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Tribological behavior of laser-textured NiCrBSi coatings

A. Higuera Garrido*, R. González[1], M. Cadenas[2], A. Hernández Battez[3]

University of Oviedo, Department of Mechanical and Civil Engineering, Ctra. deCastiello s/n, 33204 Gijon, Spain

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ABSTRACT

This work presents and discusses the tribological behavior of NiCrBSi coatings obtained by diode-laser cladding and with good high-temperature antiwear behavior, textured by aNd-YAG laser to achieve good friction behavior. Different densities and distances between dimples were tested by obtaining their coefficients of friction at different sliding speeds under a load of 100 N with a CETR UMT-3 tribometer and comparing results with a non-textured NiCrBSi coating. The study led to the following conclusions: surface texturing, carried out according to the contact area, reduces the coefficient of friction throughout the speed range tested; to obtain tribological improvement, it is necessary to focus on the relationships between density, dimple diameter and contact area; smaller diameters allow higher numbers of dimples per unit of area, improving the tribological behavior; incorrect dimple density values lead to disruptive behavior, due to both high and low dimple ratios.

1. Introduction

Society's current awareness of the consumption of energy resources, the increasing scarcity of those resources, and the pollution caused by emissions from their use modifies the traditional low-cost priority of mechanical design so that increased costs can now be justified if they are a result of a reduction in consumption and waste.

In this new scenario, engineering can produce high added-value materials through new production techniques. These materials exhibit behaviors and have properties adapted to the new goals of consumption and waste reduction. Thus, industrial applications require materials with improved mechanical and/or tribological properties intended to reduce common problems such as wear, corrosion or oxidation. Generally, materials with a good performance in these areas havehigh costs [1] compared to those with less desirable properties. That is why, in many cases, production of items made entirely with high performance materials instead of lower quality materials is not economically viable.

For years, one of the industrial sector's first responses to these phenomena has been to coat materials using different techniques to obtain better properties such as good adhesion to the substrate, temperature and wear resistance, corrosion and oxidation protection and additional material characteristics that the industry demands as technology has progresses.

1.1. Laser cladding

One set of surface treatment techniques that should be mentioned is treatments made by laser (Laser Surface Treatments). Among these, the method of laser cladding should be highlighted. The main purpose of laser cladding is to attach to a substrate, under controlled conditions, a material with different metallurgical properties by fusing a thin layer of substrate to produce a metallurgical bond with minimal dilution of the coating material [1]. The thin substrate layer should remain bounded so that it is as small as possible but, at the same time, provides a good bonding between the layers [2]. As is well known, the microstructure and chemical composition of the coating depend on the degree of mixing of both materials, which in turn is a function of convection and diffusion, as well as cooling rates during liquid–solid phase changes and solid–solid cooling [3].

One of the first citations in the literature that refers to the laser cladding dates back to 1984 [4], and even then the improved properties of corrosion, fatigue and wear resistance provided by this technique were cited. From that date until the present, the use of this technique has been extended, being commonly used in indus-

* Corresponding author at: Despacho 5.1.21, Edificio Departamental Oeste, Campus de Viesques, Gijon 33204, Asturias, Spain. Tel.: +34 610746756; fax: +34 985182433.

E-mail addresses: higueraalberto@uniovi.es (A.H. Garrido), gonzalezrruben@uniovi.es (R. González), cadenas@uniovi.es (M. Cadenas), aehernandez@uniovi.es (A.H. Battez).

[1] Despacho 5.1.28, Edificio Departamental Oeste, Campus de Viesques, Gijon 33204, Asturias, Spain.

[2] Despacho 5.1.18, Edificio Departamental Oeste, Campus de Viesques, Gijon 33204, Asturias, Spain.

[3] Despacho 5.1.29, Edificio Departamental Oeste, Campus de Viesques, Gijon 33204, Asturias, Spain.

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trial sectors such as the naval sector [5] and the manufacturing sector, including in the manufacturing of engines [6], turbines [7] and machining tools [8]. This is clear evidence of the importance of this technique in industry today. Therefore, research efforts aimed at optimizing their operation and expanding its use are justified.

The highly focused interaction between the laser beam and the treated materials makes laser cladding an interesting technique to improve the performance of coatings for materials with applications in engineering, generating a layer with low porosity, good adherence to substrate and with a controlled dilution [9].

Excessive dilution of the coating material on the substrate is one of the problems most referred to in the literature [1,5], which suggests that it is one of the main quality parameters of the coating. Similarly, and for obvious reasons, the presence of cracks and/or pores in the coating is also an indicator of the quality of the cladding. The absence of these features is preferable because of their association with fatigue and wear phenomena.

