Materials and Design 89 (2016) 815–822

Contents lists available at ScienceDirect

Materials and Design

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

Wear and friction behavior of austempered ductile iron as railway wheel material

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ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form 24 April 2015
Accepted 10 October 2015
Available online 22 October 2015

Keywords:
Austempered ductile iron
Wear
Coefficient of friction
Delamination

ABSTRACT

Austempered ductile irons (ADIs) with three strength grades and one kind of wheel steel were matched with conventional rail steel and rolling-sliding wear tests were conducted. The results show that the wear rate decreases while the friction coefficient increases with the increase of matrix hardness. The increase of subsurface hardness is due to work-hardening and stain-induced transformation of retained austenite to martensite. The main wear mechanism is delamination and becomes mild with the increase of matrix hardness. ADI austempered at 340 °C shows the reasonable friction and wear behavior as well as relatively superior mechanical properties.

1. Introduction

Austempered ductile iron (ADI), with an ausferrtic matrix microstructure, characterized by the presence of bainitic ferrite and retained austenite can be obtained by austempering treatments on ductile iron. This special microstructure provides a good combination in mechanical properties, covering high tensile strength and good ductility, high fatigue strength and fracture toughness, and superior wear resistance [1–5]. Because of these advantages, ADI has been emerged as an important engineering materials in recent years and used extensively in many structural applications in automotive industry, defense and earth moving machineries, etc. [6–8]. Many of these are subjected to rolling and sliding wear. Therefore lots of investigations on the friction and wear behavior of ADI have been reported [9–14].

With the raising speed and weight in rail traffic, the property optimization of wheel material draws more and more researchers' attention. The optimization is based on balancing the cost, weight, wear resistance, noise reduction and rolling contact strength [15]. Compared with traditional steel, ADI exhibits high strength, toughness and three times higher damping which can substantially lower the traveling noise. In addition, ADI has 10% lower density because of the graphite nodules dispersed in the matrix, which promises a decrease in components' weight. So it is considered that ADIs are suitable as an alternative material for railway wheel [16]. In fact, ADI has been applied to railway wheel successfully in Europe [17]. Though the wear tests on ADI have been conducted a lot, investigations on tribological performance of ADI matched with rail steel are not enough, while it is important for the designers to consider it as wheel material. Especially, research on wear and friction behavior of ADIs with different strengths is limited, that has kept the field of ADI in railway applications because of the fact that reasonable hardness matching plays a significant role for increasing service life of wheel/rail materials. Meanwhile, the wear and friction properties are not only attributed to the relevant material itself, but also strongly depend on the environment and other experimental conditions, such as temperature and humidity. [18–20] when the railcar runs at a high speed, strong wind will be caused and it will induce cooling effect on the wheel. Though the results of dry and uncooling tribological tests show excellent wear resistance performance, the tribological properties of ADI under cooling condition have not been investigated.

In the present investigation, the dry rolling-sliding wear tests of ADIs with three strength grades were conducted. Considering the air cooling in the actual operation, the testing procedure incorporated a blast of dry compressed air to simulate actual running contact conditions and prevent the oxidation at high temperature. For comparison, a widely used railcar wheel steel ER8 was also investigated under the same wear conditions. Meanwhile, the microstructure, friction and wear behavior as well as wear mechanism of three strength grades ADIs were discussed in detail.

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http://dx.doi.org/10.1016/j.matdes.2015.10.037
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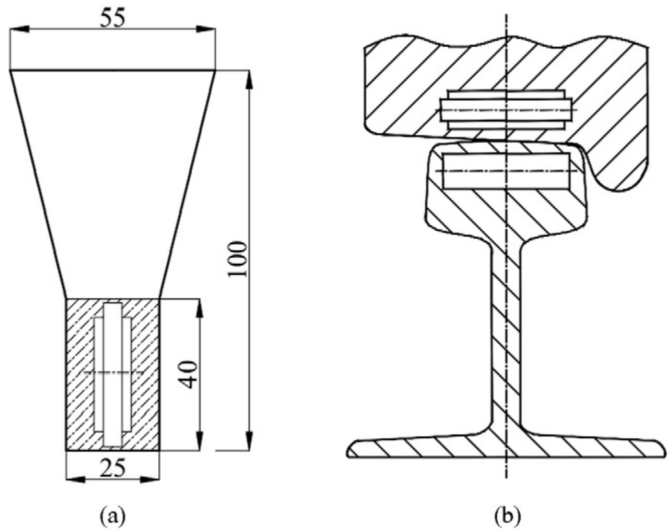

Fig. 1. Positions from where the test blanks were taken. (a) ADIs disks were taken from the bottom of ductile iron Y-blocks, (unit: mm); (b) wheel and rail steel disks were taken from railway wheel tread and railhead.

