Experimental Investigation on the Influence of Laser Power and Scan Speed on Track Geometry in Direct Laser Cladding of Al – Carbides Powder Composites on Steel Substrate

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ABSTRACT

Coating steel surfaces with hard ceramic particles in Aluminum has a great influence to improve mechanical properties and wear resistance. This research investigated direct laser deposition, where no binder is used, of pure Aluminum and its composite powder with SiCp of 30% and Mo2C 30% are conducted, applying laser cladding technique (LC) using coaxial cladding nozzle. The effects of SiCp and Mo2C content in composite and the laser processing parameters namely; laser power of 900 to 1200-watt, scan speed of 0.9 to 1.1 m.min^{-1} on clad layer formation and its geometry are studied. Results indicate that the clad geometry parameters get better quality clad layer with the increase of laser energy density to get full clad layer at energy density 25.6 J.mm^{-2}. Some parameters such as width , penetration , aspect ratio and dilution percentage are directly proportional to laser energy density. While height on the other side is inversely proportional to laser energy density due to maintaining feeding rate constant. A slight increase in clad geometry parameters was observed in Al-SiC cladding layer over Al-Mo2C.

Keywords: - *Laser Cladding, Silicon Carbide, Molybdenum Carbide.*
Nomenclatures: *Coating, MMC, Laser cladding.*

INTRODUCTION

Laser cladding is widely applied process in different industries and services such as medical, aerospace, and automotive industries [1,2]**.** It is well known for improving the surface properties via deposition of desired layer on a substrate[3], which provides a durable, corrosion-resistant, or wear resistant layer.[4,5] Different powder types are used such as; metallic powder**,**[2,6,7]ceramic powders [8] and mixture of metallic and ceramic powders (MMC). [9,10] Aluminum and its alloys are characterized by light weight and strong corrosion resistance, so it is used in different industrial fields [11]. On the other side its low hardness and wear resistance minimize its use in the field of pumps, valves and machines [12]**.** A possible solution to enhance the wear resistance and hardness of aluminum and its alloys, by adding hard ceramic particles by laser cladding technique [13], such as SiC [14,15], TiC[16], a mixture of Cr_3C_2 and Cr, or mixture of Ti and SiC.

Clad layer formation process by laser has been investigated only by few numbers of previous researchers [17]. The effect of laser power on clad layer geometry was conducted in case of SiCp depositing on vacuum-sintered substrates of (X2CrNiMo 17-12-2) austenitic, (X6Cr13) ferritic and (X2CrNiMo 22-8-2) duplex stainless steels using high power diode laser between 0.7 and 2.1 KW, at constant scanning rates between 0.3 and 0.5 m/min[17]**.**

To determine the quality of clad surface, researchers investigated some parameters such as surface shape, geometry and defect [4]. Smooth surface shape, acceptable geometry and free of defect are evidence of clad quality[18]**.** To enhance the quality, it was found that maximizing the deposition rate, minimizing dilution, and elimination of defects are needed. While implementing, it is hard to get a cladding layer that meets all quality aspects. The compromise of processing parameters is essential to achieve acceptable clad layer quality [19] The objective of this study is to develop hard clad layer on mild steel substrate by depositing pure aluminum powder /Mo2C and pure aluminum powder /SiCp powder composite mixture. The work is a systematic experimental investigation on clad layer formation and surface topography, in direct laser deposition of the powder mixture. The influence of laser processing parameters on the progress of layer formation, pore and crack formation and deposited layer topography are studied. The aim is to determine the conditions at which a uniform clad layer is formed with least defects. In this research, penetration depth and width of clad surface were investigated to increase as the laser power increases, where a good surface quality approach was obtained at high laser power of 1.2 KW and scan speed of 0.9 $m.min^{-1}$.

