Manufacturing Letters 20 (2019) 30–33

Contents lists available at ScienceDirect

Manufacturing Letters

journal homepage: www.elsevier.com/locate/mfglet

A support interface method for easy part removal in directed energy deposition

Jingchao Jiang [a,b], Fei Weng [b], Shiming Gao [b], Jonathan Stringer [a], Xun Xu [a], Ping Guo [c,*]

[a] Department of Mechanical Engineering, University of Auckland, Auckland, New Zealand
[b] Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong, China
[c] Department of Mechanical Engineering, Northwestern University, Evanston, IL, USA

ARTICLE INFO

Article history:
Received 28 November 2018
Received in revised form 9 April 2019
Accepted 18 April 2019
Available online 19 April 2019

Keywords:
Additive manufacturing
Directed energy deposition
Support interface

ABSTRACT

In traditional directed energy deposition (DED) processes, post-processing involving laser cutting or wire electrical discharge machining is necessary for removing printed parts from the substrate, which is time consuming and labor intensive. In this letter, a support interface method for DED is proposed for direct part removal without additional machining operations. A strut array is first printed as a sacrificial layer, upon which the actual part is then deposited. This letter demonstrates the method feasibility with a customized DED setup. It is expected that the proposed strategy will be beneficial in various DED processes to enhance process efficiency and automation.

1. Introduction

Additive manufacturing (AM), also known as 3D printing, enables the incremental fabrication of complex objects that cannot be achieved easily by conventional processes [1,2]. For metal-based AM techniques, research on directed energy deposition (DED) or direct metal deposition (DMD) is becoming increasingly popular [3] due to its many unique advantages, especially the capabilities to print gradient metal alloys [4] and to repair damaged parts [5]. The DED process eliminates the need of a powder bed in selective laser sintering/melting (SLS/SLM) by directly spraying metallic powders to the local melting pool created by an energy beam [6]. The melted particles then solidify to a solid part when the melting pool moves away. The energy beam usually follows preprogrammed trajectories in a layer-by-layer manner to print a designed 3D part.

After the part is printed in a DED process, it is, however, firmly attached to the substrate, which requires a following step for part removal by laser cutting or wire electrical discharge machining (wire EDM) [7], as shown in Fig. 1(a). This additional step not only increases the cost and labor, but also slows down the overall process efficiency due to the lengthy part removal procedure. To speed up the process and to avoid the additional cutting step, a support interface method is proposed in this letter for direct part removal in DED. Support interfaces (brims) have already been used in fused deposition modeling (FDM) for improving printing quality and part removal [8]. This method, however, has not been investigated in DED yet. This letter aims to demonstrate the feasibility of using a support interface in DED for easy part removal. The proposed strategy first prints an interfacial layer of strut array on the substrate before actual printing of the designed parts. The strut array serves as support structures for the part as well as a sacrificial layer that could be directly snapped for part removal. The detailed methodology and experimental verification and analysis are discussed as follows.

2. Methods

The support interface method is summarized in Fig. 1(b), where a strut array is designed as the support layer for the actual part as well as a sacrificial layer since it reduces the contact area between the substrate and part. Each strut is printed using continuous directed energy deposition with only the Z-direction motion [9]. After the strut array is printed, the actual part is then printed on top of the interface as a normal DED process.

In principle, the additional interfacial layer could achieve the goal of easy part removal without additional cutting processes. There are, however, several design considerations to be discussed. Firstly, the cross-section area of each strut should be as small as possible to reduce the contact area and interfacial strength. The achievable size is related to the powder nozzle diameter, laser beam energy, scan speed, powder feed rate, etc. The strut is preferably to have a circular cross-section area to achieve the minimal

* Corresponding author.
E-mail address: ping.guo@northwestern.edu (P. Guo).

