Wear Behavior of a Ferritic Stainless Steel with Carbides Manufactured through Powder Metallurgy

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A ferritic stainless steel has been manufactured through the powder metallurgy (P/M) route: uniaxial pressing and sintering. The sintering process was carried out in vacuum, at 1215 °C for 30 min. After sintering, materials showed nearly 90% of density. A complete metallographic study was carried out using optical microscopy and scanning electron microscopy (SEM). Wear behavior was evaluated using a "pin on disk" test according to ASTM Standard G99. Eight test conditions were studied, varying the load (5 and 10 N), the speed (0.1 and 0.4 m/s), and the counter-material (chromium steel and a martensitic stainless steel). The sliding distance was 400 m, and tests were carried out on polished materials, with less than 30% of relative humidity. Moreover, wear tracks were observed by SEM in order to understand the wear processes involved, which depend mainly on the counter-material.

Keywords ferritic stainless steel, powder metallurgy

Introduction

The applications of sintered stainless steels cover different industries, the automotive industry being the most important for components such as ABS rings or temperature control valves,[1] austenitic grades being the most commonly used. However, these materials show lower properties than their wrought counterparts: worse strength, corrosion, and wear resistance. The main reason for this lower performance is the presence of porosity and the problems these steels have when they are sintered in industrial atmospheres (such as dissociated ammonia).[2] The low hardness that these materials exhibit implies low wear properties, and martensitic grades are used when high hardness is required. Another possibility to improve the wear resistance is the use of ceramic particles such as Al_2O_3[3,4] and Y_2O_3[5,6] to manufacture metal matrix composites (MMCs). The main problem related to these particulate MMCs is the low interaction between the matrix and the reinforcement. This low interaction forces us to use, at the same time, other additions to activate the sintering process. This improvement in the wear resistance has been observed when intermetallics have been used as reinforcement, both *in-situ* produced through reactive sintering[7] and directly added as particles.[8–10]

This article deals with the possibility of using a ferritic stainless steel powder with its composition balanced to present carbides in its microstructure, in order to avoid interaction problems.

Experimental Procedure

A ferritic stainless steel prealloyed powder (Powdrex, Tonbridge, Kent, United Kingdom) called HCx23 (1.6) was used as the raw material. The composition of HCx23 powders is as follows: 24.4% Cr, 2.5% Mo, 2.1% V, 3.7% W, 1.3% Si, and 1.61% C. The powder size was 99.8% < 150 μm. This powder was designed for applications requiring a combination of wear and corrosion resistance such as water pumps or food and pharmaceutical equipment.[11]

Materials were manufactured following the conventional P/M route. Powders were uniaxially pressed at 700 MPa into cylindrical specimens according to the MPIF 45 Standard. After pressing, green specimens were sintered in vacuum at 1215 °C for 30 min. Temperature was selected to obtain high densities (close to 90%). Higher temperatures promote severe distortions of the samples.[12] Hardness (HRB) was measured. A complete microstructural study was carried out through optical microscopy and scanning electron microscopy (SEM), aided by semiquantitative microanalysis through energy dispersive x-ray analysis.

The wear behavior was measured through a pin-on-disk test. Wear tests were performed according to ASTM Standard G99 using the following test conditions:

- samples surface polished to 1 μm roughness;
- friction track diameter: 12 mm;
- sliding distance: 400 m;
- relative humidity, less than 30%;
- room temperature (22 to 25 °C);
- speed: 0.1 and 0.4 m/s;
- pin: chromium steel (57 HRC) and martensitic stainless steel (49 HRC), 6 mm diameter; and
- load applied: 5 and 10 N.

