

COB-2023-1021 COAXIAL LASER CLADDING OF TRIBALOY T800™ ALLOY

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Abstract. Laser cladding has been considered in many engineering areas as an attractive option to withstand the wear and corrosion of materials. A recent study reported that nearly 23% of global energy is consumed to overwhelm friction and to remanufacture worn components of industrial machines and equipment. Thus, the development of coatings to obtain lower friction coefficients or even to withstand the wear and corrosion degradation of components seems to fit well with sustainability claims, draining the scientific community's attention in the field of surface engineering. In this context, the CoCrMoSi alloy system - commercially known as Tribaloy™ - has shown promising performance in metal-to-metal contact wear and under corrosion-wear degradation. Also, due to the extremely refined microstructures, excellent wear behavior is associated with Laser cladding. However, the high cooling rates often can cause coating microcracks due to the thermal gradients and stresses, hindering the prompt deposition of many alloys. As a step of weldment qualification, this work aims to investigate the effect of heat input on the microstructure and hardness of CoCrMoSi (Tribaloy T800™) alloy coatings. Single and multi-beads were deposited with 2.0, 2.5-, and 3.0-kW laser powers, inspected through non-destructive testing to evaluate cracking, and characterized concerning bead geometry, dilution, microstructure, and hardness. The microstructure of single-beads is comprised of primary intermetallic Laves phase dispersed in a cobalt solid solution matrix. Multi-beads showed a similar microstructure for 2.0 kW laser power, whilst in higher laser powers the microstructure was altered to larger primary dendrites and lamellar eutectic (2.5 kW) and full lamellar eutectic (3.0 kW). Multi-bead coatings showed a trend to reduce the cracking intensity as a higher laser power is adopted, probably due to a conjugated effect of larger pre-heating leading to slightly lower cooling rates, and reduction of the Laves phase volume fraction. Irrespective of the microstructure changes, coatings showed an average hardness higher than 800 HV. This work highlighted the importance of the qualification step and showed how critical heat input is on the coatings' features.

Keywords: Laser Cladding, CoCrMoSi alloy, Tribaloy T800™, Dilution, Microstructure, Hardness.

1. INTRODUCTION

Failures due to wear, wear-fatigue, and corrosion in industrial components and products have attracted the attention of engineers and technicians for at least four decades and the impact on operating costs was a decisive factor to have surface engineering as a branch of science. Studies report that tribology represents around 23% of global energy consumption, with 20% related to friction losses and 3% to part remanufacturing processes (Holmberg and Erdemir, 2017). An estimative indicates that the global cost associated with corrosion can reach up to 2.5 trillion dollars (Koch et al., 2016). In addition, corrosion can lead to serious environmental and worker accidents (Wulpi, 1999).

Surface engineering has been recognized since the 1970s and several techniques can be adopted to promote the formation of superficial layers, usually with better properties compared to the core material of components (Burakowski and Wierzchon, 1999). This group of techniques encompasses the deposition of coatings, with great attention on the one

that uses a laser beam to melt a feeding material and to deposit it on a substrate, widely known as laser deposition or simply laser cladding (Toyserkani et al., 2005).

Laser deposition allows obtaining coatings with low dilution, ensuring metallurgical bonding coating-to-substrate. The deposited materials are subject to high cooling rates during solidification, leading to the formation of extremely refined microstructures that often provide good final properties to coatings (Toyserkani et al., 2005). On the other hand, high cooling rates can also lead to the formation of residual stresses, which can favor the formation of cracks for some alloy systems (Zhu et al., 2021). In this context, it is pertinent to conduct investigations that indicate the best deposition conditions for each alloy system, including process parameters, such as the percentual of bead overlapping, number of layers, and heat input, among others.