https://doi.org/10.1016/j.mfglet.2019.04.002
2213-8463/

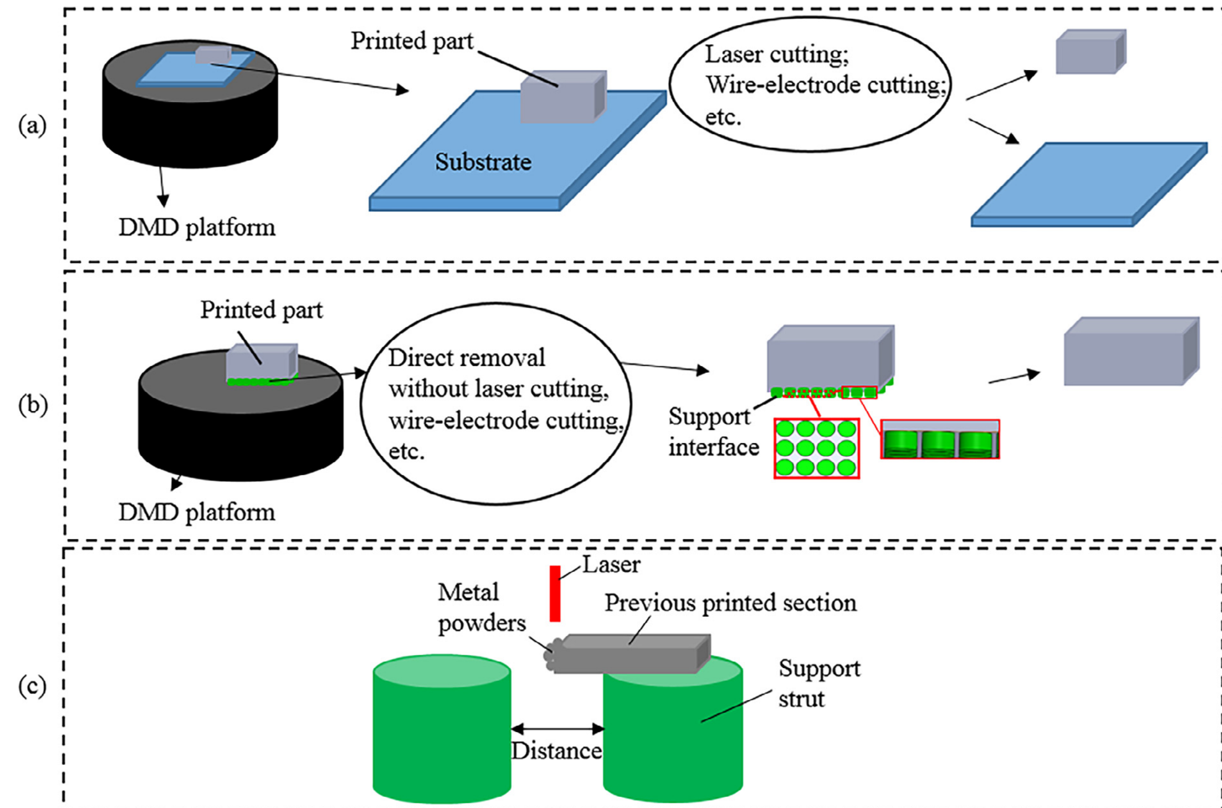

Fig. 1. (a) Conventional process of removing printed parts; (b) schematic of proposed support interface method and (c) illustration of printable distance.

bending strength. Based on the specifications of our in-house built machine, the optimized results reached a minimal diameter of 1.2 mm for each strut.

Secondly, the spacing of strut patterns determines the connecting strength between the interface and part, which is also limited by the maximal printable distance between two struts. Due to the layer-by-layer printing in DED, the printing of first layer is difficult considering the unsupported areas between two struts. We have previously shown that if the distance between two struts is small enough, an overhanging structure can be successfully printed [10]. As can be seen from Fig. 1(c), the newly melted powders will be merged into the previous printed section if the cantilever structure can hold its own weight, which is characterized by the maximal printable distance. This distance can be experimentally tested and integrated into the support strut design process. In our experiment, the distance between two struts was set to 1.6 mm, while the strut height was set at 2 mm to strike a balance between the material usage and connecting strength.

In addition, the substrate does not need to be unmounted and remounted for each print since the printed parts can be removed from the substrate directly. The substrate then can be re-used for the next part, as a new support interface will be redeposited on the substrate, which can potentially facilitate the automation of future DED processes.

3. Experiments

An in-house built DED machine setup was used in this study as shown in Fig. 2. The setup is mainly comprised of the powder feeder, laser system, control system, cooling system, and working chamber. The laser source is a 500 W multi-mode continuous-wave infrared laser with 1070 nm wavelength (YLR-500-MM-AC-Y14, *IPG Photonics*). The cladding head, 6-DOF Stewart platform (*Physik Instrumente*), and a CMOS camera are housed in the working chamber (Fig. 2(b)). During the process, powders are fed into the molten pool through a ring nozzle (*Fraunhofer ILT*) from the powder feeder (GPV PF2/2, *GTV Thermal Spray*). Nitrogen gas with purity of 99.999% is used as both the powder carrier gas and nozzle cooling gas with flow rates set at 3.0 L/min and 10 L/min, respectively. The laser focal spot is around 300 μm, while the powder stream focal diameter is 500 μm. 316L stainless steel powders (20–50 μm, *SANDVIK*) are used as the building material.

