International Journal of Engineering

Journal Homepage: www.ije.ir

Laser Cladding of PAC 718, Tribaloy T-700 and METCO 41 C Hard Facing Powders on AISI SS 304L Substrate

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P A P E R I N F O

Paper history:
Received 25 June 2020
Received in revised form 12 September 2020
Accepted 29 October 2020

Keywords:
Fiber Laser
Laser Cladding
Clad Properties
Micro-hardness
Hard Powder
SS304L

A B S T R A C T

The present investigation aims to deposit the three different hard facing powder (Triboloy T-700 and PAC 718, and TETCO 41 C) on SS 304L using laser cladding technique. The single and overlapped clad track was deposited using 2 kW laser power system. The optimized laser process parameters and 50% overlap clad track was used to deposit a large surface area. The optimum laser process parameters were finalised using single clad structure study. The cross-sections of the clad layers were used to obtain the microstructure and micro-hardness from different regions namely, clad layer, diffusion layer, and substrate. Throughout the study, the laser power was kept constant i.e. 1.2 kW. For single clad deposition, the scanning speed and powder feed rate varied from 0.3 to 0.5 m/min and 4 to 9 g/min, respectively. T-700 and PAC 718 shows uniform developing micro-structure while METCO 41 C shows the development of mixed dendritic and cellular type microstructure. The Triboloy shows the maximum surface hardness of 534 Hv, 321 Hv for PAC 718, and 294 Hv for METCO 41 C.

***doi**: 10.5829/ije.2021.34.02b.20*

1. INTRODUCTION

Laser cladding technique is an effective way to develop hard powder coating on different engineering components. The powder coating applied for a reduction in the failure of the mechanical component due to erosion-corrosion wear. The laser cladding process having two methods i.e. pre-placed (two-stage) and direct method (one stage). In the two-stage method, the re-melting of pre-placed coating powder was done with a laser beam. In one-stage method coating material in the form of powder or wire was supplied and melted simultaneously using a laser beam. Laser cladding techniques have some great advantages like good metallurgical bonding between coating and substrate, minimum dilution, less porosity and thermal distortion over the other coating methods. The quality of laser clad depends on clad geometrical properties and good geometrical properties depend on laser process parameters. Table 1 shows the effect of an increase in laser process parameters on clad geometrical properties [1-4].

Many studies on laser cladding were carried out using different coating powders like Aluminium alloys, Stellite, Titanium alloys, Inconel, Stainless Steels, mild steel, etc. Co, Cr, and Ni-base alloy have been widely used for engineering applications because of good erosion-corrosion resistance properties. Khorram et al. [4] used the RSM technique to investigate the response of scanning speed, pulse width and laser frequency on clad geometry, hardness and dilution ratio. They found that pulse width and laser frequency have a positive effect on clad angle, width and dilution ration and negative effect on hardness and clad height. Moradi et al. [5, 6] Investigated the effect of laser power, focal plane position in powder stream and scanning pattern on mechanical characterization, dimensional properties and Micro-structural changes on satellite 6 powder. They found lower Distortion, higher micro-hardness, lower

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Please cite this article as: S. R. More, D. V. Bhatt, J. V. Menghani, C. P. Paul, G. R. Desale, Laser Cladding of PAC 718, Tribaloy T-700 and METCO 41 C Hard Facing Powders on AISI SS 304L Substrate, International Journal of Engineering, Transactions B: Applications Vol. 34, No. 02, (2021) 480-486

TABLE 1. Function clad properties (Increase= +; Reduction= -) [1]

Parameters	Clad Properties				
	Clad Height	Clad Depth	Dilution	Hardness	Clad Thickness
Laser Power	-	+	+	-	+
Coating Material Quantity	+	-	-	+	+
Powder Feed Rate	+	-	-	+	-
Laser Beam Spot	+	-	-	+	-

grain size, and higher stability obtained by applying a unidirectional scanning pattern. In addition, they observed that laser power leads to change in the width and height of clad. Vyas et al. [7] investigated mechanical and metallurgical properties of high entropy alloy (AlFeCuCrCoNi-WC10) laser cladding coating on SS 316. They found a 4.5 fold improvement in micro-hardness as compared to the base metal and fine-grained non-directional microstructure away and columnar grains near the base material.