The material under study was in the form of disks. Five tests were carried out in each test condition. The objective was to study different wear conditions and their influence on wear behavior. The friction coefficient was measured continuously during the test (given value was determined when a steady state in the wear test was reached) and wear was measured through the wear coefficient *k*:

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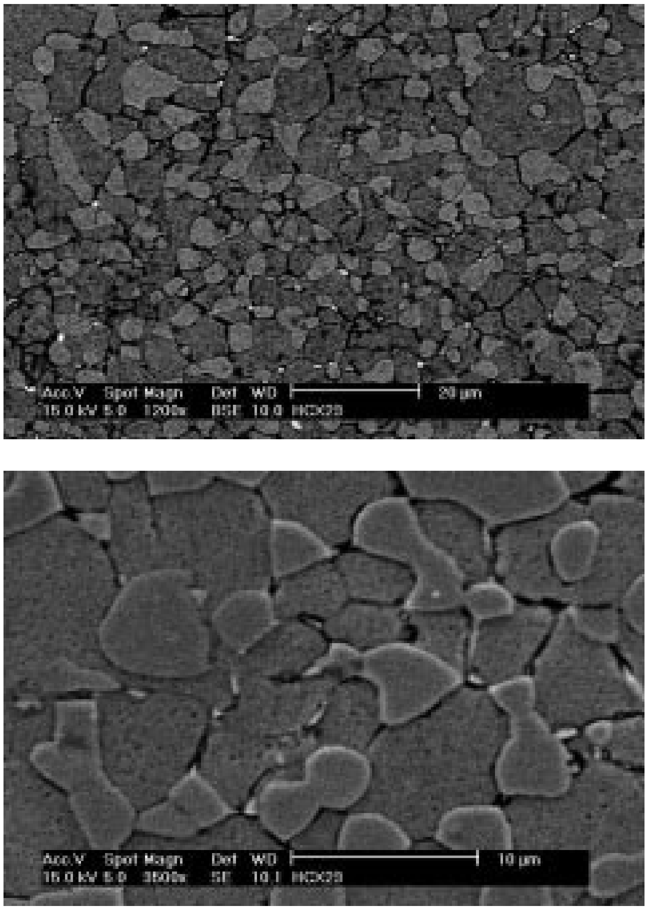


Fig. 1 Microstructure of the sintered steel at two magnifications

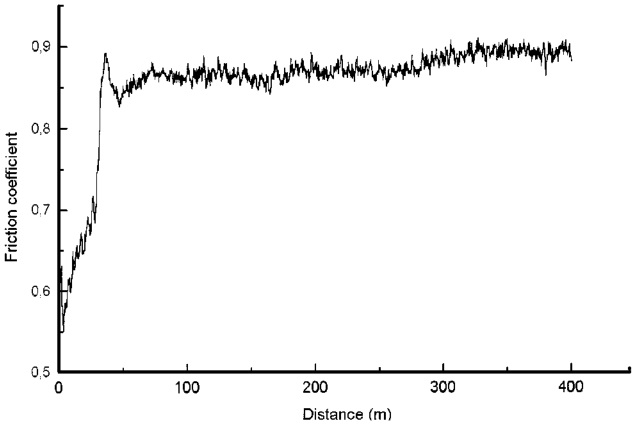


Fig. 2 Evolution of the friction coefficient during the wear test in the majority of tested conditions

$$k\ (\text{mm}^3/\text{Nm}) = \text{volume loss material (mm}^3)/\ [\text{applied load } (N) \times \text{sliding distance (m)}]$$

The wear tracks were also observed through SEM in order to establish the wear mechanisms that take place in the material.

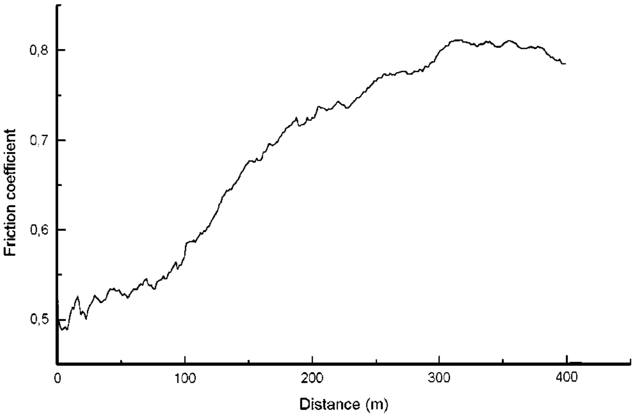


Fig. 3 Evolution of the friction coefficient during the wear test in material tested against stainless steel, at 0.4 m/s speed and 10 N load

