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Tribological effects of the geometrical properties of plasma spray coatings partially melted by laser

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ABSTRACT

The tribological behaviour of NiCrBSi plasma spray coatings partially melted by laser was investigated. Partial melting provides dual property surface coatings: melted areas, with a homogenous microstructure; and plasma spray areas, with porosity and cracks. This paper studies the influence of two geometrical properties of the partially melted surfaces: the angle of the laser tracks, and the ratio of the melted surface. Laser melting was performed using a 1700 W CO_2 laser and wear tests were carried out using a block-on-ring tribometer in pure sliding lubricated contact.

The main wear mechanism and the interaction of the geometrical properties of the coating are discussed in this paper. The results of wear tests indicate that the best percentage of melted surface to reduce the wear rate is 46%, whereas the track angle is not found to be a major factor influencing the wear rate. The study of Coefficient of Friction (COF) reveals that low track angles have the lowest friction and that the percentage of melted surface is not a major factor influencing the COF.

1. Introduction

Plasma spray technique is widely used in industry to manufacture coatings for different purposes, such as thermal barrier [1,2] or increase the wear resistance of materials [3]. The wear behaviour of coatings of this type has been studied for different coating materials and different substrates over the last few decades [4,5], although ceramic coatings are most frequently [6–9]. The success of the industrial uses of atmospheric plasma spraying (APS) is motivated by the good quality of the coatings obtained and low cost compared to other techniques such as laser cladding.

Ni alloys are one of the most widely used materials to obtain anti-wear coatings due to the balance they present between moderate hardness, low brittleness, good corrosion resistance and a relatively low price compared to other materials. For this reason, Ni alloy coatings are suitable for a broad range of contact configurations in industry. The final characteristics of Ni alloy coatings depend on the specific composition of the alloy (Chromium is usually added between 4% and 16% to increase hardness and corrosion resistance) and the technique used to obtain the coating [10].

Despite the high temperatures generated by the APS process, some of the powder material does not melt completely and, as result, a non-homogenous relatively high porosity coating is formed. Moreover, due to the non-melting process, the adherence between coating and substrate is poor, because metallurgical bonding does not occur. These features result in a worsening of the tribological behaviour in comparison with other techniques such as laser cladding, due to the decrease in the average hardness of the coating, and the increase in brittleness and the risk of stripping [11]. However, the plasma spray process provides coatings with certain advantages with respect to other techniques. One of these is the low deformation induced in the substrate during the process, owing to the fact that the substrate is not melted. This technique thus allows high dimensional accuracy parts to be obtained with low residual stress [12,13]. Porosity in coatings may be an advantage for lubricated contacts, because it acts like a textured surface, retaining the lubricant under a mixed and limit lubrication regime [14].

A well-known post-treatment technique consists in melting the coating with a heat source, such as an oxy-fuel flame or laser beam [15]. Complete melting of the coating reduces the porosity and increases the homogeneity of the coating, as well as improving the adherence between substrate and coating. Several authors have researched the laser melting post-process with the aim of improving the wear behaviour of plasma spray coatings. Serres et al. [12,16] studied the microstructure of a hybrid plasma spray process which uses a laser diode to melt the coating surface just after plasma spray deposition. Similarly, Felgueroso et al. [17] proposed a partial laser melting process to reduce the cost of the complete melting process and preserve part of the characteristic

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plasma spray porosity, thus improving the adherence between coating and substrate. The corrosion behaviour of coatings of this type has been studied previously by Navas et al.[18], who showed that the partial melting process does not affect the corrosion rate of the plasma spray coating without a laser post-process.

This paper studies the wear behaviour of partially laser-melted coatings previously obtained by APS, focussing on the influence of two geometrical parameters of the coating: the angle between the laser tracks and sliding direction, and the percentage of melted surface. The authors have observed that the results obtained using sliding distances similar to those found in the literature for this type of coating and analogous test conditions are strongly influenced by run up process. For this reason, the sliding distance employed in this study was very high and the run-up process was studied for each test condition. Consequently, the wear rate and friction coefficient were compared under steady state conditions.

2. Experimental procedure

Tribological behaviour was studied using a block-on-ring wear test under lubricated conditions. The main coating studied, a NiCrBSi alloy deposited by plasma spray and partially melted by laser, was performed on ring specimens. A WC-Co coating was used on the block so as to obtain a harder counter face.

Two geometrical parameters of the partially melted coatings were studied: the percentage of surface melted, and the angle between the parallel laser tracks and the sliding direction. The track angles tested ranged between 11.25° and 78.75°, while the melted surfaces tested were between 16% and 66%. Every test was performed three times, reporting the average results and standard deviation when comparing the friction coefficient and wear rate.