However, it is necessary to study the setting of laser process parameters for achieving good quality clad surface. Limited work is available on selection of laser process parameters especially for Nickel, cobalt and Fe base alloy cladding on SS 304L using one stage cladding process. There is scope to found the best possible laser process parameters for Nickel, cobalt and Fe base alloys coating on SS 304L. In the present work, all three powders are used to develop hard facing coating on SS 304L material and find out how the single clad is useful to investigate the best possible laser coating parameters for developing large surface coatings. In addition, the effect of laser cladding process parameters on microstructure and micro-hardness were briefly investigated.

2. EXPERIMENTAL SET UP

The laser cladding work was carried out at Department of Atomic Energy Raja Ramanna Centre for Advanced Technology (RRCAT), Indore (MP) India, using a 2 kW C-W fibre laser system as shown in Figure 1. The system consists of 2 kW fibre laser, 5 axis manipulator in a glove box, coaxial nozzle, computer numerical controller, twin powder feeder, a camera with image processing hardware and gas analyzers [8].

(a) Photographic view of LRM lab arrangement

(b) Arrangement of Co-axial nozzle

Figure 1. Photographic view of 2 kW C-W fiber laser system

3. EXPERIMENTAL PROCEDURE AND MATERIAL USED

3. 1. Laser Cladding Process

The SS304L plates of size 75 mm diameter and 10 mm thickness were used for laser cladding of three different hard facing powders. Before starting the laser cladding process, the substrates are cleaned with water and acetone to remove any contaminant present on the surface of the substrate. The coaxial nozzle and powder feeder are calibrated for various powder flow rates by collecting and measuring the weight of powder for a known period. The pressurized Argon gas is used to regulate the flow rate of cladding powder. The hard face laser cladding powders are preheated using a co-axial nozzle and 1.2 kW higher power laser beam. The substrate surface is scanned using a laser beam and cladding powder; and accordingly, the thin layer of substrate and cladding powder is melted to develop the melt pool. The melted thin layer from the substrate is known as wetting of the substrate. The clad track on the substrate surface is formed due to rapidly solidified melt pool by self-quenching when the laser beam left the melted pool. The effect of laser processing parameters on clad geometry, i.e. clad width and height, dilution and porosity are examined by depositing single clad track of length 50 mm on the substrate material. From the single clad track analysis, the optimum laser processing parameters are selected for cladding the larger surface area of the substrate. The 50% overlapped cladding process is used to clad the large surface area. These laser cladding samples are used for characterizations and microscopic analysis. The location of laser spot point is 2 mm above the powder concentration plane [5].

3. 2. Properties of Material Used

The present investigation is based on SS304 L as target (substrate) material. This material is commonly used in various industries and power plants because it has no effect of radiation; its chemical composition is shown in Table 3.

Three different powders namely, Tribaloy T-700, PAC 718 and METCO 41 C are used for cladding on steel by using 2 kW C-W fiber lasers.

Tables 2 and 3 show the physical properties and chemical composition of cladding powders. The size of powder maintained range of 45-106 µm, because it is easy to feed through feeder during the cladding process. The SEM micrographs of three powders are shown in Figure 2, which reveals the particle shape and size.

3. 3. Range of Parameters Table 4 shows the range of parameters used for single clad track for laser process parameters optimization and 50% overlapped clad for complete cladding process for all three powders on the substrate. For the process of single and 50% clad the laser power kept constant i.e. 1.2 kW. For single clad track, process the scanning speed and powder feed rate varied from 0.3 to 0.5 m/min and 4 to 9 g/min, respectively. From the result of process parameters optimization and single clad structure study, it was decided to carry out overlap cladding on stainless steel according to the parameters shown in the last column of Table 4 for all three powders. During laser cladding process the substrate was kept open in at atmospheric temperature.

