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Functionally graded 3D structures produced by laser cladding

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Abstract

In this study, three-dimensional metallic structures of functionally graded materials (FGMs) were produced using the one step laser cladding technique. AISI 316L with particle size between 63 and 125 µm and a cobalt based super-alloy with 90 µm of average particle size, were used as precursor materials. A Yb:YAG continuous wave fiber laser (λ=1075 nm) was chosen as the energy source of the laser cladding process. By means of a new powder feeder system specifically developed for this work, the precursor materials were mixed and homogenized in the desired percentage. Moreover, the new powder feeder allows the live modification (during the processing time) of the material concentrations, in order to obtain three-dimensional structures with a smooth gradient of the precursor material. The study was completed with the analysis of the microstructure, chemical composition and micro-hardness of the obtained samples.

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Keywords: Laser cladding; Functionally Graded Materials; AISI 316L

1. Introduction

Functionally graded materials (FGM) can be defined as those materials that change its structure and composition along its total volume, causing a change in the properties from one part to another of the total volume [1, 2]. This is the reason why this type of materials present a huge development potential in a wide range of fields like components of rocket engine for aerospace applications, sensors and graded band semiconductor, biomaterials for different orthopedic applications and implants, heat exchangers in energy plants or structural walls that combine sound and thermal isolation [1, 3-5].

Since the appearance of the firsts FGM in the early 1980´s in Japan, a large number of production techniques of these graded materials has been developed, like for example, die compaction of layers, controlled mold filling, infiltration process, conventional thermal spray, electrophoretic deposition or sheet lamination [6, 7]. The majority of these techniques are in a laboratory stage, and their high complexity make difficult the implementation at industrial level. In the last years, and in an effort to overcome the limitations of other techniques, different authors have explored the possibility of using the laser cladding technique to produce a wide range of FGM [3, 8-10], due to the advantage of laser cladding (low heat input, high accuracy, high repeatability, no post-processing steps or easy automation), that allows the generation of 3D pieces with complex geometries by rapid prototyping based on laser cladding [11-15].

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The objective of the present work is to investigate the generation of three dimensional structures with a smooth and controlled compositional gradient using an additive manufacturing technique based on laser cladding.

2. Materials and methods

2.1. Materials

AISI 316L plates were used as substrates with dimensions of 60 x 50 mm^2, and a thickness of 8 mm. The high flatness and the polished surface finishing (Ra < 0.5 µm) are the mean features of these substrates.

Two different powders were used as precursor materials; AISI 316L steel powder (Stelloric 1303 G3, coded S1 in this work) with a mean particle diameter between 63 - 125 µm and spherical morphology, and a cobalt based superalloy (Stelloric 1396 S, coded S2 in this work) with particle mean diameter ranging from 38 to 106 µm. According to the Geldart diagram for pneumatic conveying applications [16], both materials belong to the group B. Particles in this group are known as aeratable particles, and their fluidization is relatively simple by means of pneumatic conveying systems. Fig. 1 shows SEM micrographs of the particles of S1 and S2 precursor materials and their relative position in the Geldart diagram. Chemical composition of the substrate and precursor powders is given in Table 1.

Table 1. Chemical composition of precursor powders (% weight).

Material	C	Cr	Si	W	Fe	Co	Ni	Mn	Mo	Cu	Br
Substrate AISI 316 L	0.08	18.0	1.0	-	Bal	-	9.5	2.0	0.6	0.6	0.2
S1:AISI 316 L	0.05	17	2.5	-	Bal	0.4	11	-	2.5	-	-
S2: Co-superalloy	0.8	19.1	2.5	7.8	3.0	Bal	14.5	0.3	-	0.4	1.7

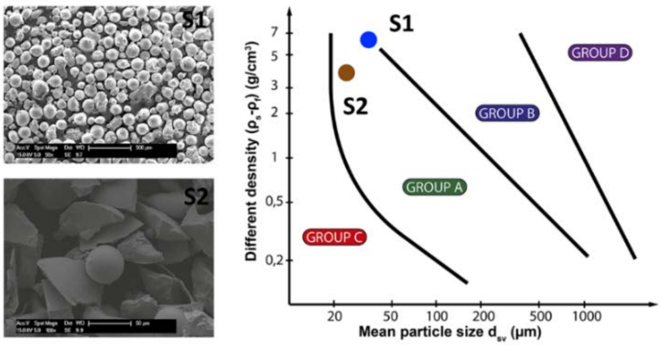

Fig 1. SEM micrograph of the precursor powders (S1 and S2), and their classification in Geldart diagram.

2.2. Laser cladding technique

In order to obtain functionally graded three dimensional structures by laser cladding, an off-axis configuration has been employed. In this technique the powder stream of precursor material, which it is carried by Argon, is injected in the interaction zone with the laser by means of an off-axis nozzle. Simultaneously, a relative movement of the substrate with regard to the laser beam and the cloud of powder is achieved by a motorized stage. The energy necessary to melt the precursor powder and the substrate is provided by a stationary high-power laser beam that heats up the precursor material and creates a molten pool on the substrate where the particles impinge. On the other hand, the oxidation of the molten material is avoided injecting a shielding inert gas into the interaction zone. Finally, a rapid quenching of the molten pool takes place as it goes away from the laser interaction region and a coating track is formed on the surface of the substrate. The outline of the method is widely referenced [17-19].

All laser cladding experiments were performed with a high power and high brightness monomode SPI Yb:YAG fiber ytterbium laser of 200 W maximum power emitting at a wavelength of λ=1075 nm. Laser radiation was guided by means of a 50 µm core diameter fiber and coupled to the working station via expanding and collimating optics. The laser beam was focused on the substrate surface by a lens of 120 mm of focal length. The spot diameter of the laser beam onto the substrate was 40 µm. Fig. 2 shows a sketch of the experimental set-up.