EVALUATION OF TRACK GEOMETRY OF SS 304L-SIC COMPOSITE FORMED BY LASER CLADDING

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ABSTRACT: *In this research, SS 304L powder is mixed with SIC reinforcement ceramic powder to produce ceramic-metal matrix composites by laser deposition of a thin layer, targeting to enhance the mechanical properties. The influence of wt.% SiC and processing parameters on the geometry of cladding tracks are studied. Results showed that Laser power, unlike scanning speed, has a positive effect on track width, penetration, aspect ratio, and dilution, while it has a negative effect on track height. The wt.% of SiC has a positive effect on track width, height, depth of penetration, and dilution, while it has a negative effect on track aspect ratio.*

Keywords: *Additive Manufacturing; Direct Laser Deposition; Silicon Carbide; Stainless Steel 304L; Ceramic Metal Matrix Composite.*

1 INTRODUCTION

Additive Manufacturing (AM) is an innovative manufacturing technology, which has several advantages such as freeform design, speed prototyping, and minimum waste (Yunlong, 2021). AM has recent potentials in different industrial fields like biomedical, automotive, aerospace, and chemical industries (Reda, 2017). However SS 304L is used in different industrial fields due to its premium strength and corrosion resistance, its lower wear and hardness properties could be a limitation for wider applications (Chew, 2016, Sergejs, 2017). To improve the mechanical properties, recently researchers evaluate adding ceramics particles to SS such as SiC (Abbas, 2005), a mixture of Cr_3C_2 and Cr, or a mixture of Ti and SiC (Tassin, 1996). The complete cladding layer profile depends on the shape and geometry of the cladding track (Zou, 2010, Wei, 2016). Fig.1 represents a schematic drawing of track profile characteristics; width; W, height; H and depth of penetration; b, which can be measured directly from metallographic cross-sections of cladding tracks. Other characteristics; dilution; D, and aspect ratio; AR, can be calculated from the measured geometry using Eq.1 and 2 as;

$$D = \frac{b}{H + b} \times 100 \qquad (1)$$

$$A_R = \frac{W}{H} \qquad (2)$$

It is stated that laser power, scan speed, and powder flow rate have noticeable effects on track profile characterizations. As increasing of laser power, the width and penetration of the deposited tracks increase. The height and width of the deposited layer increase as laser power or powder flow rate increase (Cottamac, 2011). Average particle size has a direct effect on the height and efficiency of the deposited layer. Thicker deposited layers are achieved at smaller particle sizes. This work aimed at studying the feasibility to deposit composites of SS 304L and SiC using the direct laser deposition technique. The laser powers are range from 200 to 1000 W and the scan speeds are range from 25 to 100 cm/min. The percentages of add SiC are 5, 10, and 15 Wt. %. Different samples are produced to study the effects of wt.% SiC and machine parameters; scanning speed and laser power on track characterization.

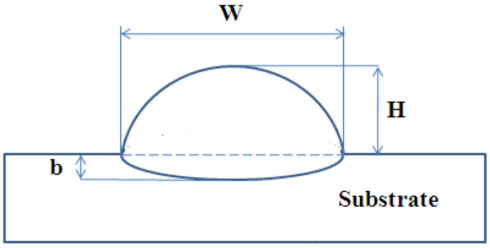


Fig. 1 Schematic representation of track geometry

2 EXPERIMENTAL WORK

2.1 Materials and Equipment

Substrate: the substrate material is sheet of mild steel with a carbon content of 0.11 %, Table 1. Each sheet has dimension of 100*100 *10 mm.

Stainless Steel Powder; the deposited powder is SS 304L (Maker: Höganäs, Sweden). Powder density is 2.7 g/cm^3 and particle sizes are less than 125 µm. The shape of powder particles is spherical, Fig. 2-a. Table. 1 shows the powder chemical composition as mentioned in the manufacturer datasheet.

