Nd-YAG laser surface treatment of Cr$_2$O$_3$ coatings. Wear tests in tribometer LWF-1
E. Fernández, a  J.M. Cuetos, a  R. Vijande, a  H. Montes, a
A. Rincón, b  M.C. Perez b

a E.T.S. Ingenieros Industriales, Carretera de Castiello, s/n. 33204 Gijón, University of Oviedo, Spain
b Unidad de Tribología, (C.S.I.C.), C/ Serrano 119, 28006, Madrid, Spain

ABSTRACT

Superficial laser treatment allows tribological behaviour of certain materials to be improved. This paper presents the results obtained using Nd-YAG laser on a plasma sprayed coating of Cr2O3 fixing the optimal parameters of such treatment.

On the other hand, wear resistance tests performed using an LWF-1 machine with pairs steel-ceramic coating, show, as a rule, a better performance of both steel and ceramic coating under dry friction and abrasive condition, mainly due to the change caused by laser treatment on the coating microstructure.

INTRODUCTION

Plasma spraying is a technique that allows high quality coatings to be obtained using materials with a high melting point, as it is the case for ceramics. The ceramic coatings thus generated show good wear, corrosion and thermal barrier resistance [1].

However, the high porosity presented by such coatings when sprayed with plasma, prevents them from being used for some applications since their behaviour is not as good as expected [2]. A recent technique, currently being
studied by few research groups, e.g. Mordike [3], Cuetos [4], Havra [5], Iwamoto [6] and Fernández [7], is the laser surface treatment, which improves the behaviour of the coatings.

The unique characteristics presented by the laser beam for thermal treatment (accuracy, energy density, and minimum heat input per unit volume), cause minimum thermal effect on the substratum when the coating is treated. This makes of laser a key element for industrial use in this field.

In this work Nd-YAG laser equipment is used to melt the plasma sprayed Cr2 O3 coatings whose behaviour at wear, before and after the treatment, is studied.

EXPERIMENTAL PROCEDURE

Wear tests on ceramic coatings have been carried out before and after the laser treatment.

The ceramic coating studied is a chromium oxide compound which was projected by the plasma, using F 1140 steel as substratum that had been previously shot blasted to give it the required roughness and cleanness. The spraying was done using METCO 9 MB equipment of 40 kW. The material used for the coating was a type of powder with the following composition: 96% Cr2 O3, 2% TiO2, 2% other oxides. Before the ceramic material was projected, a bond layer was sprayed over the shot blasted substratum. The composition of the bond was: 89.5% Ni, 5.5% Al, 5% Mo. The final average thickness of coating and bond layer together was 0.3 mm.

Two types of test specimens were used, block and ring, defined according to the ASTM G77 standard, whose geometry is described on figure 1.

The block, whose structure is shown in 2, consists of a steel substratum, a plasma sprayed bondage layer and a ceramic coating, also plasma sprayed, with the foregoing characteristics. The ring was made of SAE 4620 steel.
Surface Treatment Effects

Figure 1. Geometry of test specimens.

The two test specimens were placed in a LWF-1 tribometer with lineal contact in order to carry out wear tests with steel-ceramic pairs, under dry, abrasion and lubrication conditions at different speed and temperature rates as
table 1 shows. Alumina powder dissolved in water was used as abrasive substance with a 1:5 weight ratio. The lubricant used was a type of oil with 107 and 11.3 centistocks viscosity at 38° and 100°C respectively, and 0.882 mg/cm³ density.

<table>
<thead>
<tr>
<th>Lubrication</th>
<th>Load (N)</th>
<th>Speed (rev min⁻¹)</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>45</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>100</td>
<td>0 to 100.000</td>
</tr>
<tr>
<td>Abrasive</td>
<td>272</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>408</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>544</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>680</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1768</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Ranges of variables

Nd-YAG laser of LASTEC, model JK 704 was used for the treatments operating in multimode. The following parameters were taken to optimize the process: pulse duration, energy, frequency, beam speed, test specimens preheating and focus size. The best results were obtained using the values expressed in table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1.0 J/pulse</td>
</tr>
<tr>
<td>Frequency</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>0.3 ms</td>
</tr>
<tr>
<td>Preheating temperature</td>
<td>265 °C</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>1.65 mm</td>
</tr>
</tbody>
</table>

TABLE 2. Laser parameters.

The cracks produced because of the laser treatment in this type of coatings [7, 8], were to a large extent reduced by preheating the block in a kiln at 265° C for 4 minutes.

Micrography 1 presents a section of the ceramic coating after the treatment. In it, the external zone (0.1 mm thick) is melted by the laser treatment, cracking is minimum and porosity almost equals zero. It also shows a non-molten zone whose characteristics have remained invariable after the treatment. And
finally the bondage layer and the substratum that have not been affected by the laser treatment.

