DOUBLE-LAYER [Ni-Co] BASED COATINGS BY LASER CLADDING: THE EFFECT OF LASER POWER ON THE COATING'S FEATURES

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ABSTRACT

Laser cladding was developed in the seventies in the United States of America (Gnanamuth, U.S. Patent 3,952,180) and, after notable technological progress, it has been used in many industrial areas for more than three decades. Examples are met in power generation, aerospace turbines, marine, automotive oil&gas, and many others. In these scenarios, a hard and/or corrosion-resistant material can be deposited on a substrate to withstand the wear and corrosion degradation either in new components enhancing the service life or repairing a worn-down surface. A recent report stated that ~23% of the world's total energy consumption originates from tribological contacts, 20% to overcome friction, and 3% from remanufacturing worn parts and spare equipment due to wear and wear-related failures attracting, therefore, the attention of the scientific community in this field. However, the fast heating/cooling rates lead to high thermal gradients and stresses that may cause coating microcracks, as well as refined microstructures containing out-of-equilibrium phases, may be formed. This work aims to investigate the microstructure of double-layered coatings by laser cladding. The purpose is to pre-heat the substrate during the first layer deposition of a high ductility alloy (Ni-based Hastelloy C276) and after, to deposit a hard and wear-resistant coating (Co-based Tribaloy T800) to mitigate the degree of cracking and, at the same time, to obtain thicker deposits for components repair. Coatings were deposited with 2.0, 2.5, and 3.0-kW Laser Powers and an overlapping degree of 30%. Characterization involved dilution, chemical mapping with energy dispersive spectrometry, and microstructure description in a scanning electron microscope. The microstructure was then correlated with the hardness and the corresponding micro-abrasive wear in the Calowear tester for the second layer (Tribaloy T800). Regardless of the laser power, the first layer showed a microstructure comprised of Ni-FCC dendrites containing interdendritic carbides. Otherwise, the second layer showed a primary intermetallic Laves phase dispersed in a lamellar eutectic matrix for 2.0 kW, full cellular eutectic microstructure for 2.5 kW, and hypoeutectic dendrites of Co-FCC with interdendritic lamellar eutectic for 3.0 kW. Coatings showed a trend to reduce the cracking intensity as a higher laser power is adopted, probably due to the larger pre-heating and reduction of the Laves phase fraction resulting from higher dilution. As a consequence, the average hardness of the second layer was 1070, 900, and 570 HV_2 for 2.0, 2.5, and 3.0 kW, respectively. A lower micro-abrasive worn volume was measured for coatings deposited with 2.0 and 2.5 kW, i.e., the harder conditions.

Keywords: *Laser Cladding, Multilayer Coatings, Hastelloy C276, Tribaloy T800, Microstructure.*

INTRODUCTION

The high cost associated with wear failures, wear-fatigue, and corrosion in industrial components and manufactured products has attracted the attention of the academic engineering community over some decades and was a decisive factor to have surface engineering as a field of science. Holmberg and Erdemir (1) reported that tribology represents about 23% of global energy consumption and, of these, 20% is related to overwhelming friction and 3% to parts remanufacturing processes. According to Koch et al. (2), the estimated annual global cost of corrosion reaches 2.5 trillion dollars. In addition to the preventive and corrective costs of corrosion, this engineering problem can often lead to serious environmental and worker accidents (3). In light of this, the potential benefit of surface engineering, either to overcome sustainability challenges or to manage industrial costs and risks seems clear.

Furthermore, numerous techniques can be used to promote the formation of surface layers, which, in many cases, have superior properties to those of the core material (4). Among the process possibilities, appear laser cladding as a coating deposition technique that uses a laser beam to melt a feeding material and deposit it on the surface of a component (5).