SiC powder; the chemical composition from its date sheet is illustrated in Table 1. The shape is irregular with particle sizes less than 125µm, Fig. 2-b.

Laser Machine: The equipment is DY 022 (Maker: ROFIN, Germany). The laser type is Nd: YAG solid state with a max power of 2.2 kW, Fig. 3. The optical fiber delivers the laser beam to the coaxial nozzle Precitec YC50, Germany. The coaxial nozzle is fixed on 6 axes robot. The powder feeding apparatus is Sulzer 120A, (Maker: Sulzer Metco), the carrier gas is Nitrogen with pressure 1 bar and flow rate 5 L/min. Continuous feeding of high purity nitrogen is by N2PICO3 generator, (Maker: Claind, Italy).

Investigations: EDM wire-cut is used to prepare and separate the samples. Reichert stereomicroscopic X10 is used to inspect the surface feature. The optical microscope GX53, Olympus, Ltd., equipped with Panasonic digital camera, is used to investigate the deposited layers. Carbon Sulfur apparatus CS-530 is used to detect the carbon content in powder. Spectro Analysis Instrument (Maker: Optical emission, Germany) is used to investigate the chemical composition of specimens.

Table 1. Chemical composition of deposited materials

Material	Chemical Composition (%)				
	C	Si	Cr	Ni	Fe
SS 304L powder	0.027	0.9	18.5	11.2	Bal
SiC powder	30	70	-	-	-
Mild Steel substrate	0.11	0.07	0.03	0.06	Bal

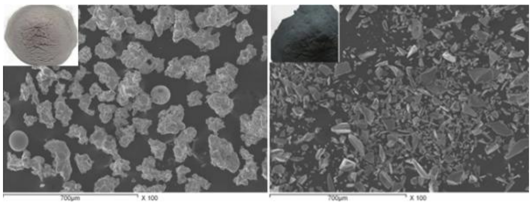
2.2 Procedure

Preparing of powder; the proposed powders of SS 304L and SiC; 5, 10, and 15 wt.%, are mixed together using VH Powder Mixer, for 1 hour.

Preparing of substrate; the substrate surface is cleaned from rust and oil by an angle grinder or ultrasonic cleaner apparatus.

Laser Deposition process: Laser beam was guided to perform four passes with a length of 40 mm each, at laser powers from 200 to 1000W and scan speeds from 25 to 100 cm/min. The powder feed rate, laser beam focus diameter, and scan spacing were fixed as 8 g/min, 3 mm, and 1.5 mm respectively.

Preparing samples; the specimens are separated by an EDM wire cutting machine. Then, it is polished by 320-1000 sandpaper.



a. SS 304L b. SiC

Fig. 2 SEM of SS 304L and SiC powders

Fig. 3 Nd:Yag laser machine quipment

3 RESULTS AND DISCUSSIONS

3.1 Effect of processing parameters

The effects of scanning speed on track characteristics of SS 304L, at laser power 800 W, are illustrated, Fig. 4. It is noticeable that the track width increases as decreasing the scan speed, Fig. 4-a. This can be explained due to increase interaction time, as decreasing the scanning speed, which enables more time to interact between laser-powder, laser-substrate, and powder-substrate leading to an increase in the powder catchment and so on increase the deposition rate. A slight decrease in track depth of penetration was achieved by increasing the scanning speed, whereas the track height increased. The laser energy density to the substrate was reversely proportional to the scanning speed, therefore as increasing the scan speed, the laser energy density decreased leading to reduce the depth of penetration and reflect on producing thicker tracks. Fig. 4-b shows the effect of scanning speed on track aspect ratio and dilution of SS 304L, at laser power 800 W. The aspect ratio and the percentage of dilution increased as decreasing the scan speed. The decrease in clad height was shown to increase the aspect ratio, whereas the increase in dilution is a result of increasing track depth of penetration. By increasing the laser power to 1000 W, it can be seen a slight enhancement in track characteristics, Fig. 4-b. It can be concluded that the cladding speed has a negative effect on track characteristics; width, depth of penetration, dilution, and aspect ratio, and the laser power has a positive effect. Whereas the cladding speed has a positive effect on track height and the laser power has a negative effect. The following polynomial equations, Eq. 3-5, using Microsoft Excel 10 software, were formulated to describe the effect of scanning speed on track characterizations: width, height, and dilution, at maximum laser power 1000W. Eq. 3 refers to the max track width ≈ 3 mm which is equal to laser beam focus diameter as stated in recent researchers (Zou, 2010, Wei, 2016).