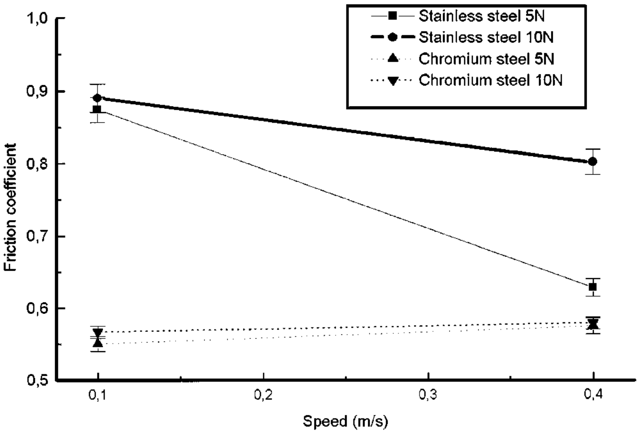


Fig. 4 Steady-state friction coefficient reached during the wear test in all tested conditions

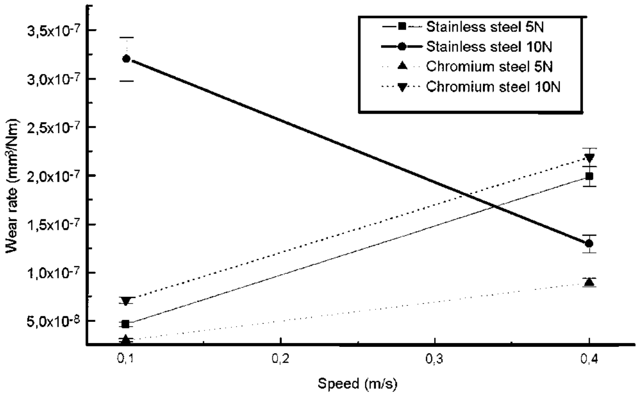
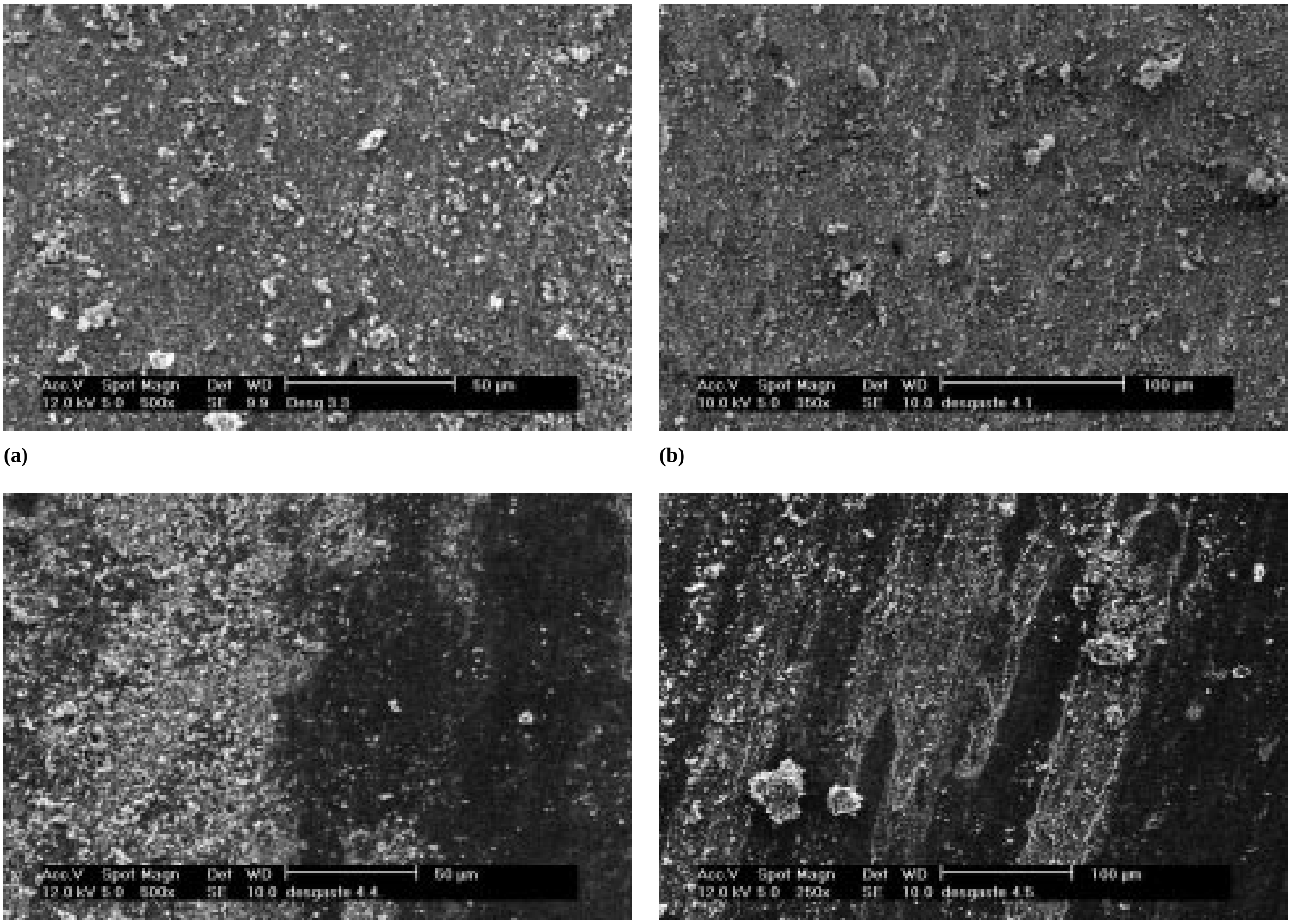