The successive passes of the laser beam on the whole of the block ceramic surface gave rise to a series of ripples that were eliminated by mechanizing the treated surface.

The laser treatment did not substantially modify the adherence between coating and substratum, though the average hardness of the former increased by 34.7%.

Corrosion tests were performed with both the treated and non-treated coatings. Na2SO4 0.1 M was used as electrolyte. The tests were carried out at room temperature, in static conditions and without agitating the electrolyte. The corresponding polarization curves were obtained using the traditional technique of three electrodes.
RESULTS

Ceramic wear.

The wear presented by the ceramic coating for all the conditions studied is quite good if compared with that of the steel as figure 3 shows.

![Graph showing wear results](image)

Figure 3. Steel wear in contact with laser treated coating.

The changes in the wear speed rates proved that there are three different wear zones that vary with time. Each of these three zones has different wear speed rates, fitting Horst Czichos' model [10].

The surface laser treatment modified substantially the behaviour at wear of the Cr\(_2\)O\(_3\) coating for some of the conditions studied. Figure 4 shows schematically the comparative study of the wear results obtained for both the laser treated and the non-treated coating.
Surface Treatment Effects

WEAR BEHAVIOUR OF TREATED AND NON-TREATED CERAMIC COATING

LOAD = 45 N
SPEED = Diveses

- DRY → ALMOST THE SAME
- ABRASIVE → LASER TREATED BETTER

LOAD = Diveses
SPEED = 150 RPM

- DRY → ALMOST THE SAME
- ABRASIVE → LASER TREATED BETTER
- LUBRICATED → GOOD IN BOTH, BUT NON-TREATED BETTER

Figure 4. Wear behaviour of treated and non-treated ceramic coating

It is worthwhile mentioning that there seems to be a sliding speed, between 100 and 150 rpm (0.183 and 0.275), at which wear is minimum. Figure 5 illustrates this fact for dry condition and with a 45 N load. This agrees with the results obtained by Denape and Lamon [11], though they studied wear of non-laser-treated massic ceramic with optimum speeds around 0.5 m/s.

Figure 5. Laser treated Cr₂O₃ wear map at different speed rates under dry conditions.
Steel wear
Steel in contact with laser treated ceramic coatings exhibits a lower level of wear than when with non-treated coatings. The reason for that being in the microstructural change that the treatment causes on the coating, the particles becoming more flattened once they have been melted by the laser and thus producing a lower level of abrasion in the steel. This improvement of wear behaviour is more remarkable under dry than for abrasion conditions, since in the latter the abrasion effect does not derive from the coating itself but from the particles of alumina used as abrasive element.

The decrease in porosity resulting from the laser treatment prevents the lubricant from depositing in the coating pores, and therefore a smaller amount of it reaches the contact zone and thus lubrication is less effective. It is on account of this that, under lubrication conditions, the level of wear in the steel that contacts the laser-treated coating is higher than when in contact with the non-treated coating, although in both cases, the behaviour is quite good as compared to dry and abrasion conditions.

Wear mechanism.
The main wear mechanism for these materials, with and without treatment would be the following:

a) Particles plastic deformation due to high temperatures and pressures.
b) Crack formation due to fatigue mechanism in the plastically deformed zones. If the coating is laser treated the cracks that occur on account of the treatment itself must be added.
c) Fracture and loosening of particles in the coating.
d) Process repetition due to contact with new particles.

This procedure agrees basically with what other authors have stated for this type of ceramic coating, e.g. Vijande [12], Zum Ghar [13].

Corrosion
The polarization curve obtained from the laser-treated Cr2 O3 coating is shown in figure 6. An electrode passivation can be observed on the anodic branches. Comparison of this curve with the one obtained from the non-treated coating evidenced a corrosion potential of 100 to 200 mV more positive for the laser-
treated coating. The cracking that may derive from the laser treatment when not properly preheated, may become a serious drawback to improve the corrosion behaviour of these coatings.

![Graph](image)

**Figure 6.** Polarization curves.

**CONCLUSIONS**

Surface laser treatment is a technique that allows, under certain conditions, the wear behaviour of plasma sprayed ceramic coatings to be improved.

The coatings increase in hardness and the microstructure thinning resulting from the laser treatment, improve the wear behaviour of the coating. In the same way, the abrasive effect of the ceramic on the steel is reduced and therefore its wear behaviour also improves.

The sealing of the coating produced by the treatment improves its corrosion resistance, although the cracks that may occur on account of lack of suitable preheating may imply a serious drawback.

**ACKNOWLEDGMENTS**

This paper has been carried out within the frame of the CICYT project called "Physical and Chemical Aspects of Wear in Moving and Surface Treated
Mechanical Systems", which has been developed jointly by CSIC Tribology Unit and the Tribology Group of the Mechanical Engineering Department of the E.T.S.I.I. in Gijón.

REFERENCES