Superalloys are special engineering alloys that contain, as a major element, Nickel, Iron, or Cobalt and are widely used in surface engineering to protect mechanical components. One of the cobalt alloy systems of industrial interest is that of Tribaloy, especially for metal-to-metal contact wear and corrosion-wear applications. However, the scientific community is aware of the difficulty of deposition of Tribaloy alloys, including T800™ due to the low ductility (Scheid, 2007) which, in turn, is due to the high Laves phase fraction - intermetallic of brittle nature - which promotes the formation and propagation of cracks in the T800™ alloy, increases the susceptibility to cracking and hinders the development of coatings (Stein and Leineweber, 2021).

Given the global sustainability challenges regarding the reduction of energy consumption, as well as the reduction of industrial costs related to wear and corrosion problems, the importance of the present research is evident. The objective of this work is to investigate the characteristics of Tribaloy T800™ alloy coatings adopting different laser powers. The present study seeks to take advantage of the potential impact of heat input on the mitigation of cracking of the T800™ alloy, as well as its repercussion on dilution, microstructure, and hardness.

2. MATERIALS AND METHODS

Gas-atomized powder-feeding alloy (Deloro-Stellite Tribaloy T800™) with particle sizes from 50 to 150 µm was used in the present work. The deposition was carried out in a high-power diode laser (HPDL) PRECO™ SL8600 deposition center with a coaxial torch device on AISI 304L 12,50 mm thick plates. Substrate chemical composition and surface preparation procedures followed (Rivero et al., 2020). The chemical composition of the feeding material is detailed in (Scheid, 2007) and shown in Table 1. Single and multi-beads were prepared from 2.0, 2.5,- and 3.0-kW laser powers, with the main parameters shown in Table 2.

Table 1. Single-bead geometry.

Feeding Material	Main Elements					
	Co	Cr	Mo	C	Si	Other
Tribaloy T800™ (CoCrMoSi)	Bal.	17,5	28,5	<0,1	3,5	Ni, Fe

Table 2. Summary of laser cladding parameters.

Parameter	Value
Laser Power (kW)	2.0 / 2.5 / 3.0
Feeding Material	Tribaloy T800™
Substrate	AISI 304L
Powder Feeding Rate (g/min)	30
Travel Speed (mm/min)	800
Bead Overlapping (%)	30
Focal Distance (mm)	20
Laser Spot Size (mm)	5
Shielding Gas Flow (L/min)	8,0

Macro and microstructural characterization were done in the beginning, center, and end of multi-bead length after discarding 15 mm from the extremities. The reinforcement thickness or clad height, wettability angle, and bead width were measured from the macrographic analysis. The dilution of single and multi-bead coatings was assessed by the iron

content (measured in SEM-EDS), density, and chemical composition of substrate and feeding material following the methodology previously described by (Toyserkani et al., 2005).

Microstructure analysis was performed in a scanning electron microscope (SEM) in backscattered electrons operational mode. Vickers hardness under a 2 kgf load was measured on the polished transversal cross-section of coatings and a hundred indentations was carried out under a 5mN load with a Berkovich indenter.

3. RESULTS AND DISCUSSION

Table 3 and Fig. 1 show the single-bead geometry, with larger bead width and lower wettability angle for 3.0 kW. As shown in Fig. 1, no cracking is observed and a lower burn-in shape is observed for all heat inputs. Fig. 2 shows the macrographic view of multi-bead coatings, and, contrary to single-beads, a higher burn-in shape is observed for higher heat inputs. In this case, it is seen coatings with apparently lower cracking intensity for 3.0 kW laser power. Fig. 3 shows the results of the non-destructive inspection on the top of multi-bead coatings, revealing lower intensity of cracking. The higher the heat input, the larger the substrate heating and visually increasing the crack spacing, in turn, indicating a promising investigation path. Further sections deal with the microstructural changes, possibly contributing to the lower crack intensity.

Table 3. Single-bead geometry.