In laser cladding, it is possible to obtain coatings with low substrate dilution and, at the same time, to obtain coating-substrate metallurgical bonding. The high cooling rates on solidification promote the formation of extremely refined microstructures, which are often beneficial to the final properties of the coatings (5). However, the high cooling rate also leads to the formation of thermal stresses, which makes it difficult to obtain crack-free coatings for some alloy systems (6). Thus, there is a need for experimental investigations to adjust the deposition parameters for each alloy, substrate adopted, and deposition strategy (parameters, overlapping degree, number of layers, dilution, and so on).

Superalloys have been widely used as coatings to protect the surface of components often manufactured from cheaper materials. Depending on the main element, they are called Nickel, Iron, or Cobalt superalloys. From the review of Stein and Leineweber (7), Cobalt-based Tribaloy alloys present a unique set of properties, and their selection involves some scenarios where wear arises in conjunction with high temperature and corrosive media. However, these alloys show extremely high hardness, sometimes hindering the direct deposition with no cracking (7-10). According to Tobar et al. (9), the cracking susceptibility of the T800 hinders the development of laser-clad layers, as a result of the high thermal stresses. The authors referred to several previous works which have been proposing alloy modifications, with the chemical compositions altered to increase the ductility. As an example, Tribaloy T900 was modified by increasing the Ni content and, therefore, - lowering the Co and Mo content – as a way to obtain a lower fraction of the Laves phase.

This work aims to investigate the deposition of double-layered coatings, being the nickel base Hastelloy C276™ selected for the deposition of the first layer (layer 1) and Cobalt-based Tribaloy T800 as the top layer (layer 2). Firstly, the idea was to deposit layer 1 between the substrate and the T800 top layer as a way to pre-heat the substrate. Secondly, the effect of the dilution as a goal is to introduce mainly nickel to T800, in the same way as the T900 alloy. Emphasis was given to understanding the effects of laser intensity on multi-layer coating formation and its potential impact on the presence of cracks, dilution, microstructure, hardness, and micro-abrasive wear of Tribaloy T800 coatings.

MATERIALS AND METHODS

This work adopted gas-atomized powder-feeding alloys, Hastelloy C276™ (Ni-14.5Cr15.9Mo4.5W) and Tribaloy T800™ (Co-17.5Cr28.5Mo3.5Si), with particle sizes from 53 to 150 µm. The alloy powders were deposited in a high-power diode laser (HPDL)

PRECO™ SL8600 deposition center with a coaxial torch device on AISI 304L stainless steel plates 12.00 mm thick. Multi-bead processing parameters included a 30% overlapping ratio and 2.0, 2.5, and 3.0kW laser powers. For additional information, processing parameters set up can be consulted in the previous study [11].

The top surface of coatings (layer 2 or top layer) was machined to remove 0.3 mm from the as-deposited weld surface, ground, and polished to a specular surface. Dilution of multi-bead coatings was assessed by the density of materials and chemical composition [5], through nickel measurements by energy dispersive spectrometry (EDS). Microstructure analysis was performed in a scanning electron microscope under backscattered electrons operational mode (BSE) and phase fraction was determined with Image J™ software [12]. X-ray diffraction analysis on the top of coatings utilized Kα-Cr radiation from 30 to 165° in a GE Sensing & Inspection GmbH, model Seifert Charon XRD.

Vickers hardness under 2 kgf load and ball cratering wear test were evaluated on the flat and polished top surface of coatings. In the Calowear test, a 25.4 mm diameter tungsten carbide (WC) ball slides under 0.45 N normal loads (α slop of 60°) on the coatings under continuous aluminum oxide suspension abrasive feeding (1 μm) in a feeding rate of 1 drop/s.

RESULTS AND DISCUSSION

Macrographic Analysis and Dilution

Figure 1 presents the machined top layer showing cracks for deposits with 2.0- and 2.5-kW laser powers and a clear trend to reduce the cracking tendency as the higher heat input is chosen.

