ELSEVIER

Tribology International 39 (2006) 748–755

TRIBOLOGY INTERNATIONAL

www.elsevier.com/locate/triboint

Friction and wear behaviour of sintered steels submitted to sliding and abrasion tests

Lorella Ceschini[a,*], Giuseppe Palombarini[a], Giuliano Sambogna[a], Donato Firrao[b], Giorgio Scavino[b,1], Graziano Ubertalli[b]

[a]*Institute of Metallurgy, University of Bologna, V.le Risorgimento 4, 40136, Bologna, Italy*
[b]*Department of Materials Science and Chemical Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy*

Abstract

Fe–C–Mo and Fe–C–Cr steels were sintered by PM processes carried out using different values of temperature and pressure, leading to different microstructures and density values. Flat specimens were submitted to tribological tests in order to evaluate their behaviour under both dry sliding and abrasive wear conditions. A flat-on-cylinder tribometer was used for the sliding tests, while a micro-scale ball cratering device was used for the abrasion tests. The dry sliding wear resistance of the PM steels was mainly influenced by the composition and sintering conditions. In this regard, the best behavior was observed for the more hardenable Fe–C–Mo steels with higher Mo content, sintered under conditions giving rise to bainitic microstructures. A determining role was also played by the porosity content and pore shape: reduction in porosity (obtained by increasing the sintering temperature and the compacting pressure), as well as an increase in pore roundness, led to a significant improvement in the resistance to sliding wear. A mild oxidative wear regime were observed for all the sintered steels under relatively low values of the applied load, while an increase of the applied load led to a delamination wear regime. The resistance to abrasive wear was low for all the tested steels, irrespective of composition and sintering cycle.

Keywords: Powder metallurgy; Sintering; Steels; Sliding wear; Abrasive wear; Friction

1. Introduction

The application of powder metallurgy (PM) manufacturing processes is growing and often it replaces traditional metal-forming operations because of a near-net shape forming capability, a more efficient material utilization, a relatively low energy consumption and capital cost [1]. In particular, the demand for PM steel components is significantly increasing and different PM steels have found applications, mainly in the automotive industry for engine and transmission systems.

The mechanical behavior of sintered steels have been studied mainly by tensile and impact testing procedures [2]. However, the demand for components displaying an adequate resistance under heavy stress conditions, e.g. engine parts and transmission gears, has promoted considerable research efforts on PM components suitable to work under dynamic conditions. The fatigue behavior of sintered parts has been widely studied, with attention to the role of microstructure and, particularly, the effect of porosity on crack initiation and propagation [3–5].

PM materials are extensively used also for the production of components subjected to working conditions giving rise to sliding, rolling or abrasive wear, such as gears or cams. Therefore, a complete understanding of their tribological behavior is important. Several results on the dry sliding behavior of sintered ferrous alloys can be found in the literature [6–11]. They generally indicate that the wear mechanisms of PM parts are similar to those displayed by wrought materials, under the same tribological conditions [12]. The literature data highlight the peculiar and complex role of porosity on the wear resistance. However, this role has not been clarified, probably also due to the strong dependence of porosity effects on the tribological testing conditions.

---

[*] Corresponding author. Tel.: +39 51 2093445; fax: +39 51 2093467.
E-mail addresses: ceschini@bomet.fci.unibo.it (L. Ceschini), gscavino@athena.polito.it (G. Scavino).
[1] Tel.: +39 011 5644675; fax: +39 011 5644699.

0301-679X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2005.07.003

In this paper sintered Fe–C–Me steels (with Me = Mo, Cr), prepared under different processing conditions leading to different microstructures and density values, were submitted to tribological tests in order to evaluate their behavior under both sliding and abrasive wear conditions. In this way, information have been obtained which are useful to: (i) improve the manufacturing process, (ii) optimize the composition and sintering conditions and, finally, (iii) to improve the friction and wear behavior of the alloy.

2. Experimental procedure

2.1. Materials

The PM steels were produced in an industrial plant using pre-alloyed Fe–Mo powders and Fe–Cr powders, whose composition is reported in Table 1. Carbon was added as fine natural graphite. Lubricant in proportion to 0.7 wt% was added to the powder-graphite mixtures.

