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Dry rolling-sliding wear of austempered cast iron

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ABSTRACT

In the present investigation, the dry rolling-sliding wear of two austempered ductile irons (ADIs), characterized by different hardness values, was investigated. The tests were carried out using disks with 40 mm diameter and 10 mm height. The applied load was in the range between 50 and 500 N. Since the initial Hertzian pressures were quite large because of the line contact, a plasticity dominated wear with the formation of delamination was obtained. Therefore, the treatment cycle of some specimens was conducted with the aim of obtaining a mild wear during rolling-sliding through the formation of a surface oxide layer. As a comparison, the dry rolling-sliding wear of a gas nitrided steel was also investigated.

The results show that the wear coefficients of the specimens with the oxide layer on their surface was actually mild. However, the specimens produced without such a layer displayed even lower wear coefficients. Although wear was by delamination, wear coefficients were still low because of the action of graphite, which was able to squeeze on the surface during sliding, thus reducing adhesional forces. In addition, a mechanically mixed layer formed on the sliding surfaces, and this provided an additional increase in the wear resistance. Because of this, the material with lower matrix hardness displayed a greater wear resistance. The wear resistance of the nitrided steel was found to be determined by the outer part of the compound layer, and it was found to be lower than that displayed by the two ADI.

1. Introduction

With austempering treatments on ductile iron, it is possible to obtain an interesting matrix microstructure consisting of ferrite and retained austenite. Such a microstructure provides a good balance in the mechanical properties, including tensile strength, ductility and toughness [1].

In the literature, several investigations on the dry sliding behaviour of austempered ductile irons (ADIs) are reported. In particular, the role of matrix hardness and graphite nodules was investigated [2,3]. In addition, the role of the tribological parameters, such as load, sliding velocity and test duration, in mild oxidative wear and in the transition from mild to severe wear by delamination was also studied by several authors [4–6].

In order to favour the use of ADI in engineering applications, it is clearly necessary to investigate their rolling-sliding behaviour, since several mechanical parts, like gears, experience this contact conditions during operation [7]. Sugisghita and Fujiyoshi [8] investigated the role of graphite nodules on the dry rolling-sliding behaviour of nodular cast iron with a ferritic–pearlitic matrix microstructure. They found that graphitic films are formed during rolling-sliding owing to the release of the graphite nodules and the formation of a squeeze film. This shows that such materials are very promising for rolling-sliding applications.

In the present investigation, the dry rolling-sliding wear of two ADIs, characterized by different matrix hardness, but roughly with the same graphite content and same dimension of the graphite nodules, was investigated. Because of the line contact, large contact pressures are attained in rolling-sliding conditions. Wear is then usually by delamination and may be severe in nature [7]. In order to obtain a mild form of wear, some specimens were thus produced with a different cycle, to induce the formation of an oxide layer on their surfaces. For a comparison, a widely used nitrided steel was also investigated. In fact, nitrided steels are often used in engineering applications characterized by rolling-sliding conditions.

2. Experimental procedure

The study was carried out on the materials listed in Table 1. The cast irons were produced in an industrial foundry. For the ADI 800 an austempering cycle was adopted comprising austenitization in the range 840–870 °C and austempering in a salt bath at 380–400 °C. For the ADI 1050, austenitization was carried out at 840–870 °C and austempering at 370–390 °C. The specimens for the rolling-sliding tests were produced by machining the heat-treated blocks. Some specimens of ADI 1050 were produced before the

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Table 1
Chemical composition of the materials under study (wt%) and treatment cycles.

Material	Chemical composition	Treatment cycle
ADI 800	3.13%C, 0.15%Mn, 2.34%Si, 0.022%P, 1.1%Ni, 0.28%Mo, 0.69%Cu	Austempering and specimen machining
ADI 1050	3.84%C, 0.15%Mn, 2.34%Si, 0.017%P, 1.1%Ni, 0.24%Mo, 0.7%Cu	Austempering and specimen machining
ADI 1050-Ox	3.84%C, 0.15%Mn, 2.34%Si, 0.017%P, 1.1%Ni, 0.24%Mo, 0.7%Cu	Austempering after specimen machining
42CrMo4	0.39%C, 0.77%Mn, 0.25%Si, 1%Cr, 0.1%Ni, 0.15%Mo, 0.23%Cu	Quenching, stress relieving, specimen machining and gas nitriding

austempering cycle. The successive heat-treatment therefore produced an oxide layer on the surface of the specimens. This material is codenamed ADI 1050-Ox.

For a comparison, steel specimens submitted to a conventional gas nitriding cycle (30 h at 515 °C and 40 h at 540 °C) were also produced. The steel is codenamed 42CrMo4, and its chemical composition is included in Table 1.

