Wear 267 (2009) 1393–1398

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Abrasion and erosion behaviour of manganese alloyed permanent moulded austempered ductile iron

K. Narasimha Murthy[a,*], P. Sampathkumaran[b], S. Seetharamu[b]

[a] Department of Mechanical Engineering, PES Institute of Technology, 100 Feet Ring Road, BSK III Stage, Hosakerehalli, Bangalore, India
[b] Materials Technology Division, Central Power Research Institute, Bangalore, India

ARTICLE INFO

Article history:
Received 5 September 2008
Received in revised form 24 December 2008
Accepted 24 December 2008

Keywords:
Permanent moulded
Ductile iron
Manganese content
Abrasion
Erosion
Austempered

ABSTRACT

Laboratory abrasion and erosion tests have been reported on permanent moulded austempered ductile iron with manganese as alloying element at three levels, i.e., 1%, 2% and 3%. The influences of Mn addition on the wear and tensile properties have been studied and discussed. The results indicate that with increase in Mn content from 1% to 2%, the abrasion and erosion volume losses are exhibiting decreasing trend. Further increase in Mn addition to 3% has resulted in an increase in wear losses. Same is the case with the tensile strength and percentage elongation properties. These data have been interpreted based on the structural features including graphite morphology.

1. Introduction

Austempered ductile iron (ADI) is being used increasingly in engineering applications in recent years in view of higher strength and wear resistance being achievable in these castings without sacrifice of toughness and ductility. In addition they respond to work hardening treatments at the surface resulting in further improvement in bending fatigue strength and wear resistance. The major applications of ADI include power plants, mining, rail-road, automotive, military and agricultural industries.

The production and use of austempered ductile irons have been standardized fairly well. Conventionally ADI are made in sand moulds for specific applications. However, utilization of permanent moulds for producing ADI has specific advantages such as better surface finish, fine graphite nodules, less environmental pollution and better dimensional stability. Seetharamu et al. [1] have reported that the permanent moulded austempered ductile iron (PMADI) castings have been found to possess better abrasion and erosion resistance compared to the sand moulded counter parts. Rundman [2] suggested that permanent moulds could be used in the production of ADI castings to minimize the negative effects of alloy segregation. Sahin and Durak [3] have reported improved abrasive behavior of ADI with dual matrix structures. Further, improved fracture toughness characteristics of ADI produced by two-step austempering process have been reported by Ayman et al. [4].

Alloying additions can render ductile irons more suitable for commercial austempering because certain elements affect the solubility of carbon in the austenite, thereby influencing bainitic transformation. The alloying additions are made to improve the hardenability and also affect the mechanical properties [5]. Several researchers [6–8] have reported that ADI possesses good wear resistance than steel castings and ductile iron.

Gundlach [9] has emphasized the use of manganese as a potential austenite stabilizer to provide increased hardenability. Gagne [10] has reported the wide range of mechanical properties in ADI with varied manganese levels. Wei Bing-Qing et al. [11] have reported an increase in tensile strength when the manganese content is between 1.5–2.0%. It is reported by Nili Ahmadabadi et al. [12] that increasing the manganese content not only delays stage I of the bainitic reaction but also delays stage II transformation. Chang et al. [13] have studied the effect of austenitization temperature on the erosion behavior of austempered ductile iron. They have reported that erosion behavior of ADI is found to be microstructure sensitive, resulting in obtaining a good correlation between the erosion behaviour and mechanical properties. There is an increase in the demand for higher wear resistant material in the industries especially the utilization of ADI. Further, the information on the influence of manganese as an alloying element on the wear behavior of PMADI castings is scanty.

Hence, the paper focuses on the response of laboratory made manganese alloyed PMADI castings on the abrasion and erosion

* Corresponding author. Tel.: +91 8026721983; fax: +91 8026720886.
E-mail address: narasimhamurthy@pes.edu (K.N. Murthy).

0043-1648/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2008.12.033

Table 1
Chemical composition (wt.%) of manganese alloyed permanent molded austempered ductile iron (PMADI).

Sample designation	C	Si	Mn	Mo	S	Mg
1% Mn PMADI	3.34	2.96	1.16	–	0.03	0.040
2% Mn PMADI	3.18	2.87	2.12	–	0.03	0.041
3% Mn PMADI	3.31	2.91	3.21	–	0.03	0.040

behavior. The results are discussed in terms of microstructural features; hardness, abrasion and erosion resistance and strength. Further, the work reports on the optimum level of manganese that can be added to PMADI castings to achieve the best abrasion and erosion resistance as well as strength.

2. Experimental

The experimental work consists of melting and casting, austempering heat treatment followed by characterization work on wear (abrasion and erosion), tensile and microstructure.

