Wear 302 (2013) 829–836

Contents lists available at SciVerse ScienceDirect

Wear

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

Tribological behaviour of shot peened Cu–Ni austempered ductile iron

A. Zammit [a,*], S. Abela [a], L. Wagner [b], M. Mhaede [b], M. Grech [a]

[a] Department of Metallurgy and Materials Engineering, Faculty of Engineering, University of Malta, Msida MSD 2080, Malta
[b] Institute of Materials Science and Engineering, Clausthal University of Technology, Agricolastrasse 6, D-38678 Clausthal-Zellerfeld, Germany

ARTICLE INFO

Article history:
Received 6 August 2012
Received in revised form
10 December 2012
Accepted 13 December 2012
Available online 23 December 2012

Keywords:
Austempered ductile iron
Sliding wear
Shot peening
Phase transformation

ABSTRACT

Wear and fatigue properties of power transmission components are usually improved by various surface engineering processes. One surface modification process is shot peening which is generally carried out to improve bending fatigue. However there are contrasting studies meant to investigating whether shot peening actually increases the sliding wear resistance of austempered ductile iron (ADI). Unlubricated wear tests were conducted on ground ADI and shot peened ADI pins. Hardness measurements of the worn ADI surfaces showed a 19% increase in hardness after testing at low loads, possibly due to strain hardening and frictional heating. Metallography of the worn surfaces showed a distorted microstructure at the surface, indicative of surface flow. On the other hand, samples tested at high loads showed a 73% increase in hardness. A white non-etchable layer which was identified as untempered martensite formed upon cooling of wear test samples. Calculation of the wear factors and friction coefficients showed that shot peening does not improve the wear resistance. This has been attributed to the fact that the potential advantages resulting from the higher hardness at the surface, stress-induced austenite to martensite transformation and the residual compressive stresses of the shot peened specimens are counteracted by the induced surface roughness.

1. Introduction

Careful selection of austempering heat treatment parameters applied to ductile iron results in a variety of microstructures and a correspondingly wide range of bulk mechanical properties. This renders austempered ductile iron (ADI) a potential alternative to steel, having comparable strength and toughness, lower density and greater damping capacity, combined with excellent castability. ADI is in fact suitable for automotive components such as crank shafts, connecting rods and transmission gears [1,2].

It has been reported [3–6] that the unique wear behaviour of ADI is affected by the presence of surface graphite nodules as well as the ability of the retained austenite, which is metastable at room temperature, to transform to martensite when loaded. Straffelini et al. [4] show that ADI exhibited a lower coefficient of friction and wear coefficient than that of nitrided steel during dry rolling-sliding wear testing. The authors attribute this to the smearing of graphite on to the surface which in turn served as a solid lubricant between the two wear surfaces. Straffelini et al. [4] determined the wear mechanism occurring during sliding of austempered ductile iron by using the wear-mechanism maps described by Lim and Ashby [7]. The latter authors gave graphical presentations of wear phenomena showing the wear rate and the wear mechanism dominance in steel/steel tribocontacts over a wide range of loads and sliding speeds.

Surface engineering techniques are usually applied to improve the surface properties namely by changing the microstructure or the composition of the surface. This can be achieved by thermal, chemical, thermochemical or mechanical treatments. Tan et al. [8] reported that after laser hardening, the surface hardness and abrasive wear resistance of nodular cast irons could be considerably improved due to a predominantly martensitic structure produced in the hardened zone. Lu and Zhang [9] obtained relatively high sliding wear resistance for both austempered and laser-hardened Cu–Mo ADI specimens when compared to ductile iron specimens. This was attributable to the strain-induced martensite transformation of the retained austenite occurring during the wear process and the martensite formed during laser processing. In addition, Xue et al. [10] reported that ADI specimens with and without laser hardening showed a higher contact fatigue resistance than that of induction hardened steel.

Shot peening (SP) is a conventional mechanical surface treatment that may be used to improve the fatigue strength of automotive components subjected to fatigue loading. In this process, the surface of a material is bombarded with a flow of spherical media, creating a layer of compressive residual stress and inducing high dislocation densities [11]. The compressive layer induced by shot peening increases the resistance to crack

* Corresponding author. Tel.: +356 2340 2066; fax: +356 21343577.
E-mail address: ann.t.triccas@um.edu.mt (A. Zammit).

0043-1648/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2012.12.027

initiation and propagation which in turn prolongs the lifetime of components. However, as the spherical shots hit the surface, dimples are formed which roughen the surface. The surface finish of mating surfaces affects the wear resistance of components. This combination of a high friction coefficient at the beginning of the test and a work hardened surface was also observed by Ohba et al. [12] when studying rolling contact fatigue properties of ADI. Similar findings were also reported by Ho et al. [13] who showed that shot peening did not improve the sliding wear resistance of annealed 1018 steel, but it did decrease the wear rate of hardened 4340 steel. On the other hand, work by Vaxevanidis et al. [14] showed that shot peening had a beneficial effect on the tribological behaviour of steel.