$$W = -0.00003\, v^2 - 0.01042\, v + 3.0262 \qquad (3)$$

$R^2 = 0.9941$

$$H = -0.00004\, v^2 + 0.0189\, v + 0.1835 \qquad (4)$$

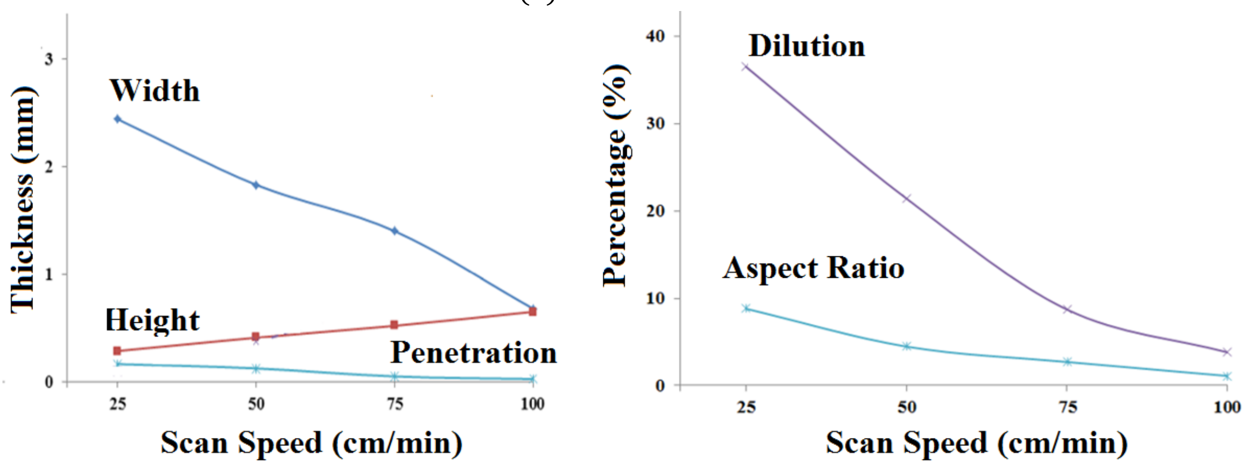
$R^2 = 0.09968$

$$D = -\ 0.0998\, v^2 - 4.9955\, v + 63.319 \qquad (5)$$

$R^2 = 1$

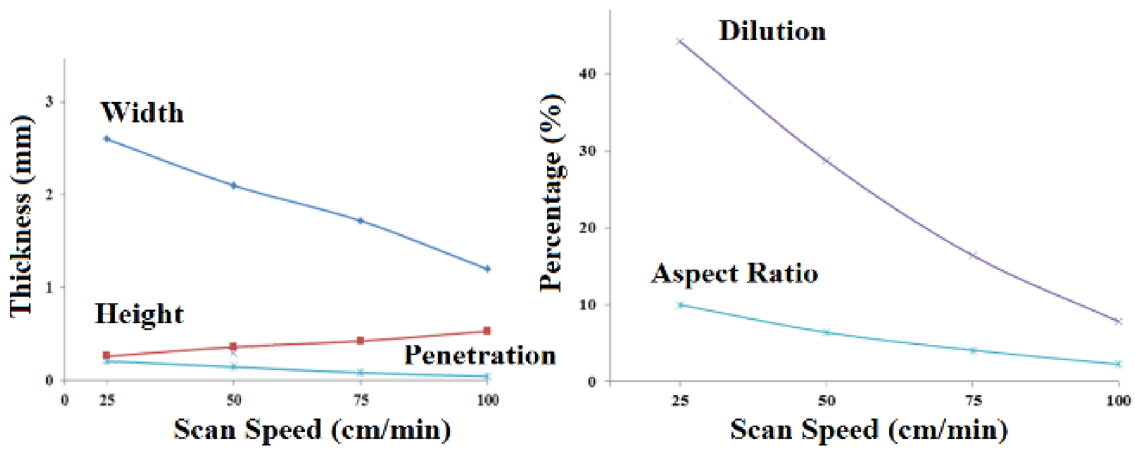
3.2 Effect of SiC powder

The track characterizations are illustrated for different composites of SiC at various laser powers and scan speeds. The effects of wt.% of SiC powder on track height are illustrated in Fig. 6 as well. As shown in the figure, thicker tracks are observed for composites of SiC than the stainless steel 304L. At constant laser power and scan speed, the track height increases as increases the percentage of SiC powder, Fig. 6 a-b. It is due to the presence of ceramic particles which have a larger absorption coefficient than stainless steel powder, leading to an increase in the effective heat input to the molten pool and an increase in the powder catchment rate.



a. Track width, Height and penetration **b. Track Dilution and Aspect Ratio**

Fig. 4 Effect of scanning speed on track characteristics of SS304 at laser power 800 W



