CO₂ laser cladding of VERSAlloy™ on carbon steel with powder feeding

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Abstract. Laser cladding processing with metal powder feeding has been experimented on carbon steel with VERSAlloy™. A special device for the metal powder feeding was designed and manufactured. By adopting proper cladding parameters, good clad layers and sound metallurgical bonding with the base metal were obtained. Analysis indicates that the micro hardness of clad layer and the heat-affected zone increased with increasing of cladding speed. The experimental results showed that VERSAlloy™ cladded well with carbon steel.

1. Introduction
Laser cladding with metal powder feeding has the following potential advantages: low dilution and limited heat effects on the base metal, metallurgical bonding, minimum distortion of the components, low cracking susceptibility and suitable automation. Laser cladding has been used to form a clad layer on the selected areas of valves, shafts and other components to improve wear and corrosion resistance. The laser cladding process can control the thickness of the clad layer by adjusting the feed rate and beam absorption [1-3].

CO₂ laser cladding processing with metal powder feeding has been experimented on carbon steel with an alloy of type VERSAlloy™ (PMA Company, USA). VERSAlloy™ offers excellent resistance to corrosion, erosion, high temperature oxidation, abrasion and wear. VERSAlloy™ has a low melting point (1093 °C) and enables overlay processing with minimum dilution and low distortion of the base metal in laser clad processing.

To get a high quality clad layer, a metallurgical bond and low dilution of the clad layer are required. If the proper processing parameters are not adopted, the above requirements may not be satisfied. If the melt pool is significantly diluted, the properties of clad layer will be influenced. Modeling the heat flow during laser cladding provides useful guidance for experiments. One-dimensional heat flow was proposed by Bamberger et al. [4] and a three dimensional analytical solution of the melt pool of laser cladding was proposed by Picasso et al. [5]. Temperature fields and microstructures for general laser cladding have been reported [6]. In this paper, FEM analysis has been applied to estimate the depth of molten pool and dilution during laser cladding and compared with experiments. In this model, the adaptive mesh method was adopted for the time-dependent finite element method computation so that the shape of melt pool can be represented [7]. During computation the mesh adapts its shape and position according to the shape of melt pool automatically. The thermo-physical properties of a material were allowed to vary with temperature.
2. Experiment

2.1. Materials
Carbon steel of type SM20C is widely used as a base metal in mechanical components. Its chemical composition is shown in table 1. VERSAlloy™ 50 with the mesh number 300 was used as the metal powder. Its chemical composition is shown in table 2. This nickel based alloy has good properties of resistance to corrosion, wear, high temperature oxidation and erosion.

| Table 1. Elemental composition of SM20C carbon steel in percent. |
|---------------------|-------|-------|-------|-------|-------|
| C       | Si    | Mn    | P     | S     | Fe    |
| 0.20    | 0.25  | 0.76  | 0.02  | 0.006 | Bal.  |

| Table 2. Elemental composition of VERSAlloy™ (PMA Company, USA) in percent |
|---------------------|-------|-------|-------|-------|
| C       | Si    | Fe    | B     | Cr    | Ni    |
| 0.6     | 4.0   | 4.0   | 3.0   | 11.0  | Bal.  |

2.2. Laser cladding with metal powder feeding
A CW CO₂ laser with a maximum power of 4 kW was used for laser cladding processing. The spot size with a single mode beam was around 2 mm. Samples were exposed with a laser power of 2.1 kW. Argon gas was used as for shielding to protect the molten metal from being oxidized at high temperature, to reduce the spattering of laser beam at the laser head and to cool the nozzle of laser beam. The nozzle for metal powder delivery was located 5 mm above the spot of laser beam. The powder delivery and laser beam were controlled simultaneously. The feed rate of metal powders was controlled by varying the revolution of a feed screw. To get a higher efficiency of metal powder delivery, argon gas was flowed in the feed tube.

Optical microscopy was used to characterize the cladding morphology, microstructure and adherence to the substrate. Mechanical properties were evaluated by microhardness measurement on the cross-sectional samples. Elemental analysis of bonding constituents was performed by using a scanning electron microscope with an energy dispersive X-ray analyzer.

3. Results and discussion

3.1. Laser cladding with metal powder
A good clad layer was obtained at a powder feed rate of ~50 g/min. The dilution decreased with increasing of cladding speed of laser beam. A good clad layer was obtained at an angle of powder delivery between 60 and 70 degrees. Under 60 degrees of powder delivery, the clad layer was deposited irregularly on the base metal since the metal powder was not well flowing in the tube. Cracks and porosities formed in the clad with unsuitable angle condition because the metal powder could not be fully melted.

Figure 1. SEM cross-sectional images if (a) good clad layer formed with P = 2.1 kW, V = 3 mm/sec and powder feed rate of 50 g/min and (b) a clad layer with a crack at the boundary under dilution formed with P = 2.1 kW, V = 2 mm/sec and powder feed rate of 30 g/min.
Figure 1(a) shows an SEM image of a good clad layer on the substrate processed with optimum feed and laser conditions while figure 1(b) shows a crack at the boundary when there was insufficient supply of metal powder. Exposure conditions are given in the figure caption.

Figure 2 shows the micro Vickers hardness distribution measured as a function of position orthogonal to the cladding line, beginning on the as-deposited alloy (0 mm position) and ending on base metal (1.5 mm position). Two speeds are compared for the same 2.1-kW laser power. The microhardness of the clad layer is higher than that of the base metal and heat-affected zone. The hardness decreases from the top of the clad layer to the base metal because of the higher cooling rate at the clad surface increases the microhardness.

![Figure 2. Vickers microhardness distribution across a laser clad line, formed with two different cladding speeds.](image)

Figure 3 shows the bonding zone between a strongly bonded clad layer and the base metal, where the molten pool metal is seen to bond metallurgical well with the base metal. Dilution was observed in a very thin layer and the microstructure of heat affected-zone has become coarse by the laser heating.

![Figure 3. SEM images of the bonding zone between the clad layer with base metal at low (a) and high (b) magnification.](image)

The X-ray diffraction spectra in figure 4 show that nickel is rich in the dilution area, which must originate from the metal powder according to tables 1 and 2.

3.2. Modelling molten pool and dilution
To estimate the depth of molten pool and the dilution during laser cladding, FEM has been computed by C-language programming developed by our group [6-7]. The depth of the clad layer increased rapidly within very short time after the start of cladding processing, then slows and eventually becomes almost constant. Before a quasi-static state is reached, the heat inputted into the melt pool is faster than heat conducted away from the area. For a longer cladding time, the cooling rate is slower than that after shorter cladding time. This means that with the increase of cladding time the metal will stay at high temperature for a longer time.
Figure 4. X-ray diffraction spectrum from (a) the dilution area and (b) the heat-affected zone.

Figure 5. Depth of clad layer versus cladding speed and comparison with FEM analysis.

Figure 5 shows the computed and measured depth of clad layer versus cladding speed. The depth of clad layer decreased with increasing of cladding speed because of decreasing of heat input. The depth of clad layer computed by FEM analysis coincided well with the two experimental values, but further experiments are required over a large range of cladding speed to fully text the present FEM model.

4. Conclusion
With appropriate laser cladding parameters, a good cladding with sound metallurgical bonding was obtained between VERSAlloy™ and carbon steel. The maximum microhardness of clad layer was three times that of the base metal. One method to maintain low dilution during cladding is to decrease the input energy so that the depth of melt pool can be kept low and allow the molten metal bond with the base metal.

References
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