CHAPTER VI
CHAPTER VI

SEM ANALYSIS OF THE WORN SURFACES

6.1 INTRODUCTION

The common objectives of thermal spraying in tribological applications are to increase the wear resistance of the surface material and to modify its frictional behavior. In some cases, both are achieved. Wear, which occurs when two bodies are in contact with relative motion, can not be totally eliminated, though it can be minimized to an acceptable level. The choice of suitable thermal spray process to improve the wear resistance depends on the type of wear mode, which the component may undergo during service. With the increasing knowledge of these, it is possible to save energy and costs, prolong and/or predict the life of the wearing parts of machines and so on. Hence, there has been a great interest among engineers and tribologists in deepening their understanding of the phenomena of friction and wear.

Ceramics, with high surface hardness and good chemical stability, have shown themselves to be potentially wear resistant engineering materials, especially at high temperatures. For a better understanding and application of ceramic coatings in anti-wear practice, a complete tribological investigation in understanding the specific details of material removal in relation to underlying mechanisms is required. A number of friction and wear theories have been proposed and they give us some valuable guidance; although none of them is completely in agreement with the experiments, all of them provide some
qualitative predictions of trends of wear. Much more attention is now focussed on simple and practical tribological systems [1]. Studies on the basic wear mechanisms provide an indication of the inherent capability of the coating to effectively function in a given wear environment [2]. A wear mechanism study indicates that the material removal occurs by abrasive wear, adhesive wear and fracture, depending on the wear test employed. The removal of material from a solid surface by any particular wear mode is influenced by the material parameters (hardness, fracture toughness, yield strength, surface free energy, etc.) as well as system parameters (force, loading velocity, environment, etc.). Since the processes involved in material removal occur at the surface, changes in the surface mechanical properties and in the surface composition should strongly affect the tribological response [3]. It is therefore, essential to understand the specific details of material removal in relation to the underlying mechanisms.

Plasma and D-gun sprayed Al$_2$O$_3$ coatings are mainly characterized by their high hardness and excellent wear resistance and many authors have made generalized statements about the relative merits of the coatings or presented data on a wide variety of wear tests [4-6]. However, there have been a very few studies that attempted an elucidation of the mechanism of wear. The purpose of this study is to analyze the wear behaviour of the best and worst performing Al$_2$O$_3$ coatings as identified in Chapter IV with the Taguchi (L8) approach.

6.2 EXPERIMENTAL DETAILS

The abrasive wear tested specimens under the test conditions (as listed in Table 6.1) were collected for the coating qualities: good, poor and standard parameter conditions, as
characterized and described in the Tables 4.6 and 4.7 of Chapter IV. Samples were cleaned with acetone and dried, without damaging/affecting the wear tested area. The worn surfaces of the wear tested specimens were then analyzed with a scanning electron microscope (SEM).

### Table 6.1 Abrasive wear test conditions

<table>
<thead>
<tr>
<th>Abrasive material</th>
<th>Silica (150 – 250 μm)</th>
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</thead>
<tbody>
<tr>
<td>Rotation speed of the wheel, rpm</td>
<td>200</td>
</tr>
<tr>
<td>Applied load, N</td>
<td>50</td>
</tr>
<tr>
<td>Duration of each test, s</td>
<td>60</td>
</tr>
<tr>
<td>Number of tests</td>
<td>5</td>
</tr>
<tr>
<td>Sand feed rate, g/min</td>
<td>200 ± 10</td>
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</tbody>
</table>

### 6.3 RESULTS AND DISCUSSION

The wear resistance of the ceramic materials is fairly a complex property, influenced by several factors and the degree of influence changes with the conditions of application. Most engineering components of ceramic materials experience wear in one or the other form. Among the three wear modes, significant variation has been observed in abrasion wear, relative to those of erosive and sliding wear. Therefore, the variation in the abrasion wear loss is an indication of the effect of process parameters. The wear tested specimens were collected only for the abrasive wear mode, corresponding to the coating qualities: good, poor and standard parameter settings and were analyzed for both the APS and D-gun spray processes.
6.3.1 SEM analysis of worn surfaces under abrasion wear mode

Abrasive wear is generally characterized by the removal of material from one of two surfaces in relative motion caused by the presence of hard protuberances or hard particles either between the surfaces or embedded in one of them [1]. The harder surface asperities are pressed into the softer surface, which results in plastic flow of the softer material around the hard one. When the harder surface moves tangentially, the harder surface removes the softer material by combined effects of microploughing, microcutting and microcracking [7]. In the present investigation, SEM micrographs of abrasion tested specimens at low and high magnifications were taken to see the morphological changes in the Al₂O₃ coatings around the area of abrasion of the silica particles.

