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Fiber laser cladding of nickel-based alloy on cast iron

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ABSTRACT

Gray cast iron is a ferrous alloy characterized by a carbon-rich phase in form of lamellar graphite in an iron matrix while ductile cast iron presents a carbon-rich phase in form of spheroidal graphite. Graphite presents a higher laser beam absorption than iron matrix and its morphology has also a strong influence on thermal conductivity of the material. The laser cladding process of cast iron is complicated by its heterogeneous microstructure which generates non-homogeneous thermal fields. In this research work, a comparison between different types of cast iron substrates (with different graphite morphology) has been carried out to analyze its impact on the process results. A fiber laser was used to generate a NiCrBSi coating over flat substrates of gray cast iron (EN-GJL-250) and nodular cast iron (EN-GJS-400-15). The relationship between processing parameters (laser irradiance and scanning speed) and geometry of a single laser track was examined. Moreover, microstructure and composition were studied by Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and X-Ray Diffraction (XRD). The hardness and elastic modulus were analyzed by means of micro- and nanoindentation. A hardfacing coating was generated by fiber laser cladding. Suitable processing parameters to generate the Ni-based alloy coating were determined. For the same processing parameters, gray cast iron samples present higher dilution than cast iron samples. The elastic modulus is similar for the coating and the substrate, while the Ni-based coating obtained presents a significantly superior hardness than cast iron.

1. Introduction

Laser cladding is a technique that is gaining popularity in the industry for commercial applications, encouraged by the development of reliable and robust industrial high power lasers. It is a manufacturing process to generate a dense and metallurgical bonded coating over a substrate. Laser beam is used as heat source to generate a melt pool in a substrate, in which the precursor material is fed [1]. The relative movement between the beam and the workpiece makes possible to generate a layer with a thickness ranged from microns to millimeters [2]. On new components, laser cladding can be applied to improve the surface properties; on old components, it can be applied to restore worn or damaged surfaces in order to reuse them.

Cast iron is a group of ferrous alloys which contains, at least, 2% carbon and 1–3% silicon [3]. The most common types of cast irons are gray cast iron, which exhibits a carbon-rich phase composed of lamellar graphite, and ductile cast iron, which presents a carbon-rich phase composed of spheroidal graphite. In 1700s, the development of cast iron as an engineering material made the industrial revolution possible. Nowadays, it is seen as a brittle, weak and dirty material that is not proper for applications that require high strength in comparison to other alloys. In some applications, it is being substituted by more expensive metallic materials like steel, aluminum-alloys, titanium-alloys, etc. However, the good castability and machinability of cast iron are an opportunity for significant cost savings in manufacturing those parts which are not the more likely to break. Moreover, its high damping capacity is interesting to reduce noise and vibrations. So, cast iron alloys are still being widely used in industry to manufacture brake discs and drums, bearings, gears, engine components, machine tool structural parts, components in rock crushers, etc.

There exists a high demand in industry to improve the performance and durability of all the components. In order to increase the life of cast iron parts, it has been proposed to enhance its surface properties like its hardness, wear resistance and corrosion resistance [4–6] or to restore worn or damaged components for reusing them [7,8]. It can be possible to do both using the here

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proposed technique, laser cladding, and the same precursor material, a nickel-based alloy.

Nickel-based alloys have an outstanding wear and corrosion resistance, even at elevated temperatures and it is a recommended filler alloy to weld cast iron. Therefore, the performance and durability of cast iron parts can be improved by the generation of a coating of this alloy on new parts. It can be used also to rebuild old components and increase their life. Among Ni-based alloys, NiCrBSi presents particularly good performance [9]. In this alloy, chromium improves the high temperature corrosion and oxidation resistance; it also increases the hardness. Boron and silicon decrease the melting point of this material.

There is an intense research on the generation of NiCrBSi coatings by different thermal spraying techniques like flame spraying (FS) [10], atmospheric plasma spraying (APS) [11] or high velocity oxygen fuel (HVOF) [12]; and also it has been widely studied the laser cladding of NiCrBSi over carbon steel [13–15], or pure Ti and Ti6Al4V [16,17]. It was possible to find only one research work of laser cladding of NiCrBSi over cast iron using a CO_2 laser source [6], but mainly focused on studying the wear behavior of the coatings.

Laser cladding on cast iron is difficult because of its heterogeneous composition and it is not very frequently reported on literature as it has been pointed out [4]. Graphite presents higher laser beam absorption than iron matrix. Additionally, the graphite morphology has a strong influence on thermal conductivity of this material. The thermal conductivity of the iron matrix is considerably lower than the thermal conductivity of graphite and the thermal conductivity of gray iron is superior to that of ductile cast iron. As a result, non-homogeneous thermal fields are generated in the laser process and the type of cast iron may strongly influence on the results. Moreover, metals present a higher absorption coefficient for 1 μm laser radiation (Nd:YAG, diode, disk, or fiber laser) than for 10 μm (CO_2 laser). Diode, disk or fiber lasers present a greater wall-plug efficiency than CO_2 lasers and they can be delivered using optical fiber. All these features make high power diodes, disk or fiber lasers the most interesting choices for industrial cladding applications.

