The Effect of Sliding Friction Rate and Contact Pressure Variation on the Wear of Ferrous Materials Having Different Densities

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Abstract

Oil-impregnated ferrous sintered materials were submitted to dry-wear tests in air, using an AMSLER machine, with the aim of a tribological chara-racterization of sintered materials.
As-received, oil-impregnated and steam-treated ferrous sintered materials with 10% sliding friction rate, four different densities (6,5;6,8;7,1;7,3 g/cm³) and different reactive environments (argon, air, oxigen) had been tested in previous works; the present work was focused on testing oil-impregnated sintered materials with different sliding friction rates (0%, 5%, 10%, 100%) and different contact pressures, observing the effect of oil during the sliding contact.

Riassunto

Con lo scopo di una caratterizzazione tribologica di materiali sinterizzati, sono state effettuate prove di usura a secco, in aria, con un tribometro Amsler.
In precedenti lavori sono stati studiati i fenomeni di usura per sinterizzati ferrosi tal-quali e trattati a vapore, con uno stesso tasso di strisciamento (10%), per quattro densità (6.5, 6.8, 7.1, 7.3 g/cm³) e per differenti ambienti (argon, aria, ossigeno); in questo lavoro, i sinterizzati imbibiti sono stati provati in aria variando sia il tasso di strisciamento (0%, 5%, 10%, 100%) che la pressione di contatto.
Sono stati osservati gli effetti della presenza dell'olio durante il contatto strisciante.

Introduction

Powder metallurgy and sintering show many advantages as alternative technologies to traditional metallurgy in the creation of complex shape particulars, as gear wheels, not only for the high level of accuracy reached, but also for the reduction of manufacturing costs (1).
Sintered materials, in fact, do not need chip machining, being formed by pressing; then, due to their porosity, they can be efficiently recovered by polymeric materials or impregnated with oils.
This last feature permits surface autolubrication during service, thanks to the pores content of oil, and gives the possibility of reducing all wear phenomena which appear during the normal service of gear wheels due to lubrication difficulties (2).

Materials Used and Test Methodology

Dry-wear tests in air were made using an Amsler tribometer. Oil-impregnated (mineral oil without additivies) ferrous sintered material was used, with four different density values: 6.5, 6.8, 7.1, 7.3 g/cm³.
After sintering, porosity values (pores volume fraction per unit total volume) for each density were as follows (3, 4):
P_1=0.17, P_2 = 0.13, P_3 = 0.098, P_4 = 0.07
Materials were supplied by Hoganas in the form of washers (thickness: 10 mm; diameter: 50 mm).

Two different kind of tests have been done, applying a load of 25 daN:
1) Variable sliding friction rate tests;
2) Variable pressure tests.
In the first case, 0%, 5%, 10% and 100% sliding friction rates (s.f.r.) were used.
10% s.f.r. was obtained by coupling washers with the same diameter (50 mm).
0% and 5% s.f.r. were obtained by changing the lower washers diameter by turning, (45.2 mm for 0% s.f.r. and 47.4 mm for 5% s.f.r.), keeping constant the upper washers one (50 mm).
Tests at 0%, 5% and 10% s.f.r. were carried out until 50,000 cycles, and weight loss was measured every 10,000 cycles.
For tests at 100% sliding friction rate, a fixed parallelepiped insert (2xlxl mm), coupled with a washer (50 mm) was used.
These tests were carried out until 5,000 cycles.

In the second case, in order to increase the contact pressure, the contact surface was reduced and the load was kept constant.
This was obtained by shaping the lower washer surface. The 10 mm original thickness of washers was reduced to 8, 6 and 4 mm.
The average contact pressure (183 MPa with no-shaped washer), increased up to:
- 203 MPa (8 mm lower washer)
- 252 MPa (6 mm lower washer)
- 278 MPa (4 mm lower washer) .
A sliding friction rate of 10% and only one density (7 .1 g/cm^3) were used.
Before wearing, Vickers (HV_5) hardness tests were carried out on surfaces; an increase in hardness was observed as density increased.
Also the turning process produced an increase in superficial hardness.
Fig. 1 shows the comparison between the as-received material surface hardness and the turned material one.
Normal sections of each tested washer were submitted to SEM analysis.

