Temperature Monitoring in Laser Cladding Process

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Abstract. This paper investigates the temperature monitoring technique during the laser cladding process. Experimental trials are made to understand the variation in temperature when cladding is going on. In this work, SS316L powder is cladded on martensitic stainless steel AISI 410 with an objective to study the temperature variation on the surface during the process of cladding. There are three K-type thermocouples are placed beneath the substrate (centre, right and left) to measure the temperature with a data acquisition system. Two sets of experiments are performed; one set consisting of single/multiple layers and the second set has single/multiple passes. The results obtained reveal the difference in temperature gradient which is low during the cladding process, and if the temperature increases, this may lead to distortion of the substrate. This also shows that the temperature rise is nominal as compared to other coating processes.

Key words: Laser Cladding, SS316L, Thermocouple, Data Acquisition

1. Introduction

The process of laser cladding involves a laser heat source which melts the required metallic powder and deposits as a thin layer over the substrate forming a metallurgical bond. This process is more economical to repair or build components that are subjected to the harsh environments like high temperatures, pressures, humidity, grinding, scouring, and radiations that are of high cost in nature and are also made of exotic materials. These components erode, corrode and are subjected to severe wear. It will be very expensive to replace these components. In order to overcome these problems of replacement, laser cladding is one such technique where a thick coating can be applied on the surface subjected to wear and tear with the required metal powders. This process gives a better coating with minimum dilution, minimal distortion, least HAZ, better surface quality and also requires reduced post machining as compared to other conventional coating processes of spraying [1]. Figure 1 gives the basic principle of laser cladding process [2].

The temperature variation during the process of cladding is an important parameter to be observed, because of the fact that the temperature of the substrate beyond a certain limit may lead to distortion of the workpiece as similar to welding process. This distortion even at micron level is not allowed in components like aerospace application, etc. R. Jendrzejewski et al. studied the distribution of temperature in multi-layer laser cladding using numerical analysis approach and thereby compared the
results with experiments and thus prepare a suitable mathematical model to predict the temperature rise in laser cladding process [3]. Zhengtao Gan et al. developed a thermal cycle model for predicting the temperature behavior and concluded that the cooling rate decreases progressively as the subsequent layers deposit resulting in coarser solidified grains in the upper portion of part [4]. Yanping Jia et al. studied the effect of process variables on temperature field in laser cladding where the powder feed rate is considered to study the temperature variation at the melt pool and reported that the maximum temperature at the melt pool is proportional to laser power and the preheated temperature while the maximum cooling rate is inversely proportional [5]. J.C. Heigela et al. investigated the distortion characteristics in multilayer cladding and also to study the temperature behavior. It was investigated that maximum temperatures were recorded at the centre of the substrate and the distortion increases as heat input increases [6]. Fang Luo et al. studied the effect of laser power on the cladding temperature field and the heat affected zone (HAZ) and found that as the laser power is small, decalescence of cladded layer is also small and the alloy powder of surface melts incompletely, and the size of the HAZ is small and vice versa [7]. It is therefore from the literature it is observed that the study of temperature profile plays an important role in laser cladding.

Several researchers studied the temperature behaviour during laser cladding process, but majority of the literature reported the influence of coating interface temperature and very few explored the temperature variation in the substrate. The present work is an attempt to perform in-situ monitoring of the temperature and predict its effect over the base surface during the process of cladding.

2. Experimental Setup:

A Laserline LDF 4000-100 Fibre coupled diode laser, with a maximum output of 4 kW laser power is used for experimentation. The powder is delivered by a Sulzer Metco Twin10C powder feeder and injected into the processing area through a co-axial nozzle. All the optics and nozzles are integrated with a KUKA KR16 robotic arm with 6-DOF controller for flexible and fast positioning. Argon is used as the carrier and shielding gas in the process. The focal spot was positioned 20 mm above workpiece while a laser spot diameter of 5 mm in this system.

In the present set of experiments, austenitic SS316L powder of 20-120 µm size is used as the clad material, which has good corrosion and heat resistance properties. The substrate samples are made of AISI 410 grade, martensitic SS with dimensions 75 mm × 25 mm × 10 mm respectively. Nickel-alloy high temperature spring loaded K-type thermocouples having a measurement range of -50°C to 1350°C are used. Figure 2 shows the fabricated fixture designed for experimentation. The schematic of the thermocouples positioning is shown in Fig. 3 which are fixed in such a way that all the three thermocouples touch the base and will not deflect during experimentation. Figure 4 gives the actual positioning of the thermocouples. The need for three thermocouples is that we can extract the
temperature variation data over the surface across the surface during laser cladding. A 32 channel NI DAQ system, model 9213 is used for online data acquisition through LabVIEW software.

![Figure 2 Fixture for experimentation](image1)

The fixture is designed with a holding mechanism to accommodate the substrate and thermocouples such that both of them will not lose any physical contact during the experimentation. The substrate is preheated to 200°C before the cladding process starts to decrease the cooling rate, as crack formation takes place during high cooling rates.