Plasma spraying: Figures 6.1 (a), (b) and (c) depict SEM micrographs of abrasion tested Al₂O₃ specimens deposited by APS, for the combination of process parameters corresponding to the coating quality: good (PA02), poor (PA07) and for standard settings (PA09). Consistent with the results obtained from the abrasive wear testing (see Table 4.6 in the Chapter IV), the micrographs in Figures 6.1 (a), (b) and (c) clearly reveal the amount of damage relative to the coating qualities. The coating PA02 exhibits the least amount of fracture (abrasion mass loss = 9.78 mg/min), while the coating PA07 exhibits the most amount of fracture (abrasion mass loss = 88.05 mg/min), which may explain their highest and lowest rankings, respectively. The low and high magnification photographs reveal the presence of many macro and micro brittle fractured areas. Examination of SEM micrographs at high magnification shows that the wear track is covered with compacted wear debris particles (Figure 6.1). Cleaning of the specimens in an ultrasonic bath with acetone removed some of the loose debris, revealing the grain...
Figure 6.1 SEM micrographs of the worn surfaces of the plasma sprayed Al$_2$O$_3$ coatings for the performances (a) good, PA02, (b) poor, PA07 and (c) standard settings, PA09
structure of the Al₂O₃ specimen at certain spots on the wear track, as shown in Figures 6.1 (a) & 6.1 (c). This suggests that the primary wear mechanism is intergranular fracture, which results in severe wear. A comparison of these pictures shows that the severity of wear is the highest for the coating of poor quality (Figure 6.1(b)) and is lowest for the coating of good quality (Figure 6.1(a)). Severe plastic flow and adhesive damage were clearly evident for the coating of poor quality. Closer examination of the wear scars for the poor coating quality reveals extensive crack formation and rimming of individual splats. Microcutting or ploughing marks due to abrasives are also visible.

**D-gun spraying:** Figures 6.2 (a), (b) and (c) depict a comparison of SEM micrographs of abrasion tested Al₂O₃ specimens deposited by D-gun, for the combination of process parameters corresponding to the coating quality: good (DA03), poor (DA07) and for standard settings (DA09). Similar to the APS process, consistent with the results obtained during abrasive wear testing (see Table 4.7 in the Chapter IV), the micrographs in Figures 6.2 (a), (b) and (c) clearly reveal the amount of damage relative to the coating qualities. The coating DA03 exhibits the least amount of fracture (abrasion mass loss = 5.36 mg/min), while the coating DA07 exhibits the most amount of fracture (abrasion mass loss = 21.38 mg/min), which may explain their highest and lowest rankings, respectively. All the micrographs in this figure appear largely similar and it can be seen that all of these wear-tested specimens exhibit some fracture resulting in material removal due to the abrasive action of the sand particles.

A comparison of the SEM micrographs (Figures 6.1 and 6.2) shows the extent of fracture in both the spray systems and the amount fracture is very high in the case of
Figure 6.2 SEM micrographs of the worn surfaces of the D-gun sprayed $\text{Al}_2\text{O}_3$ coatings for the performances (a) good, DA03, (b) poor, DA07 and (c) standard settings, DA09
APS process. As the density of the plasma coating was lower than that of the D-gun coating, the adhesion strength between the deformed layer and the substrate of the plasma coating was lower than that of the D-gun coating. As a result, the deformed layer of the plasma coating fractured severely. Therefore, a higher density and adhesive strength of the D-gun sprayed Al₂O₃ coatings result in a higher wear resistance, relative to that of the plasma sprayed Al₂O₃ coatings.

6.4 CONCLUSIONS

A preliminary attempt at understanding the mechanism of wear was carried out on the worn surfaces of the best and worst performing Al₂O₃ coatings, as described in the previous Chapter IV. Based on the microscopic studies, the following conclusions may be drawn:

- Mechanisms of abrasive wear involve both plastic flow and brittle fracture, that affect the plasma and D-gun sprayed Al₂O₃ coatings.

- SEM observations of the worn surfaces are consistent with the results obtained during abrasive wear testing and clearly reveal the amount of damage relative to the Al₂O₃ coating qualities. The severity of wear is highest for the coating of poor quality and is lowest for the coating of good quality, in both the plasma and D-gun spray systems. Closer examination of the wear scars for the poor quality reveals extensive crack formation and rimming of individual splats.

- It can be said that all of these wear tested specimens exhibit some fracture resulting in material removal due to the abrasive action of the sand particles and the amount fracture is very high in the case of plasma spray process.
REFERENCES


