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Laser cladding of phosphor bronze

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ABSTRACT

Phosphor bronze is a suitable bearing material because of its good fatigue strength and excellent wear properties under corrosive conditions, high temperatures and high loads. Bronze is usually continuously cast as bar or tube and machined into bushes, cam followers, washers or other bearing components. It is common to mount bronze bushes around shafts by means of warm shrink fitting. Laser Cladding is a manufacturing process to generate a dense a metallurgical bonded coating over a substrate and it can be employed to deposit a phosphor bronze coating directly over a shaft improving its wear properties. In this paper, the feasibility of the Laser Cladding to produce phosphor bronze coatings on alloy steel is demonstrated. Suitable processing parameters to generate phosphor bronze coatings are presented. The hardness of the bronze coating obtained is 172 ± 12 HV, 56% higher than the one reported for cast bronze. Finally, Laser Cladding is proposed as a method to create a bronze surface in an area of a shaft as a substitute of warm shrink fitting of machined bronze bushes.

1. Introduction

Laser cladding is one of the industrial preferred surface engineering techniques for its ability to apply a chemically different material as a layer onto a given substrate. Laser beam is used as heat source to generate a melt pool in a substrate, in which the 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, 3]. This technique can be applied to improve the surface properties of a new part and also in the restoration of worn or damaged components.

Different surface properties can be improved by coatings applied by laser cladding: mechanical (hardness, fatigue resistance, wear resistance) [4–6], corrosion resistance [7,8], biocompatibility [9–11], etc. On the other hand, this technique is very flexible in materials; many different coatings have been investigated, from superalloys [12,13] to advanced ceramics [14], in form of single or multiple layers [15,16].

Phosphor bronze is an alloy of copper, tin (3.5 wt%–20 wt%) and phosphorus (<1 wt%). The increase of tin content increases gradually the tensile strength of bronze reaching a maximum at 20% Sn. Small quantities of phosphorous are added to tin bronze as deoxidizer to avoid the formation of SnO_2 [17]. Phosphor bronze is employed in industry because of its good fatigue strength, excellent machinability and solderability. In addition, this alloy is a suitable bearing material because of its excellent wear properties under corrosive conditions, high temperatures and high loads [18].

Bronze is usually continuously cast as bar or tube and machined into bushes, cam followers, washers or other bearing components [19]. Metal machining results in the waste of work material in the form of chips. However, bronze machining chips can be recycled and converted into bronze powder suitable to be employed as precursor material in Laser Cladding [20]. Therefore, Laser Cladding could be employed to avoid the waste of work material produced in the machining of bronze.

Bronze bushes use to be mounted by warm shrink fitting around shafts [21]. Laser Cladding can be employed to deposit a phosphor bronze coating directly over a shaft improving its wear properties and avoiding the use of machined bushes. It has been demonstrated that tin bronze samples fabricated by selective laser melting (SLM) have a higher yield and ultimate strength and better ductility than cast samples [22]. This improvement is attributed to the refined microstructure of the SLM material resulting from high cooling rate obtained by laser processing.

The objective of this paper is to demonstrate the feasibility of the Laser Cladding to produce functional phosphor bronze coatings on alloy steel, optimize the processing parameters and study its geometry, microstructure and hardness. Moreover, Laser Cladding is proposed as a

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method to create a bronze surface in an area of a shaft as a substitute of warm shrink fitting of machined bronze bushes.

2. Materials and methods

The laser cladding with side setup was selected to generate the coatings (see Fig. 1a). In this setup, laser beam is employed as heat source to generate the molten pool in a substrate. The coating precursor material is fed into the molten pool in form of particles. The relative movement between the beam and the workpiece makes possible to generate a clad layer. The coatings were generated on cylindrical AISI 4340 alloy steel (UNS G43400) substrates with dimensions of 32 mm in diameter and 27 mm in height. AISI 4340 is a Nickel-Chromium-Molybdenum high tensile steel. It offers a very good balance of strength, toughness and wear-resistance, being used in heavy-duty axles, shafts, torsion bars, connecting rods, etc. The chemical composition of AISI 4340 is detailed in Table 1.

The experiments were done using a High Power Diode Laser from DILAS with a wavelength between 915 and 976 nm and a maximum output power of 1600 W. A CNC table with a rotatory axis was employed to move the substrate with regard to the laser head. Commercial phosphor bronze alloy powder, B15 from Sandvik Osprey Ltd., with a particle size between 150 μm and 180 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 and their chemical composition is detailed in Table 1.

Table 1
Chemical composition (wt.%) of the experimental materials, AISI 4340 alloy steel substrates and phosphor bronze B15 particles.

	AISI 4340		Phosphor Bronze B15	
	Min	Max	Min	Max
Fe	Bal.	Bal.	–	–
C	0.38	0.43	–	–
Ni	1.65	2.00	–	–
Cr	0.70	0.90	–	–
Mo	0.20	0.30	–	–
Mn	0.60	0.80	–	–
Si	0.15	0.35	–	–
S	–	0.04	–	–
P	–	0.04	0.1	0.4
Sn	–	–	13.0	15.0
Cu	–	–	Bal.	Bal.