a. Track width, Height and penetration **b. Track Dilution and Aspect Ratio**

Fig. 5 Effect of scan speed on track characteristics of stainless steel at laser power 1000 W

The track height of composites is larger than the track height of SS 304L and the resultant clad height increases as increasing the wt.% of SiC, Fig. 7 a-b. a slight enhancement of penetration can be seen by increasing the laser power or wt.% of SiC powder, Fig. 8 a - b. The measurements represent increasing in dilution as increasing the wt.% of SiC, whereas lower aspect ratios are recorded for composites of SiC than SS 304L, Fig 9 & 10. The measurements of track geometry for SiC composites could formulate the effect of wt.% of SiC on track characterizations; width, height, and dilution, at maximum laser power 1000 w and lower scanning speed 25 $cm.min^{-1}$. Choosing the maximum laser power and minimum scanning speed is to achieve higher applied laser energy input. The resultant equations:

$$W = 0.003\,X^2 + 0.083\,X + 2.615 \qquad (6)$$

$R^2 = 0.9783$

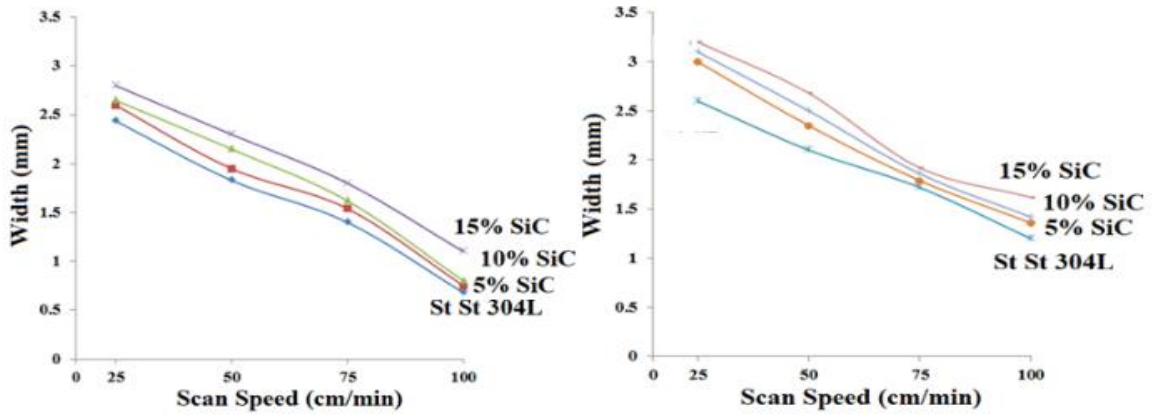
$$H = 0.0002\,X^2 + 0.0016\,X + 0.2608 \qquad (7)$$

