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Optimization of Track Height of LDED Inconel Alloy-718

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Abstract

Laser directed energy deposition (LDED) is an additive manufacturing technology that builds a component by simultaneously supplying energy and material. Laser is used to melt work material then it placed on a certain surface and allows for solidification. Complex geometries are common in aero-space components. Some of these components are typically manufactured from nickel superalloys. However, conventional manufacturing processes are time consuming and costly. Optimum values of powder feed rate, laser power, and deposition speed on geometrical characteristic track height of laser directed energy deposited single track Alloy Inconel 718 (IN718) are investigated in this paper. At optimum parameter level an improvement of 0.78% is found in track height.

Keywords

Laser directed energy deposition, Inconel 718 alloy, Process parameters

Introduction

Additive manufacturing, sometimes known as AM, of metallic materials has emerged as one of the most significant and potentially revolutionary technologies of the twentieth century. It is a bottom- up technique to near-net-shape manufacture of complicated geometrical structures, reducing the requirement for machining. Direct energy deposition (DED) techniques include direct metal deposition, laser engineered net shaping, and directed laser fabrication. The DED technique includes exposing metal powder to a heat source, such as a laser, which melts the metal particles as they are deposited. This allows for more uniform deposition of the metal powder. Laser cladding and blown powder AM are two other names for this process. One of the primary categories of metal AM, laser directed energy deposition (LDED) provides a means of production, prototyping, and repair applications. The method is adaptable to a variety of uses and is regarded as a particularly desirable option in the aerospace sector.

IN718 is a nickel-based superalloy utilized in aerospace, maritime and chemical applications due to its exceptional corrosion resistance, high temperature tensile strength, fatigue, and creep. However, it has poor machinability, high hardness, and low heat conductivity. Therefore, IN718 components with complicated geometry have traditionally been difficult to fabricate. But because of its excellent weld ability, it is a fantastic material for high heat input fabrication methods. A net-shaped 3D object may be created from a digital model using the layer-by-layer metal fabrication technique known as additive manufacturing. Parts made from this work material i.e., superalloy have generated a lot of interest in LDED processing. The properties of the laser source, powder feed rate, and scan speed are the main process variables related to LDED. Pinkerton et al. [1] reviewed the development of the LDED modeling method and identified key factors including deposition speed, feed rate laser power, and beam diameter. It has been discovered that the beam diameter has a significant impact on the deposit width and powder capture efficiency. Kiani et al. [2] successfully developed a process parameter for the DED of AlSi10Mg 3D blocks and single-track thin walls. It was demonstrated that even with the identical processing settings, single-track deposition's capacity to scale to 3D blocks or thin walls constrained. To make a model that can predict how different DED process parameters will affect the multilayer geometrical features (flatness, area, and width).

Guo et al. [3] integrated the central composite matrix approach and analysis of variance method. The response surface method was also used to figure out the best process parameters for a multilayer clad. With the use of central composite matrix and analysis of variance, Lian et al. [4] developed a prediction model to examine the impact of crucial process variables (overlapping rate, gas flow rate, scan speed, and laser power) on the geometrical properties (flatness and width) of the clad of M2 tool steel. This result is in good agreement with what other studies on different materials have found [5-7]. In contrast, a combination of scan speed and lower laser power, additionally, a larger overlap rate led to less dilution. Finally, the response surface method approach was used to determine the best process parameters for achieving maximum deposit width with low dilution and deposition layer flatness. Experimental design techniques have also played a prominent role during analysis of processes behaviors [8-9]. In reported literature authors rarely found optimal study of geometrical characteristic of LDED of IN718. This study examines a unique process window involving the deposition of single-track IN718 alloy specimens at a high feed rate. Single-track being the basic building unit in LDED, investigations on single tracks are carried out to evaluate the optimum values of process parameters using desirability approach.

Materials and Methods

The deposition system consisted of a 2-kW Ytterbium fiber laser (wavelength 1080 nm) capable of operating in continuous wave mode. The laser setup also includes a delivery mechanism that utilizes fibers with a 50 μm core diameter. The system has a collimator of 160 mm focal length facilitating laser beam of 20 mm and it is focused with refractive optics (material: Quartz) of 200 mm focal length. The focusing optics is the part of the co-axial nozzle used for deposition. It consists of 5 axis manipulators, gas analyzers, dual powder feeder, and a coaxial nozzle in a glove box, and computer numerical controller. The deposition head, which was supported by an overhead gantry system, was made up of the laser system, the powder feeder, and the gas feeder systems. For the purpose of insulating the melt pool from oxidation and eventual contamination, argon was utilized as both a carrier and shielding gas. The substrate plate on which deposition procedure was performed was supported by a fixed workstation. The coaxial nozzle and other equipment characteristics utilized for the deposit of single track LDED deposits are shown in figure 1.

