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A Study on the Effects of the Deposition Path on Thermo-mechanical Characteristics for the Case of Gridur6 Deposited on a Thin AISI4140 Substrate Using an LMD Process

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The laser metal deposition (LMD) process is one of directed energy deposition (DED) processes. The deposited region is formed by repetition of melting and solidification of the feeding powder on the substrate and the previous layer for the case of the DED process. A typical cooling rate of the DED process lies in the range of 10^3-10^5 ℃/s. The rapid temperature change causes an excessive residual stress in the vicinity of the deposited region and a large deformation of the fabricated part. The distribution and the history of the temperature are greatly dependent on the deposition path, dwell time, interlayer time, etc. The objective of this paper is to investigate the effects of the deposition path on thermo-mechanical characteristics for the case of Gridur6 (G6) deposited on a thin AISI4140 substrate using the LMD process. In order to estimate temperature and residual stress distribution for different times, a three-dimensional non-linear finite element analysis (FEA) model is developed. The substrate is designed to be a cantilever beam structure. The deposited region with a rectangular cross-section is fabricated from the deposition of G6 powders on AISI4140 substrate. Characteristic dimensions of the deposited bead are obtained from the results of the experiments. The dwell time between successive paths and the inter-layer time between successive layers are estimated from the investigation of the movement of the deposition head. The laser is assumed to be a three-dimensional heat flux with the penetration depth. The distribution of the laser intensity in a plane is assumed as a Gaussian distribution. An equivalent heat loss model, including the forced convection by shielding gas and the radiation, and the heat sink model are applied to top surface of the specimen and the clamped region of the specimen by the fixture, respectively. The natural convection, the forced convection by the fume and the radiation are assigned to bottom and side surfaces. The clamped condition is applied to one end region of the specimen. Temperature dependent thermo-mechanical properties considering phase changes are estimated from JmatPro V12. The FEA was carried out by a commercial software SYSWELD V16. Through comparison of the results of experiments and those of FEAs from viewpoints of HAZ formation and temperature history, a proper FE model is obtained. Using the results of the FEAs, the influence of the deposition path on temperature, residual stress and displacement distributions for different times are investigated. In addition, the effects of the deposition path on the deformation and the warpage characteristics are examined. Finally, a suitable deposition path is proposed.

NOMENCLATURE

P = power
V = scan speed
D = beam diameter
c = laser beam shape factor
η = efficiency of laser beam

1. Introduction

The laser metal deposition process (LMD) process is one of the directed energy deposition (DED) processes. During the deposition process, metal powder is melted by a laser heat source almost instantly as it is being supplied. Similarly, solidification occurs rapidly. The high rate of temperature change results in residual stress and distortion of deposited part. The final thermo-mechanical properties in the vicinity of deposited part are highly dependent on thermal history. Thermal histories are highly dependent on deposition patterns.

The goal of this study is to investigate the effects of deposition strategy on post process residual stress and distortion characteristics in

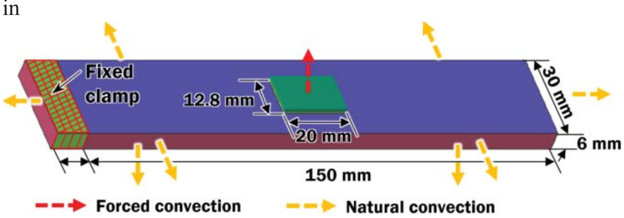


Fig. 1 Boundary conditions of FEA models

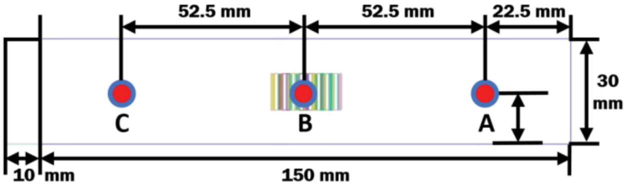
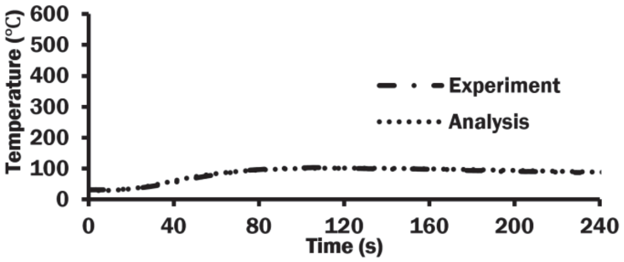


Fig. 2 Locations of the thermocouples

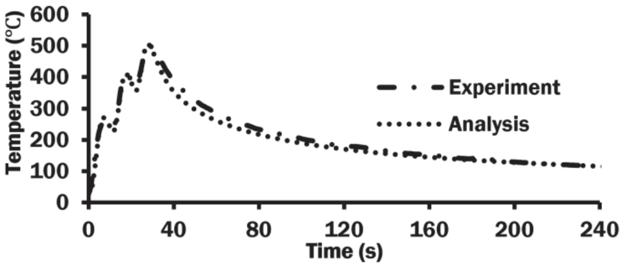
Table 1 Process parameters of deposition process