Laser Power (kW)	Single-bead coatings		
	2.0	2.5	3.0
Height (mm)	1.2	1.3	1,2
Width (mm)	3.9	4.1	4.2
Wettability Angle (°)	57	54	51

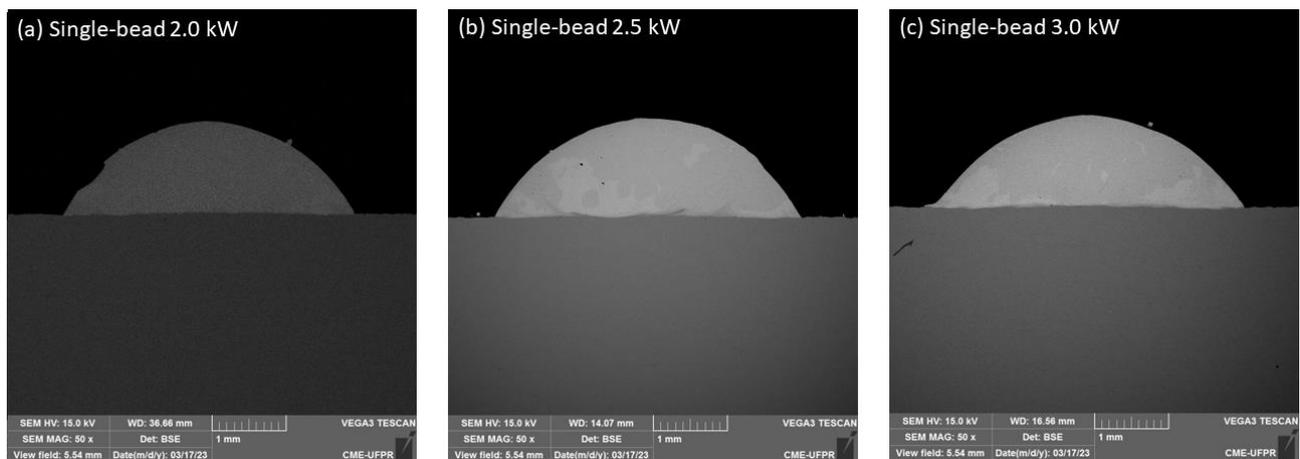


Figure 1. Macrographic analysis of the single-bead coatings.

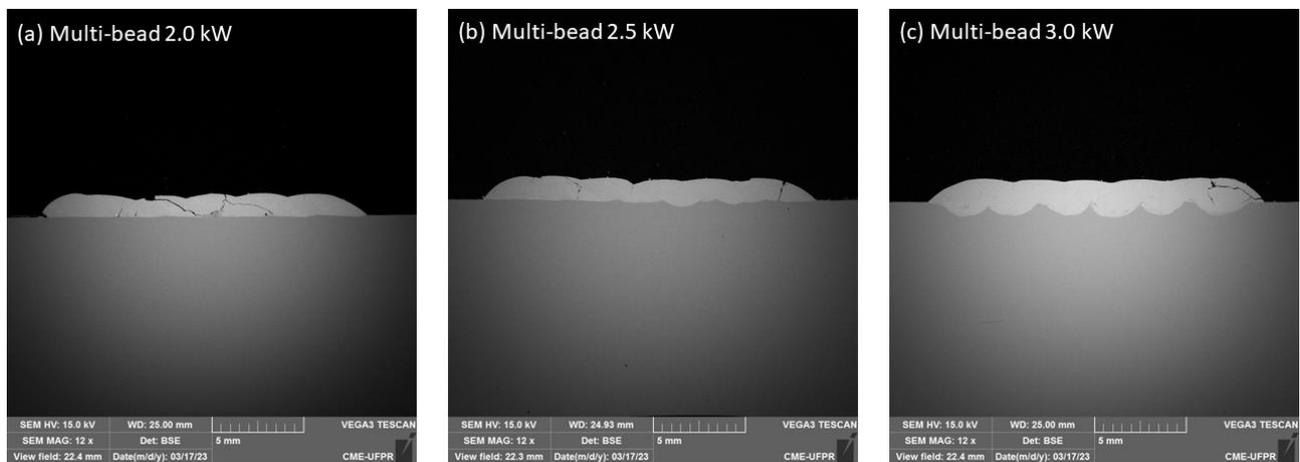


Figure 2. Macrographic analysis of the multi-bead coatings.