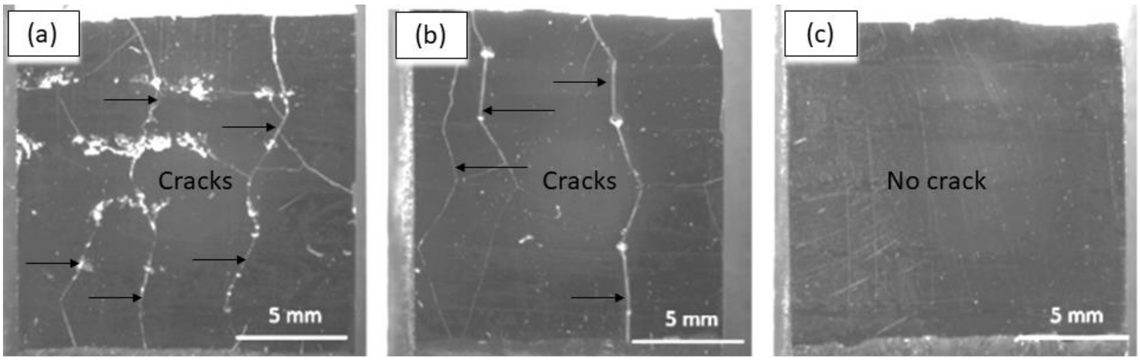

Figure 1: Machined top surface of coatings: (a) 2.0, (b) 2.5, and (c) 3.0 kW.

Figure 2 shows a cross-sectional evaluation of the double-layers, showing the EDS mapping showing in detail the layer formation and materials mixing for distinct heat inputs.

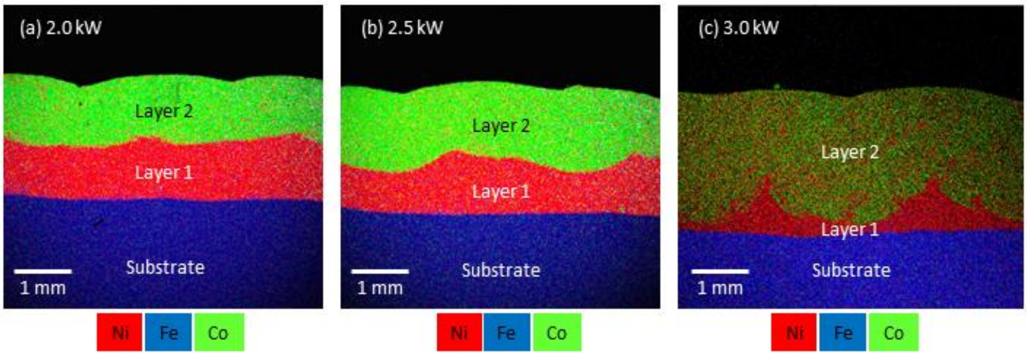

Figure 2: EDS mapping on the cross-section of multi-layer coatings: (a) 2.0, (b) 2.5, and (c) 3.0 kW.

A minimum burn-in shape was observed for 2.0 kW laser power and, from 2.5 kW on, the burn-in-shape increases resulting in a most pronounced mixing of layers 1 and 2 (see Figure 2). According to Goodarzi, Pekkarinen, and Salminen [13], a higher substrate burn-in means that higher dilution must be observed. Table 1 shows the dilution calculated following the Toyserkani method [5], corroborating with the verified burn-in-shape.

Table 1: Dilution calculation, being ρ_c the density of the feeding material (T800 alloy), ρ_s the substrate density (C276 alloy), $X_{substrate}$ the nickel content (C276 layer 1), $X_{coating}$ the nickel content in the Tribaloy T800 alloy, and X_{c+s} the nickel content by EDS analysis (T800 layer 2).

kW	ρ_c (g/cm³)	ρ_s (g/cm³)	$X_{substrate}$ (EDS Layer 1 – Ni-wt%)	$X_{coating}$ Ni (wt%)	X_{c+s} (EDS Layer 2 - Ni-wt%)	**Dilution** η **(%)**
2.0	8.6	8.9	54.5	2.2	5.1	5.4
2.5	8.6	8.9	46.5	2.2	7.6	11.9
3.0	8.6	8.9	40.5	2.2	23.5	54.8

Coatings Microstructure and Phase Description

Regardless of the laser power, the typical XRD patterns for the top layer coatings mainly showed Co-FCC solid solution, CoMoSi, and Co_3Mo_2Si Laves phase, and Co_3Mo_2 and Co_7Mo_6 intermetallic phases. From a preliminary analysis, it seems that the heat input does not change the formed phases in layer 2 (Tribaloy T800).