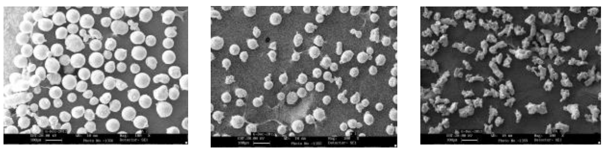
3. 4. Microscopic Analysis with Sample Preparation The transverse section of single and 50% overlap clad track was obtained by cutting the clad track with a diamond cutter. The cut sample was mounted using resins with hot mounting process. After hot mounting, initially, the sample was ground using abrasive belt (180 grit) grinder. Then, fine polishing was done on sandpapers of different size up to # 1200. The mirror finishes of the sample obtained by polishing on wheel machine with the size of 1 µm diamond paste. The microstructure of claded samples with three types of powders was observed by using samples etched with an etchant of composition: 10% Oxalic acid in water kept for 60 sec. at 12 Volts and 2 Amp current. The Vickers hardness tester is used to measure the micro-hardness of laser clad samples. The micro-hardness is measured by applying 0.981 N loads on polished laser clad surface for the 30-sec.

4. RESULTS AND DİSCUSSİON

4. 1. Single Clad Structure Study The laser cladding process parameters are responsible for the quality and quantity of clad track. Figure 3 (a-c) shows the photographic view of a single clad structure for all three powders. Figure 4 (a and b) shows the effect of powder feed rate and scanning speed on the width of

TABLE 2. Physical properties of cladding powders

Powder	Density (g/cm^3)	Melting Temp (°C)	Micro Hardness (0.981 N)	Grain Size (µm)
Tribaloy T-700	7.92	1200 -1300	543 Hv	
PAC 718	8.19	1260 – 1336	353 Hv	106 /45
MEC 41-C	8.35	1000 – 1150	344 Hv	



(a) Tribaloy T-700 (b) PAC 718 (c) METCO 41C

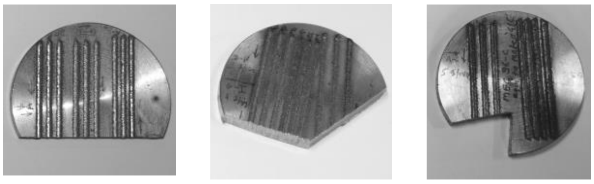
Figure 2. SEM of Three Hard Facing Powders

TABLE 3. Major chemical composition of substrate material and three different cladding powders

Substrate and Powder	Major elemental composition (wt. %)									
	C	Mn	Si	Cr	Ni	Mo	Fe	Ti	Co	Al
AISI SS304L	0.03	2.0	0.75	17.50-19.50	8-12	---	---	---	----	----
Tribaloy T-700	0.08	--	3.4	16	Balance	32	1.5	---	1.5	----
PAC 718	0.08	0.35	0.35	17-21	50-55	2.80-3.30	1.5	0.65-1.15	1	0.20-0.80
MEC 41-C	0-1	--	1	17	12	2-5	Balance	--	--	--

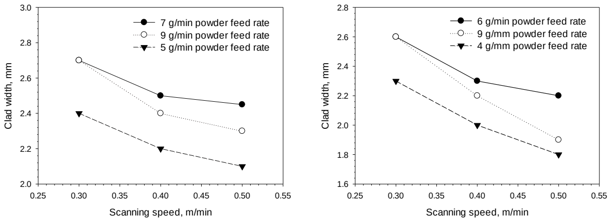
TABLE 4. Range of parameters for laser cladding

Substrate (base) material	Cladding Powder	Laser beam power, kW	Laser Beam Diameter, mm	Laser scanning speed, m/min	Powder feed rate, g/min	Overlapping, 50 %	
						Scan Speed	Powder Feed Rate
	Tribaloy T-700	1.2	2.5	0.3, 0.4, 0.5	5, 7, 9	0.4 m/min	7 g/min
AISI SS 304 L	PAC 718	1.2	2.3	0.3, 0.4, 0.5	4, 6, 8	0.4 m/min	6 g/min
	METCO 41 C	1.2	2.5	0.3, 0.4, 0.5	5	0.4 m/min	5 g/min