To achieve best-clad layer it is required to maximize the powder deposition. Experimentally it is hard to control the laser cladding process due to massive interference between injecting powders, substrate and laser beam [20].Powder deposition is evaluated through powder catchment efficiency, η, which is the ratio of the deposited powder in the cladding track to the total injected powder, which depends on different parameters such as; laser beam properties, nozzle standoff, powder particle size, powder jet velocity, cladding nozzle geometry and injection conditions. Moreover, the adhesion mechanism between the powder particles and the substrate influence the deposition rate of powder [18]

EXPERIMENTAL WORK

The powder used for deposition is mixtures of gas atomized aluminum (Al: 45-90 µm), tungsten carbide powders (Mo_2C: 45-90 µm) and (SiC: 45-90 µm), both with particle sizes less than 125 µm. The substrate is a mild steel 15 x100 mm surface dimensions and 10 mm thick.

The laser used in this research was at the CSIR-NLC in Pretoria, South Africa. It consists of a 4.4kW Nd; YAG laser system. It is focused using a series of mirrors that reflect the laser beam into the precise location that it is needed. The laser head is then positioned to a height that gives the laser beam a desired diameter for the particular sample. The laser was manipulated using an 8-axis Kuka robot arm that can be programmed to produce the desired part.

The applied scan speeds are 0.9, 1 and 1.1 $m.min^{-1}$ and the laser powers are 0.9, 1, 1.1, and 1.2 KW. The powder feed rate is 1.8 $g.min^{-1}$. Five overlapped tracks and double layer were produced at the different laser powers and scanning speeds applied.

Laser energy density (applied energy per unit area, E, $J.mm^{-2}$) is used in this work as to express the laser processing parameters [9], as calculated by the following equation [18]:

$$E = \frac{4P}{\pi * d * \nu} \qquad \text{Eq. 1}$$

Where P is the laser power (watt), d is the focus diameter (mm), ν is the scanning speed (mm/s).
The clad samples are cut by wire cut F1 EDM wire cutting machine and are polished by 320, 400, 600, 800, and 1000 sandpaper. No Etchant was used. Olympic metallurgical microscope type PME with magnification up to X500, equipped with

Panasonic digital camera was used to investigate the microstructure.

In these experiments, catchment efficiency has been evaluated using weight method that depends on the difference in weight of sample before and after deposition by equation of [18–20];

$$\eta = \frac{100 * (wa - wb)}{wi} \qquad \text{Eq. 2}$$

Where, w_a, w_b and w_i (gm) are the weights of samples after and before deposition, and the total injected powder, respectively. The w_i is calculated as;

$$\mathrm{wi} = \frac{\mathrm{F} * \mathrm{l}}{\mathrm{V}} \qquad \text{Eq. 3}$$

Where, F is the powder feed rate (gm.s^{-1}), l is the clad track length (mm) and V is the scan speed (mm.s^{-1}).

RESULTS AND DISCUSSIONS

Powder Catchment Efficiency

The powder efficiency of Aluminum and its composites increases with increasing the E, while a slightly increasing of powder efficiency is noticed as changing from SiC to Mo2C, Fig.1. Previous studies have reported that the low E is unable to melt the entire powder resulting in reduced powder efficiency [4,18,21]. With increasing E, more powder melts and reduces powder loss, thus increasing the powder efficiency. While using Al-SiC clad with heat input above 22.93 J.mm^{-2} it is observed unexpected phenomena that catchment efficiency decreased due to detachment of full layer from the substrate (Figure 1). This can be explained that at high temperature, aluminum tend to reject SiC particles at the top and agglomerate which lead to a SiC layer that didn't diffuse with Aluminum.

