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Experimental Study on Deformation Behavior of Cantilever Structure with G6 Deposited Region by a DED Process Through in-situ Measurement

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The rapid heating and the rapid cooling (RHRC) phenomenon occurs in the vicinity of the deposited region when the directed energy deposition (DED) process is used to create the deposited bead on the substrate and the previous layer. The residual stress induced by the RHRC phenomenon during deposition causes excessive deformation and significant warpage of the fabricated part for the case of cantilever structure with a slender beam shape. Hence, in order to indirectly estimate the residual stress distribution in the deposited region, the interest in the in-situ measurement of the deformation in the vicinity of the deposited region is greatly increased. The goal of this research work is to experimentally investigate the deformation behavior of the cantilever structure with gridur6 (G6) deposited region by a DED process through in-situ measurement. The substrate with the cantilever structure is fabricated from machining of a Cr-Mo low alloy steel plate. The deposited region with multiple layers is created on the mid region of the substrate through the deposition of G6 powder using a DED process. The experimental set-up with the fixing end of the substrate and the holder of the measurement sensor is designed. IL-030 sensors are attached to bottom region of the experimental set-up to obtain the displacement history of the specimen in a real time. In order to obtain in-situ temperature histories at indicated locations, thermocouples are attached to the specimen. Comparing the displacement history with the temperature history, the influence of the temperature history on the deformation characteristics is investigated. The effects of the deposition strategy and the part thickness on the deformation behavior of the fabricated part are examined. From the results of the examination, proper deposition strategies to reduce the deformation of the cantilever structure are proposed. In addition, the influence of the thickness of the deposited region on deformation and thermal characteristics is discussed.

NOMENCLATURE

CH = channel of temperature measurement
D_L = deposited layers

1. Introduction

DED processes can easily create three-dimensional metallic structures on the metallic substrate.[1] RHRC phenomenon occurs in the vicinity of the deposited region when the DED process is used to create the deposited bead on the substrate and the previous layer. Due to the RHRC phenomenon, undesirable residual stress takes place in the vicinity of the deposited region. The residual stress induced by the RHRC phenomenon during deposition causes excessive deformation and significant warpage of the fabricated part for the case of cantilever structure with a slender beam shape. Hence, in order to indirectly estimate the residual stress distribution in the deposited region, the interest in the in-situ measurement of the deformation in the vicinity of the deposited region is greatly increased. [2,3] The goal of this research work is to experimentally investigate the deformation behavior of the cantilever structure with gridur6 (G6) deposited region by a DED process through in-situ measurement.

The experimental set-up for the deformation behavior of the cantilever structure is shown in Fig. 1. The substrate with the cantilever structure is fabricated from the machining of a Cr-Mo low alloy steel plate. The deposited region with multiple layers is created on the mid-region of the substrate through the deposition of G6 powder using a DED process. The experimental set-up with the fixing end of the substrate and the holder of the measurement sensors is designed. IL-030 sensors are attached to bottom region of the experimental set-up to obtain the displacement history of the specimen in a real time. In order to obtain in-situ temperature histories at indicated locations, thermocouples are attached.

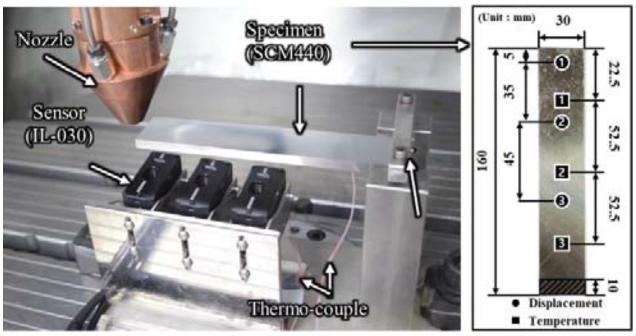

Fig. 1 Experimental set-up for the deformation behavior of the cantilever structure

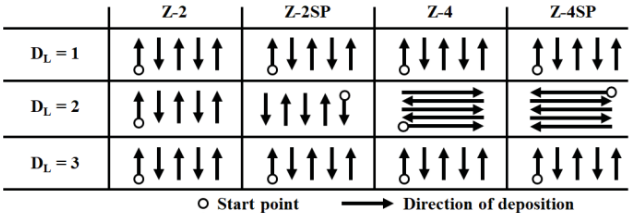

Fig. 2 Deposition strategies for experiments

The deposition strategy for experiments is shown in Fig. 2. Four strategies with zig-zag paths were selected depending on the start point of the deposition and the presence or absence of cross-deposition. A three-layer deposition experiment using all deposition strategies was performed and selected the strategy with the least deformation. The selected deposition strategy was applied to the layer thickness experiments, and the temperature change and displacement change according to the stacked layers were analyzed.

2. Results and discussions

2.1 Effects of deposition strategy

The temperature history of the three-layer experiment (Z-2SP) is shown in Fig. 3. Since there was no change in the temperature history and the maximum temperature according to the deposition strategy, only one result was shown. The temperature history measurement central point (CH2) rapidly rises and cools according to deposition, and the other points (CH1, CH3) are indirectly heated by conduction and cooled by convection and conduction. These temperature changes were compared with the deformation.

