Optical Monitoring
of Nd:YAG Laser Produced
Hastelloy C Clad Layers

by

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Abstract

The main objective of laser cladding is to improve the wear and corrosion property of a specified metallic substrate by creating a coating of material on its surface with superior properties. Coating is made by injecting powder alloy into the molten pool created by laser on the surface of metallic substrate. Common problems that may occur during laser cladding are high level of dilution between the clad layer and substrate which can affect wear and corrosion properties of the produced clad, and layer defects such as pores or cracks which influence the layer integrity. As part of a bigger module studying the monitoring and control of the cladding process, a series of experiments was conducted using a 2.5 kW fiber delivered Nd:YAG laser, Hastelloy C powder, and two optical sensors namely pyrometer and photodiode to monitor the laser cladding process by recording the light emission generated during the process. This paper reports the results of these experiments and the ability of such detectors to recognize changes in process parameters.

1. Introduction

The use of a laser beam as the energy source has opened up new opportunities in the surface engineering of materials [1]. Laser cladding is a process which involves the application of a hard and wear resistant material to the surface of a component in order to reduce wear loss of material by abrasion, impact, erosion, galling, corrosion and cavitation [2]. Cladding is distinguished from alloying in the sense that it melts small amounts of the base material relative to the deposited layer [3]. Figure 1 illustrates laser cladding using the injected powder method.

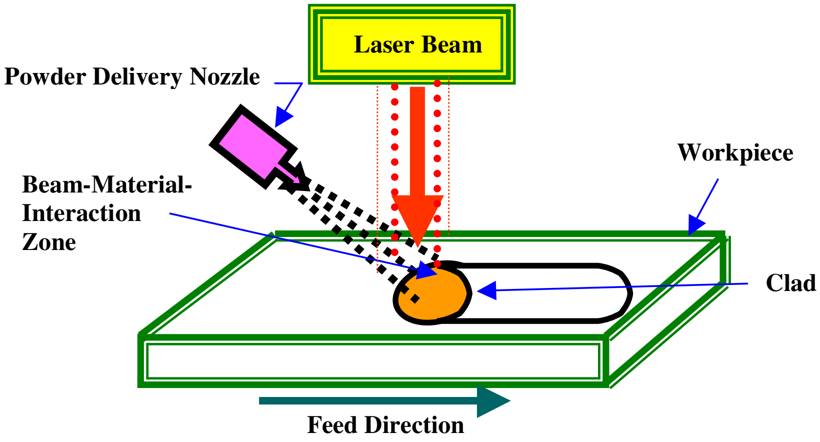

Figure 1 - Laser Cladding using the "Injected Powder Method"

Since the process is still experience based, a poor clad may result if the operating conditions are not set properly or become unstable during processing. Such instabilities may include the rise of substrate temperature, the change of laser beam quality or the variation in powder flow rate (as the powder level and compactness of powder in the feed hopper may vary). Therefore in order to minimize these unstable factors it is desirable to monitor and control directly the quality of the clad produced. Materials used for laser cladding mainly have their melting point above 800°C, therefore the wavelength of radiated light will be visible and this is what sensors will pick up [4]. The sensor signal is based on the melt pool radiation and consequently dependant upon melt pool temperature, shape and size, and also dependant on distance between the sensor and the melt pool as well as the viewing angle of sensor [5].

Uses of optical methods for monitoring laser surfacing with a CO_2 laser have been reported in the literature [4,6,7]. Monitoring of the laser process can be performed in two distinct ways: sensing and measuring either the laser operating parameters or the process parameters. For example, it is possible to measure the laser power or the temperature rise of the workpiece [8]. Temperature, as an important parameter in determining the extent of the level of dilution expected during laser cladding [9], was measured by a two colour pyrometer and revealed the effect of processing parameters on the degree of dilution [10]. For the monitoring of the melt pool characteristics, optical sensors are normally employed due to their flexibility compared for example with ultrasonic sensors. Optical sensors are relatively cheap, fast and the light emission possesses good spatial information [11]. The utilization of photodiode has shown that it is to detect a range of clad faults without intruding into the process [4].