Fig. 5 Wear coefficients of material in all tested conditions

Results and Discussion

The material sintered in the indicated way showed a sintering density of 6.8 g/cm^3, close to 90%. This value is very high and comparable with typical values achieved in sintered



(a) **(b)** **(c)** **(d)**

Fig. 6 Wear tracks of material tested against chromium steel: (**a**) 5 N load, 0.1 m/s speed; (**b**) 10 N, 0.1 m/s; (**c**) 5 N, 0.4 m/s; and (**d**) 10 N, 0.4 m/s

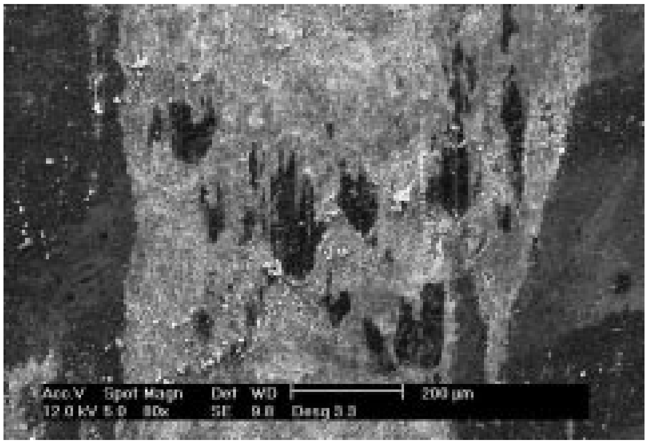
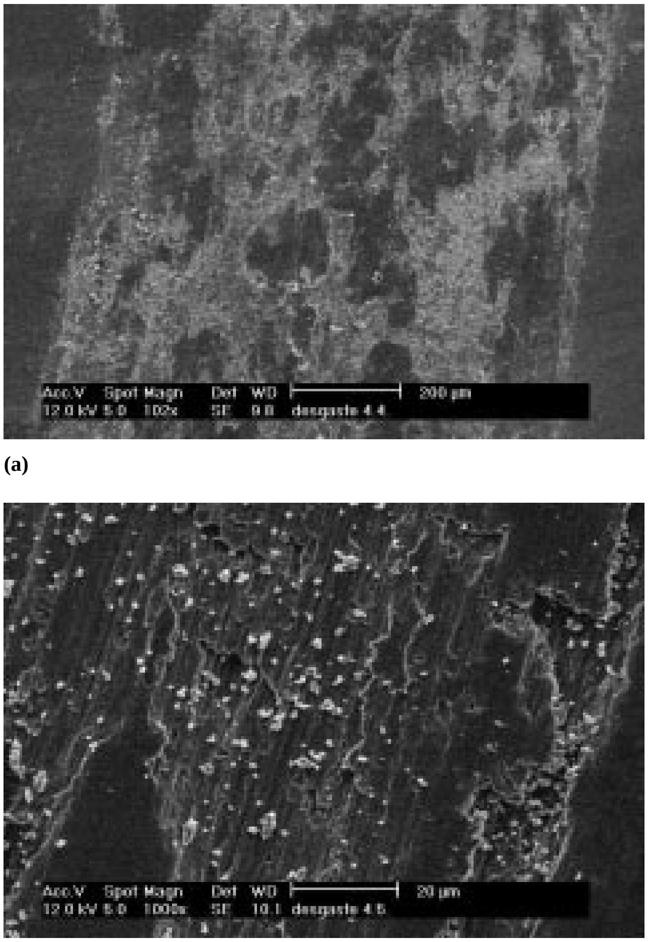