$R^2 = 0.9943$

$$D = -\,0.109\,X^2 + 2.549\,X + 44.645 \qquad (8)$$

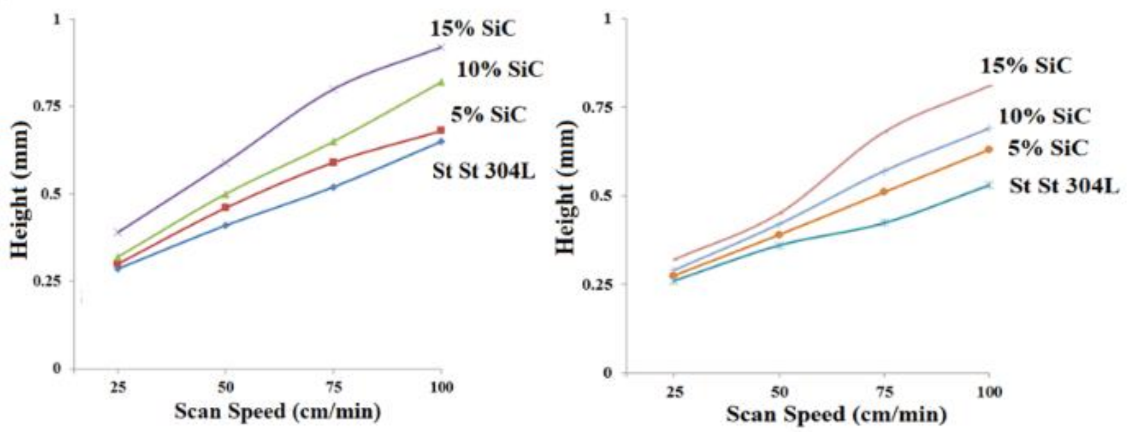
$R^2 = 0.9144$

Where X is the wt.% of SiC; 5, 10, and 15. It can be concluded that the wt.% of add SiC powder and the processing parameters; laser power and scanning speed, control the track characteristic; width, height, depth of penetration, aspect ratio, and dilution. Laser power has positive effects on track width, depth of penetration, aspect ratio, and dilution, but it has negative effects on track height. While the scan speed has negative effects on track width, depth of penetration, aspect ratio, and dilution, but it has positive effects on track height. The wt.% of SiC has positive effects on track width, height, depth of penetration, and dilution, but it has negative effects on the track aspect ratio.



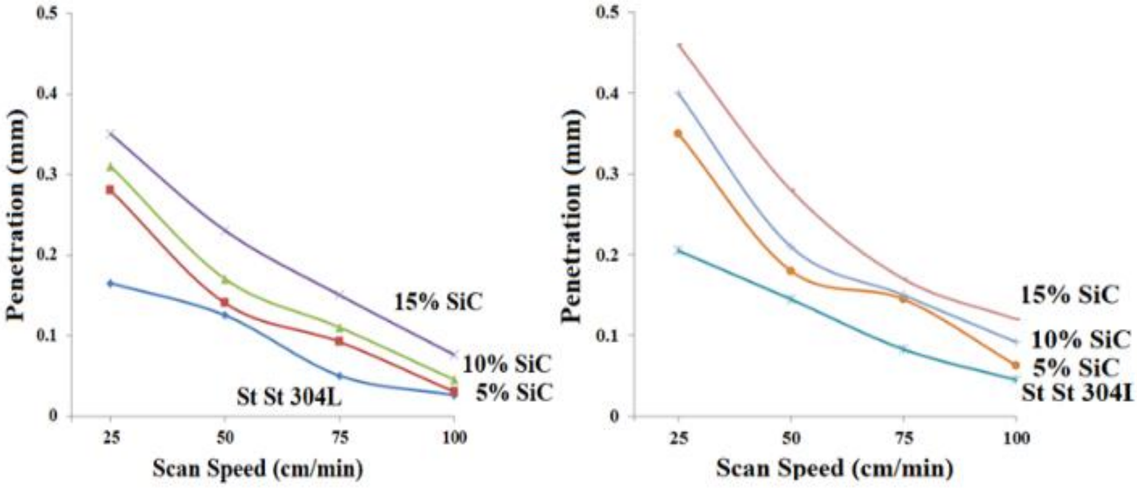
a. laser power 800 W **b. laser power 1000 W**