Results

Mechanical tests

Variable sliding friction rate tests

Fig. 2 shows the total wear of as-received upper washers coupled with turned ones, vs. the sliding friction rate.
As shown, a slight wear is already present, for 6.5 and 7.3 g/cm^3 densities at 0% sliding friction rate.
As the sliding friction rate increases from 0% to 5% and to 10%, wear regularly increases.
It has been observed that, for all densities, wear values are below 0.1 g, and then increase as density decreases.
In order to compare wear values at 0%, 5%, 10% sliding friction rates (at 50,000 cycles), with the values obtained at 100% (at 5,000 cycles), a multiplicative factor 10 was used (Fig. 2).

Variable-pressure tests

Fig. 3 and 4 respectively show the total wear of the lower shaped washers and the total wear of the upper as-received ones, vs.the number of cycles, for material of 7.1 g/cm^3 density.

It was observed that wear of shaped washers, with a higher contact pressure (203, 252 and 278 MPa) than no-shaped ones (183 MPa), was paradoxically smaller.

It can be noticed that the highest wear of shaped washers was obtained with the 6 mm one, the lowest with the 4 mm one.

Micrographic observations

Washer sections of oil-impregnated sintered materials, after wear tests, have been examined by SEM, and compared to those of other materials already studied by the Authors (no-impregnated ferrous sintered material, steam-treated ferrous sintered material) (5, 6, 7), submitted to the same operating conditions (dry wear in air), at 10% sliding friction rate.

Fig. 5 shows the wear surface section of a no-impregnated, ferrous sintered material; it can be noticed a great grain compression, together with a plastic deformation of material which increases towards the surface.

The strain-hardened area is nearly 190 µm deep for the no-impregnated sintered material.

The steam-treated sintered material also shows a smaller plastic deformed area, 60 µm deep (Fig. 6).

Fig. 7 shows the wear surface section of an oil-impregnated ferrous sintered material, in which it is not visible any grain compression, but only a thin strain-hardened layer, which can be removed, during the wear process.

Discussions and conclusions

This study carried out on oil-impregnated ferrous sintered materials, has shown a regular wear increase for all density values, increasing the sliding friction rate.

The same material has shown wear values much lower than obtained in analogous operative conditions, both for dry and for steam-treated ferrous sintered materials (5, 6, 7).

Comparing wearing data and micrographic tests of oil-impregnated materials and no-impregnated ones (5, 6), it is possible to hypothesize the effects of oil during contact-surface rolling.

In fact, it is considered that oil in pores, due to cyclic Hertzian pressures and consequent deformations, is expelled out of the wear surface, to be later partially re-absorbed, during the unloaded phase.

This means that the sliding-rolling movement produces a local cyclic stress of porous material, like if it would "breathe".

Due to the presence of a superficial oil layer, friction generated during this contact, is of fluid-dynamic type (indirect friction): this layer reduces microweldings formation between peaks of contact surfaces and so, wear is quite only due to periodical collisions between these peaks which later, due to fatigue, break away.

A direct consequence is the reduction of the friction coefficient and of weight loss.

When sliding friction rate increases, share stresses increase, the interaction between peaks is exalted, and this causes a greater material remotion.

Tests carried out by changing the area of contact between surfaces show that the increase of the contact pressure, and therefore of deformation, causes an oil expulsion at higher pressure which exalt the reduction of peaks interaction.

The result obtained is a reduction in wear as pressure increases (Fig. 3 and 4).

In conclusion, oil presence within the material, permits a continuous surface lubrication during contact, also when external lubrication is impossible.

Therefore, it is evident how this material could be suitable for all mechanical couplings which need a poor service maintenance.

