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Development of a Cyber-Physical System on Laser Additive Manufacturing

Xun-Yu Zhuo[1], Der-Min Tsay[1], Jau-Woei Perng[1], Bor-Jeng Lin[2], Guan-Shong Hwang[3,*], Chien-Chou Tseng[4]

[1]*Department of Mechanical and Electro-Mechanical Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan*
[2]*Department of Automation Engineering, National Formosa University, Yunlin 63201, Taiwan*
[3]*Department of Computer Science and Information Engineering, Nanhua University, Chiayi 62248, Taiwan*
[4]*Department of Mechanical Engineering, National Cheng Kung University, Tainan 70101, Taiwan*
*Corresponding author: gshwang@nhu.edu.tw

Abstract: To develop a cyber-physical system (CPS) utilized in the laser additive manufacturing (AM) machine center, this study analyzes the machining parameters applied in the processes of directed energy deposition (DED) and powder bed fusion (PBF), virtually simulates the results of laser cladding and melting manufacture, and establishes the manufacturing databases. The developed CPS can improve the simulation results and the real-time manufacturing processes by capturing the necessary machining signals from the installed sensors. Experiments conducted in this study will demonstrate the feasibility of the proposed CPS embedded in the laser AM machine on the cooperation between physical processes and feedback information in laser additive manufacturing techniques.

Keywords: cyber-physical system **(**CPS**),** laser additive manufacturing **(**AM**),** directed energy deposition **(**DED**)**, powder bed fusion **(**PBF**)**、lobe-cam reducer, shrouded centrifugal impeller.

1. Introduction

The cyber-physical system (CPS), initiated by the US National Science Foundation (NSF), aims at merging the gap between the cyber and physical spaces by utilizing the technologies of computing, control, and communication. Apparatus equipped with CPS could quickly react to the overall demands and achieve the functions of self-awareness, self-prediction, self-comparison, self-configure, self-maintenance, and self-organization [1]. The results obtained by the apparatus with CPS would be the key factors to reach the goals of intelligent manufacturing upheld in the era of industry 4.0.

Comparing to conventional approaches, processes of additive manufacturing (AM), which are based on the additive principle of fabricating production parts, obviously have the main advantages of much less limitation on complex geometries and more reduction on the overall building time [2]. According to the differences in manufacturing processes and material shapes, the processes of AM can be classified as stereolithography (SLA), powder bed fusion (PBF), fused deposition modeling (FDM), directed energy deposition (DED), sheet lamination, and binder jetting [3-5]. With the advantage of complex shape manufacturing ability, however, the processes of AM still have challenges in forming the workpieces with abrupt geometrical changes in their surface shapes. Because it would eventually yield a resulting part with unacceptable geometrical tolerances.

Considering the researches about the simulating problems of phase changes on metals deduced by laser effects, the most well-known numerical approach is the volume of fraction method [6-8]. To discuss the machining parameters affecting the processes of laser cladding, several works of research can be provided for references [9-13]. The early research on machining data detection, such as temperature, images of melting pool, laser power, etc., and methods of big-data analysis, this study can refer to Ref. [14-17].

To develop a CPS utilized in the laser AM machine center, this study analyzes the machining parameters applied in the processes of DED and PBF, virtually simulates the results of laser cladding and melting manufacture, and establishes the manufacturing databases. The developed CPS can improve the simulation results and the real-time manufacturing processes by capturing the necessary machining signals from the installed sensors. Experiments conducted in this study will demonstrate the feasibility of the proposed CPS embedded in the laser AM machine on the cooperation between physical processes and feedback information in laser additive manufacturing techniques. It is also expected that the developed laser AM machine with CPS could optimize the manufacturing process and add the value of domestic advanced manufacturing machines.

2. Analysis and Optimization of Manufacturing Parameters for laser AM

Considering the two important methods of AM, i.e., directed energy deposition (DED) and powder bed fusion (PBF) shown as Figs. 1-2 respectively, this study has conducted the analysis and optimization of machining parameters. Figures 3-4 demonstrate the simulating model of metal powder flow in DED and an experiment image with the density of metal powder flow, respectively. The obtained simulating and experimental fusion results for DED and PBF models are respectively shown in Figs. 5-6.