Fig. 6 Track width for stainless steel and its composites at different scan speed



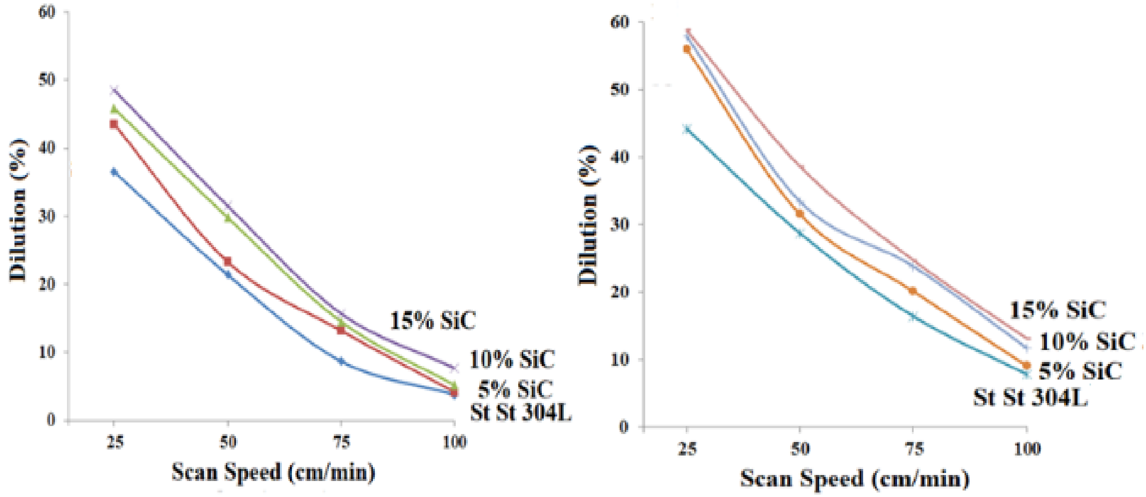
a. laser power 800 W **b. laser power 1000 W**

Fig. 7 track height for stainless steel and its composites at different scan speed



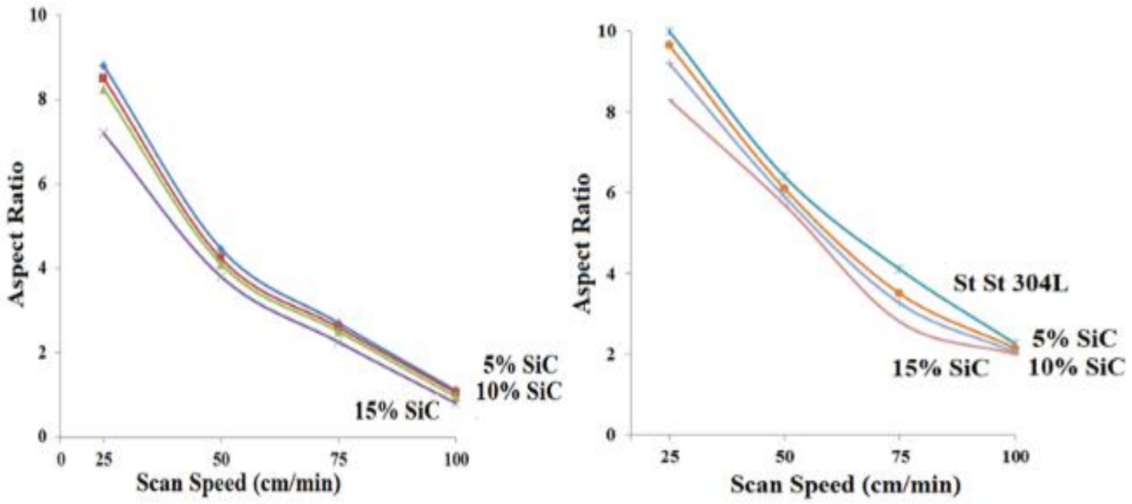
a. laser power 800 W b. laser power 1000 W