The specimens were disks with a diameter of 40 mm and a height of 10 mm. Dry rolling-sliding tests were carried out on an Amsler type tribotester. In Fig. 1a schematic representation of the apparatus is shown. Specimens of identical material and treatment ran against each other, with a 10% difference between the rotation speeds of the two disks (400 rev/min for the upper disc and 360 rev/min for the lower disc). The sliding velocity was therefore 0.084 m/s. On the basis of literature data and previous experience, the following applied loads were selected: 50, 100 and 500 N [7,9]. The tests were carried out at room temperature and weight changes of the upper disc were measured with a precision balance at intervals of 10, 20, 50 and 80 min. The upper disc is the driven one and is characterized by a larger wear damage and subsurface straining because of the particular stress and strain field that occur on the surface of the disc as a consequence of contact pressure and friction coefficient [7,9]. The evolution of friction coefficient was also monitored during each test.

The microstructure of the materials was evaluated by optical microscopy after etching with 2% Nital solution. The amount and dimension of the graphite nodules were determined by means of image analysis system interfaced with the optical microscope. The phase constitution of the materials was determined by X-ray diffractometry (employing Cu Kα radiation). The relative amounts of the phases were determined using the Rietveld analysis [10].

The wear mechanisms were investigated by microstructural investigations of the cross-sections of the worn specimens and the morphological characterization of the worn surfaces. The surface and subsurface layers were also analyzed by means of microhardness measurements using a Vickers indenter and a load of 50 g.

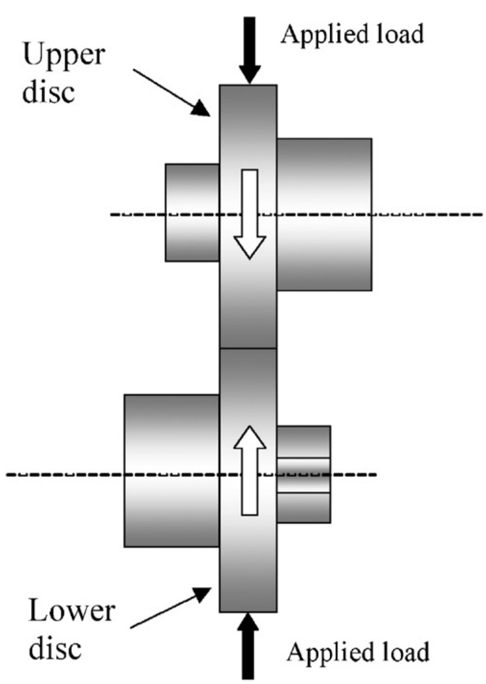

Fig. 1. Schematic representation of the testing rig.

3. Results

3.1. Microstructures

Fig. 2 shows the microstructure of ADI 800. The matrix is characterized by the typical microstructure of austempered irons, i.e., by the presence of bainitic ferrite and retained austenite. According to X-ray diffraction the amount of retained austenite was 8%. The fraction of graphite nodules was 7%, the average dimension of the graphite nodules was 43.8 μm and the matrix microhardness was 350 HV 0.1. The ADI 1050 displayed a similar microstructure. The content of retained austenite was 12% and the matrix microhardness was 470 HV 0.1. The fraction of graphite nodules was 8%, and the average dimension of the nodules was 42.8 μm.

Fig. 3a shows a cross section of material ADI 1050-Ox at the surface. The presence of a surface oxide layer can be appreciated. Its thickness is in the range 8–10 μm, as obtained by measurements from the metallographic observations. It can be also noted that the oxide is quite defective. A more compacted morphology could be obtained after optimization of the treatment cycle. In addition, oxidation involved also the interface between graphite and the matrix in the case of the nodules emerging at the surface. This caused the expulsion of the surface graphite nodules. Fig. 3b shows the XRD spectrum of the surface of the specimen. The spectrum revealed the presence of Fe_3O_4 (magnetite) and Fe_2O_3 (hematite), in addition to the ausferrite and the retained austenite present in the underlying matrix. The estimated fraction of hematite is 32% and that of magnetite is 16.5%.

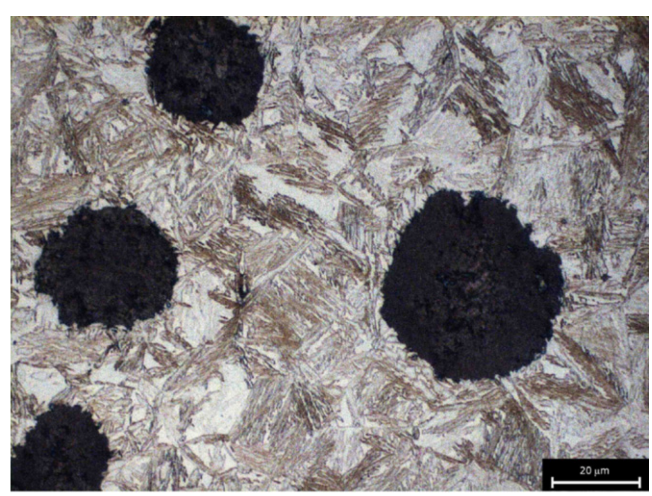

Fig. 2. . Microstructure of ADI 800.