Carbon dioxide lasers are the most appropriate in cases requiring high power, large size and relatively low precisions; Nd-YAG lasers perform best at low and medium powers, working on an average material size and with high accuracy [10]. The diode laser is presented as particularly suitable for surface treatment techniques, most notably for the cladding, because it is able to create layers with little or no porosity and with excellent substrate binding. Also, this type of laser, with the same focus, creates cladding tracks wider than others with low levels of dilution and presents a metallurgical structure less coarse than that achieved with other lasers. This is the reason why high power diode laser cladding is more effective than other laser techniques [11].

In particular, the use of a laser diode on lower absorption substrates, due to its shorter wavelength, shows better performance than CO_2 lasers, generating more stable coating droplets and less thermal stress [12]. It likewise generates a particular beam profile, with a low cost per unit of power, a compact design and high efficiency [13,14].

1.2. Laser texturing

The use of texturing as a surface treatment to improve the friction is widespread in various industrial and scientific sectors and is applied in the improvement of performance in internal combustion engines [15–17], in biomechanical applications [18,19], in manufacturing processes [20,21] and a full range of other applications.

The generation of laser micro-holes can be regulated by different phenomena, each presenting different results. The search for one formation mechanism or another depends on the desired results in terms of shape, depth and profile.

In some cases, the incidence of the laser beam on the surface will generate only a pool of melted material with subsequent solidification so that there will be no change in the mass of material, but, rather, in the surface profile. The geometry of the laser-incised area depends on the behavior of the melted material pool and, more particularly, on the variation of surface tension γ vs. temperature T [22].

In other cases, the aim is the sudden vaporization of surface material, which requires a high energy density impacting during a short span of time. Therefore, short pulses are used with relatively high energy peaks. However, the greatest influence on the vaporization of the material is in the energy level used. The pulse duration is a parameter with less influence on that phenomenon [23], so increasing the rate of vaporized material rather than the pulse duration is a more efficient method to increase the energy.

Texturing processes involve the modification of the surface of the material by removal under the action of the laser beam. During the impact of the beam, a layer of material is melted and then sprayed on the surface producing a steam jet. This is jet projected out from the surface and causes a reaction pressure that pushes the molten material in the pool toward the lateral sides [24]. During this phase, the temperature of the pool remains constant at the temperature of vaporization, and the remaining energy is used to achieve the phase change.

The appearance of this ridge usually requires surface grinding after the texturing treatment. In some cases, the created edge is similar to the valley effect generated by texturing materials with negative $d\gamma/dT$ and, if that were the desired effect, no further grinding of the surface would be required.

An interesting technique for texturing is the surface melting and subsequent removal of the material by the action of a stream of inert gas because it requires less energy input and thus reduces the material's thermal stress. One major inconvenience this technique presents is the projection of molten droplets that solidify both above and within the adjacent micro-holes on the work piece.

In cases in which the aim is to generate micro-holes by melting and blowing, it is beneficial to use an assistant gas that hits the surface with a proper angle and pressure [25]. This ensures the removal of the molten material without causing its solidification on either the walls of the micro-hole or on the surface of work piece.

The combination of two treatments, one with high wear resistance (laser NiCrBSi cladding) [30,31] and another that improves the behavior of the material under lubricated conditions (laser surface texturing) [16,26–29], is proposed as a promising choice for a new type of coating with improved tribological behavior. The original contribution of this paper is to achieve a laser surface texturing on a NiCrBSi coating and to study its tribological behavior.

Although scientific references to similar process have been found, none of them concerns the laser texturing on a laser coating process described in this paper. Other authors have carried out texturing process on predeposited WC, TiC and Co powder, obtaining a mixture of cladding and texturing, but only in areas around the micro-holes [32], which causes the loss of the anti-friction property of the external surface of the coating.

References to texturing on 2 μm thickness layers, that were obtained by physical vapor deposition (PVD), have also been found [33], although that range of thickness severely limits the range of depths available for the texturing process.

A more similar process to the one described in this paper is the texturing of a Ni layer obtained by powder metallurgy [34]. In this process, the presence of micropores, which are a result of the cladding technique, can hide the influence of the texturing process because surface pores can exhibit a similar behavior to micro-dimples. Therefore, it can be difficult to isolate micropores' effects on tribological behavior from micro-dimples' effects. However, the interest of this technique lies in its ability to obtain relevant coating thickness with little or no residual stress.

The main objective of this paper is to report on a laser surface texturing on a NiCrBSi laser cladded coating whose tribological properties are widely documented [35] and to analyze the influence of different texturing geometrical parameters on its tribological behavior.

2. Materials and methods

The NiCrBSi coatings were obtained using a Rofin® DL 014 Q diode laser with four diode racks and nominal power from 0.1 to 1.4 kW. The focused laser spot shows a rectangular shape with a size of 3.3 mm × 2 mm while the laser beam's wavelength is940 nm + 10 nm. A Type 4MP SulzerMetco powder feeder was used to obtain the feeding rate. The hopper was pressurized and shaken with compressed air, and argon was the carrier and assistant gas.