Fig. 8 Track penetration for stainless steel and its composites at different scan speed



a. Laser Power 800 W b. Laser Power 1000 W

Fig. 9 Track dilution for SS 304L and its composites at different scan speed



a. Laser Power 800 W b. Laser Power 1000 W

Fig. 10 Track aspect ratio for SS 304L and its composites at different scan speed

4 CONCLUSION

Direct Laser Deposition of the ceramic metal matrix composite of SS 304L powders reinforced by 5, 10, and 15 wt.% SiC, achieved strong cladding tracks with good metallurgical bonding. The wt.% of add SiC powder and processing parameters; laser power and scanning speed, control the track geometry. Laser power, unlike scanning speed, has a positive effect on track width, depth of penetration, aspect ratio, and dilution, whereas it has a negative effect on track height. The wt.% of add SiC particles influence the track profile and characteristics; width, height, depth of penetration, aspect ratio, and dilution. The wt.% of SiC has a positive effect on track width, height, depth of penetration, and dilution, whereas it has a negative effect on track aspect ratio.

5 REFERENCES

Yunlong F., Ning G.,Cheng Z.,Guanghui W., Jicai F., (2021), “Investigation on in-situ laser cladding coating of the 304 stainless steel in water environment”, Journal of Materials Processing Technology, V. 289

Reda S., Hussein A., Nofal A., Ibrahim S., Elgazzar H., Sabour H. (2017) “Laser powder cladding of Ti-6Al-4V alloy”, Materials 10(10), 1178-1194.

Chew Y. and Pang J., (2016) Fatigue life prediction model for laser clad AISI 4340 specimens with multiple surface cracks. International Journal of Fatigue, 87, 235-244

Sergejs L., Irina B., Armands L., Pavels D., (2017) “experimental study of coaxial laser cladding of tool steel”, Engineering for Rural Development, Jelgava, 24.-26

Abbas G. and Ghazanfar U, (2005), “Two-body abrasive wear studies of laser produced stainless steel and stainless steel + SiC composite clads”, Wear 258, 1-4, 258-264.

Tassin C., Laroudie F., Pons M. and Lelait L., (1996), “Improvement of the wear resistance of 316L stainless steel by laser surface alloying”, Surface & Coatings Technology 80,1-2, 207-210.

Zou J.X., Zhang K.M., Hao S.Z., Dong C.,Grosdidier T., (2010), “Mechanisms of hardening, wear and corrosion improvement of 316 L stainless steel by low energy high current pulsed electron beam surface treatment”, Thin Solid Films, 519, 4, 1404–1415.

Ya W., Pathiraj B. and Liuc S., (2016), “2D modeling of clad geometry and resulting thermal cycles during laser cladding”, Journal of Materials Processing Technology, 230, 217–232.

Ya W., (2015), “laser materials interactions during cladding”, PhD Thesis, University of Twente, Enschede, Netherlands, October

Cottamac R. and Brandt M., (2011), Laser cladding of Ti-6Al-4V powder on Ti-6Al-4V substrate: Effect of laser cladding parameters on microstructure. Physics Procedia 12, 323– 329