![Figure 3 Schematic of thermocouple position](image2)

A laser power of 2.5 KW is maintained during the experimental trials with a powder feed rate of 46g/min and a scanning speed of 15 mm/sec. These process parameters are kept constant for the entire set of experiments. Two sets of experiments are performed which include single and multi layers with single and multi passes. The pre-heated substrate is fixed over the designed fixture; a temperature loss of 40-50°C is observed due to convection and radiation as it takes about 3-4 min to ensure proper thermocouple contact with the bottom surface of the substrate. The DAQ system connection along with the experimental setup is shown in Fig. 5.

![Figure 4 Thermocouples mounting](image3)
During the process of cladding, the laser heat through the robotic arm and a simultaneous axial blowing of powder particles through the nozzle are surrounded with a shielding gas. As the powder particles come in contact with the laser, some part of the laser heat is consumed to melt the powder and some heat is used to melt the substrate surface to develop a metallurgical bond. Figure 6 shows the laser cladding experimentation. The NI DAQ system is set to acquire data 4-5 sec before and after the process to avoid any data loss.

Figure 5 Experimental Setup

Figure 6 Laser cladding process

3. Results and Discussion:

SS316L powder is cladded on SS410 samples at different operating conditions. A total of 6 experiments are performed and the temperatures are recorded. The rise in temperatures recorded through the DAQ system is listed in Table 1. Before the start of cladding process, the substrate temperature is recorded after fixing it on the fixture. For a single pass with multi-layer cladding, the temperatures recorded by different thermocouples are: RTC - 110.36 °C, CTC - 120.36 °C and LTC - 86.46 °C respectively. For a double pass multilayer cladding initial temperature measured are: RTC - 128.42 °C, CTC - 142.92 °C and LTC - 97.67 °C. The cladding time for the first set of experiments is 8s per layer and the second set is 15s per layer.

The laser beam in laser cladding process is very narrow and can be concentrated on a very small area which makes the laser highly directional. Also laser light spreads in a very small region of space. Hence, all the energy is concentrated on a narrow region than the ordinary light which makes this cladding a unique than the other coating processes. In the process of laser cladding, 60-70% of the laser power is utilised in melting the powder and the remaining is used for substrate surface melting. This interface creates a strong metallurgical bond between powder and substrate. Due to this power distribution only, a small amount of laser power is incident on the substrate. As the laser spot diameter is very small, localised heating take place and as spot moves forward the melt pool gets solidified. Also the thermal conductivity of SS410 is less which ranges from 24 to 28 W/m-K, the heat transfer rate from surface to bottom is less.
Table 1. Temperature rise per pass.

| S. No. | Experiment | Temperature Rise $\Delta t$ ($^\circ$C) |
|--------|------------|---------------------------------------|
|        |            | RTC        | CTC        | LTC        |
| 1      | 1 pass 1 layer | 1.03       | 1.38       | 0.15       |
| 2      | 1 pass 2 layer | 1.73       | 2.42       | 0.26       |
| 3      | 1 pass 3 layer | 2.45       | 3.92       | 1.06       |
| 4      | 2 pass 1 layer | 1.13       | 3.42       | 2.55       |
| 5      | 2 pass 2 layer | 5.4        | 9.52       | 3.75       |
| 6      | 2 pass 2 layer | 7.8        | 12.77      | 4.84       |

Results show that the rise in temperature in subsequent deposited layer is more than the previously deposited layer. This happens because of re-melting of previous layers. In addition to this, several previous layers may also see some degree of re-heating. Thus, the layering process will cause multiple temperature gradients during the course of deposition. Also due to the addition of subsequent layer more heat is added to the substrate which increases the thermal conductivity of the substrate. More number of layers depositions slows down the cooling rate. It is also observed that the temperature difference between the previous and present layers is very small, as a result of the data acquired at the end of second layer shows high temperature rise than the previous layer. Figures 7 (a, b, c) shows the temperature variation with time in single pass cladding with single, double and triple layers, as recorded from right, centre and left thermocouples.

Figure 7 (a) Temperature in RTC for single pass cladding

Figure 7 (b) Temperature in CTC for single pass cladding

Figure 7 (c) Temperature in LTC for single pass cladding
From the readings obtained, it is observed that the rise in temperature in the centre thermocouple is comparatively more in all the cases. This is due to the fact that the cladding takes place on either side of the centre thermocouple (CTC) while depositing a layer from the right thermocouple (RTC) to left thermocouple (LTC). Whereas, for right and left thermocouples, the laser heat will be stopped, due to which heat released at that particular location is less hence the temperature rise.

The temperature rise at bottom of the substrate during the laser cladding is very less and can be assumed that the distortion in the laser cladded components can be very less in comparison to other conventional processes. Because of this, laser cladding technique is more suitable for components where distortion is not allowed. Multi-track cladded layers show higher temperature rise in comparison to single-track cladded layers due to longer exposure time at high temperature. The plots shown in Figures 8 (a, b, c) give similar temperature profiles for double pass cladding. Further experimental studies are still on to understand the phenomenon of temperature and distortion measurements with numerical investigations.

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