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Influence of nickel on mechanical and slurry erosive wear behaviour of permanent moulded toughened austempered ductile iron

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ABSTRACT

This paper presents a study on the role of nickel content on the slurry erosive wear, strength and impact toughness behaviour of permanent moulded toughened austempered ductile iron (PMTADI) samples subjected to a special austempering heat treatment. The nickel additions were made at five levels ranging from 0.5 to 2.5% in steps of 0.5%. Toughened ADI samples have shown an increase in slurry wear and impact toughness and a slight reduction in tensile strength than samples subjected to conventional austempering heat treatment. The results indicate that there is a significant improvement in slurry erosion resistance for 2.0% nickel PMTADI samples. Samples containing 2.0% nickel shows superior slurry erosion and impact toughness than samples containing either 1% or 2.5% nickel content. The retained austenite content, distribution of bainite and the matrix microstructure play a vital role on the slurry erosive wear and mechanical properties of PMTADI samples.

1. Introduction

Austempered ductile iron (ADI) is an engineering material which is currently being used widely in mining, automotive, agriculture and power plant applications because of benefits such as high strength, wear resistance and toughness [1–4]. Components made of ADI are used in coal handling equipments such as chutes, gears in automotive sector and liners in power plants. The enhanced wear and mechanical properties of ADI are achieved by proper austempering heat treatments and the resulting bainitic matrix obtained. While sand castings are employed for production of ADI, the application of permanent mould casting offers several distinct advantages like better mechanical properties, environmental cleanliness, higher production rate and improved dimensional stability. Seetharamu et al. [5] have reported that dry sand abrasion and jet erosion wear resistance of ADI has been superior for castings poured into permanent moulds compared to sand moulded counterparts. Rundman [6] has suggested the utilization of permanent moulds to produce ADI so as to minimize the negative effects of alloy segregation. Murthy et al. [7] have reported superior abrasive and erosive wear resistance and strength of permanent moulded austempered ductile iron (PMADI) castings alloyed with manganese.

It is well established that the wear and mechanical properties of ADI are dependant on the matrix microstructure, which can be altered either by heat treatment conditions or alloying additions. Many researchers have successfully employed novel heat treatment procedures to enhance wear and mechanical properties of ADI. Kobayashi et al. [8] have developed a special austempering heat treatment process (generally termed as QB[1] process), which has resulted in enhancing toughness of ADI with least sacrifice in strength levels. The resulting ADI is being referred to as toughened ADI. Yamamoto and Kobayashi [9] have reported that the structure and mechanical properties of toughened ADI are determined by the composition, heat treatment conditions and microstructure of ductile iron before austempering. Kobayashi and Yamada [10] have reported that austempering from the $(\alpha+\gamma)$ temperature range (B[1] process) was effective in improving the toughness of ADI irrespective of the prior structure. In the QB[1] process, longer holding times resulted in both a reduction of carbides and the toughness increasing with increasing holding times.

The refinement of matrix microstructure by prequenching is reported to be very effective in improving toughness of ADI. Ayman et al. [11] have used a novel two step austempering process to achieve improved fracture toughness and mechanical properties of ADI. Yang and Putatunda [12] have carried out investigations to study the influence of novel two-step austempering process on the microstructure and abrasive wear behaviour of ADI. They have reported significant improvement in microstructure parameters and abrasive wear resistance in ADI from this process.

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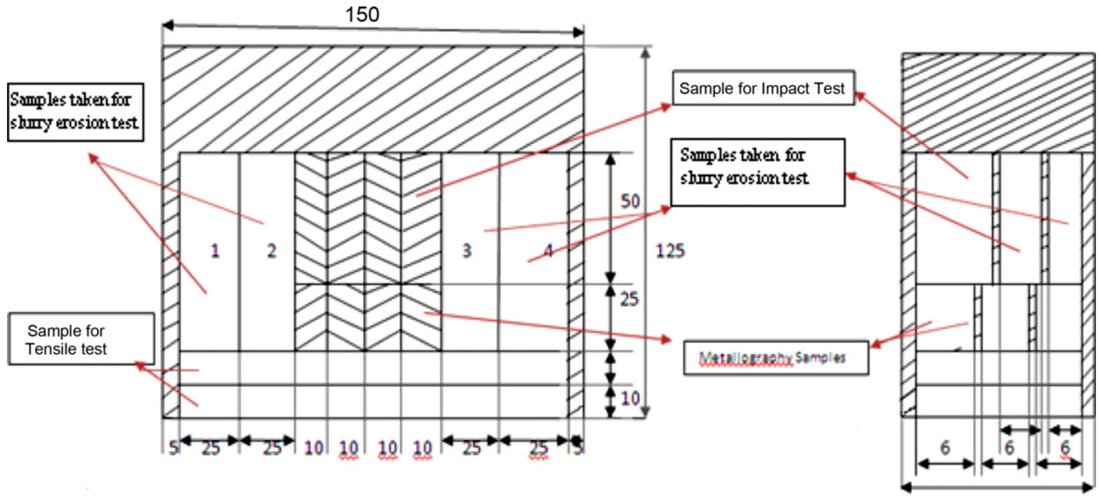

Fig. 1. Location of test samples within castings.