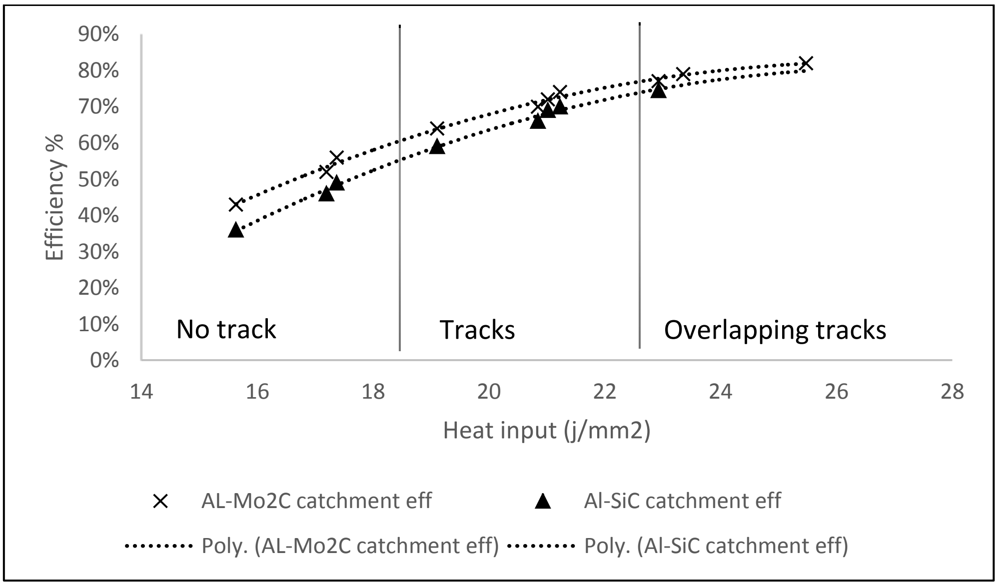

Fig.1:-*Variation of Powder Efficiency, η with Laser Energy density E*

TRACK GEOMETRY

Final clad layer profile formed by overlapped tracks, depends on the shape and geometry of cladding tracks [4,18].The regular shape of a continuous formed single track is presented, for example, by the photomicrograph in Figure 2***Fig.2***, for Aluminum composite 30% Mo2C powder, produced at E of 19.11 J.mm^{-2}. A schematic presentation describes the track geometry in the transverse direction by track width (W), track height (H) and track depth of penetration (B), Figure 3.

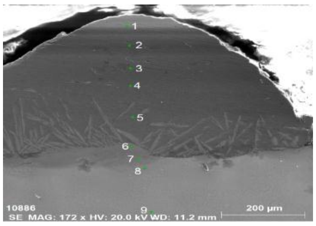

Fig.2:-Track cross section of Aluminum composite 30 wt.% Mo2C produced at E =19.11 J.mm^{-2}

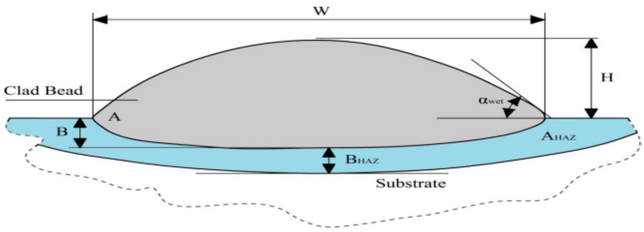

Fig.3:-Typical clad cross-section with most common geometrical characteristics. [22].

The evolution of track geometrical dimensions and features with various laser energy density E, for Aluminum composites of 30% SiCp and 30% Mo2C, represented in Figure 411. Track width is directly proportional with the laser energy density, Figure 4. This observations has been discussed in earlier investigations as due to the increase in the temperature of the melt pool, which led to the increase in the rate of powder catchment [18,19,21]. By lowering laser scan speed, longer interaction time results which leads to increasing deposition thus increasing track width Track height is inversely proportional with the laser energy density, while the penetration is directly proportional, Figure 5.As discussed in previous researches [18,21], this phenomena can be explained by the rise in molten pool of the aluminum and steel substrate surface temperatures, leads to the increase of track penetration on account of height reduction [18,19,21].