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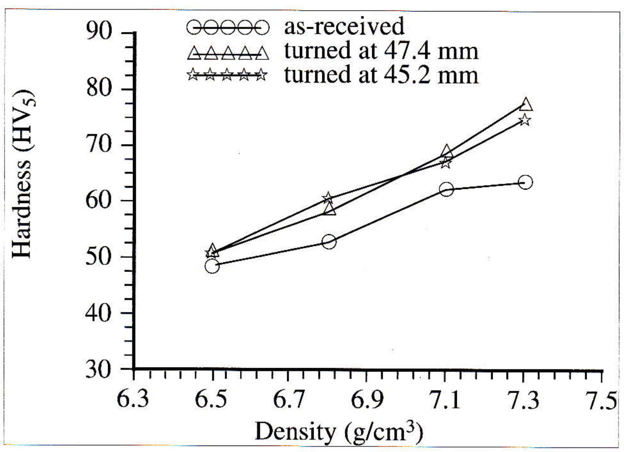

Fig 1
Hardness (HV_5) of wear surfaces (material as-received and turned), vs. the different densities.

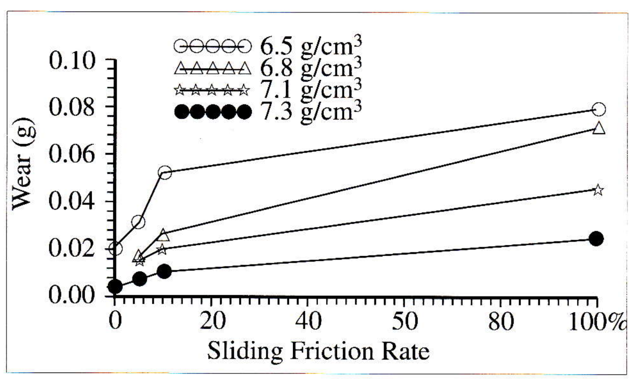

Fig. 2
Total wear of as-received upper washers vs. the sliding friction rate.

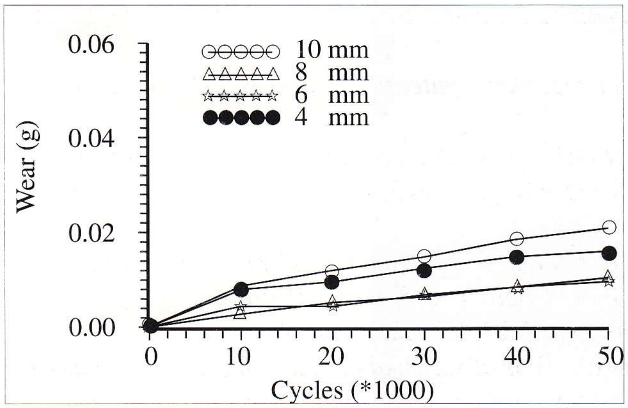

Fig. 3
Total wear of the lower shaped washers, coupled with as received ones (7.1 g/cm^3 density), vs. the number of cycles.

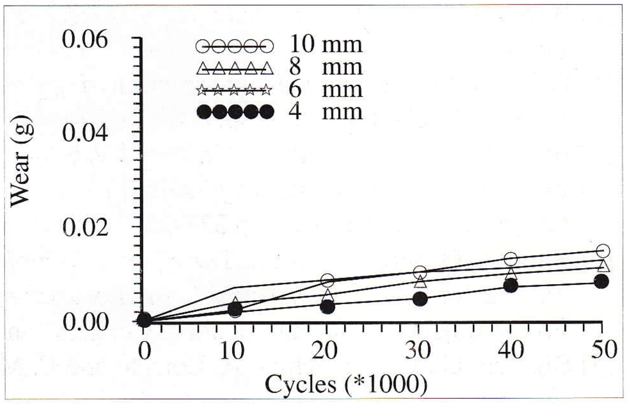

Fig. 4
Total wear of the upper as-received washers, coupled with shaped ones (7.1 g/cm^3 density), vs. the number of cycles.

