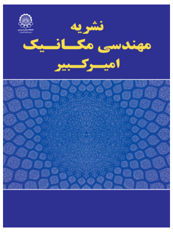

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Laser Cladding of TiC/316LSS and Analysis of Input Parameters using Response Surface Method

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ABSTRACT: Laser cladding is an effective modification surface approach resulting in a surface with appropriate mechanical characteristics like high wear resistance, high resistance from oxidation in high temperature, suitable hardness, and high corrosion resistance. The effective parameters in this process include the power laser, relative laser speed, the type of coating material, the focal length of the laser, the diameter of the laser spot, the pulse width, etc. Here, the first three cases are considered to find optimum parameters to create proper cladding layer with excellent mechanical properties with high hardness and minimum porosity, dilution, and crack. In this research, the cladding of composite powder of *TiC/316LSS* with certain volume percentages (*TiC/316LSS*) 5, 10, 15 on steel 316LSS by using laser type Nd:YAG is investigated. Output parameters include the value of porosity in cladding, the value of transverse crack, and the value of dilution of cladding. With designing experiments and analyzing output results by using response surface method , the effect of input parameters on the quality of cladding surface is investigated. Besides, by obtaining the optimized value of input parameters for creating cladding surface with the lowest value of porosity and crack, cladding surface with hardness of 660 HV 0.1 is achieved, which is 4 times harder than substratum with hardness of 150 HV 0.1.

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1. INTRODUCTION

The laser cladding process is a new method in which ceramic particles can be matched with a homogeneous distribution over a matrix phase. Laser as a thermal source melts the cladding material which has been placed on the surface of the piece in the form of wire or powder. Spray using flame, plasma spray, arc welding, and so on are among the other methods for surface cladding. Some advantages of laser cladding compared with the other methods are controlling the required energy, the possibility of the localization of the process, non-contact being of the process, and the controllable dilution degree.

There has been extensive research on the history of laser industrial applications, especially laser cladding. Moradi et al. [1] considered the effect of gas pressure and the position of the focal point of laser on the geometric quality, surface roughness, and shear stress in laser cutting of injectable polycarbonate with 3.2 millimeters thickness using laser CO2 continuously which is low-power. They found that positioning of the focal point of the laser in the depth of the piece leads to an increase in the quality of laser cutting. Reduction of the surface of the cutting groove and the angle of the cone groove respectively are attributed to the degradation of focal point and growth of the gas pressure. Li et al. [2] carried out laser cladding of *CNT/TiC* on titanium and as a result, the abrasion resistance of cladding was significantly increased by adding CNT while, friction coefficient to substratum was reduced. Improvement of abrasion resistance can be due to the existence of titanium carbide phase because it has hardness and has improved abrasion resistance by its uniform distribution in cladding. Majumdar et al. [3] carried out a composite of *SiC/316LSS* with a volume percentage of 5 and Sic 20 using a laser cladding process with the power of 700 watts, the laser velocity of 7.5 mm/sec, and the powder feed rate of 60 mg/sec. In the research, hardness was increased for the composite including 5 volume percent of *Sic/316LSS* and 20 volume percent of 340 VHN *SiC/316LSS* and 800VHN. In addition, its abrasion resistance was improved compared to the initial mode by testing on diamond surface; it showed the highest value of abrasion resistance in 20 volume percent of *SiC*. It should be noted that the improvement of abrasion resistance is due to beads getting bigger. In 2018, Moradi and colleagues [4] investigated laser cladding of the AISI410 steel using the response surface method.

Here, the effects of the relative velocity laser, the volume percentage of titanium carbide in the composite of *TiC/316LSS,* and the laser power on the output of the surface are evaluated. In the present research, cladding of powder of *TiC* and *316LSS* with the specific volume percentage of 316LSS by using preaddressing approach is studied. The effect of the mentioned input parameters on porosity and transverse crack and dilution are evaluated. Regarding the high coverage of test parameters with regression equation, the Response Surface Method (RSM) is a suitable method for analyzing output parameters.