The objective in conducting the present investigation was to monitor optical emissions in the form of light and thermal radiation being emitted from the molten pool created by Nd:YAG laser on the workpiece, during laser cladding of Hastelloy C powder. The concluding intention was to correlate the generated signals by a photodiode and pyrometer, with the observed profiles and dilution levels of the produced clad layers.

2. Experimental Procedure

The experiments were performed with Nickel (Hastelloy C) based alloy powder with elemental composition given in Table 1, and with steel substrate of thickness 10mm. A range of operating conditions used in the experiments is given in Table 2.

Composition	C	Cr	Si	W	Fe	Co	Ni	Mn	Mo	V	Powder Size (microns)
Hastelloy C	0.03	15.92	0.62	4.48	6.02	0.15	Bal.	0.62	17.1	0.29	45 - 125

Table 1 - Hastelloy C alloy powder elemental compositions (wt%) and size

Laser Power (W) =	1400	to	2200
Processing Speed (mm/min) =	600	to	1600
Focal Length (mm) =	200		
Mass Flowrate (g/min)=	5	to	24
Carrier Gas Flowrate (l/min)=	3		
Defocused Spot Size Used for Cladding (mm)=	Approx. 5		

Table 2 - Nd:YAG laser operating

The temperature was measured using a Maurer two colour pyrometer with a spectral range of 1.4 – 1.75µm and a response time of 20ms, capable of measuring temperature in the range of 800-2400°C. The pyrometer was positioned so that it looked directly into the melt pool trough a bending cube which in turn bends the Nd:YAG laser beam and reflects it down onto the workpiece. The alignment of pyrometer was made with a diode laser beam illuminating a spot on the interaction point. The pyrometer sampled an area of 0.5mm in diameters in the center of the melt pool.

The arrangement for the monitoring of optical emissions from the melt pool involved a light-collecting lens, placed in a shielding tube which transmitted the collected light from the interaction area via an optic fiber to a Thorlabs high-speed photodiode. The spectral response of the photodiode is in the range of 300-950nm. It had an active area of 13mm^2 (3.6x3.6mm). The photodiode was connected to a Textronix digital oscilloscope via a coaxial cable. A KG3 filter glass was used to filter out the 1.06µm Nd:YAG radiation.

A series of experiments was conducted by depositing single and multiple track clad layers which were produced in a plane perpendicular to the axis of the powder nozzle and laser beam. In the case of single tracks, a length of approximately 40mm was produced in one direction and 40mm in reverse direction with a 10mm separation between the tracks. As for overlapping layers a raster scan pattern was adopted with each track being 25mm in length and overlapped 50%.

3. Results and Discussion

(i) Temperature and Optical Emission Dependence on Powder Mass Flow Rate

In this run the laser power and the process speed were kept at constant values of 1800W and 600mm/min respectively, and the powder mass flow rate was varied from 5 to 24g/min. Illustrated in Figure 4, is the surface of single clad tracks produced at 5 and 24g/min powder mass flow rates respectively. At the lower mass flow rate (Figure 2A) the clad layer is thinner. At the higher feed rate a thicker clad layer was produced (Figure 2B) with a different surface profile. Both surface profiles indicate that the clad height in the starting directions is lower than the one in the returning directions. As the powder feed rate increases, the amount of energy required for melting the powder increases, and correspondingly less energy remains available to melt the substrate. As observed in [12], a low powder feed rate resulted in higher detected temperature, and inversely when the mass flow rate was high, lower temperature was recorded (Figure 3a). The fluctuation in the pattern of the acquired signal may be related to optical emission of the powder particles irradiated by the laser before entering the melt pool. The optical emission detected by the photodiode increased with an increase in the quantity of the injected powder (Figure 3b). Both temperature and optical emissions showed a more stable pattern in the generated signal on the returning direction giving the indication that the stream of the injected powder was steady and consistent.

