INVESTIGATING THE EFFECT OF TYPE AND THICKNESS OF THE OXIDE LAYER PRODUCED BY STEAM TREATMENT ON WEAR BEHAVIOR OF SINTERED STEEL COMPACTS

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Abstract:
Steam treatment is a significant method for modifying the surface properties and sealing porosity and improving aesthetics in sintered iron components. Steam treatment as a promising approach increases the weight, size, density, and hardness of the parts. In the present work, the effect of steam treatment on the wear behavior of a Fe base alloy processed by powder metallurgy was investigated. Wear tests were carried out to evaluate the durability of steam oxidized layer and its effect on wear mechanism. Pin-on-disc tribological tests according to ASTM G-99 standard were conducted at a normal load of 50N and a constant speed of 0.1 m/s in dry conditions and at room temperature. The wear rate was measured. The microstructure and worn surfaces were also studied. Results showed that steam treatment by producing a magnetite layer on the surface and in the pore network makes a remarkable change on hardness and modifies the wear behavior of the compacts.

Keywords: Steam treatment, porosity, density, wear, powder metallurgy

1. INTRODUCTION:
Steam oxidation is the most widely used surface treatment for sintered iron and iron alloy parts [1]. It is a frequently applied secondary process, with fairly low costs and requiring little attention during operation [2]. Initially used to seal the network of interconnected pores, thus makes the component impervious to liquids and gases. Steam treatment is also applied to improve other properties of sintered iron. This is achieved by the formation of a tenacious magnetite layer at the temperature of 550 °C. The oxide layer formed on the surface and in the interconnected porosity is reported to provide an increase in hardness, in mechanical properties and in wear resistance, a decrease in friction coefficient and an increase in corrosion resistance in moderately aggressive environments [2–5]. Furthermore, steam oxidation produces a blue/black layer, which enhances the aesthetic appearance of components. The main disadvantages of the process are the reduction in tensile strength, impact resistance and ductility [6].

Steam oxidation is not very effective since surface oxide may be quickly removed even at low loads, and the only positive effect on wear is the slight strengthening produced by oxide growth in the interconnected porosity [7].

Molinari and Straffelini [8] analyzed the effect of load on the tribological behavior of steam-treated iron-based alloys and introduced the concept of durability distance. The concept of surface durability was related to the wear resistance of the oxide layer on the external surface and reported to be the focal factor affecting the tribological behavior [8, 9]. If the layer remains undamaged on the surface, wear resistance is higher and greater than that provided by conventional heat treatment or case hardening [9]. Finally, they pointed out that variations in compactness and constitution of the oxide layer, obtained by changing the belt speed and steam flow during a continuous industrial steam treatment, strongly influence the wear resistance of oxidized sintered iron [4,7].

As asserted by Strafellini and Molinari [8], the permanence of an undamaged layer of oxide on the surface can be effective in the tribological behavior of iron-based steam-oxidized alloys. The presence of the
undamaged layer has been used as an indication of surface durability, defined as the sliding distance at which wear of surface oxide occurs and is detected by means of a change in the friction coefficient. This point has been related to the first major fluctuation in the friction force and associated with the first occurrence of oxide debris [7]. There is a clear indication that the optimal exposure of sintered iron and iron-based alloys to an overheated steam atmosphere, leading to the formation of a compact and adherent layer of magnetite, will enhance their tribological behavior. Unfortunately, this commonly accepted idea is neither well documented nor well proven in the context of powder metallurgy[10].

The present work investigates the effect of type and thickness of the oxide layer produced by steam treatment on wear behavior of sintered steel compacts. The effect of steam treatment and density on the wear resistance of sintered steels (%0.6 C) is also studied.

2. EXPERIMENTAL:

Specimens were produced from ABC100 iron powder which mixed with %0.6 carbon. Powder was mixed with %0.6 zinc stearate as lubricant. After mixing, the powders were compacted at four different densities (5.8, 6.2, 6.4, 6.8 g/cm³) with a double action automatic press. Green densities were controlled by varying the mass at constant dimensions. The resulting compacts, 23 mm in diameter and 7mm in height, were sintered in an industrial furnace. Specimens were coded according to their condition as shown in Table 1. Sintering was conducted in a mildly reducing atmosphere (H₂ + N₂) at a constant temperature of 1120°C for 55 min. After cooling to room temperature in 75 min, some of the specimens were steam-treated. The steam treatment was carried out at 550°C for 60 minutes in an industrial furnace.

<table>
<thead>
<tr>
<th>Code</th>
<th>Density (g/cm³)</th>
<th>Steam Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>S58</td>
<td>5.8</td>
<td>×</td>
</tr>
<tr>
<td>S62</td>
<td>6.2</td>
<td>×</td>
</tr>
<tr>
<td>S64</td>
<td>6.4</td>
<td>×</td>
</tr>
<tr>
<td>S68</td>
<td>6.8</td>
<td>×</td>
</tr>
</tbody>
</table>

Wear tests were carried out in the pin-on-disc apparatus according to the standard ASTM-G 99, keeping sliding distance, applied normal load and sliding velocity constant. Table 2 shows the used parameters during the tests.