A large number of studies have shown that shot peening improves the bending fatigue strength [15–19]. However, very few works have been conducted on the tribological behaviour after shot peening, and it is thus not clear whether it actually improves the wear resistance. This paper compares the sliding wear behaviour of ground ADI with shot peened ADI specimens tested under dry conditions.

2. Experimental procedure

2.1. Material and processing

Test pins of 5 mm diameter used for the pin-on-disk wear testing were machined from ductile iron keel blocks, having the composition shown in Table 1. After machining, samples were austenitised at 900 ± 2 °C, and then rapidly quenched in a salt bath at 360 ± 5 °C and held for 1 h. The samples were then air cooled to room temperature. These austempering parameters were optimised in a previous study [20]. Samples were coated using a dedicated paint (SEMCO Zir H) to prevent decarburisation during the austempering process.

Test disks of 90 mm diameter were made out of D2 tool steel of chemical composition shown in Table 2 and heat treated to a hardness of 61 HRC. The heat treatment cycle consisted of preheating, followed by austenitising at a temperature of 1025 °C and then quenching using nitrogen at a pressure of 5 bar. After that, the disks were tempered at a temperature of 190 °C for 3 h.

2.2. Surface treatment

After heat treatment of both pins and disks, the surfaces were ground up to a mean surface roughness R_a of 0.2 μm. After grinding, half of the pins were shot peened. Shot peening was carried out using S330 shots, with an Almen intensity of 0.38 mmA up to 100% coverage. The stand-off distance was 90 mm while the angle of impingement was set at 90°. The surface roughness R_a of the shot peened pins was measured to be 3.7 μm.

2.3. Characterisation

The microhardness measurements were taken using a Mitutoyo MVK-H12 microhardness tester. Three measurements for the hardness were taken. The coefficient of variation (the ratio of standard deviation to the mean) of the measurements was in all cases below 5%.

Phase analysis before and after shot peening was carried out using the X-ray diffraction method and a Bruker D8 Advance X-Ray diffractometer (Mo-K_α radiation). The scanning step was 0.01°, the dwell time 0.2 s and 2θ values between 15 and 40°. The tube acceleration voltage and current used were 45 kV and 35 mA, respectively. The XRD patterns obtained were subjected to the Savitzky–Golay smoothing filter which performs a local polynomial regression to the raw data reducing the signal noise [21]. A 3rd order regression was found to preserve features of the pattern including relative maxima and width of peaks. The retained austenite content (γ_{ret}) in the ADI was measured with the X-ray diffractometer using the simplified method described by Miller [22].

2.4. Test equipment and conditions

Dry sliding wear tests were carried out using a conventional pin-on-disk tribometer capable of maintaining a constant unidirectional, sliding velocity between the pin and disk. The machine used was an Italdesign TR-20 which allowed control of the load, velocity, duration of test and radius at which the pin acts on the disk. In this study, a cantilever loaded flat ended cylindrical ADI pin was made to slide over a rotating hardened steel disk. The pin was fixed to one end of the cantilever arm, and the other end was attached to displacement and force transducers. The tribometer was connected to a computer which monitored and recorded the displacement of the pin and disk and the frictional force.

Tests followed ASTM G99-05 (*Standard test method for wear testing with a pin-on-disk apparatus*) procedures and were carried out in ambient air held at room temperature. Tests were performed at two values of pressure acting between the cylindrical surface of the pin and the horizontal rotating disk namely at 2.5 and 10 MPa, while the sliding distance, sliding velocity and radius at which the pin acted upon the disk were kept constant at 3.6 km, 4 m/s and 26 mm, respectively.

Before and after tribological tests, both the pins and the disks were cleaned for 10 min in an acetone ultrasonic bath, and then rinsed in isopropanol and dried in a jet of hot air. For each experiment, a new pin and new counter body were used. The mass of both the pins and the disks was measured before and after each test using a digital balance having an accuracy of ± 0.1 mg. The mass lost was converted into *wear volume* W, taking the *density* ρ of the ADI material as 6890 kg/m^3. The *wear factor* K was then calculated using the relation $K=W/Fs$, where W represents the wear volume in mm^3, F is the applied load in N and s is the sliding distance in m [23]. Two surface conditions of ADI were tested namely: ground ADI (G) and shot peened ADI (SP) (Table 3). At least five sliding tests were carried out for each condition and applied load, and the average data is reported.

Table 2
Chemical composition of the steel reference disks.

Element	Cr	C	Mo	V	Mn	Si	Fe
Composition (wt%)	11.8	1.55	0.8	0.8	0.4	0.3	Bal

Table 1
Chemical composition of the keel blocks.

Element	C	Si	Cu	Ni	Mn	P	Mg	Al	S	Fe
Composition (wt%)	3.26	2.36	1.63	1.58	0.24	0.011	0.057	0.024	0.006	Bal