Gas atomized IN718 powder is used for the experimentation. According to ASTM F3055-14a, table 1 lists the nominal chemical components of IN718 alloy powder which is mostly made up of Ni and Cr. Table 2 gives the process parameters employed in the current investigation that were determined from preliminary iterations. In this specific process, some parameters, including the laser power (LP), the powder feed rate (PFR), and the deposition speed (V) are varied across three separate levels while other process parameters are maintained at their original settings. The range of laser power is 800 - 1200 (W), powder feed rate (6 - 9) g/min, and scan speed (0.4 - 0.8) m/min. The laser spot diameter 2.0 mm is used for deposition. The gas flow rate 6 - 8 liters per minute are used. The track deposition is processed over a solid stainless steel 316 L substrate; twenty-seven single tracks are deposited at different process parameters as shown in figure 1.

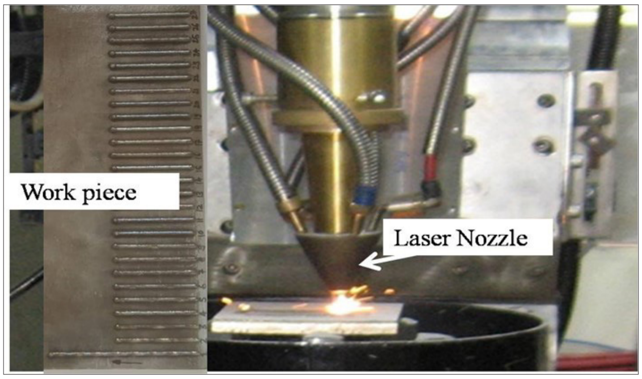

Figure 1: LDED coaxial nozzle used for deposition.

Table 1: IN718 alloy powder's chemical composition.

Element	Weight (%)
Ni	50 - 55
Cr	17 - 21
Nb	4.75 - 5.5
Mo	2.8 - 3.3
Ti	0.65 - 1.15
Al	0.2 - 0.8
Co	≤ 1
Cu	≤ 0.3
C	≤ 0.08
B	≤ 0.006
Fe	Balance

The height of the track is measured with a digital vernier caliper at a minimum of five distinct locations, and the average value of the track height is provided in table 3. In this investigation, the processing parameters for geometry were evaluated, and it was found that they provided the best results. In present work the radiation and convection losses are neglected while the heat transfer occurred due to conduction mode. All the laser power is used to melt the powder and deposit it on the substrate with maximum powder catchment

Table 2: Process parameters with three levels.

Process parameter	Units	Levels		
		1	2	3
Laser power (LP)	W	800	1000	1200
Scan speed (SS)	m/min	0.4	0.6	0.8
Powder feed rate (PFR)	g/min	6	9	12

Table 3: Experimental matrix and measured response.

Sr. No.	Input parameters			Track height values	
	LP	SS	PFR	Experimental	SNR
1	800	0.4	6	0.4517	-6.903
2	800	0.4	9	0.9040	-0.760
3	800	0.4	12	0.9017	-0.775
4	800	0.6	6	0.3733	-8.559
5	800	0.6	9	0.7133	-2.935
6	800	0.6	12	0.6750	-3.414
7	800	0.8	6	0.3367	-9.455
8	800	0.8	9	0.5233	-5.625
9	800	0.8	12	0.4233	-7.467
10	1000	0.4	6	0.8233	-1.689
11	1000	0.4	9	0.9033	-0.768
12	1000	0.4	12	0.9030	-0.773
13	1000	0.6	6	0.5650	-4.959
14	1000	0.6	9	0.8033	-1.902
15	1000	0.6	12	0.6683	-3.501
16	1000	0.8	6	0.5067	-5.905
17	1000	0.8	9	0.6783	-3.372
18	1000	0.8	12	0.4000	-7.959
19	1200	0.4	6	0.8633	-1.277
20	1200	0.4	9	0.6950	-3.160
21	1200	0.4	12	0.9050	-0.867
22	1200	0.6	6	0.6933	-3.182
23	1200	0.6	9	0.6333	-3.968
24	1200	0.6	12	0.6767	-3.392
25	1200	0.8	6	0.4867	-6.255
26	1200	0.8	9	0.4433	-7.066
27	1200	0.8	12	0.4883	-6.226

efficiency. Flow rate of powder made constant. The substrate material is isotropic and homogenous, so it is assumed temperature independent. No contamination or oxidations were taken place due to argon that acts as a shielding gas. The unidirectional scan pattern has been used to deposit the material. The melting of the powder takes place just below the materials' melting point after deposition a very higher cooling rate typically ranges from 10^3 to 10^5 °C/s occurs in the DED process [10].