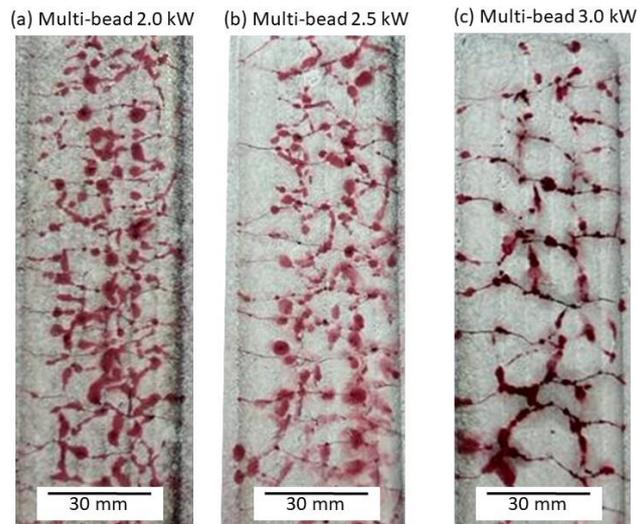


Figure 3. Non-destructive inspection of multi-beads.

Regardless of the Laser power, the microstructure is comprised of Cobalt solid solution metal matrix and globular intermetallic primary Laves phase, as shown in Fig. 4. Otherwise, it is notably seen for 2.0 kW the effect of low heat input on the Laves phase refinement, with the microstructure comprised of more refined globules of primary Laves phase.

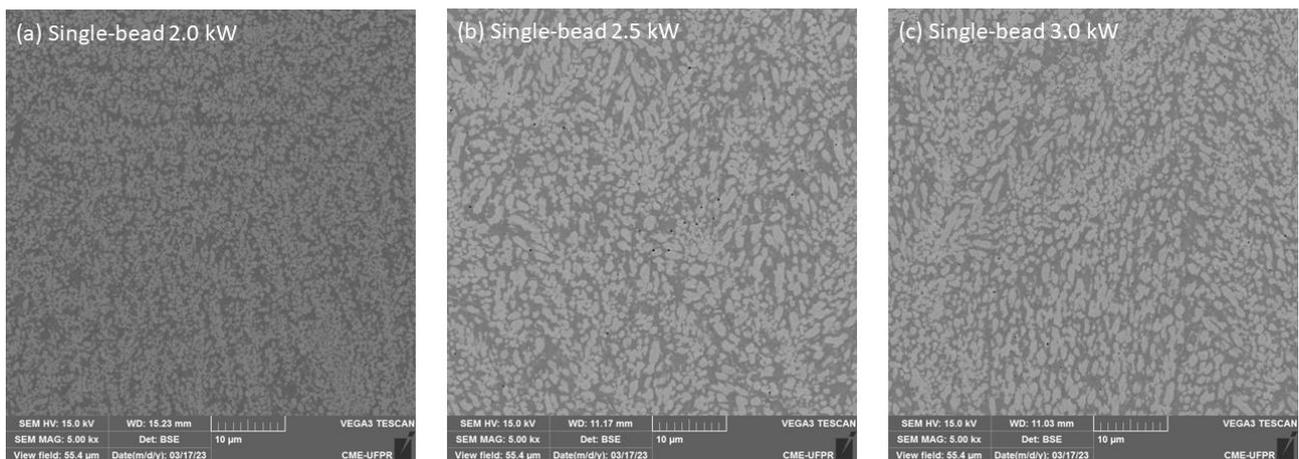


Figure 4. Microstructure of the Tribaloy T800 coatings (single-beads).

Fig. 5 presents the microstructure of the multi-bead coatings, comprised of a cobalt solid solution metal matrix and globules of primary intermetallic Laves phase (2.0 kW, Fig. 5a), larger primary Laves phase dendrites with an interdendritic lamellar eutectic constituent (2.5 kW, Fig. 5b), and finally, a full lamellar eutectic constituent (3.0 kW, Fig. 5c). The lamellar eutectic constituent is comprised of thin and interchanged lamellas of cobalt solid solution and secondary Laves phase.