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Table 1. Input parameters of laser with cladding

Variable	Symbol	Unit	1	0	-1
Laser Scanning Speed	*V*	mm/sec	3	5	7
Laser Power	*P*	W	100	150	200
Volume weigh of TiC in Tic/316LSS	*W%*	-	5	10	15

Table 2. Optimal parameters to create the appropriate cladding layer

Optimization Parameters		
Volume weigh of TiC in TiC/316LSS	*Power*(w)	*Scanning laser velocity* (mm/sec)
8.7374	154.54	154.54

2. EXPERIMENTAL PROCEDURE

The main required materials are a substratum of AISI316L SS and powders of Titanium Carbide and 316LSS for pre-addressing. The powder size used from 316LSS is approximately medium 50 microns in an irregular shape. The medium size of titanium carbide powder is 60 microns with a spherical geometric shape. The experimental setup includes the laser apparatus, the equipment related to the preaddressing process, the cutting equipment, mounting, and metallography of samples. In the intended experiments, the static frequency is 35 Hz, the pulse width is 3 msec, the nozzle distance from the surface is 7 mm, the laser diameter is 1 mm, and the argon flow rate is 15 lit/min. The laser used in this research is Nd:YAG with a wavelength of 1064 nm and average power of 700 W, a frequency range from 1 to 1000 Hz, a pulse width from 0.25 to 25 milliseconds, an input power of 20 kW, a beam width of 0.4 mm and a peak power of 10 kW. Design of experiments based on Central Composite Design (CCD) 15 experiments were set by minitab.17. Outputs including the crack, porosity and melting have been determined.

3. RESULTS AND DISCUSSION

In this part, the effective input parameters using response surface method are determined, also the trend of their effect on porosity, dilution and crack are described.

3.1. Porosity

According to the analysis of variance for the values of the porosity of the cladding, it is observed that the laser velocity, the power, quadratic effect of laser power and the interaction of laser power-laser scanning speed are the contributing factor in the porosity. *R-Sq* (99.04%) indicates that the mathematical model matches the experimental data, that its proximity to 1 indicates the validity of this mathematical model on experimental data.

For The porosity decreases with the increase of laser power because the thermal energy forced to the work piece and the possibility to repel holes' increase.

3.2. Dilution

The effective factors on dilution value of cladding include the power, the laser velocity, the velocity-power interaction, the square of volume percentage, the square of power laser. As it is clear from the variance analysis, parameters with a *p-value* less than 0.05 are effective on output results.

3.3. Crack

There are different reasons for creation of a crack; the most important one is related to the residual stress that comes from three cases: thermal stress, stress of transferring phase- as a result of transferring phases in molten pool- and constrained stress -that is related to area of substratum and cladding layer. The formation of crack in cladding layers is mainly due to large thermal stresses caused by large thermal gradients from the cooling process and the difference between the thermal expansion coefficients of the powder and the substratum**.**

Table 3. Output parameters with the given optimum input parameters

	Dilution	*Porosity*	*Crack*
Prediction	8.76398	2.21857	2.5609
Test	7.81	2.6	2
Error (%)	10.88	-14.67	22

4. CREATING AN APPROPRIATE CLADDING

The final cladding layer was performed according to the optimization of the software and Table 3 show the optimization results along with the empirical test with the percentage of the error. Obviously, the percentage of error is acceptable for engineering applications.

5. CONCLUSIONS

In this paper, *TiC/316LSS* composite was cladded on 316L stainless steel using Nd:YAG laser with the maximum power of 700 Watts, and the surface quality parameters were analyzed with the response surface method using Minitab 17 software. The optimal values were obtained in order to have a coated layer with the least degree of imperfections and high hardness. Reviews of analysis of variance showed that all three variable inputs, scanning laser speed, laser power and volume percent *TiC* in the transverse cracks are effective. According to the analysis of variance, it was determined that scanning laser speed and laser power are two effective factors in porosity and dilution. Therefore, increasing the laser power and decreasing the scanning laser speed causes degradation of porosity and increment of the dilution rate.

In the optimum condition, hardness after the laser cladding process with a power of 155 W, the laser scanning speed 3 mm/sec and 8,7374% volume weigh of *TiC* reached to 606 HV0.1, which is about 4 times higher than substrate 150 HV0.1.

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