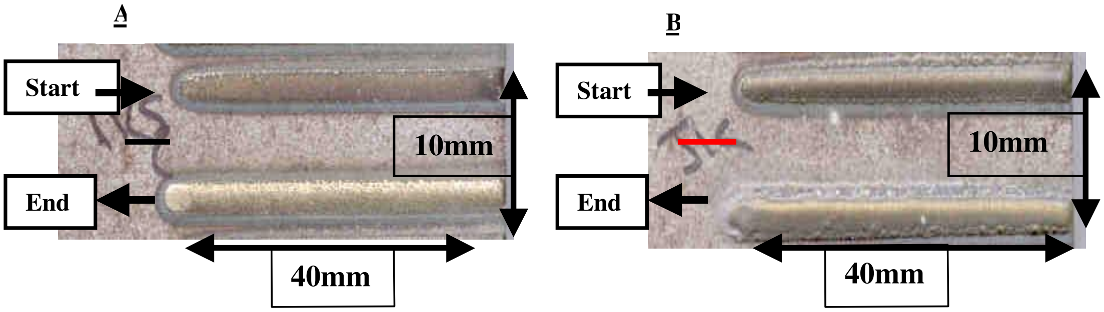

Figure 2. Surface profile of clad layers produced with powder mass flow rate set at (A)

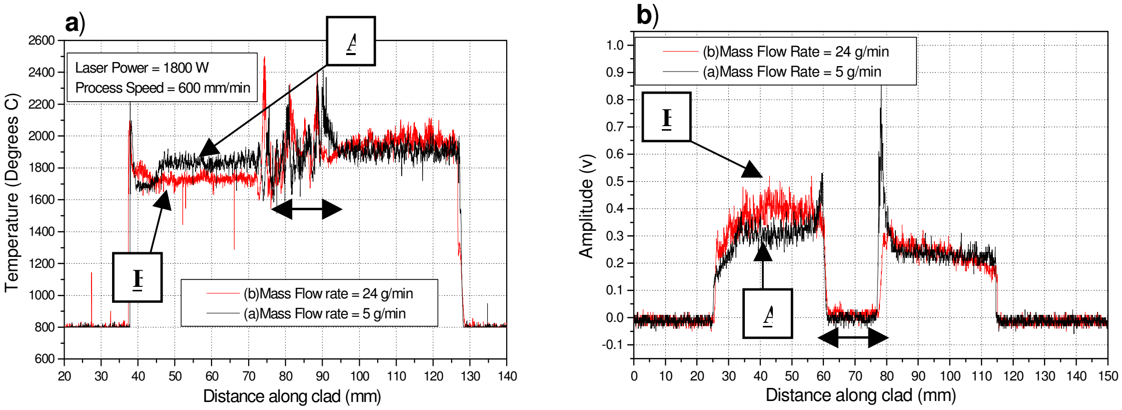

Figure 3. Dependence of Temperature (a), and Optical emission (b) on mass flow rate.

(ii) Temperature and Optical Emission as a Function of Laser Power

In this experiment the processing speed and powder mass flow rate were set at constant values of 600mm/min and 14g/min respectively, and the laser power was varied from 1400 to 2200W. Surface profile of the created layer in Figure 4A, clearly reflects the smaller diameter melt pool created at the lower laser power. The increase in laser power increased the size of the melt pool, and therefore more powder fell into it creating a clad bead with greater thickness and width (Figure 4B). Referring to Figure 5, it is shown that temperature and amplitude were reacting in the same manner towards the applied changes in the laser power, increasing as the laser power was increased. With the view of the fact that unstable supply of powder feed may cause inferior clad beads to be produced, therefore the sensor responses during the formation of a rough clad and a smooth one occurred in the form of sever fluctuations in either measured temperature or recorded amplitude. In addition it should be noted that when the powder mass flow rate and the laser processing speed are kept constant while the temperature of the substrate increases, the excess energy is used to melt the substrate, and increase the level of dilution.