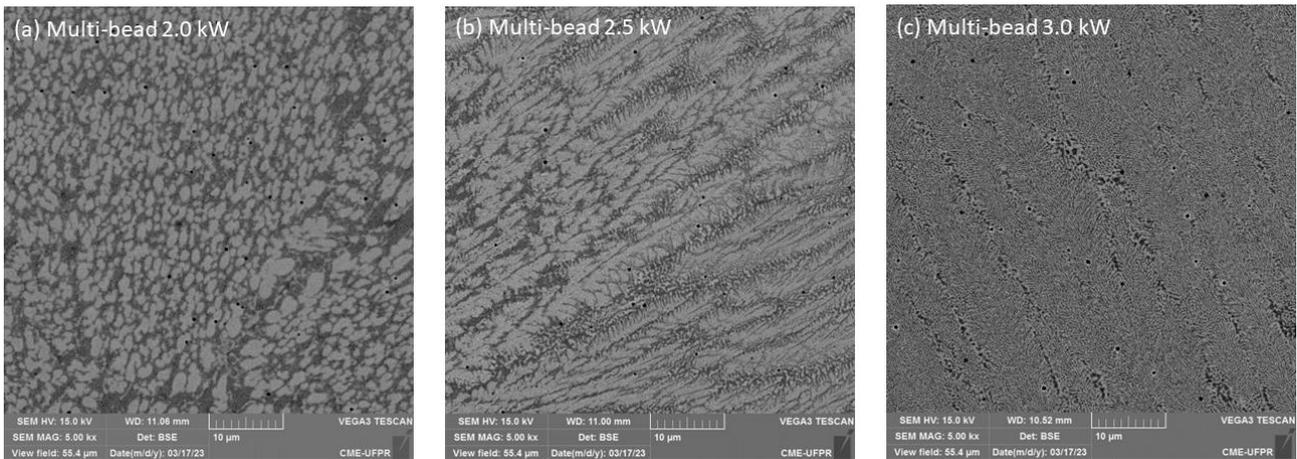


Figure 5. Microstructure of the Tribaloy T800 coatings (multi-beads).

Fig. 6 shows the dilution with the substrate measured from the EDS analysis, taking into account the iron contamination from the substrate melting. Dilution from virtually zero to 2.2 % was measured for single-beads and from 3.3 to 27.0 % was measured for multi-bead coatings. The highest hardness was measured for the less diluted specimens, but, owing to the high cooling rates associated with the laser cladding processing, a high hardness is observed for all processing conditions, as shown in Fig. 7.

Things become interesting when the repercussions of the distinct dilution on the microstructure are discussed. Regardless of the laser power in single-bead and at the lowest heat input of 2.0 kW condition for multi-bead coatings, the chemical composition of the Tribaloy T800 alloy was kept close to the original feeding material. Also, the extremely high solidification rates promoted the formation of small nuclei of the primary Laves phase, with a refined and globular morphology. Besides, the increase in the laser power to 2.5 kW for multiple bead deposits led to slightly lower solidification rates, in turn, favoring the primary Laves phase dendrites growth and formation of interdendritic lamellar eutectic constituent. Thus, larger primary dendrites surrounded by lamellar eutectic structures were observed. Utmost, the further increase in the laser power to 3.0 kW accounted for even lower solidification rates which, together with the higher dilution, led to the modification of the chemical composition of the alloy, suppressing the primary Laves phase formation and resulting in a full lamellar eutectic microstructure.