The displacement history relative to deposition strategies is shown in Fig. 4. The deformation increased with the rapid temperature increase in the temperature history and then decreased with cooling. In particular, it can be seen that the deformation rapidly decreases until the temperature of the deposition region and the surrounding region becomes similar, and then decreases slowly thereafter. Depending on the deposited layer, the case without cross-deposition showed lower deformation compared to the case proceeding with cross-deposition. In the Z-2SP path where the minimum deformation occurred, the maximum deformation during deposition was 0.51 mm, and the deformation after cooling was 0.04 mm. In the Z-4SP path where the maximum deformation occurred, the deformation during deposition was 0.63 mm and the deformation after cooling was 0.13 mm.

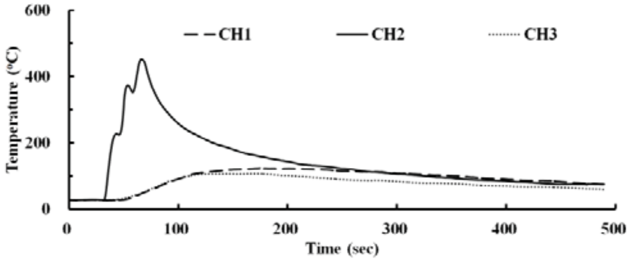

Fig. 3 The temperature history of the three-layer experiment (Z-2SP)

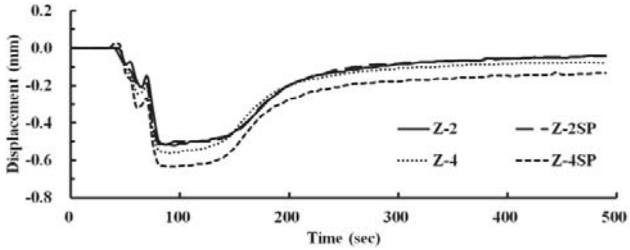

Fig. 4 Displacement history relative to deposition strategies

2.2 Effects of deposition thickness

The temperature history relative to the number of deposited layers is shown in Fig. 5. As the deposition layer increases, the maximum temperature increases non-linearly. This phenomenon is considered to be because when the deposition layer is increased, the temperature of the entire specimen increases due to heat conduction, and heat loss occurs more due to an increase in the temperature difference with the surroundings. In addition, the temperature increase of the entire specimen due to the conduction phenomenon decreases the cooling rate, and the decrease in the cooling rate affects the deformation.

The displacement history relative to the number of deposited layers is shown in Fig. 6. As the deposition layer increased, the maximum deformation increased, but the deformation increase during deposition was not large. When the deposited layer is low, the post-deposition strain is maintained and then decreased. However, when the deposition layer was high, the deformation after deposition

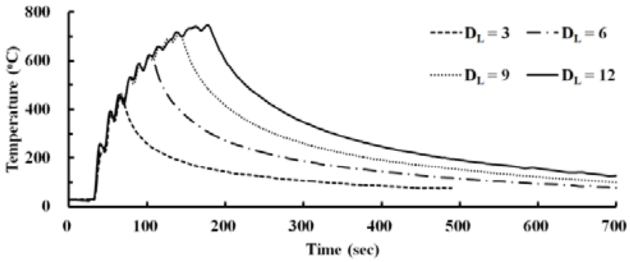

Fig. 5 Temperature history relative to the number of deposited layers

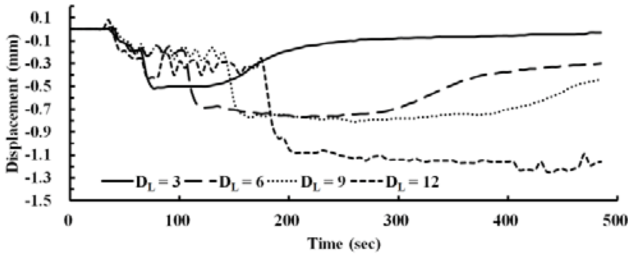

Fig. 6 Displacement history relative to the number of deposited layers

increased and then decreased. In all experiments relative to deposition strategies, a sharp decrease in deformation was observed near 200°C, and the deformation gradually decreased after 150°C. The deformation was maintained longer as the deposited layer increased due to the cooling rate decreasing with increasing the deposited layer.

3. Conclusions

This research work experimentally investigated the deformation behavior of the cantilever structure with gridur6 (G6) deposited region by a DED process through in-situ measurement. Temperature and strain were measured in real-time, and comparative analysis was performed according to deposition paths and stacked layers. The deformation rapidly decreases until the temperature of the deposition region and the surrounding region becomes similar, and then decreases slowly thereafter. When cross-deposition is not performed, less deformation is derived than when cross-deposition is performed, and in order to reduce the deformation of the cantilever structure, it is necessary to apply a deposition path without cross-deposition. As the deposition layer increased, the maximum deformation increased, but the deformation increase during deposition was not large. In all experiments relative to deposition strategies, a sharp decrease in deformation was observed near 200°C, and the deformation gradually decreased after 150°C. The deformation was maintained longer as the deposited layer increased due to the cooling rate decreasing with increasing the deposited layer.

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