2. Experimental procedure

2.1. Material and processing

Wheel specimens of ADIs used for dry rolling-sliding wear testing were machined from ductile iron keel blocks (Fig. 1(a)). For comparison, specimens codenamed ER8 cut from railway wheel tread were also used to carry out the study. Specimens for rail codenamed U75V were gained from the top surface of railhead showed in Fig. 1(b). The main chemical compositions and hardness of ER8 and U75V are given in Table 1. By controlling the heat treatment, three strength grades ADIs (shortened as ADI1, ADI2 and ADI3) with different matrix structures were obtained. Table 2 shows the mechanical properties of ADIs and heat treatments employed on the ductile irons.

2.2. Test equipment and conditions

2.2.1. Tensile and impact testing

After machining to final dimensions, tensile testing was carried out based on ASTM standard E-8 [21]; five samples were tested in each heat treated conditions. The tests were performed on a servo-hydraulic MTS (Material Test System) test machine. All of the samples were tested at room temperature and ambient atmosphere. Load and displacement plots were obtained on an X-Y recorder; from these load–displacement diagrams, the ultimate tensile strength and elongation values were calculated. Impact toughness of the ADI samples was measured by the Charpy impact test. Tests were performed at room temperature with unnotched specimens, three samples were tested in each grade of ADI.

2.2.2. Wear testing

Dry rolling-sliding wear tests were carried out on an Amsler type tribotester on the basis of the Chinese standard GB 12444. 1–90 [22].

Table 1
Main chemical composition of the test materials.

Material	Compositions(%)					Hardness (HV0.2)
	C	Si	Mn	P	S	
Ductile iron	3.7	2.6	0.19	0.025	0.013	–
ER8	0.51	0.93	0.93	0.009	0.001	325
U75V	0.75	0.7	0.95	≤0.03	≤0.03	350

Table 2
Heat treatment and mechanical properties of ADIs specimen.

Sample	Heat treatment		Ultimate tensile strength (MPa)	Elongation (%)	Impact energy (J)
	Austenitized	Austempered			
ADI1	910 °C/120 min	380 °C/60 min	963	11.2	125
ADI2	900 °C/110 min	340 °C/60 min	1140	10.2	115
ADI3	910 °C/150 min	300 °C/120 min	1290	7.5	98

This twin-disk rolling-sliding testing machine can provide a load range of 0–2000 N and promise a line contact between the two cylindrical test disks which simulates the normal load and slip presenting at rail/wheel contact area. Fig. 2 shows the dimensions and shapes of rolling-sliding wear test specimens and schematic representation of the wear apparatus. The upper disk is made of railway steel U75V with a diameter of 40 mm, while the lower disks are made of three grades strength ADIs and one kind of wheel steel ER8 with a same diameter of 38 mm. The contact width between the test disks is 5 mm. The rotation speeds of the upper disk (rail material) was 180 rev/min compared to 200 rev/min for the lower disk (wheel material). This results in a 0.0209 m/s sliding speed in the tests. To simulate the wearing condition in actual running operation, all wear tests were carried out under a high contact load of 870 N. The maximum Hertzian contact pressure, P_0, and the contact length, a, between the test disks can be obtained by the following equations quoted by Johnson [23]:

$$P_0 = \sqrt{P/\pi bRE^*} \tag{1}$$

$$a = \sqrt{4PRE^*/\pi b} \tag{2}$$

$$E^* = \left(1 - v_1^2\right)/E_1 + \left(1 - v_2^2\right)/E_2 \tag{3}$$

where P is the contact load (N), b is the line contact width (mm), E_1 and E_2 is the modulus of elasticity of rail (upper) and wheel (lower) disk in GPa, respectively, R is given by:

$$R = R_1R_2/(R_1 + R_2) \tag{4}$$

where R_1 and R_2 are the radii (mm) of the rail (upper) and wheel (lower) disk, respectively.

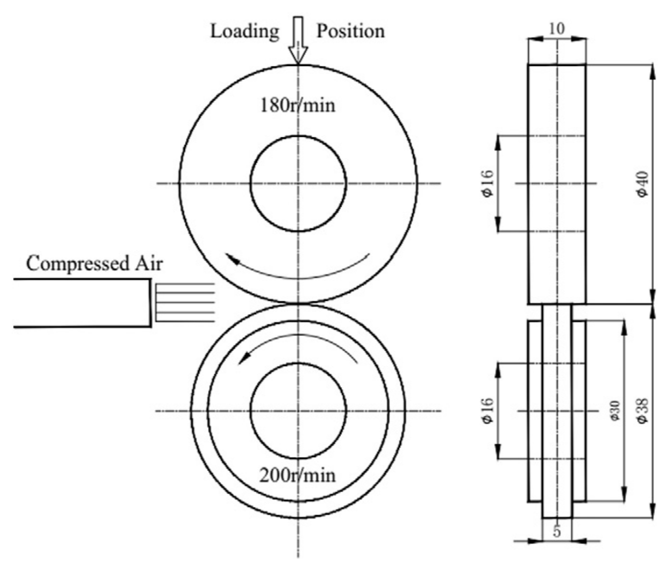

Fig. 2. Schematic diagram of wear tests (unit: mm).