P (W)	V (mm/s)	D (mm)	c	η (%)
1400	23.333	2	0.5	44

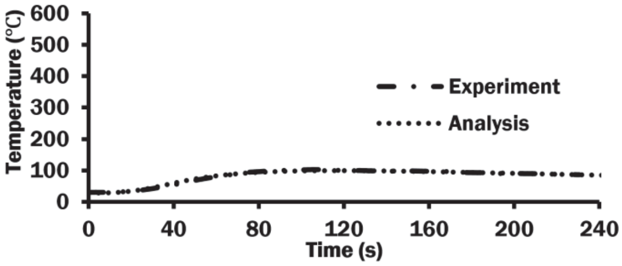
the vicinity of deposited bead using finite element analysis (FEA) methods. FEA models are experimentally calibrated. The developed models are used in order to study the effects of deposition path on residual stress distribution and displacement and distortion



(a) Thermal histories at point A



(b) Thermal histories at point B



(c) Thermal histories at point C

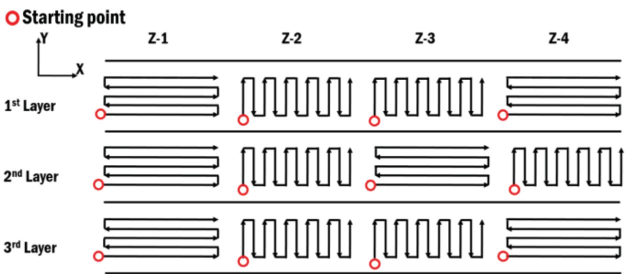
Fig. 3 Comparison of thermal histories between experiment and analysis
characteristics of deposited bead.

2. Thermo-Mechanical Analysis

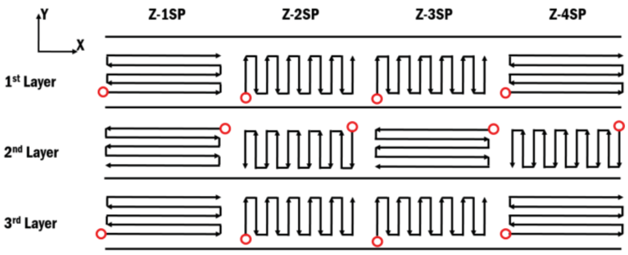
FEA models were developed in order to analyze deposition of G6 powder over AISI4140 cantilever beam structure substrate. Boundary conditions of FEA models are shown in Fig 1. The clamp is applied on one side of the substrate. Heat loss due to convection was considered from all sides. The conduction heat losses are applied on clamping region. Table 1 shows process parameters of deposition process.

Thermal histories were obtained by attaching thermo-couples to the bottom of the specimen during the experiment. The locations of thermo-couples are shown in Fig 2. Point A is primarily affected by convection heat losses. Point B shows effects of conduction heat transfer inside the specimen. Heat loss due to conduction to the clamping fixture is estimated through the data from thermo-couple at point C. Fig. 3 shows comparison of the results of experiment and analysis at points A, B, C.

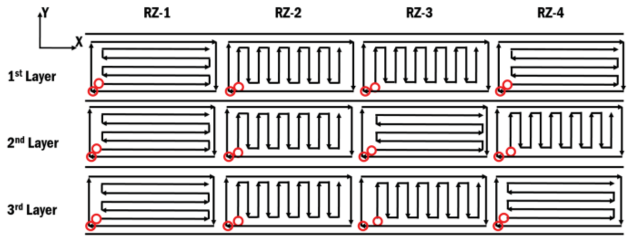
The data from the experiment is used to calibrate FEA models. The calibrated models are used to investigate the effects of deposition patterns on thermo-mechanical characteristics of G6 powder deposited on AISI4140 substrate. Deposition strategies are shown on Fig 4. Total of 16 strategies are selected for the analysis. All strategies are based on zigzag deposition pattern.



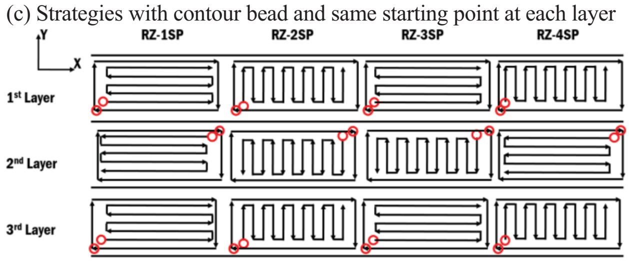
(a) Zigzag strategies with same starting points



(b) Zigzag strategies with different starting point at each layer



(c) Strategies with contour bead and same starting point at each layer



(d) Strategies with contour bead and different starting point at each layer

Fig. 4 Deposition strategies

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