mm starting from the chill by using the Image Pro Plus software. The magnification used was 50× in order to obtain data from a sufficiently large area. Each reported value is the average of three determinations.