The individual strut was printed by continuously moving the Z axis, while keeping the X and Y axes stationary [9]. The optimized process parameters were chosen using a laser power of 67.5 W, Z-direction scan speed of 0.6 mm/s, and powder feed rate of 2.29 g/min. The achieved minimal strut diameter was 1.2 mm. Fig. 3(b) shows the design and dimensions of the support interface and a rectangular test part. Six struts were used as the interface for this part. The diameter of each strut was 1.2 mm with a height of 2 mm.

The process parameters for printing the rectangular part were set using a laser power of 83.9 W, scan speed of 0.3 mm/s, powder feed rate of 1.41 g/min and layer thickness of 0.1 mm for the first layer. For the rest of layers, the scan speed was changed to 2 mm/s while the other parameters were kept constant. Surface morphology of the substrate after part removal was measured using a high-resolution optical microscope (RH-2000, *Hirox*).

4. Results and discussion

Fig. 3(a) shows the printed part before being removed from the substrate. The whole printed part along with the interface was easily removed from the substrate by simple snapping. As can be observed from Fig. 3(c), the bottom surface of struts forms a convex shape and only connects to the substrate at the lowest region.

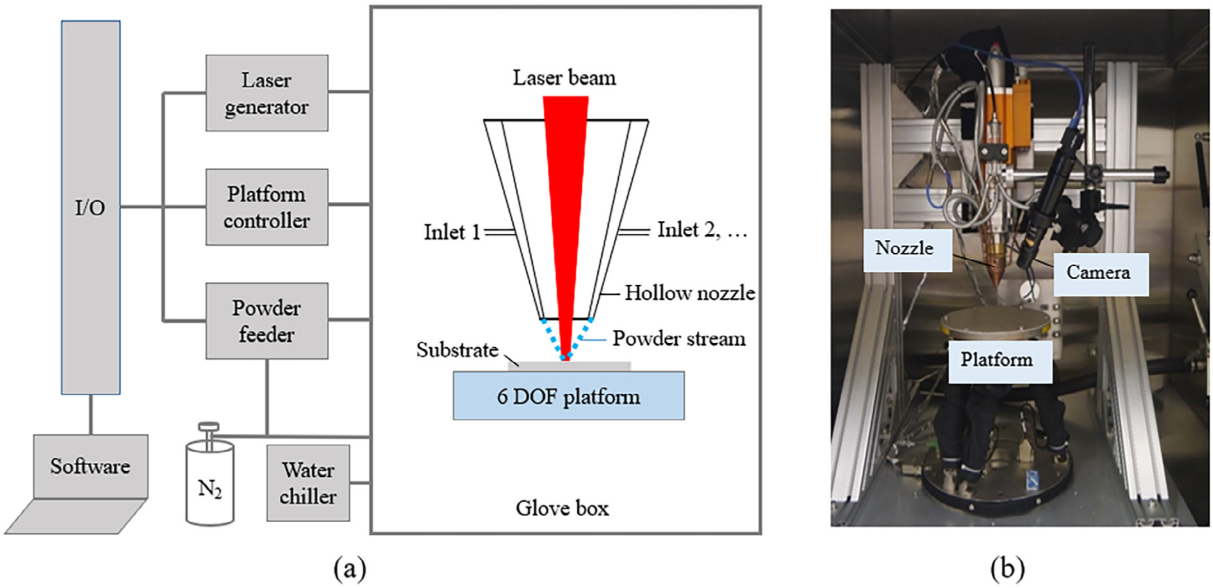

Fig. 2. (a) Schematic of the DED equipment and (b) printer assembly in the working chamber.