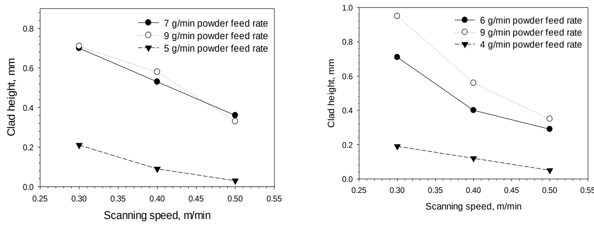
(a) Tribaloy T–700 (b) PAC 718 (c) METCO 41 C

Figure 3. Photographic view of single pass clad track of different materials



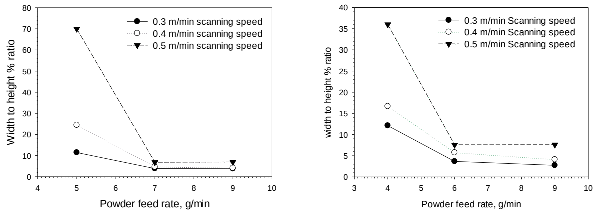
(a) Tribaloy T-700 (b) PAC 718

Figure 4. Clad width as a function of powder feed rate for single track clad layer on AISI SS304 L



(a) Tribaloy T-700 (b) PAC 718

Figure 5. Clad height as a function of powder feed rate for single track clad layer on AISI SS304 L



(a) Tribaloy T-70 (b) PAC 718

Figure 6. Dilution as function of powder feed rate for single track clad layer on AISI SS304 L

clad track for Tribaloy T-700 and PAC 718, respectively. Width of the clad layer is approximately equal to the laser beam diameter and inversely proportional to laser scanning speed with constant feed rate [9, 11]. This happens due to shorter contact time and heat (laser beam) on the surface of the substrate, as available laser beam power (J/mm) decreases with a reduction in scanning speed. Most of the time clad track width is small as compared to laser beam diameters. This happens due to higher laser scanning speed with the laser power decreases [10].

Similarly, Figures 5(a) and 5-b) show the effect of feed rate and laser scanning speed on clad height. The clad height increases with reducing scanning speed at constant feed rate. In addition, clad height increases by increasing powder feed rate at constant scanning speed as shown in Figure 5 (b) [10, 12]. The powder feed rate is a significant parameter for clad track height as it has stronger effect on variation in dilution. The lower scanning speed is more significant as compared to higher speed for different powder feed rate on different clad heights as shown in Figure 5 (a and b) [15]. The width to height ratio of clad layer was calculated for both Tribaloy T-700 and PAC 718 powders. Figures 6(a) and 6(b) show the effect of change in scanning speed and powder feed rate on clad geometry. The results show that the percentage width to height ratio of the clad layer decreases with increasing the scanning speed and powder flow rate, a trend generally reported in the literature [10-16]. The ratio of clad width to height is directly proportional to laser scanning when flow rate of clad powder remains constant. This is happened due to availability of cladding per unit length is less, so higher amount of availability of laser energy on substrate surface causes the increasing the surface melting and depth of penetration of substrate surface [10, 15]. The highest percentage width to height ratio of 70% was observed for Tribaloy T-700 clad layer at the 5 g/min, 0.5 m/min powder flow rate and scanning speed, respectively. For PAC 718 it 37% at 4 g/min, 0.5 m/min powder flow rate and scanning speed, respectively. For both coating powders the lowest percentage of width to height ratio 5 to 7% is obtained at 9 g/min, 0.3 m/min powder flow rate and scanning speed, respectively as shown in Figure 6.

4. 2. Overlapped Clad Structure Study The 50% overlapped clad tracks for three powders were performed based on single pass clad experimental study at 1.2 kW laser power with a scanning speed of 0.4 m/min for three powders. Powder feed rate was kept at 7g/min for Tribaloy T-700, 6 g/min for PAC 718 and 5 g/min for METCO 41 C. Figure 7 (a-c) shows the surface morphologies of Tribaloy T-700, PAC 718 and METCO 41 C hard face clad layer on the substrate (SS 304L). These figures did not show any porosity, distortion and cracks on overlap clad surface of all three powders. The microstructures of clad layers of three powders at the junction and clad surface along the cross-section were examined under optical microscope (Figure 7 (a-c)). PAC 718 and Tribaloy T-700 microstructures show the development of a uniform type of dendritic growths along the direction of clad height at the junction and clad surface (Figure 7 (a,b)). Whereas, mixed dendritic and cellular type microstructure was observed for the clad layer of METCO 41C (Figure 7(c)).