Fig. 7 Wear tracks of material tested against chromium steel. Wear test conditions: 5 N load and 0.1 m/s speed

stainless steels. The hardness achieved was 42 HRB, a typical value within the hardness range of sintered ferritic stainless steels, and even austenitic steels.[6] Figure 1 shows the microstructure of the steel. A ferritic matrix with a fine and homogeneous distribution of carbides is observed. Two kinds of carbides are present: M_6C (Cr-rich carbides) and MC (W-rich carbides).

Figure 2 and 3 show the evolution of the friction coefficient during the test. Two different behaviors were found. Most of the tested conditions promote the behavior shown in Fig. 2. At the beginning, materials present a low friction coefficient (around 0.5), which increases quite rapidly with time and with the formation of wear debris. The friction coefficient reaches a maximum value, when the roughness in the contact surface is higher. From this moment, the friction coefficient decreases, reaching a stationary value around 0.6 when the counter-material is chromium steel, and higher (0.85) against the martensitic stainless steel (Fig. 4). This behavior is related to wear conditions that promote adhesion between the pin and the material, but this will be discussed in the wear track study.

The friction coefficients reached in this material are typical of those seen in abrasive conditions in other sintered materials. Values of about 0.8 are found in high speed steels and their composites tested against alumina.[13,14] Austenitic stainless steels reinforced with ceramic particles (yttria and alumina)



(a)