In previous researches [4,18-21], more features are calculated; namely aspect ratio (A_R), which is the ratio between track width and track height, and dilution percentage (D) which is the ratio of interference between substrate and clad layer, those features are calculated as follow:

$$AR = \frac{W}{H} \qquad \text{Eq. 4}$$

$$D = \frac{B}{H+B} * 100 \qquad \text{Eq. 5}$$

Figure 411 shows changes associated with the increase of laser energy density of different track geometry aspects. The increase in track width W Figure 4, penetration depth Figure 6 and decrease in track height H 5 is reflected on increasing aspect ratio A_R Fig.77 and Dilution Percentage Figure 8 as calculated by equation 5.

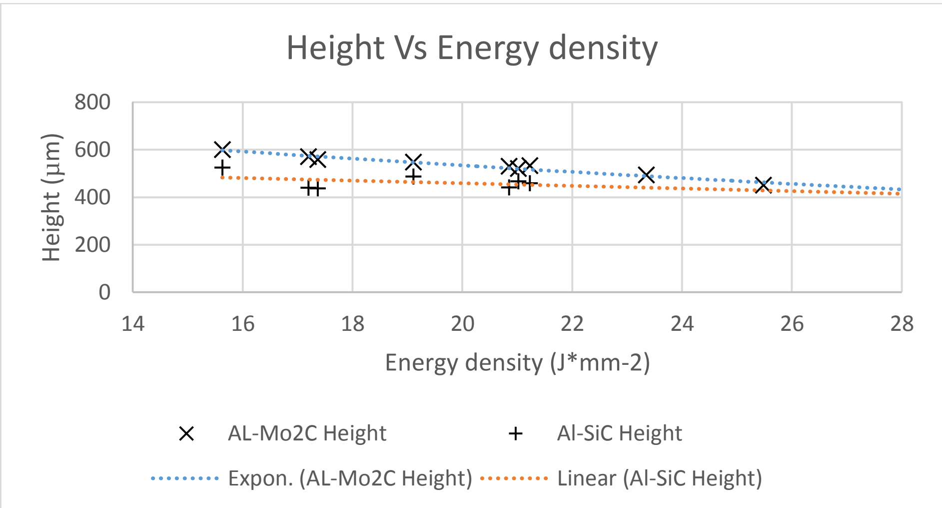

Fig.4:-The effect of laser energy density on clad layer width for Aluminum and its composites of 30% SiC and 30% Mo2C