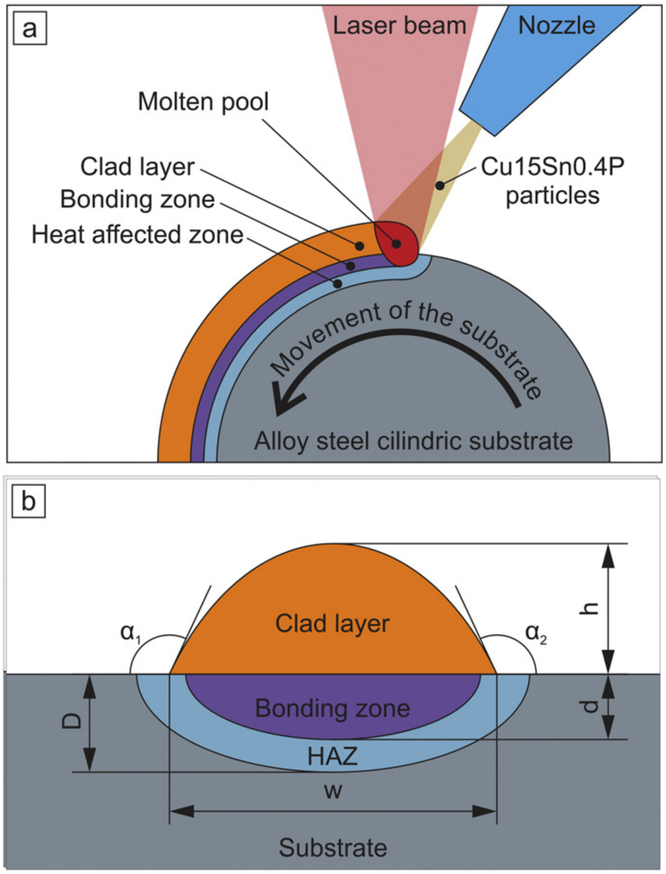

Fig. 1. a) Outline of the laser cladding with lateral particle injection experimental set-up; b) Sketch representing geometrical parameters of single laser clad track: height (h), depth of molten substrate (d), depth of heat affected zone (D) and width (w); and clad angles (α_1 and α_2).

The processing parameters for single clad tracks are shown in Table 2. 10 samples were generated in total, varying power (500 W, 700 W and 1000 W), scanning speed (2.5 mm/s, 5 mm/s, 10 mm/s and 20 mm/s) and powder feeding rate (12 g/min and 24 g/min). Laser beam was focused employing a lens with a diameter of 50 mm and a focal length of 250 mm. The laser spot diameter on the surface of the substrate is 3 mm. The mean irradiance was 71 W/mm^2, 99 W/mm^2 and 142 W/mm^2 for a delivered laser power of 500 W, 700 W and 1000 W, respectively.

Samples of single laser clad tracks were cut, embedded in resin and polished to observe the cross-section. The analysis of the morphology was done by optical microscopy in order to determine the optimum processing parameters. Geometrical parameters represented on Fig. 1b were measured on the cross-section of the samples: height (h), depth of molten substrate (d), depth of heat affected zone (D), width (w) and clad angles (α_1 and α_2). These 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).

Optimum processing parameters were employed to produce bronze single layer bronze coatings by overlapping single clad tracks. The microstructure of the bronze coatings was studied by means of scanning electron microscopy (SEM, Philips XL30) employing a backscattering electron detection mode. The qualitative elemental composition was determined via Energy-dispersive X-ray spectroscopy (EDS, EDAX PV9760 coupled to the SEM). X-ray diffraction analysis was carried out by means of a PANalytical X'Pert Pro X-ray diffractometer, using monochromated Cu-Kα radiation ($\lambda = 1.54$ Å) over the 20–100° 2θ range with step size of 0.02°. The surface to be analyzed by this technique must be flat because a rough sample would give spurious results. Therefore, before the X-ray diffraction test, the top surfaces of the samples were polished with a series of abrasive SiC papers. The polishing process was done to obtain a smooth flat surface with a roughness

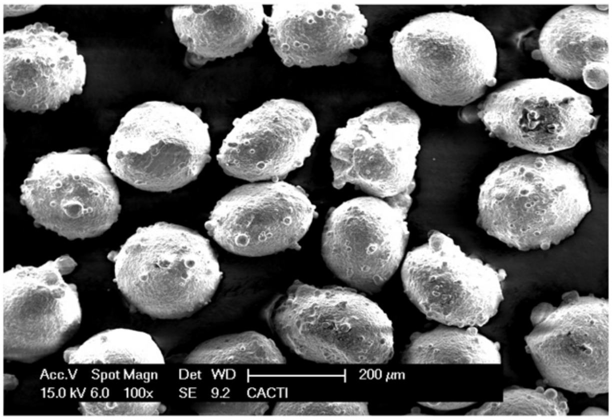

Fig. 2. SEM micrograph showing particle size and morphology of phosphor particles employed in this work.