<table>
<thead>
<tr>
<th>Sliding distance (m)</th>
<th>Velocity (m/s)</th>
<th>Load (N)</th>
<th>Track radius (mm)</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.1</td>
<td>50</td>
<td>6.5</td>
<td>Dry sliding, 27°C, 40% Humidity</td>
</tr>
</tbody>
</table>
3. RESULTS AND DISCUSSION:
Magnetite is a brittle phase and this leads to removal of surface oxide layer at the beginning stages of wear test. Hence, Fig. 1 illustrates the weight reduction after 500 meters sliding distance to investigate the effect of this layer on wear characteristics. As it can be obviously seen from Fig. 1 that steam treated samples have less reduction in weight and it can be concluded that they have a higher wear resistance.

![Graph showing weight loss vs. density](image)

**Fig 1.** Weight loss after the first 500 meters dry sliding as a function of density for Steam Treated (ST) and Not Steam treated (NST) samples.

The percentage of open porosity in the sintered samples is greater than that in the steam treated samples. As a result, the possibility of formation of a crack by plastic deformation in sintered specimens is higher. This causes more wear sheet formation and an increase in the wear loss in the sintered case. The extent of internal oxidation during steam treatment is directly related to density (porosity). Therefore, by increasing density, there is not enough passage for steam to the deeper parts of specimens. Also at high oxidation temperatures and high densities the capillary inlets eventually become blocked by oxidation products. As shown in Fig. 1, by increasing density, the weight loss is decreased. Minimum weight loss occurs in density of 6.4 gr/cm³ for both steam treated and not steam treated samples.

Sample with density of 6.4 gr/cm³ have more porosity than that with 6.8 gr/cm³ density and as Leheup et al [10] explained, surface breaking pores in sintered iron act as sinks for wear debris. In addition, the amount of wear debris which can act as abrasive particles in this level of density is smaller than the other and debris are cached in the pores. But in the lower densities the amount of pores are so high and the deformation and cracking is the dominant mechanism.

The weight loss versus sliding distance for the steam treated and as sintered samples with the density of 6.4 gr/cm³ and 6.8 gr/cm³ is respectively shown in Fig. 2.(a) and (b). Both illustrate that steam treatment plays a significant role on modifying the wear resistance. Subsequently, it can be inferred that at the initial stages of test when the surface oxide layer is presented, the wear rate is very low and venial. It can be clearly seen from fig.2 that the more the sliding distance, the more the rate of weight loss. It can be mainly attributed to generation of wear debris which are increasing in amount by sliding distance and can act as abrasive particles.

In the first 200 meters a sharp increase in lost weight can be seen and then from 200 to 300 meters a decrease and after 300 meters graphs have generally an increasing progress. This peak can be due to the wear in running-in period which is usually accompanied by scuffing and then large changes in surface morphology and loss of material [11, 12]. Then the mechanism of mild wear prevails again and so the weight loss decreases and after this stage, because of increasing in distance and generation of more debris, which can cause abrasive wear, graphs show an increasing progress in weight loss. But in the steam treated samples this peak is not obvious as it is in the not steam treated samples and this can due to the fact that steam treating increases the hardness of specimens and until the oxide layer remains undamaged, the wear
rate is very slow and surrounding conditions have not any effect on wear behaviour. Straffelini and Molinari [1] showed that the wear rate is low and independent of the chemical composition of the specimens as long as the oxide layer produced by the steam oxidation is able to carry out its lubricating function between the sliding surfaces.

Mello and Hutchings [7] suggested that both plastic shearing and oxidation mechanisms were observed in the as sintered and steam treated materials, when heat treated materials suffered from oxidative wear only. Steam oxidation is not very effective since surface oxide is quickly removed even at low loads, and the only positive effect on wear is the slight strengthening produced by oxide growth in the interconnected porosity. as we can see in Fig. 3, steam treatment has a significant positive effect on wear. By increasing in density, the weight loss is decreased. Consequently, it can be deduced that the steam treated specimens with density of 6.8 gr/cm$^3$ have the highest wear resistance among other specimens.

Fig 3. The comparison of the amount of weight loss, for Steam Treated (ST) and Not Steam Treated (NST) specimens with various densities.

4. **CONCLUSION:**
   - Steam treatment, by producing a magnetite layer on the surface and in the pore network, modifies the wear behavior of the compacts.
   - Steam treated samples have less reduction in weight and a higher wear resistance.
• By increasing the sliding distance, more weight loss was observed.
• Increasing the density of the samples leads to the lower weight loss during wear test.

LITERATURE