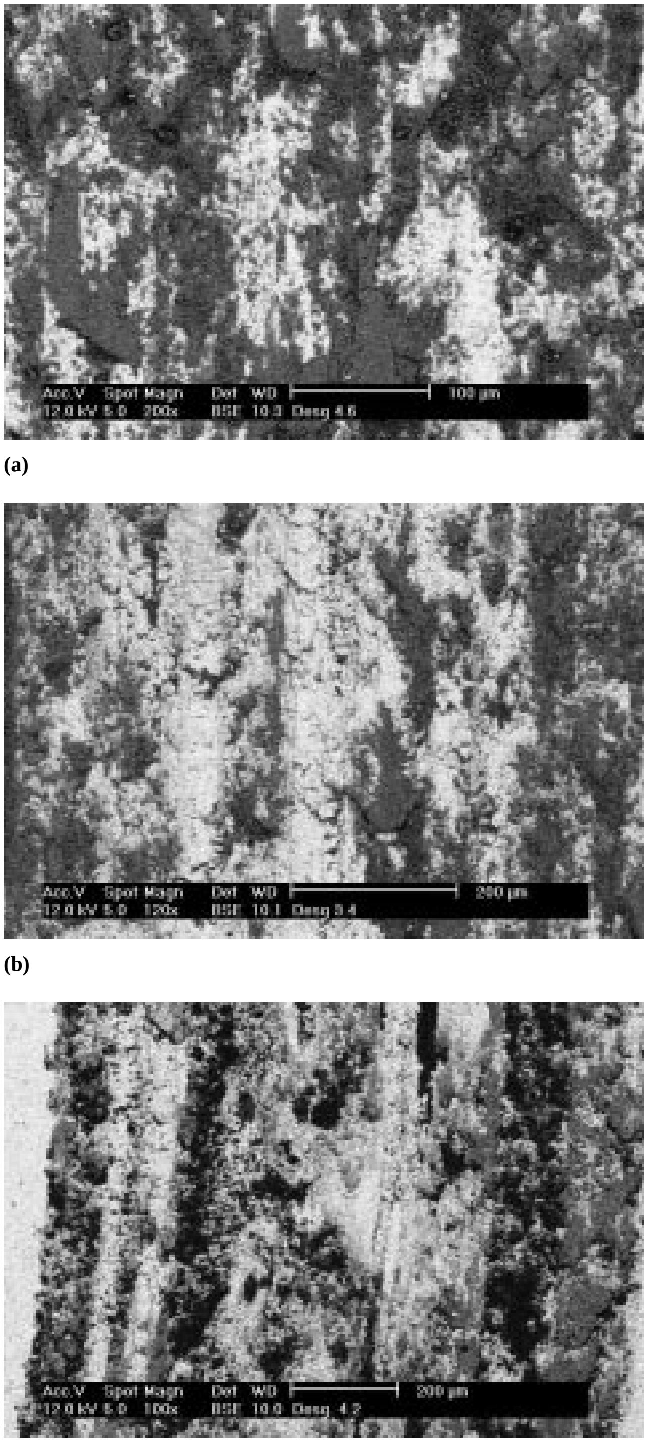
(b)

Fig. 8 Wear tracks of material tested against chromium steel at 0.4% m/s speed: (**a**) 5 N load and (**b**) 10 N

tested against alumina present lower values, around 0.6 to 0.7,[6] and the addition of intermetallics gives similar results.

However, when the material is tested against stainless steel counter-material, at 0.4 m/s speed and 10 N load, the material presents a different behavior, as shown in Fig. 3. The static friction coefficient is also about 0.5, and it increases continuously during the test, reaching its maximum value at the end of the test (0.8, Fig. 4). This indicates that the ball slides over the studied polished sample during a longer time than in other studied conditions (Fig. 2). When the sliding distance reaches 300 m, wear begins to be significant. This different behavior is also found in wear coefficients.

Figure 5 shows wear coefficients of material in all tested conditions. As can be clearly appreciated, the phenomena found were as expected: increasing load and increasing speed promote higher wear coefficients. These findings vary only in the material tested at 0.4 m/s with 10 N load against the martensitic stainless steel, the same one that presented different behavior in its friction coefficients. Moreover, the wear is more important when the material is tested against stainless steel for the same load. The wear coefficients achieved are lower than those obtained in austenitic stainless steel reinforced with intermetallics[8] and similar to those reinforced with oxides,[6] all of them against alumina.