The Vickers hardness tester was used to measure the micro-hardness of all three laser clad layer (Tribaloy T-700, PAC 718 and METCO 41 C). Micro-hardness was measured in three regions along the cross-section on the base metal (SS 304L), the junction (fusion line) and clad layers to investigate variations developed in hardness due to laser cladding as shown in Figure 7. The distance between two indentations was kept at 0.05 mm of all three regions for micro-hardness testing. Figure 7 (a-c) shows the size difference in micro-hardness indentation marks for all three regions. It shows that the size of the indentation mark decreases from the substrate to the top layer of the clad surface. This shows that micro-hardness increases from the substrate to the top layer of the clad surface. In addition, porosity and the crack was not observed on the fusion line (interfacial region), which indicates good bonding between the coating material and base metal (substrate) [3, 18]. Figure 8 is the graphical representation of micro-hardness distribution on the clad cross-section for three different clad powders. The two different zones appear in the graphical representation of micro-hardness curve corresponding to clad layer and base metal. On base metal 212 Hv (0.981), micro-hardness was observed which is representative and nearer to SS 304L (substrate). The Tribaloy T-700 shows the noticeable improvement in micro-hardness 246 Hv (0.981) on fusion line as compared to the other two powders cladding. The significant improvement in micro-hardness value i.e. 246 to 510 Hv (0.981 N) is observed from fusion line to top layer of Tribaloy T-700 clad surface. This sudden change in micro-hardness may be credited due to change in microstructure along the interface in the clad layer [3, 17]. Similarly, micro-hardness of clad layer PAC 718 and METCO 41C was investigated on 0.981 N load and graphically represented in Figure 10. The PAC 718 shows 206 Hv, 202 Hv at base metal and fusion line (interaction region), respectively as shown in Figure 8. Approximate micro-hardness values of 260 and 290 for PAC 718 and METCO 41C, respectively were observed by further increasing distance of indentation from interaction (fusion line) towards the top surface of the clad layer. Then, the value of micro-hardness suddenly drops to 211 Hv and 202 Hv for PAC 718 and METCO 41C, respectively at the top surface of the clad layer. This may be due to presence of some porosity, or inappropriate sample preparation (not up to the mark). Thus, it can be concluded that desirable micro-hardness on the substrate material could not be achieved by cladding with either of PAC 718 and METCO 41 C powders; this can be attributed to the higher dilution and growth of grains.