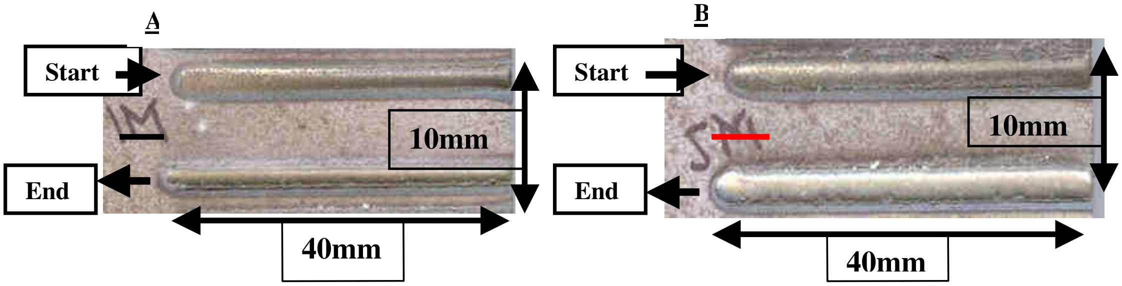

Figure 4. Surface profile of clad layers produced at (A) 1400W and (B) 2200W.

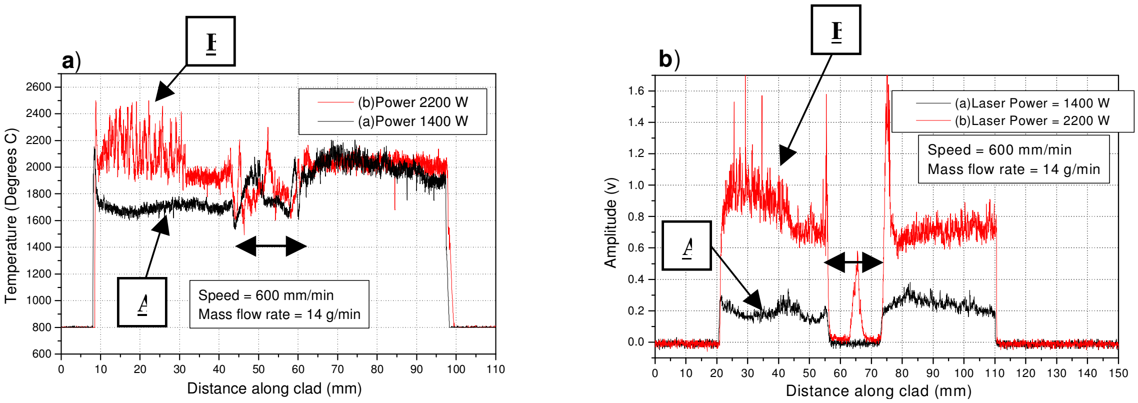

Figure 5. Temperature (a), and Optical emission (b) as a function of laser power.

(iii) Effect of Processing Speed on Temperature and Amplitude

In these experiments the laser power and powder mass flow rate were kept constant at 1800W and 14 g/min respectively, and the processing speed was varied from 800mm/min up to 1800mm/min. At slower processing speed more powder per unit length is delivered to the substrate leading to thicker clad layer (Figure 6A). At higher speeds less powder per unit length is delivered leading to thinner clad layers (Figure 6B). An increase in the processing speed leads to a decrease in the surface temperature and the clad tracks would not correctly fuse to the surface. Inversely, for a slower processing speed the surface would reach higher temperature, leading to a deeper penetration thus a higher dilution level (Figure 7a). Unlike the detected temperature, optical emission showed higher amplitudes as more powder was fused onto the substrate (Figure 7b). It is possible that as the optical emission is proportional to the size of the melt pool, the smaller pool obtained of higher speeds would result in less light being emitted and consequently detected by the photodiode.