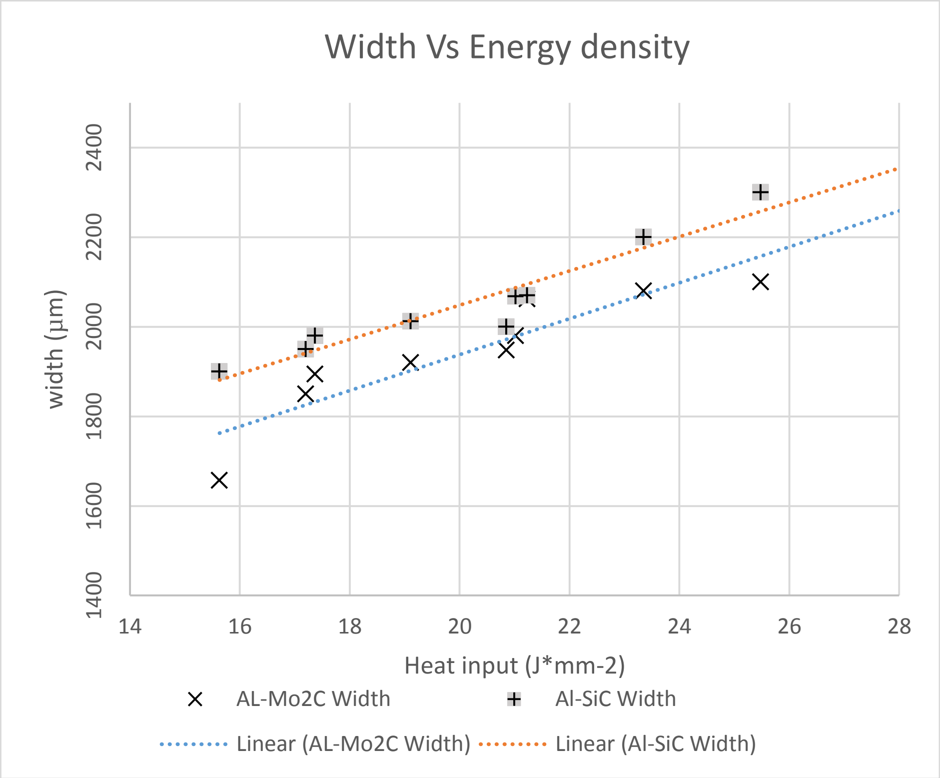

***Fig.5:-**The effect of laser energy density on clad layer height for Aluminum and its composites of 30% SiC and 30% Mo2C*

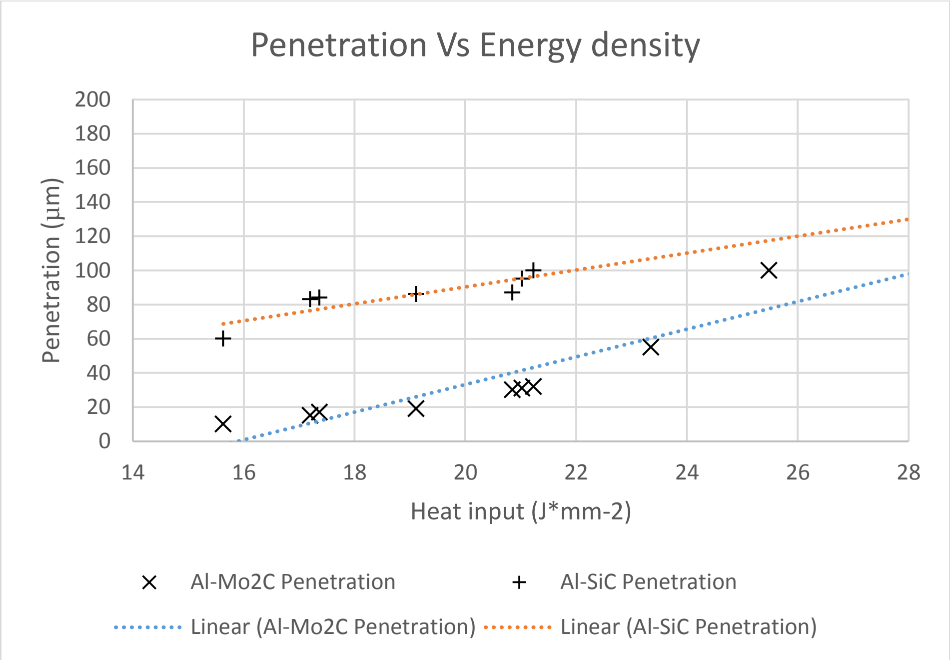

***Fig.6:-**The effect of laser energy density on clad layer penetration for Aluminum composites of 30% SiC and 30% Mo2C*