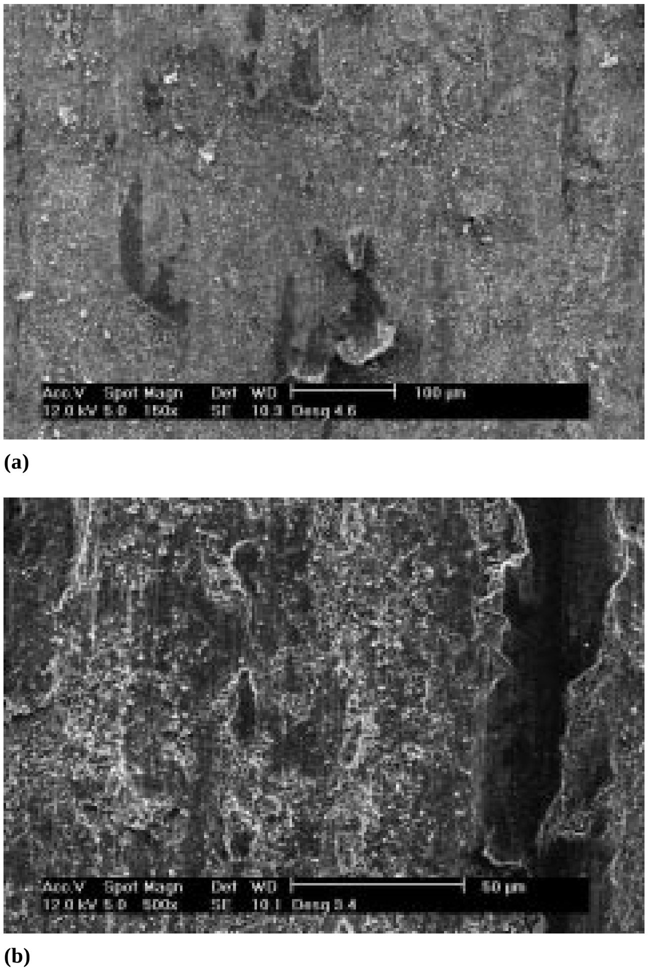
(a)

(b)

(c)

Fig. 9 Wear tracks of material tested against stainless steel: (**a**) 5 N load, 0.1 m/s speed; (**b**) 10 N, 0.1 m/s; and (**c**) 10 N, 0.4 m/s

Figure 6 to 11 show wear tracks and explain the phenomena that occur during wear test. Wear against chromium steel promotes, for all wear conditions, three-body wear (Fig. 6). In all cases, stainless steel debris appears in the wear track, appearing as small particles with an angular morphology.



(a)

(b)

Fig. 10 Wear tracks of material tested against stainless steel: (**a**) 5 N load, 0.1 m/s speed; and (**b**) 10 N, 01 m/s

However, the mechanism of debris formation seems to depend on the speed. Low speed (0.1 m/s) promotes abrasion, and areas where material has been detached can be found (Fig. 7). On the other hand, high speed (0.4 m/s) promotes adhesion between the studied material and the pin (Fig. 8).

Wear against stainless steel promotes the presence of oxides in the wear track for all wear conditions (Fig. 9). Abraded particles appear in the wear track, except for the worst testing condition. These particles come from the abrasion of the steel (Fig. 10). Finally, the material tested at high load (10 N) and high speed (0.4 m/s), which had a different behavior in the friction coefficient, presents a different wear mechanism. In this case, adhesive wear appears (Fig. 11) due to the high load and speed conditions and the fact that two stainless steels are being tested.

Conclusions

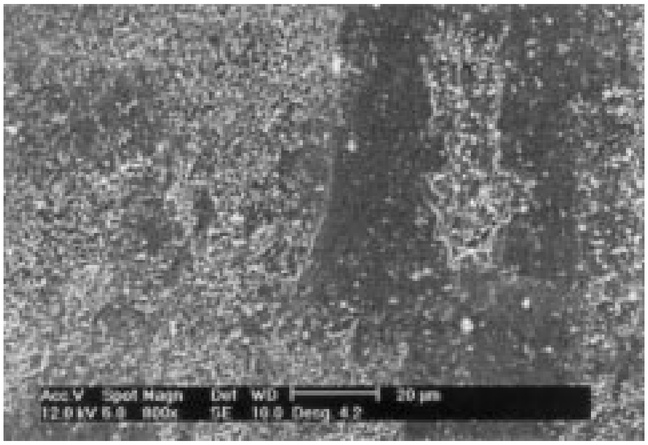


Fig. 11 Wear tracks of material tested against stainless steel. 10 N load, 0.4 m/s speed

Except in one case, wear increases with applied load and speed. Using stainless steel as the counter-material also increases wear. Stainless steel gives, for high loads and speeds, sliding between the pin and disc, promoting low wear rates. Using stainless steel as the counter-material promotes oxide formation on the wear track. The chromium steel pin promotes three-body abrasion.

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