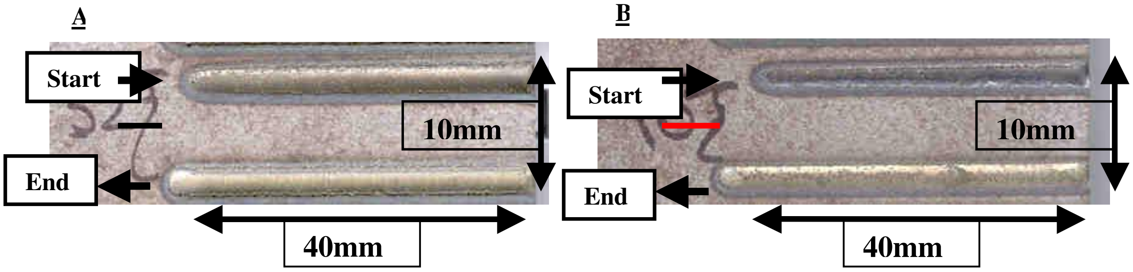

Figure 6. Surface profile at speed of (A) 800mm/min and (B) 1800mm/min.

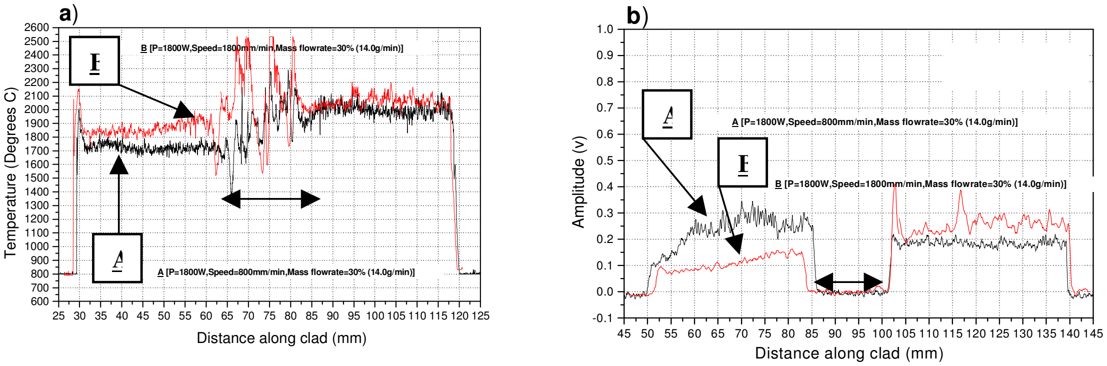

Figure 7 Processing speed vs Temperature (a) and Optical emission (b).

(iv) Effect of Direction of Cladding on Temperature and Optical Signal

It was observed that the direction of motion had an effect on the temperature of the melt pool. This was investigated further by changing the scanning direction. The laser power, processing speed and powder mass flow rate were 1800W, 800mm/min and 14g/min respectively. The surface profile of clad layers is illustrated in Figure 8. The response of the pyrometer and photodiode is illustrated in Figure 9. It can be observed from the Figures that both the temperature and optical emission is higher when the cladding direction is from right to left regardless of the starting point of the clad bead. The reasons for these are not clear, but possible causes may include asymmetrical laser beam interaction with the workpiece and the relative position of the cladding nozzle with respect to the molten pool.