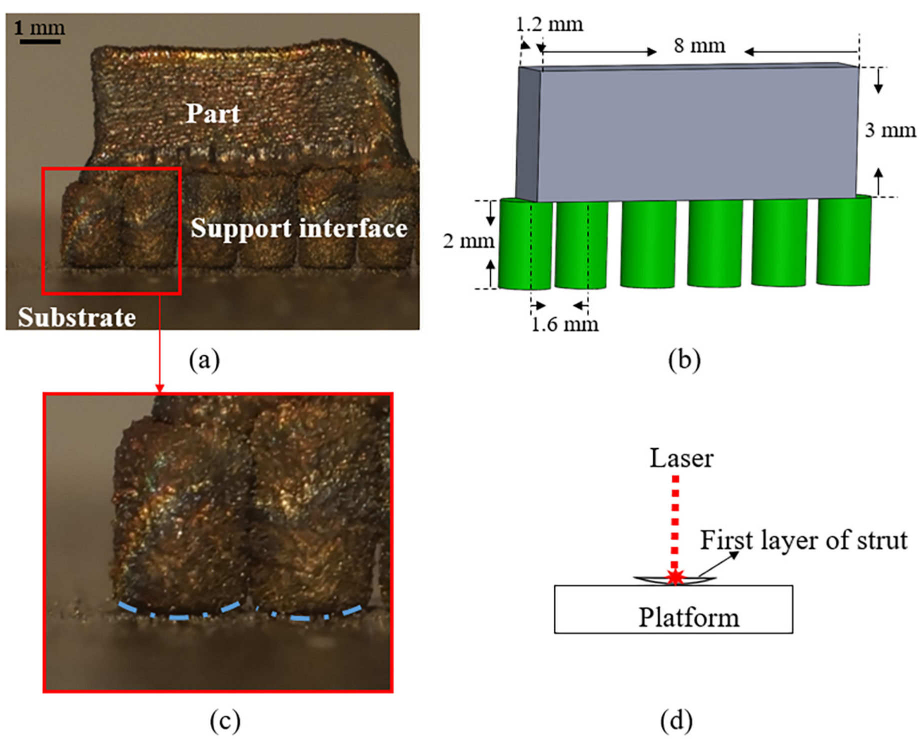

Fig. 3. (a) Printed part; (b) design and dimensions of the support interface and test part; (c) close view of the connection between the struts and substrate; and (d) schematic of laser energy distribution.

When the platform moves only in the Z direction and the laser focus is at the strut center, the Gaussian distribution of laser energy makes the center temperature much higher than that at the peripheral. Since the heat dissipation is much more significant at the substrate, the strut-substrate connection will follow the Gaussian energy distribution to have the partial connection concentrated at the strut center, as illustrated in Fig. 3(d). This also contributes to the easy removal of struts.

Surface quality of the platform substrate after part removal is measured using a microscope and shown in Fig. 4. The enlarged view of surface morphology of the remaining strut base is illustrated in Fig. 4(b). Fig. 4(c) shows one of the micro-surface analysis photos with the remainder height measured at 288.3 μm. The substrate can be re-used for the fabrication of following parts by building the strut arrays at the same locations. To test the reusability of the platform substrate, single strut was fabricated at the same position where the previous strut was removed. The fabrication and removal processes were repeated 20 times. The step heights of the remaining strut base after the repeated processes were on average 164.9 μm.