Alloying additions to ADI render the material more suitable for commercial austempering because certain elements affect the solubility of carbon in the austenite. Gundlac et al. [13] have reported favourable tensile properties for castings alloyed with nickel. Kovacs [14] has reported that nickel increases impact toughness. Earlier researchers [15] have reported that nickel is known to shift the transformation temperature range, i.e. the effect produced at higher temperatures for nickel–free iron is attained at lower temperature ranges when it is alloyed with nickel. Nickel has the ability to stop the precipitation of secondary carbides in the upper bainitic range. Industrial applications demand ADI possesses good wear resistance and a higher level of toughness than that currently employed.

The demand for an alternate wear resistant material to replace steels for various applications is now becoming a reality [16]. There is no sufficient published information on the mechanical and slurry wear behaviour of toughened ADI. The impact of the QB[1] process on the slurry erosion behaviour of ADI is investigated in the present work. Since as previously mentioned, the role of nickel as an alloying element is known to strengthen the bainitic matrix and stabilize the austenite phase, the present work is focussed on the investigation of strength, toughness and slurry erosion behaviour of PMTADI alloyed with nickel. The results are analysed based on graphite morphology and bainitic matrix.

2. Experimental details

2.1. Melting and casting

Nickel alloyed ductile iron castings were melted in a coreless induction furnace of 15 kg capacity. The charge material was low manganese carburized steel of low sulphur and low phosphorus content. Carbon additions were made using petroleum coke. Silicon content was built up to the required level using ferrosilicon. Nickel additions were made to the melt in different levels (i.e. 0.5%, 1.0%, 1.5%, 2.0% and 2.5%). The melt was superheated to 1500 °C. Ni–Mg alloy was used as spherodizer and post inoculation was done using ferrosilicon (inoculation grade). The melt was poured at 1400–1425 °C into a preheated (200 °C) grey cast iron mould of dimensions 150 mm × 125 mm × 25 mm. The mould temperature was measured by thermocouples soldered to the surface of the mould. The castings were allowed to cool to room temperature before being stripped out. The chemical compositions (wt%) of the castings poured are shown in Table 1. Fig. 1 shows the locations in the castings of samples prepared for slurry erosion, tensile and impact tests.

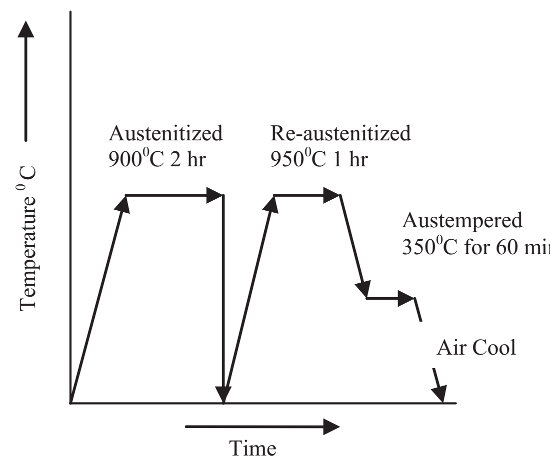

Fig. 2. Special austempering heat treatment process. (QB[1] process).

2.2. QB[1] process

The special heat treatment process consisted of the samples austenitized at 900° C for 2 h followed by an oil quench to room temperature (Q process). The samples were then re-austenitized at 950° C for 1 h. They were subjected to an isothermal treatment at 350 °C for 60 min (B process) in a salt bath containing a mixture of sodium nitrate and potassium nitrate. The salt bath size was big enough to prevent any drastic increase in the temperature of the salt bath following the quenching of samples into the bath. The temperature of the salt bath was monitored and controlled using digital temperature controller. The test samples were then cooled to room temperature followed by removal of the decarburized layer. The QB[1] process has been schematically represented in Fig. 2.

Table 1
Nominal composition (wt%) of nickel alloyed (PMTADI) samples.

Casting designation	C	Si	Ni	S	Mg
0.5% Ni PMTADI	3.31	2.93	0.55	0.03	0.04
1.0% Ni PMTADI	3.28	2.88	1.06	0.03	0.04
1.5% Ni PMTADI	3.30	2.92	1.52	0.03	0.04
2.0% Ni PMTADI	3.29	2.90	2.01	0.03	0.04
2.5% Ni PMTADI	3.32	2.89	2.54	0.03	0.04
PMADI[a]	3.30	2.91	2.01	0.03	0.04

[a] Casting poured into permanent mould to be subjected to conventional austempering heat treatment for comparison.