The microstructure of layer 1 (Hastelloy C276) is comprised of Ni-FCC dendrites and a low volume fraction of interdendritic carbides, following the previous works [11,14] and, for sake of objectivity, only top coatings (layer 2) will be described in detail. Figure 3 presents the microstructure of the coatings, comprised of the primary Laves phase and lamellar eutectic matrix (Co-lamellae and Laves-lamellae) for 2.0 kW (a), a fully lamellar eutectic microstructure (Co-lamellae and Laves-lamellae) for 2.5 kW (b) and, a hypoeutectic structure comprising of Co-FCC dendrites and interdendritic Laves phase network for 3.0 kW (c).

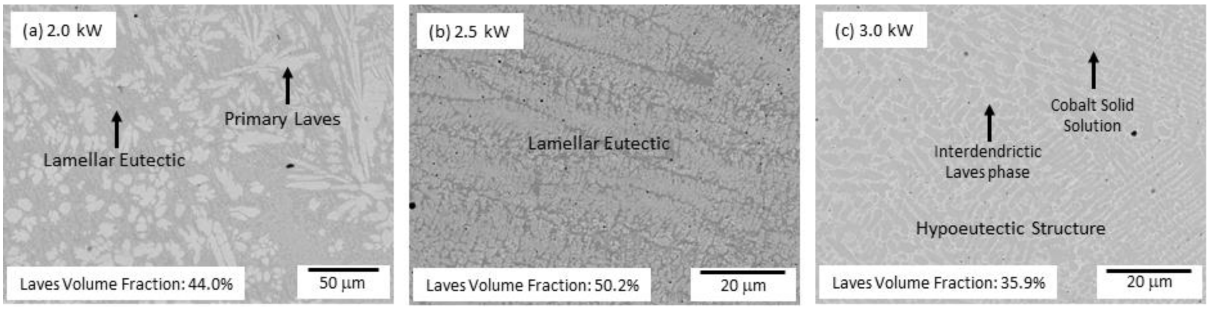

Figure 3: Typical microstructures of the top layer.

The top layer microstructure was modified accordingly to the dilution with layer 1. The increase from 5.4% to 11.9% dilution suppressed the primary Laves phase, leading to a fully eutectic lamellar structure, and for 54.8% dilution, the microstructure was similar to the T900 alloy. The dilutions accounted for a not-so-different Laves fraction for 2.0 and 2.5 kW showing 44.0 and 50.2%, respectively, being reduced to 35.9% for 3.0 kW laser power, following the previous report [9].

Coatings Hardness and Wear Behaviour

Figure 4 presents the coating's hardness and worn hubcap volumes after *Calowear* tests for a constant sliding distance of 315 m.