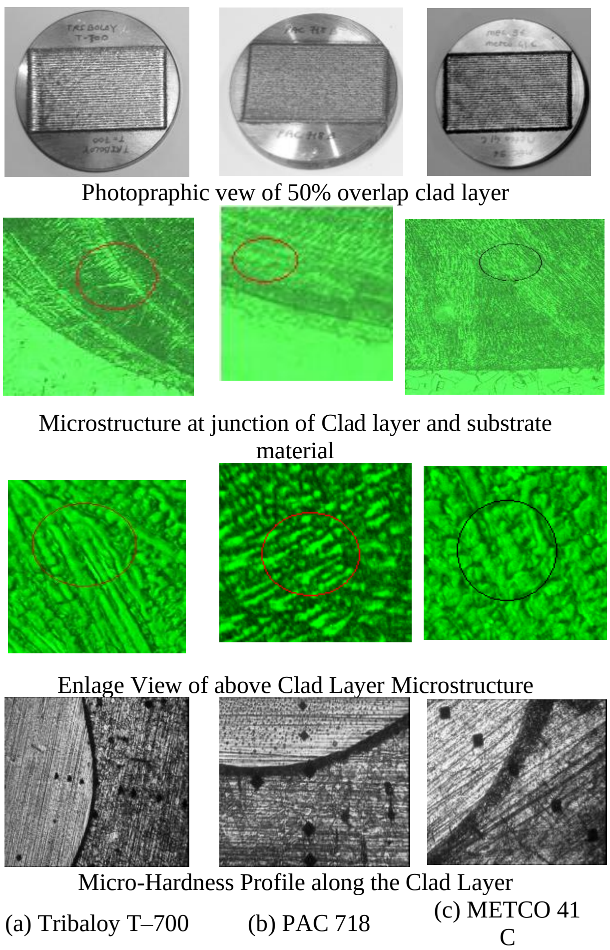


Figure 7. Photographic view of 50 % overlapped cladding structure

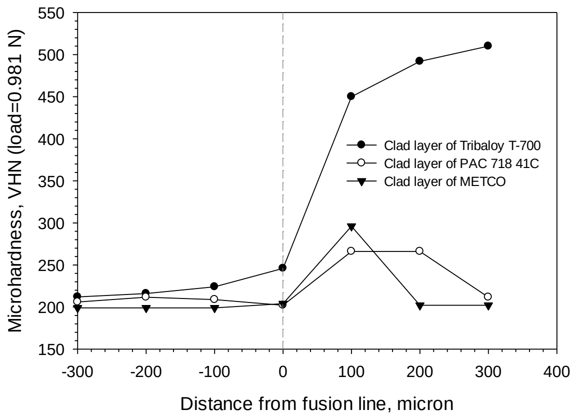


Figure 8. Micro-hardness profile of clad layer on substrate at 1.2 kW laser power

5. CONCLUDING REMARKS

The single-pass clad tracks were observed free from cracks, porosity and any distortion. The size, shape and quality of clad track is based on variation in cladding process parameters. The higher percentage of width to height ratio of 27% is obtained for Tribaloy T-700 cladding,while 17% for PAC 718 cladding. The maximum micro-hardness (0.981 N) at the clad surface was observed to have remarkable improvement around 246-534 Hv for Tribaloy T-700 clad, 202-321 Hv for entire PAC 718 clad and 196-294 Hv for METCO 41 C which is nearer to that of substrate (204 Hv). The microhardness of Tribaloy T-700, PAC 718 and METCO 41C are approximately 2.61, 1.5 and 1.4 times higher than the substrate, respectively. The cladding zone microstructure shows uniform type of dendritic growth along the direction of clad height at the junction for Triboloy T-700 and PAC 718, while mixed dendritic and cellular type microstructure was observed for the clad layer of METCO 41C.

6. ACKNOWLEDGEMENT

The present work was supported by CSIR-National Chemical Lab Pune and RRCAT Indore. Thanks to Director NCL Pune and Director RRCAT Indore.

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Persian Abstract

چکیده

پژوهش حاضر با هدف رسوب‌دهی سه پودر مختلف سخت‌کاری (Triboloy T-700)، (PAC 718) و (TETCO 41 C) روی فولاد زنگ‌نزن 304L با استفاده از روش روکش‌کاری لیزری انجام شده است. مسیر پوشیده شده یک‌پارچه و هم‌پوشان با استفاده از سیستم لیزر ۲ کیلووات رسوب کرده است. پارامترهای فرایند لیزری بهینه شده و مسیر ۵۰٪ پوشانده شده برای برهم‌نشینی یک سطح وسیع استفاده شد. پارامترهای بهینه‌ی فرایند لیزری با استفاده از مطالعه‌ی ساختار تک‌پوش نهایی شد. از سطح مقطع لایه‌های پوشیده‌شده برای به دست آوردن ریزساختار و ریزسختی مناطق مختلف، یعنی لایه‌ی روکش‌شده، لایه‌ی انتشار و بستر استفاده شد. در طول مطالعه، قدرت لیزر در سطح ۱.۲ کیلووات ثابت بود. برای رسوب تک‌پوش، سرعت اسکن و میزان تغذیه‌ی پودر به‌ترتیب از ۰.۳ تا ۰.۵ میلی متر در دقیقه و ۴ تا ۹ گرم در دقیقه متفاوت بود. ریزساختار در حال توسعه‌ی T-700 و PAC 718 یک‌نواخت است، درحالی که METCO 41 C توسعه‌ی ریزساختار مخلوط دندریتیک و نوع سلولی را نشان می‌دهد. بر اساس آزمون Triboloy سختی سطح بیشینه‌ی 534 Hv؛ 321 Hv برای PAC 718 و 294 Hv برای METCO 41 C است.