The final composition of the sintered samples was the same of the metal powders, the carbon content resulting about 0.1% lower than that of the graphite percentage added in the mixtures. Different processing conditions were selected, in order to determine the influence of compacting pressure, sintering temperature and furnace atmosphere on the physical and mechanical properties of the PM steels. Two pressure ranges, 500–550 and 700–750 MPa, and two sintering cycles were selected: 1120 °C for 30 min in endogas atmosphere, and 1250 °C for 60 min in vacuum. The sintering conditions are reported in Table 2.

Table 1
Chemical composition of powders and alloys (wt%)

Composition		wt%	
Powder	Alloy	Powder	Graphite
Astaloy 85 Mo (Mo = 0.85%)	Fe–Mo–C (Mo = 0.85%)	99.4	0.6
Astaloy Mo (Mo = 1.5%)	Fe–Mo–C (Mo = 1.5%)	99.4	0.6
ASC 100.29 (Fe = 100%)	Fe–Cr–C (Cr = 3%)	74.70	0.6
AISI 410 L (Cr = 12%)		24.70	

The characterization of the PM steels were carried out by means of optical microscopy, also determining the volume mass and the interconnected (open) porosity (according to UNI 7825). Vickers hardness measurements ($HV_{5/15}$) were made on cross sections of the samples and Charpy tests were carried out on unnotched samples.

2.2. Sliding and abrasion wear tests

The dry sliding wear behavior of the sintered steels was studied using a slider-on-cylinder tribometer, illustrated schematically in Fig. 1(a). The tests were carried out at room temperature in laboratory air ($T = 18 \div 25$ °C, relative humidity. $45 \div 60\%$). The sintered steels were machined in the form of flat sliders ($5 \times 10 \times 55$ mm^3) and finished to a surface roughness Ra = 0.3 μm using abrasive papers up to 800 grit. The counterfacing material was a hard chromium coating ($HV_{0.3} = 1000$; Ra = 0.1 μm), electrodeposited on an AISI 1040 steel cylinder (diameter 40 mm). The sliding tests were carried out under normal loads of 5, 10 and 20 N, at 0.3 m s^{-1} speed, for sliding distances up to 10^4 m. During the tests, the friction resistance and total wear (i.e. cumulative wear of both slider and cylinder) were continuously measured by means of a bending load cell and a linear variable differential displacement transducer (LVDT), respectively, and were recorded as a function of the sliding distance. The wear of each slider was evaluated at the end of the test by measuring the maximum depth of the wear scar with a stylus profilometer (pick-up curvature radius, 5 μm). The line profiles were recorded perpendicularly to the wear scar.

The abrasion wear tests were performed using a ball-cratering micro-scale abrasion apparatus (MSAT), illustrated schematically in Fig. 1(b) [13–14]. A ball of martensitic steel (radius $R = 12.7$ mm; hardness 900 HV), clamped between coaxial shafts, rotates against the specimen under investigation (sliding speed 0.05 ms^{-1}) in presence of an abrasive slurry (Fig. 2).

The sintered sample is mounted vertically on a pivoted L-shaped arm and is loaded against the steel ball by means of a dead weight hanging from an horizontal lever. The diameter b of the spherical cap, produced on the specimen by abrasion, is measured with a calibrated optical microscope, and the value can be used to calculate the wear volume V:

$$V \approx \frac{\pi b^4}{64R} \quad \text{for } b \ll R \tag{1}$$

where R is the radius of the steel ball. A simple model for abrasive wear of bulk materials (equivalent to the Archard equation for the sliding wear) can be used and leads to the following equation for the wear volume V:

$$V = kSN \tag{2}$$

where S is the total sliding distance of the sphere relative to the specimen surface, N the normal load, k the wear coefficient or specific wear rate. Therefore, the wear rate can be calculated from Eq. (2) for each set of experiments.

The abrasive medium was a slurry of SiC particles (size 4–5 μm) in distilled water, with a concentration of 0.75 g cm^{-3}, maintained and replenished at the contact region by a slow constant drip feed ($\sim$0.25 cm^3 min^{-1}). The slurry was stirred continuously throughout the test to prevent settling of abrasive particles. All tests were