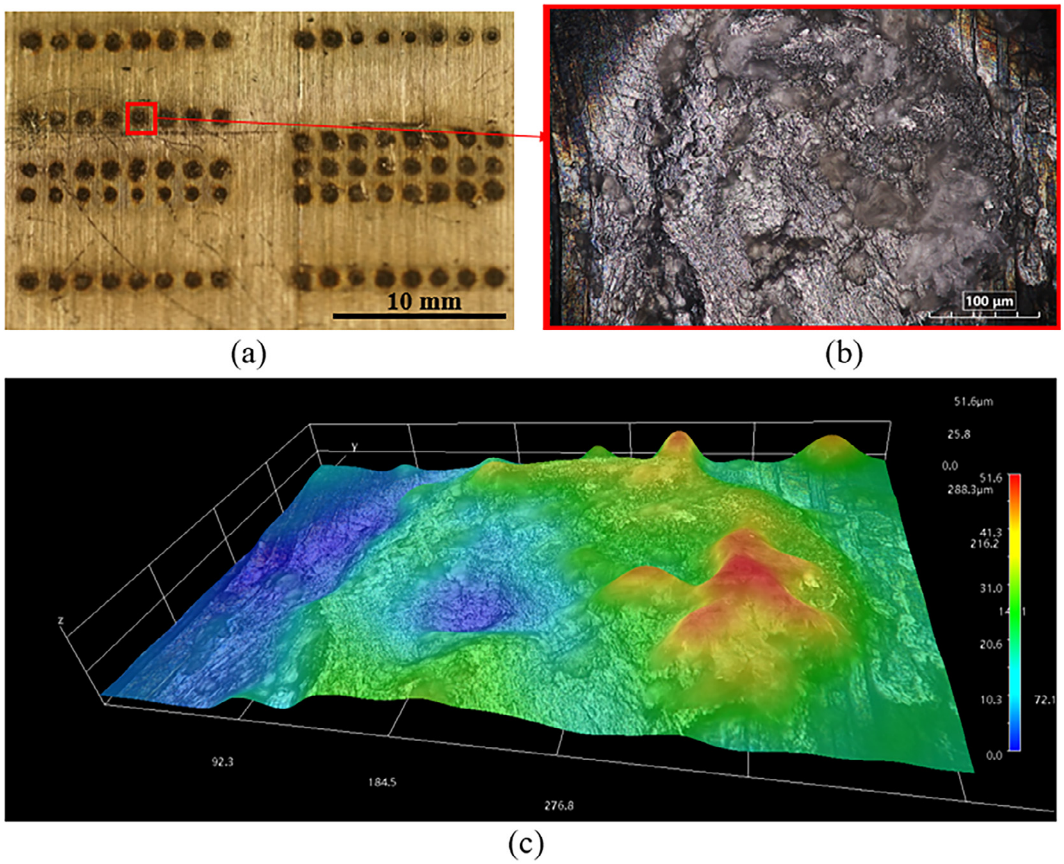

Fig. 4. Photos of (a) the substrate surface after part removal, (b) the enlarged view of the remaining strut base and (c) micro-surface analysis.

5. Conclusions

In this letter, a support interface method is proposed for easy part removal without laser cutting/wire-EDM in DED. A strut array pattern is utilized as a sacrificial layer as well as a support interface for the actual printed part. The design consideration and process parameters have been discussed in this letter. A rectangular part with the support interface has been fabricated as an example to demonstrate the feasibility. The support interface could largely reduce the contact area between the substrate and printed part, thus minimizing the contact strength for part removal without additional cutting operations. In addition, the proposed method could potentially facilitate the automation of various DED processes to include a part ejection system in the chamber to automatically break and collect parts for continuous printing.

Declaration of interests

None.

Acknowledgments

This research is funded by Global Scholarship for Research Excellence and Academic Equipment Grant from the Chinese University of Hong Kong, and the start-up fund provided by McCormick School of Engineering, Northwestern University.

References

[1] Liu J, To AC. Deposition path planning-integrated structural topology optimization for 3D additive manufacturing subject to self-support constraint. Comput Aided Des 2017;91:27–45. https://doi.org/10.1016/J.CAD.2017.05.003.

[2] Jiang J, Xu X, Stringer J. Support structures for additive manufacturing: a review. J Manuf Mater Process 2018;2:64. https://doi.org/10.3390/JMMP2040064.

[3] Spranger F, Graf B, Schuch M, Hilgenberg K, Rethmeier M. Build-up strategies for additive manufacturing of three dimensional Ti-6Al-4V-parts produced by laser metal deposition. J Laser Appl 2018;30:. https://doi.org/10.2351/1.4997852022001.

[4] Schneider-Maunoury C, Weiss L, Perroud O, Joguet D, Boisselier D, Laheurte P. An application of differential injection to fabricate functionally graded Ti-Nb alloys using DED-CLAD® process. J Mater Process Technol 2019;268:171–80. https://doi.org/10.1016/j.jmatprotec.2019.01.018.

[5] Zhang X, Li W, Liou F. Damage detection and reconstruction algorithm in repairing compressor blade by direct metal deposition. Int J Adv Manuf Technol 2018;95:2393–404. https://doi.org/10.1007/s00170-017-1413-8.

[6] Thompson SM, Bian L, Shamsaei N, Yadollahi A. An overview of Direct Laser Deposition for additive manufacturing; Part I: transport phenomena, modeling and diagnostics. Addit Manuf 2015;8:36–62. https://doi.org/10.1016/J.ADDMA.2015.07.001.

[7] Hildreth OJ, Nassar AR, Chasse KR, Simpson TW. Dissolvable metal supports for 3D direct metal printing. 3D Print Addit Manuf 2016;3:90–7. https://doi.org/10.1089/3dp.2016.0013.

[8] Alafaghani A, Qattawi A, Ablat MA, Alafaghani A, Qattawi A, Ablat MA. Design consideration for additive manufacturing: fused deposition modelling. Open J Appl Sci 2017;07. https://doi.org/10.4236/OJAPPS.2017.76024.

[9] Weng F, Gao S, Jiang J, Wang J, Guo P. A novel strategy to fabricate thin 316L stainless steel rods by continuous directed energy deposition in Z direction. Addit Manuf 2019. https://doi.org/10.1016/J.ADDMA.2019.03.024.

[10] Jiang J, Stringer J, Xu X. Support optimization for flat features via path planning in additive manufacturing. 3D Print Addit Manuf 2018. https://doi.org/10.1089/3dp.2017.0124.