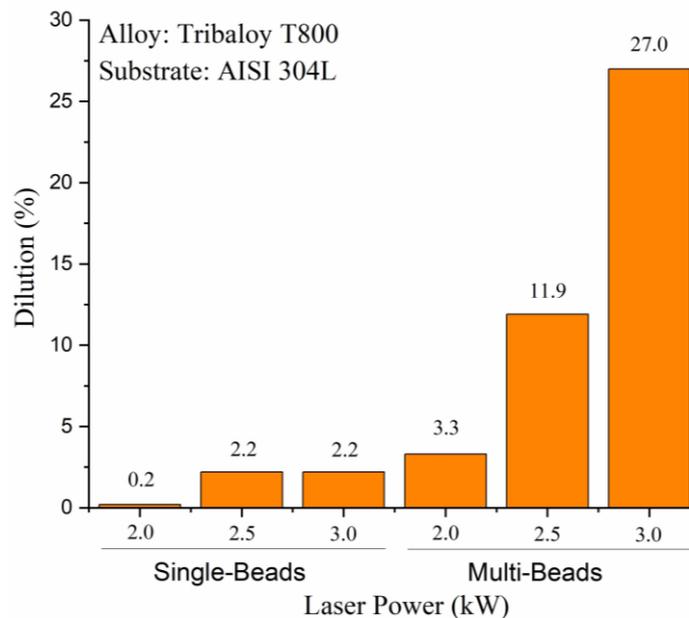


Figure 6. Dilution of single and multi-bead coatings.

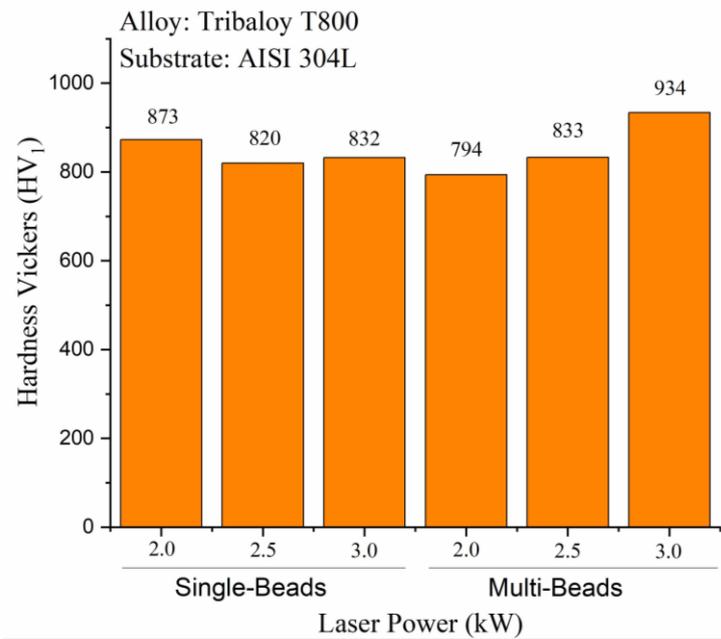


Figure 7. The hardness of single and multi-bead coatings.

Fig. 8 presents the schematic view of the SEM analysis to check the local nanoindentation, as a way to differentiate the hardness of each microstructural constituent. As expected, the analysis revealed a high hardness for the globular primary Laves phase, ranging from 15 to 18 GPa, and a lower hardness for cobalt solid solution matrix ranging from 6 to 8 GPa (at all laser powers in single-bead, and 2.0 kW laser power in multi-bead coatings). Also, the microstructure of multi-beads at 2.5 kW showed larger dendrites of primary Laves phase with approximately 14 to 15 GPa and interdendritic constituent comprised of large lamellas of Laves phase and cobalt solid solution with lower hardness ranging from 7 to 9 GPa, being the most heterogeneous condition. Finally, multi-bead specimens deposited with 3.0 kW were the most diluted coatings, and, as a consequence, the iron introduction lead to the suppression of the primary Laves phase and a full cellular eutectic microstructure. In this case, the extremely refined lamellar microstructure showed not-so-high hardness (~12 GPa) but was most uniform and less variable among all the evaluated conditions.