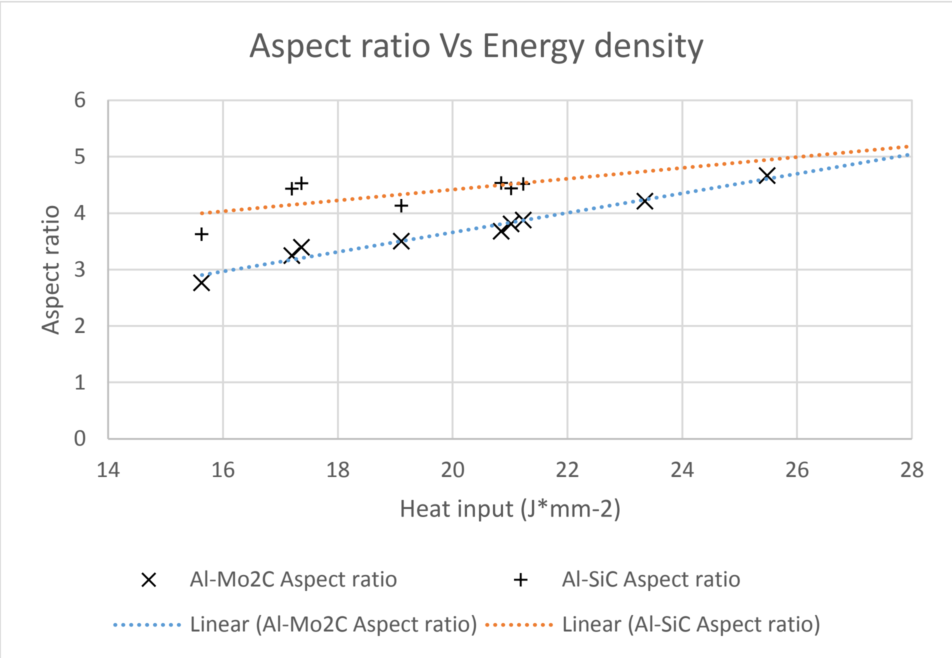

Fig.7:-*The effect of laser energy density on clad layer Aspect ratio for Aluminum composites of 30% SiC and 30% Mo2C*

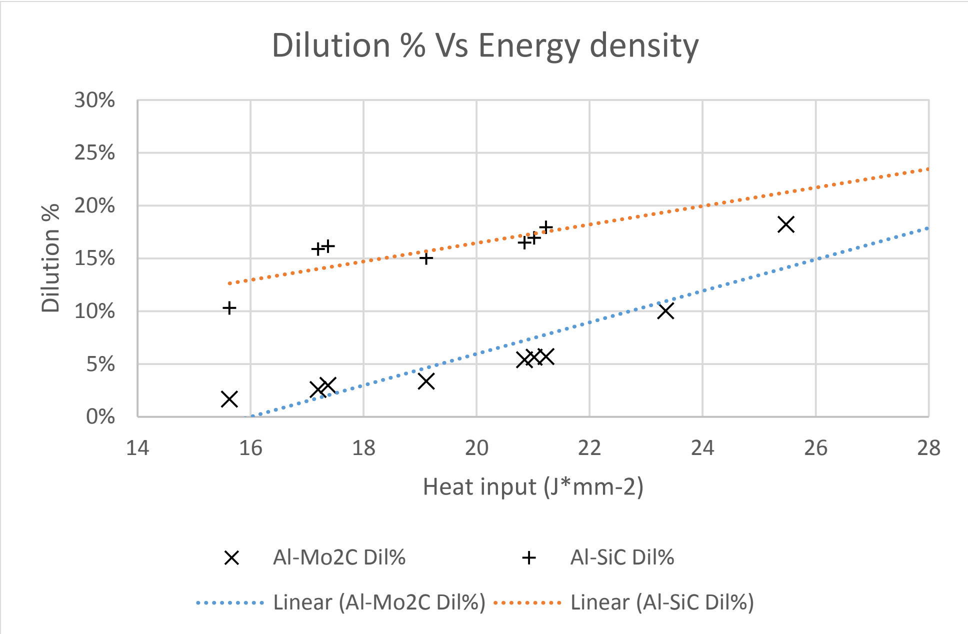

Fig.8:-*The effect of laser energy density on clad layer Dilution % for Aluminum composites of 30% SiC and 30% Mo2C*

CONCLUSIONS

The cladding layer formation and geometry of 30 wt. percentage SiC and 30% wt. percentage Mo2C are direct result to the change of laser energy density. The single-track geometry (width, depth of penetration, aspect ratio and dilution) increases with the increase of the laser energy density, while the height decrease. The influence of SiCp addition rather than Mo2C is such that as we use SiCp, the tracks width, aspect ratio, penetration and dilution percentage increase, while the height decreases. For accepted quality, the recommended processing parameters throughout the implemented experiments, for deposition of pure Aluminum and its composites layer are 1200 w laser power and 1 $m.min^{-1}$ scan speed, which equal to 22.93 $J.mm^{-2}$ laser energy density.

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