2.1. Induction melting and casting

Ductile iron castings were made using a coreless induction furnace of 15 kg capacity. The charge material used was low manganese carburized steel of low sulfur and low phosphorus content. Carbon additions were made using petroleum-coke. Ferro-silicon addition was made to control the silicon content, and to make up different levels (i.e., 1%, 2% and 3%) of manganese, ferro-manganese was added. The melt was superheated to 1500 °C and treated with ferrosilicon-magnesium alloy and post-inoculated using ferro-silicon (inoculation grade). The melt was poured at 1400–1425° C into a pre-heated (200 °C) grey cast-iron mould after de-slagging. The mould was instrumented with thermocouples to measure the temperature. The casting obtained had dimensions of 150 mm × 125 mm × 25 mm. All castings were stripped from the mould at room temperature. Table 1 shows the chemical composition (weight percent) of the castings made. Fig. 1 shows the location of the samples prepared for wear and tensile tests.

2.2. Austempering heat treatment

The test samples of size 75 mm × 25 mm × 6 mm taken from the castings were given an austenitization soak at 900 °C followed by austempering in a salt bath held at 300 °C for 60 min. The salt bath temperature was monitored using thermocouple placed very close to the test sample. The salt bath size (250 mm diameter and 250 mm height) was good enough to control the temperature of the bath and remained constant during quenching. The austempering time in the salt bath was fixed at 60 min. The austempered samples were prepared by cutting and grinding process to the required sizes and subsequently used for wear and tensile tests after removing the decarburized layer.

2.3. Hardness

The hardness of the samples were measured in the Rockwell “C” scale using a diamond cone indenter at a load of 150 kg. Here, the average value of six readings on two representative samples were noted.

2.4. Microstructure

The microstructures of as cast and austempered samples were examined under an optical microscope. The retained austenite content of the samples was determined using a Phillips X-ray diffractometer with cobalt radiation (30 kV and 30 mA). It was assumed that the matrix and retained austenite amount to 100%.

2.5. Dry sand rubber wheel abrasion test

Silica sand with AFS No.60 is made to flow from a hopper between the sample (size:75 mm × 25 mm × 6 mm) and chlorobutyl rubber wheel at a speed of 200 rpm. The test was conducted at a load of 13 kg for 6000 revolutions as per the ASTM G-65 guidelines. The test sample was cleaned in an ultrasonic cleaner and accurately weighed using a digital balance before the test. At the end of the test, the sample was again cleaned and accurately weighed in the same balance. The loss of weight in the specimen determined was converted to volume loss by using the measured density value. The abrasion volume loss was expressed as the vol-

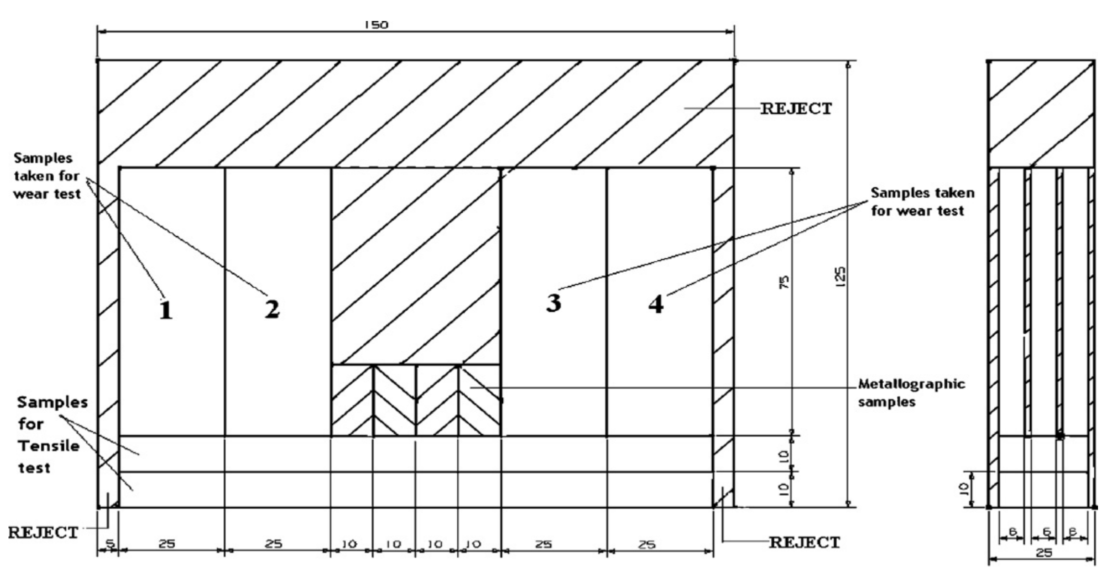

Fig. 1. Sketch showing the locations in the casting from where the test samples were taken (dimensions in millimeters).