So, there is a lack of research on the processing parameters to generate Ni-based coatings over cast iron by means of a near-infrared laser. Particularly, it may be of interest a comparison between different types of cast iron substrates (with different graphite morphology) to analyze its impact on the process results. The objective of this work is to generate a NiCrBSi coating over cast iron by means of fiber laser cladding over flat substrates of gray cast iron (EN-GJL-250) and ductile cast iron (EN-GJS-400-15), also known as nodular cast iron. The relationship between processing parameters (laser irradiance and scanning speed) and geometry of a single laser track were examined. Moreover, microstructure and composition were studied by Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and X-Ray Diffraction (XRD). The hardness and elastic modulus were analyzed by means of micro- and nanoindentation.

2. Materials and methods

The laser cladding with side setup was selected to generate the coatings (see Fig. 1(a)). In this setup, laser beam is employed as heat source to generate the molten pool in a substrate. A material in form of particles is fed into the molten pool. The relative movement between the beam and the workpiece makes possible to generate a clad layer. The coatings were generated on flat substrates of cast iron with dimensions of 50 mm × 50 mm × 15 mm. Two different types of cast iron were employed: gray cast iron (EN-GJL-250) and nodular cast iron (EN-GJS-400-15). Fig. 2(a) and (b)

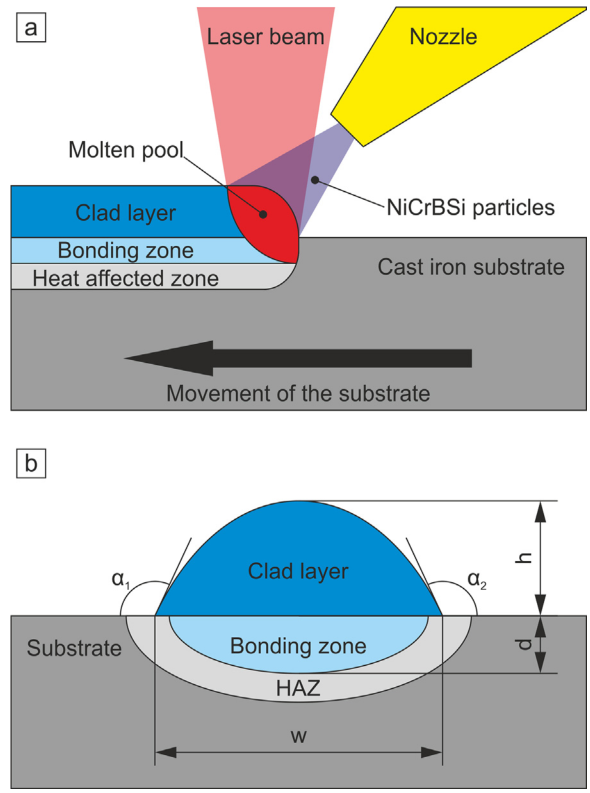

Fig. 1. (a) Outline of the laser cladding with lateral particle injection experimental set-up; and (b) sketch representing geometrical parameters of single laser clad track: height (*h*), depth (*d*), width (*w*) and clad angles (α_1 and α_2).

shows the characteristic microstructure of each type of cast iron; the corresponding chemical compositions provided by the supplier are detailed in Table 1.

The experiments were done using a high power fiber laser (IPG YLR 3000) to generate the molten pool and a CNC table was employed to move the substrate with regard to the laser head. Commercial NiCrBSi alloy powder, Ni401 from Sandvik Osprey Ltd., with a particle size between 125 μm and 150 μm was used as precursor material for the coatings. The powder was carried by argon and laterally injected in the molten pool by a convergent nozzle. Morphology and size of the particles can be seen in Fig. 2(c) and the chemical composition provided by the supplier is detailed in Table 1.

The processing parameters for single clad tracks are shown in Table 2. 12 samples were generated in total, 6 samples for ductile cast iron (from a1 to a6) and 6 samples for gray cast iron (from b1 to b6), varying power (300 W and 500 W) and scanning speed (1 mm/s, 2 mm/s and 5 mm/s). Laser beam was focused employing a lens with a diameter of 50 mm and a focal length of 200 mm. The working distance, from the substrate to the lens, was longer than the focal length to obtain a spot diameter of 1.7 mm; this value was kept constant for all the experiments. The mean irradiance was 132 W/mm^2 or 220 W/mm^2 for a delivered laser power of 300 W or 500 W, respectively. Mass flow of NiCrBSi alloy particles is fixed at a rate of 8.5 g/min.

Samples of single laser cladding tracks were cut, embedded in resin and polished to observe the cross-section. The geometrical parameters represented on Fig. 1(b) were measured on the cross-section of the samples: height (*h*), depth (*d*), width (*w*) and clad angles (α_1 and α_2). This parameters were also employed to calculate the width-to-height aspect ratio (wh), a ratio between width and height of the clad [1]; and the mean clad angle (α_m), the average between both clad angles (α_1 and α_2). By studying