Results and Discussion

According to the findings that are presented in table 3, the range of possible values for the track height was measured from 0.3360 mm to 0.9633 mm. Table 4 represents the result of analysis of variance at 95% confidence interval [11-12]. Linear parameters have the greatest influence as compared to interaction or square effect of parameters on track height. Scan speed found significant followed by powder feed rate and laser power on track height. The second order regression model is also developed between track height and input variables at 95% confidence level as shown in Eq. (1). Obtained S-value = 0.09252 and R-square = 86.7 values represent the goodness of developed model. The effect plot shown in figure 2 illustrates how each process parameter affects the measured dimension. From figure 2 laser power increases up to mid-level track height increases then it slightly decreases due to high laser power. As scan speed increase track height decrease. Maximum track height found at lower scan speed. At mid value of powder feed rate track height is high then it is reduced at high rate of powder feed. Further, experimental values of track height corresponding to design orthogonal run are used for the optimization. The desirability function approach is used for deciding the optimum value of process parameters and track height. The desirability value is 1 and optimum value of track height is 0.9121 corresponding to laser power (1200), scan speed (0.40) and powder feed rate (12) as shown in figure 3. Optimal value of track height is compared with experimental value at same level. At optimum parameter level an improvement of 0.78% is found in track height. Further, photographs of the track height at non optimum and optimum process parameters are shown by figure 4a and 4b.

Table 4: Analysis of variance result of track height.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.814265	0.814265	0.090474	9.49	0
Linear	3	0.638228	0.638228	0.212743	22.32	0
Square	3	0.087723	0.087723	0.029241	3.07	0.056
Interaction	3	0.088314	0.088314	0.029438	3.09	0.055
Residual Error	17	0.162066	0.162066	0.009533	-	-
Total	26	0.976331	-	-	-	-
S = 0.09764; R-Sq = 83.4%; R-Sq (adj) = 74.6%						

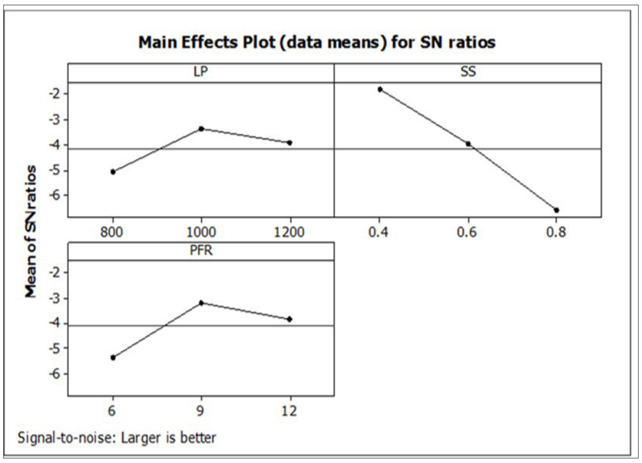

Figure 2: Effect of process parameters on track height.

$$TH = 0.76441 + 0.02898\ LP - 0.17806\ SS + 0.05398\ PFR - 0.0786\ LP * LP - 0.09137\ PFR * PFR - 0.06847\ LP * PFR - 0.05168\ SS * PFR \tag{1}$$

Conclusion

This study focused on the LDED process using an IN718 powder. As part of the ongoing investigation, the effects of processing variables including laser power, deposition rates, and feed rates are being examined. These variables are evaluated in a special window that allows for a high deposition rate. Analysis of variance is performed at 95% confidence level. This demonstrates that the primary factor determining the height of the deposit is the scan speed followed by powder feed rate and laser power. At optimum parameter level an improvement of 0.78% is found in track height.

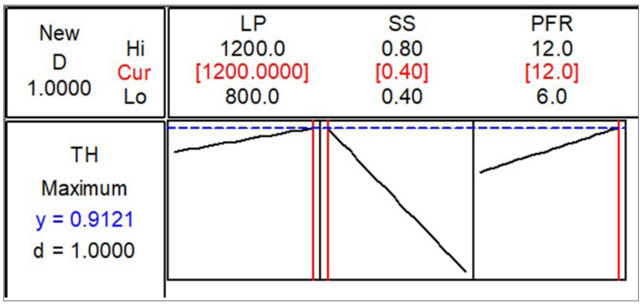

Figure 3: Optimum value of input parameters and response.

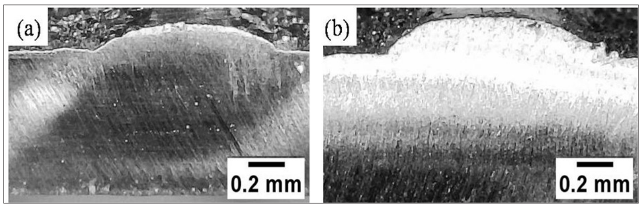

Figure 4: Photographs of track height at **(a)** non-optimum and **(b)** optimum level.

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Conflict of Interest

The authors declare that they have no known conflict of interests.

Credit Author Statement

Ajay K. Maurya: Conceptualization, Methodology, Formal analysis, Writing - original draft preparation; Amit K: Resources, Supervision; Surendra K. Saini: Optimization, Writing - review and editing; Christ P. Paul: Writing - review and editing. All the authors read and approved the manuscript.

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