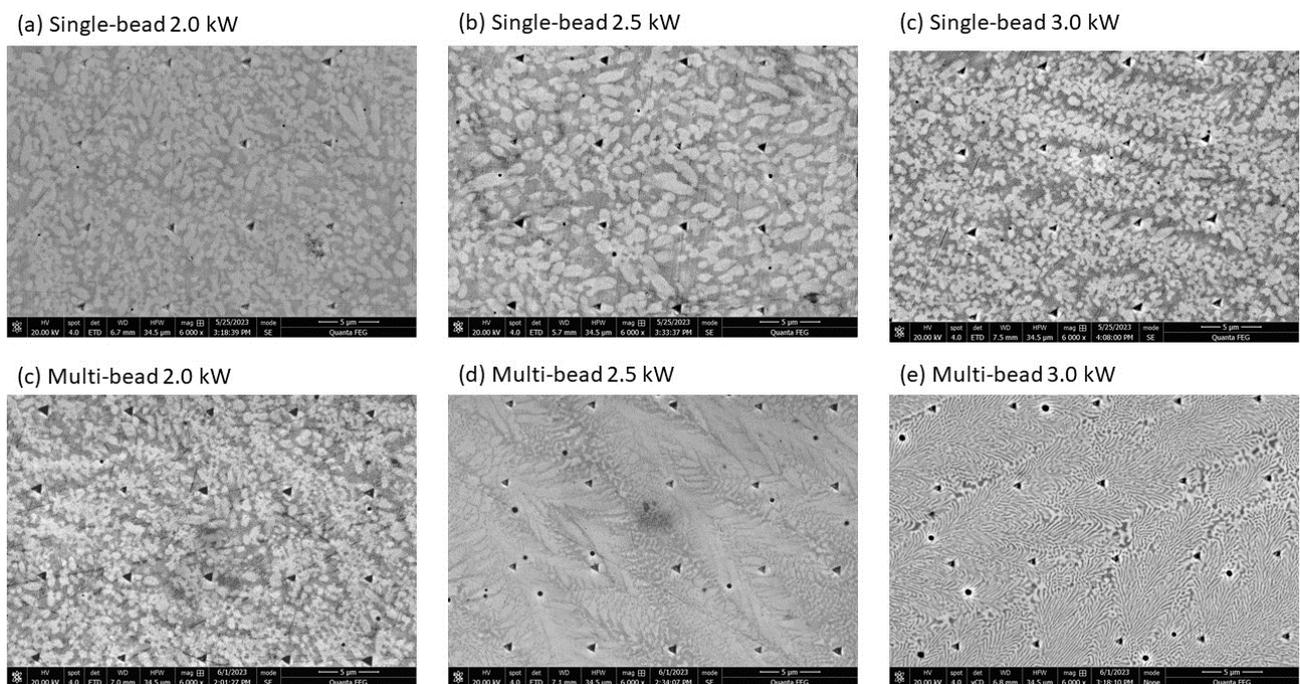


Figure 8. SEM images of the localized nanoindentation.

4. FINAL REMARKS

This work analyzed the bead geometry, defects, dilution, microstructure, and hardness of Tribaloy T800™ alloy as single and multi-bead coatings by laser cladding. The main conclusions can be drawn:

- As a consequence of the Gaussian energy distribution across the laser spot size, the increase in the laser power led to higher bead width, lower wettability angle, and lower clad height.
- The faster solidification cooling rates associated with low dilution induced a microstructure comprised of refined and globular primary Laves phase in a cobalt solid solution matrix.
- The increase in the heat input promoted either higher dilution with the substrate or slower solidification cooling rates, resulting in larger primary dendrites of Laves phase and a full lamellar eutectic constituent in the highest diluted specimens.
- Regardless of the heat input, coatings showed hardness over 794 HV₁, because of the considerably high volume fraction of Laves phase and extremely refined microstructures.
- From the analysis of the cracking tendency, one can be clear now that either the slower solidification cooling rates decurrent from the higher heat inputs or even the suppressing of primary Laves phase obtained in the most diluted condition help increase the crack spacing in Tribaloy T800 coatings, i.e., lightly lowering its intensity.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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