EFFECT OF PROCESSING PARAMETERS ON THE WEAR BEHAVIOUR OF SINTERED IRON AND STEAM OXIDIZED SINTERED IRON IN RECIPROCATING SLIDING WEAR TESTS

Bozzi, A.C. and De Mello, J.D.B. / Laboratório de Tribologia e Materiais, Universidade Federal de Uberlândia, Uberlândia, MG, Brazil

ABSTRACT
In spite of the extensive use of sintered iron-based components in sliding situations, there are very few studies about their wear behaviour. In this paper, the effect of processing parameters on the wear behaviour of sintered iron and steam oxidized sintered iron were analyzed. Three levels of density were used, ranging from 7.10 to 6.55 g/cm$^3$. In addition, two different steam oxidation processes were used with the objective of obtaining different types of surface oxides. Reciprocating sliding wear tests in a ball on flat geometry were performed under a constant stroke and frequency. Three levels of normal load were used. Wear was evaluated in terms of the volume loss by using data of surface topography provided by a 3D laser interferometer. The wear mechanisms were analyzed by scanning electron microscopy. The wear behaviour of the specimens was compared and analyzed in terms of the wear volume and wear mechanisms. The results show that wear behaviour is influenced mainly by the load level and steam oxidation. Steam oxidation greatly decreased the wear volume of these materials under low and medium loads.

INTRODUCTION
The powder metallurgy (PM) manufacturing process is experiencing growth and replacing traditional metal-forming operations because of its low relative energy consumption, high material utilization and low cost. These powder metallurgy products are often used in conditions in which their surfaces are subject to sliding contacts, such as plain bearings, cams, gears, compressor parts, pulleys, etc. These products are usually made of sintered ferrous alloys (pure iron, low-carbon iron or iron-copper alloys). Further, they are subjected to a surface engineering treatment known as steam treatment, or steam blueing [1].

In fact, steam oxidation is the most widely used surface treatment for sintered ferrous alloy parts. This process is applied to sintered components whose density is between 5.4 and 7.0 g/cm$^3$. In this class of component there is an interconnected pore network which allows a gas flow throughout the pore network. In this way, when superheated water vapour passes through this pore network, a layer of iron oxides grows on the internal walls of pores and also on the external surface of the component. So, the main objective of this process is to produce a layer of magnetite ($\text{Fe}_3\text{O}_4$) on the exposed surfaces of the components.

In order to increase the use of sintered iron-based materials in new applications, a complete understanding of their sliding behaviour has to be achieved. However, in spite of this, the literature in this area is very scarce, in particular concerning the wear behaviour of steam oxidized sintered iron-based materials [2,3].

EXPERIMENTAL TECHNIQUES
Specimens consisting of sintered pure iron having three different levels of density (high, medium and low) were used. Half of the specimens were compressed in a single action press in the active surface, in order to emulate the process of sizing. Steam oxidation was performed by using two different cycles in order to produce superficial oxide layers composed mainly of magnetite (magnetite cycle) and wustite (wustite cycle).

The specimens were characterized physically, mechanically and microstructurally. XRD spectra were used to determine the constitution of the oxide layers and their quantifications were made by using the Rietveld method.

The tribological characterisation was carried out in air in an unlubricated reciprocating wear test (Plint & Partners, TE 67), in which both contact potential and friction force were continually logged (acquisition rate of 1 Hz) with a microcomputer. A hard steel sphere (AISI 52100, 5 mm diameter) was held on a pivoted arm, and rested against the specimen surface under constant dead weight load (4.9, 8.8 and 29.4 N), stroke (6 mm) and frequency (2 Hz).

The tests were conducted during one hour under controlled room humidity (<50%) and temperature (22 ± 4°C) conditions.
Wear was evaluated in terms of the volume loss of wear scar by using the data of surface topography provided by a 3D laser interferometer (UBM MESSTECHNIK GmbH) and a software specially developed for this purpose. The wear mechanisms were analysed by scanning electron microscopy.

RESULTS AND DISCUSSION
Steam oxidation produced oxide layers with an average thickness of about 4 µm. In addition, steam oxidation produced an oxide layer compound of 99% magnetite in magnetite cycles, and 55% of magnetite plus 40% of wustite, in wustite cycles.

The results of the tribological tests are summarized in figure 1. In this figure, the wear volume of the specimens under every normal load are shown.

![Figure 1. Wear volume in function of the condition of specimen and normal load.](image1)

From this figure, becomes evident the beneficial influence of the steam oxidation in increasing wear resistance of specimens, in tests performed with low and medium normal loads (4.9 and 8.8 N). However, the same is not true for tests performed with the highest normal load (29.3 N). In this case, steam oxidation was not effective in increasing the wear resistance of the specimens, and all the specimens presented high wear volumes. Also, it must be said that wear volume was not influenced by the process of compression in all conditions.

Analysing in detail the influence of normal load on the wear volume of the specimens, it became evident that wear volume increased in an apparently linear mode in specimens without steam oxidation. This suggests the absence of wear transitions in the range of loads studied for these specimens.

For specimens steam oxidized, on other hand, wear volume did not increase when changing the load from 4.9 to 8.8 N. However, by increasing the load from 8.8 to 29.4 N, the wear volume substantially increased in about one order of magnitude. This is a strong evidence of a wear transition.

To help us to better picture the wear behaviour presented by oxidized specimens, a simplified wear map was proposed, figure 2, based on results of the tribological tests performed and other evidences.

Figure 2. Simplified wear map proposed for steam oxidized specimens.

![Figure 2. Simplified wear map proposed for steam oxidized specimens.](image2)

By using this wear map, we can explain the wear behaviour of these specimens. In this way, in tests at a load of 29.4 N, region A, due to the rapid removal of the oxide layer, “severe” substrate wear occurred. On the other hand, in tests at loads of 4.9 and 8.8 N, region B, the oxide layer was present during most part of the test time, resulting in “severe” oxide wear. Then, the sharp increase in wear volume in changing the test load from 8.8 to 29.4 N is due to a wear transition from wear mainly in coating (oxide) to wear mainly in substrate.

Figure 3, shows the typical aspect of the wear surfaces of specimens without compression at a load of 8.8 N, which is representative of wear surfaces in other conditions. As can be seen, the morphological characteristics of the surface are very similar, with predominance of plastic deformation by microwear and microwear. Some microcracking, figure 3 c), also was observed.

![Figure 3. Typical aspect of the wear surface of the specimens. Test load = 8.8 N. SEM. a) Without oxidation. b) Magnetite cycle. c) Wustite cycle.](image3)

CONCLUSIONS
Steam oxidation by magnetite and wustite cycles significantly increased the wear resistance of specimens in tests at loads of 4.9 and 8.8. However, in tests at a load of 29.4 N, steam oxidation was not effective in increasing wear resistance. The predominant wear mechanism was plastic deformation by microwear and microwear.

ACKNOWLEDGMENTS
The authors are grateful to FAPEMIG and EMBRACO S.A. for financial support for this work.

REFERENCES