The chemical composition of the NiCrBSi alloy studied is the shown in Table 1, according to analysis certificates of powder manufacturer. In a first manufacturing step, a 0.5 mm thickness of NiCrBSi alloy was deposited on a S355 J2G3 steel substrate with a blasted surface. The plasma spray process was performed using 75 l/min of N_2 as the primary plasmogen gas and 15 l/min of H_2 as the secondary plasmogen gas, both at a pressure of 3.4 bar. The powder feed rate was 8 kg/h and the distance between the nozzle and the surface was 100 mm, using an automatic carrier to apply a homogenous thickness of coating on the entire area of the steel substrate.

The second manufacturing step consisted in a grinding process to obtain an accurate coating thickness of 0.45 mm and homogeneous roughness. This procedure is absolutely necessary before the laser-melted post-process to ensure correct control of this process, especially the metallurgical bonding between coating and substrate.

The next manufacturing step consisted in the partial laser-melting process using a CO_2 laser operating in TEM 01* mode. The geometric shape performed to generate the partial melting consisted of parallel straight laser tracks. The power used was 1260 W at a processing speed of 335 mm/min, using 0.5 bar of argon as the protection gas. The distance of focalization was 8 mm, obtaining a track width of 1.48 mm.

Table 1
Chemical composition (w.t. %) of the NiCrBSi alloy employed.

Ni	71.7
Cr	15.7
B	3.35
Si	4.27
Fe	4.08
C	0.81

The last manufacturing process to obtain the ring specimens consisted of a new grinding process. This is necessary to ensure the final roughness of the surface and to homogenize the thickness of the coating to 0.35 mm. Due to the laser-melting process, the coating loses porosity and, resulting in a reduction in the thickness of the coating in the melted areas.

Fig. 1 shows an end-manufactured specimen after the wear test. The wear scar produced during the wear test can be seen on right of the cylindrical face, along with the block counter face situated as in its position during the test. The end-manufactured surface of the coating can be seen on left of the cylindrical face, where two different types of regions can be observed. One corresponds to non-melted areas, which have a high porosity, while the other corresponds to the laser-melted areas, which are non-porous, as can be seen in the detail of these regions in Fig. 1.

The counter face block consisted of a C45E steel part with a WC coating obtained by laser cladding. This coating was manufactured using a CO_2 laser and lateral injection nozzle, using argon as the carrier gas. The powder used had a chemical composition of 17% Co and 83% WC and angular shape with an average grain size of 43 μm.

The lubricant used in the wear tests contained an anti-wear additive and had a viscosity of 43.87 mm^2/s at 40 °C and 6.481 mm^2/s at 100 °C. The viscosity index of this oil is 96, according to ASTM D2270.

Wear tests were performed using a block-on-ring contact configuration, according to ASTM G77 standards. The partially melted NiCrBSi coating was performed on the ring specimen, with a final diameter of 55.7 mm. All tests were carried out under room temperature conditions, using a constant mass flow of 20 ml/min of lubricant applied over the contact area. The normal load applied was 400 N, which corresponds to 0.36 GPa of maximum contact pressure according to Euler's theory. The tested sliding speed was 3 m/s and the sliding distance was 122.5 km (equivalent to 700,000 cycles). The coefficient of friction (COF) was measured continuously using a torque sensor situated on the shaft of the tribometer. The wear rate was determined by measuring the loss in weight of the specimens, stopping the test every 100,000 cycles. The contact temperature was estimated as the temperature of the block specimen and the block holder measured with a monochromatic infra-red pyrometer on the side section of the block, near to the contact area.

Scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) were used to characterize the microstructure of the NiCrBSi coating in both regions, with and without laser post-treatment. The Vickers hardness of the NiCrBSi and WC-Co coatings was determined using a micro-durometer at 300 gr of load for 15 s, according to ASTM E384 standards. A 1000X optical microscope was used to check the quality of the coatings with respect to the presence of pores and cracks. Roughness was determined for different areas of the coating using a contact profilometer.

3. Results and discussion

3.1. Testing the coatings

Partial laser post-treatment generates two different areas on the coating, as can be seen in Fig. 2a, which shows a cross section of the Ni alloy coating deposited by plasma spray and partially melted by laser. On the left, the melted area presents a homogeneous non-porous coating, with a metallurgical bonding between the Ni alloy and the steel substrate. The non-melted plasma spray area seen on the right presents high porosity due to the non-melted powder particles, and oxidation of powder particles during the APS process. No cracks have been detected in cross