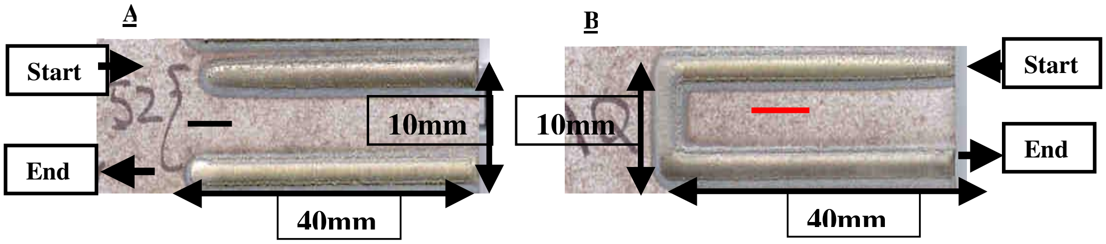

Figure 8 - Surface profile of clad layers - same process parameters but different feed direction.

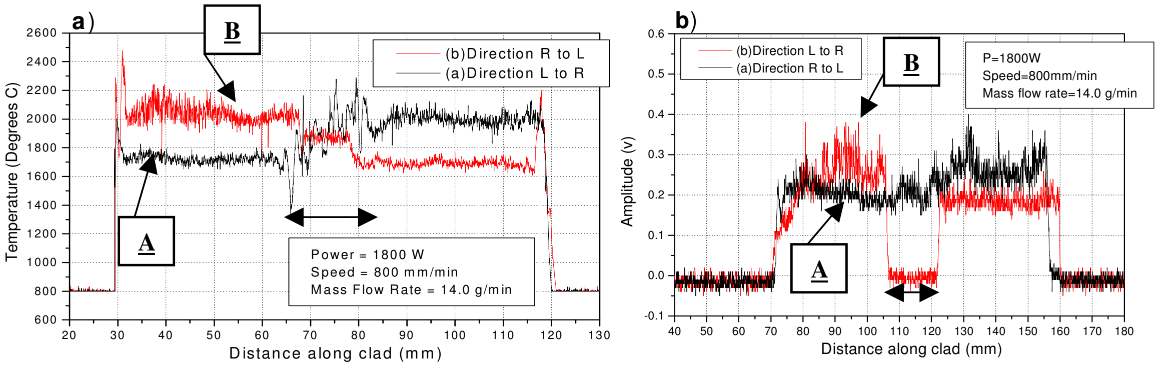

Figure 9 - Direction Effect on Temp (a) & Optical emission (b).

(v) Detection of Defects by Temperature and Optical Emission

Sensor responses in the form of large fluctuations in the measured temperature and sharp optical emission occurred, due to defects in clad surface (Figure 10). This is similar to that observed in [4] using a CO_2 laser. It can be observed from the figure that sharp decreases in the signals were recorded at various locations along the clad layer. Visual examination of the clad layer indicated defects at the locations indicated by the sensors.

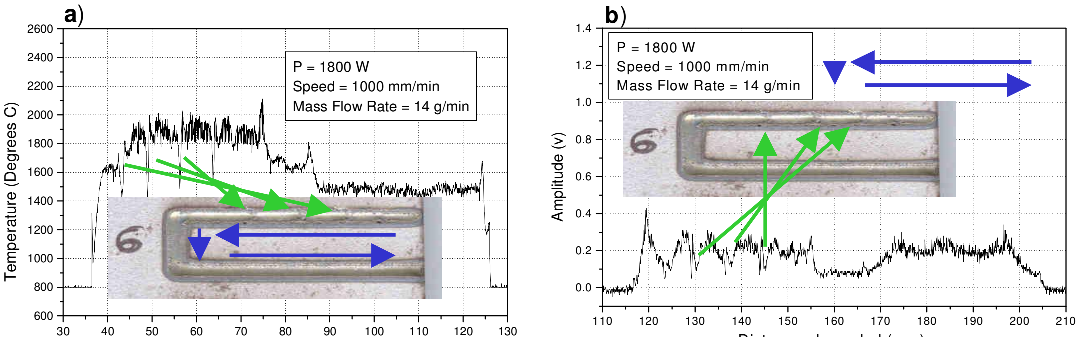

Figure 10 - Detection of defects by Temperature (a) and Optical emission (b).

