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ScienceDirect

Materials and Design 28 (2007) 1844–1850

Materials & Design

www.elsevier.com/locate/matdes

Abrasive wear behaviour of austempered ductile iron

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Received 21 June 2005; accepted 11 April 2006
Available online 27 June 2006

Abstract

This paper presents a study of the abrasive wear behaviour of austempered ductile irons (ADI's) with dual matrix structures under different conditions. The wear resistance model was developed based on the type of the material, applied load and sliding distance. The orthogonal array and analysis of variance were employed to find out which design parameters significantly affect the quality characteristic. The experimental results show that the sliding distance was the major parameter among other control factors on abrasive wear of both types of materials, followed by applied load for ADI's austempered at 180 min. For ADI's austempered at 60 min, however, type of the material played a significant effect on the abrasive wear, followed by applied load. Moreover, a good agreement between the predicted and actual wear resistance was observed at 95% confidence level.

Keywords: Austempered ductile iron; Orthogonal array; Wear; Load; Sliding distance; Analysis of variance

1. Introduction

Austempered ductile iron (ADI) has attracted much attention for its excellent mechanical properties such as high strength, toughness and excellent fatigue strength. The resulting properties are strongly dependent upon the time and temperature of the austempering treatment [1,2]. Because of these properties, ADI has become increasingly important for the manufacturing of components such as gears, crankshafts, camshafts and rolls [3,4]. The developed ductile cast iron with dual matrix structure consists of ferrite, and martensite or ausferrite which is called dual matrix structure (DMS). The ADI with DMS has been found to be validated for suspension parts of the automotive owing to its higher ductility than the conventionally heat treated ADI. The ADI with DMS is obtained by the intercritical austenitization, partially austenitizing, the ductile iron in two-phase region and then austempering for a given time. Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components, particularly abrasion. Wear resistance, is not an intrinsic property of the material but depends upon the tribological system, such as properties of materials tested, abrasive grit size, test condition, equipment, and environment [5–7]. In order to obtain optimal wear properties, an accurate prediction of wear of ADI's is essential. Therefore, several mathematical models based on statistical regression techniques have been constructed to select the proper testing conditions [8–11]. The Taguchi's design can be further simplified by expanding the application of the traditional experimental design to the use of orthogonal array.

Most of the study has been focused on the experimental work of dry wear behavior of ductile iron, cast iron, compact graphite iron and ADI's [12–18]. However, a few research works have been conducted on the abrasive wear of ADI sample [19–24]. Furthermore, no efforts have so far been made to optimize the wear resistance of ADI with DMS using a statistical analysis. The aim of the present study is, therefore, to investigate the wear behaviour of ADI'samples with dual matrix structures based on the

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doi:10.1016/j.matdes.2006.04.015

Taguchi method under various testing conditions. Furthermore, the analysis of variance is employed to investigate the testing characteristics of ADI's with dual matrix structures.

2. Experimental details

2.1. Experimental procedure

The ductile iron was produced in a medium frequency induction furnace in a commercial foundry. The tundish cover ladle method was used to treat a 250 kg melt of iron with 6–7% Mg containing ferrosilicon alloy at 1450 °C. Final inoculation was carried out with a 75% ferrosilicon alloy. The melt at the temperature between 1450 and 1400 °C was cast into Y block sand mould which was prepared in accordance with ISO 1083. The dependence of austenite (martensite at room temperature) volume fraction on intercritical annealing temperature (ICAT) was determined. Samples $10 \times 10 \times 5$ mm thick machined from the bottom section of Y-block were annealed for 20 min in normal atmosphere at a series of temperatures from 780 °C to 840 °C for lower and upper critical temperature, respectively. They were then quenched into water held at room temperature. Austenite formed during intercritical annealing was assumed to transform into martensite (Table 1). Cast sample was labeled as "A" for the coming section. Specimens $10 \times 10 \times 5$ mm thick machined from the bottom section of Y block of as cast structure A were intercritically annealed at various temperatures of 795 and 815 °C for 20 min. The specimens were then rapidly transformed to a salt bath containing 50% $KNO_3 + 50\%$ $NaNO_3$ held at 365 °C for austempering various times to produce dual matrix structure with different ausferrite volume fractions (AFVF) in ferrite matrix. The specimens were coded according to starting microstructure and intercritical annealing temperature (ICAT). For example, in specimen code A795, A815, A stands for starting microstructure and 815 for ICAT. The conventionally heat treated sample is also coded as a C900. The cast samples were heat-treated at the conventional austenitizing temperature of 900 °C in austenitic single-phase region (γ) for 60 min and then rapidly transforming to austempering temperature at 365 °C and holding at this temperature for various times, and then air cooling to room temperature. The proportions of the constituents present were determined by point counting on nital etched metallographic sections. Hardness measurements were made using an Instron Wilson Tukan 2100 Version 1-36,7 hardness-testing machine. At least five indents were made and the average values were taken for each condition.

2.2. Experimental design

The experiments were carried out to analyze the influence of control parameters on weight loss of ADI workpieces. The code and levels of control parameters are shown in Table 2. This table shows that the experimental plan had three levels. A standard Taguchi experimental plan with notation L9 (2^4) was chosen (Table 3). In the Taguchi method, the experimental results are transformed into a signal-to-noise (S/N) ratio. The Taguchi method uses the S/N ratio to measure the quality characteristics deviating from the desired values. There are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the-nominal-the-better. The S/N ratio for each level of testing parameters is computed based on the S/N analysis. Moreover, a statistical analysis of variance is performed to see which test parameters are statistically significant. With S/N ratio and ANOVA analyses, the optimal combination of the testing parameters can be predicted.

2.3. Wear test

A pin-on-disc type of apparatus was employed to evaluate the abrasive wear characteristics of materials. The specimens were 6.4 mm in diameter and 6 mm long. To form a pin of the necessary length the ADI cylinders were bonded using an epoxy adhesive to a 50 mm long steel extension pin of the same diameter. A brass sleeve was fitted over the joint for extra strength. The wear pin was held in a brass holder in wear machine. The emery paper was fixed to a 12 mm thick and 160 mm diameter steel wheel to serve as the abrasive medium. The samples were ground using #800 SiC paper to remove the rough surface layer. The samples were loaded against the abrasive medium with the help of a cantilever mechanism. In this method, the specimens experienced continuous motion while the abrasive changed its position by the time the specimen completed its cycle or the corresponding travel distance. The specimen was continuously in contact with a new abrasive paper. A silicon carbide (120 grit SiC) abrasive is substantially harder than either as cast, ADI and C900 samples were used. After the test, the wear pin was ultrasonically cleaned in acetone prior to and after the wear tests, then dried after being weighed on a micro-bal-

Table 1
The metallographic measurements and some properties of tested samples

Sample code and austenitized temperature	Austenitized time (min)	Ausferrite volume fraction (%)	Marten, volume fraction (%)	Total elon (%)	Hardness (HV5)
A795	60	13.4	6.58	26	195
A795	180	15	0	24.5	205
A815	60	28.4	23.15	19.66	253
A815	180	42.4	0	20	240
C900	60	56.2	33.55	10.62	324
C900	180	89.7	0	10.0	315

Table 2
Control factors and their levels

Parameter	Code	First level	Second level	Third level	
Type of material	A	S795-60	S815-60	G-900-60	ADI's austempered at 60 min
Applied load (N)	B	10	20	30	
Sliding distance (m)	C	30	60	90	
Type of material	A	S795-180	S815-180	G-900-180	ADI's austempered at 180 min
Applied load (N)	B	10	20	30	
Sliding distance (m)	C	30	60	90	