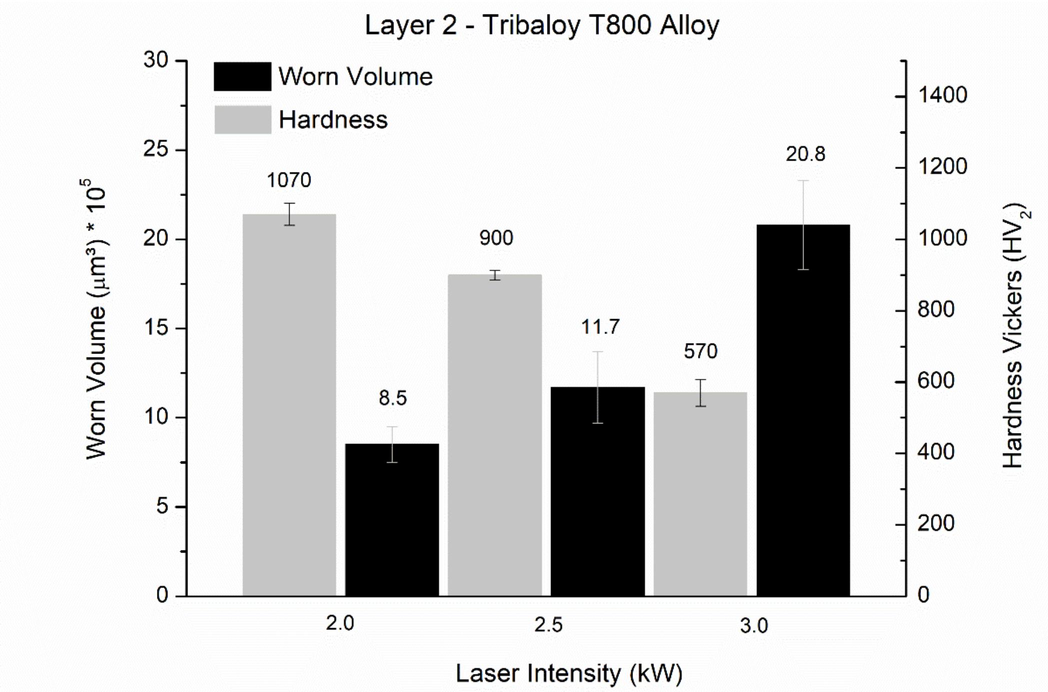

Figure 4: Typical coatings hardness and hubcaps worn volume for the top layer.

First, the crack tendency was reduced as a higher heat input was chosen, probably because of the lower thermal stresses, and notable microstructure changes. It seems that despite showing a slightly lower laves fraction (44.0%), coatings processed with 2.0 kW showed a bit higher crack intensity, probably due to the primary Laves phase compared with a fully lamellar eutectic microstructure (50.2% Laves fraction) of the 2.5 kW deposits. Otherwise, 3.0 kW presented a decrease in the volume fraction of the hard and brittle intermetallic Laves phase (35.9%), in turn, leading to a free of crack coatings. Therefore, one may be argued here is the potential benefit of the heat input increase on the substrate pre-heating altering the thermal stress level, probably acting in a conjugated effect with the dilution and microstructural features on crack mitigation. However, the benefit of dilution on the crack mitigation compromised the wear resistance of the Tribaloy T800 coating, resulting in a higher than 140% increase in the total hubcaps worn volume if analyzed the results of 2.0- and 3.0-kW specimens.

CONCLUSION

This work analyzed the cracking tendency, macro and microstructure, and micro-abrasive wear of double-layer coatings by laser cladding. The main conclusions can be drawn:

- Tribaloy T800 cracking intensity is notably reduced as a higher heat input is adopted, i.e., due to the higher dilution with the Hastelloy C276 alloy. It was because of the mixing of the brittle Tribaloy alloy with the nickel base one and also due to the most pronounced substrate pre-heating when depositing the first layer.
- The dilution of the T800 with C275 alloy leads to an increase in the nickel content and, consequently, reduces the molybdenum and silicon content. Since these elements are the main formers of the intermetallic Laves phase, its volume fraction is proportionally reduced. Thus, the microstructure ranged from hypereutectic at 2.0 kW to full eutectic at 2.5 kW and hypoeutectic at 3.0 kW.
- Double-layer coatings deposited with higher dilution (3.0 kW) showed lower hardness, in turn, compromised to a certain point the micro-abrasive wear performance of the T800 alloy. However, since the alloy was diluted with a high molybdenum-nickel alloy, it seems

to be an opportunity to obtain coatings with a still good hardness (570 HV), no superficial cracks, and a low amount of iron.

- Dealing with the laser cladding process - dual-feed system with distinct laser power - this work highlights a path for research of multi-materials as a strong tool for composition control and modification of coatings to protect the surface of components operating under harsh environments.

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