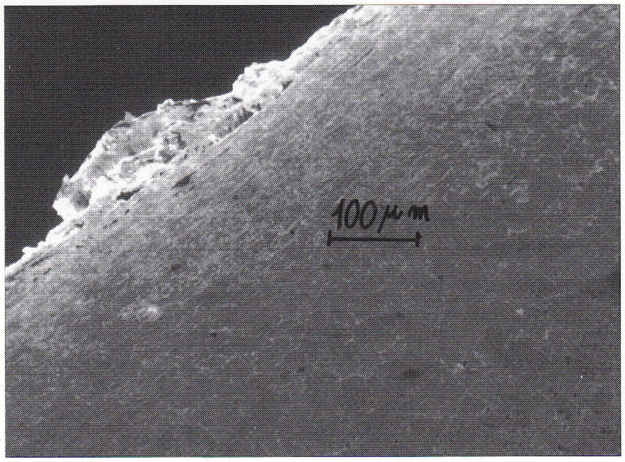

Fig. 5
Wear surface section of a no-impregnated ferrous sintered material. 6.5 g/cm^3 density, 10% sliding friction rate, in air, 25 daN, after 50,000 cycles.

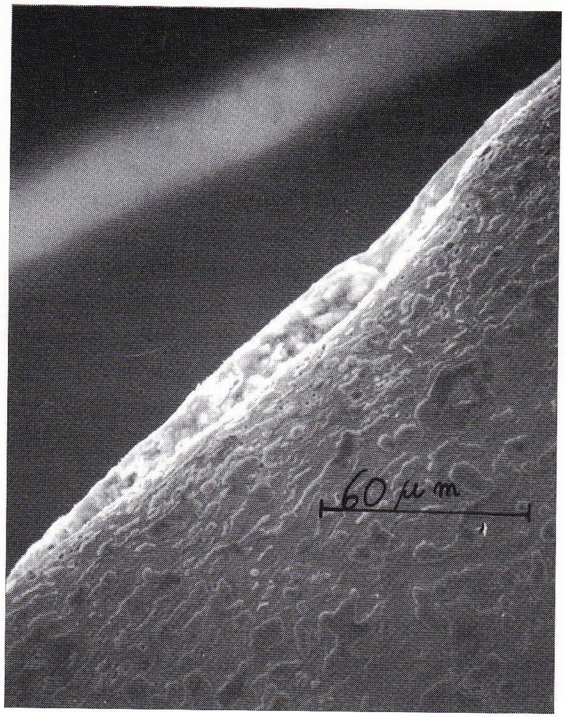

Fig. 6
Wear surface section of a steam-treated sintered material.
6.5 g/cm^3 density, 10% sliding friction rate, 25 daN, after 50,000 cycles.

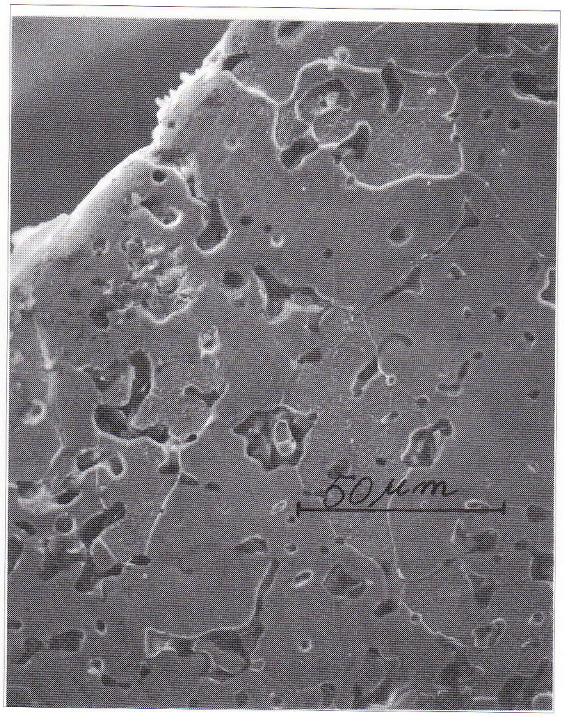

Fig. 7
Wear surface section of an oil-impregnated ferrous sintered material. 6.5 g/cm^3 density, 10% sliding friction rate, 25 daN, after 50,000 cycles.