4. Multiple Track Monitoring

Multiple track clad layers were formed to view the responses from the pyrometer and photodiode to changes in the formation of such clads. Laser power, processing speed and powder mass flow rate were set at 1800W, 600mm/min and 14g/min respectively. The clads were 20mm in length and 25mm in width, and the space between each track was 1mm. Figure 11 illustrates the temperature dependence of such a clad surface. It can be observed that the temperature exhibited a similar pattern to that observed with single track, namely a higher temperature when cladding from right to left. Again the reasons for this are not clear at this stage.

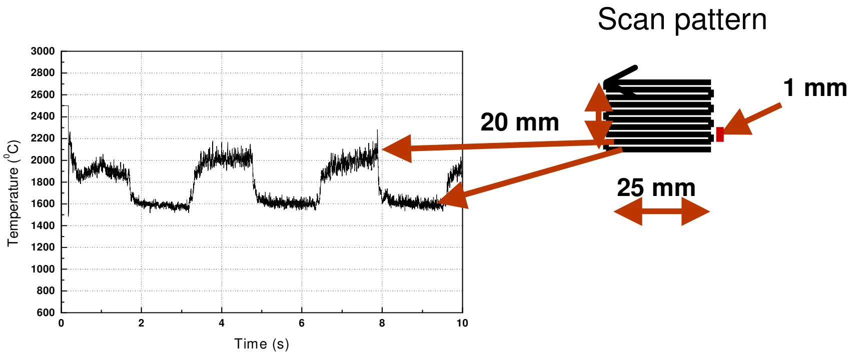

Figure 11- Multiple track laser cladding.

In attempts to investigate the reasons for observed temperature dependence, a number of multiple cladding tracks were produced under the same operating conditions. It was observed in some cases that the clad layer surface changed colour (Figure 12). It is presumed that this change is due to the formation of slag, or oxides on the surface. Presence of oxide showed its effect by a decrease in the measured temperature. It was also observed that the detected back reflected light from the interaction zone, had the same response towards the presence and absence of oxides on the surface of the produced clad layers.

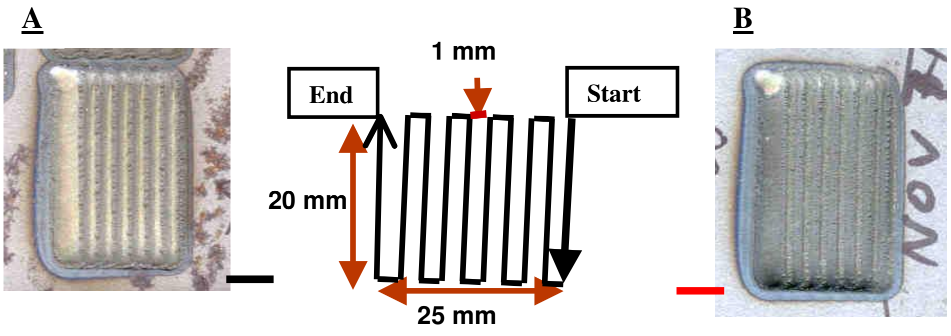

Figure 12 - Surface profile of multiple clad layers produced under the same conditions: (A) without, and (B) with the presence of oxide on the surface layer.

5. Conclusion

In experiments utilizing thermal and optical sensors, and performing single and multiple track laser cladding, the responses of such sensors to the selected conditions were examined. Results suggest that the temperature of the melt pool decreases with increasing powder per unit length, and that optical emission increases with increasing powder per unit length. Temperature and optical emission increased with increasing laser power. Cladding direction caused different responses from the sensors. Temperature and optical emission can detect defects on layer surface, and the presence of oxides on melt pool surface lowers both temperature and optical signal.

6. Acknowledgements

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7. References

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