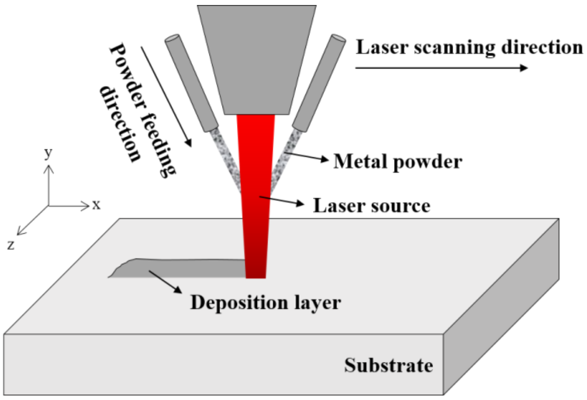

Fig.1. Model of directed energy deposition (DED)

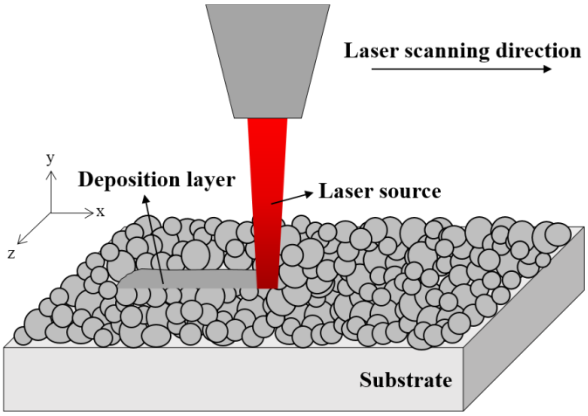

Fig.2. Model of powder bed fusion (PBF)

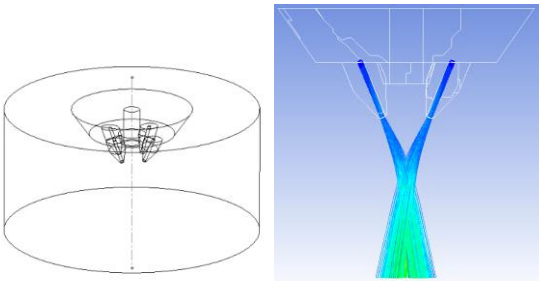

Fig.3. Simulating model of metal powder flow in DED

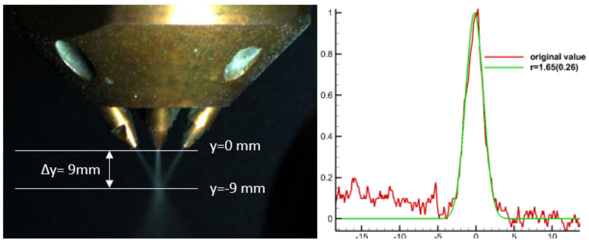

Fig.4. An experiment image with the density of metal powder flow in DED

Fig.5. Results of simulation and experiment for DED model

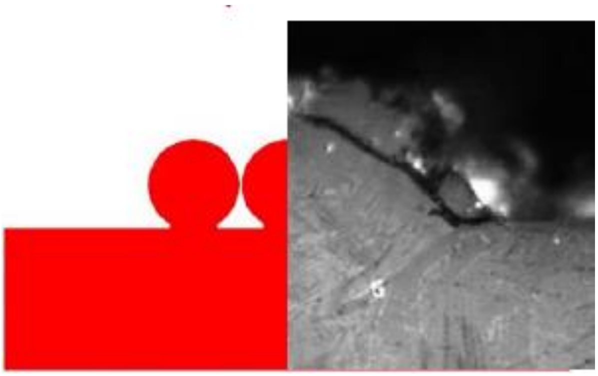

Fig.6. Results of simulation and experiment for PBF mode

3. Synchronous detected data processing and integration of CPS for laser AM machines

In this study, the theories of big data are used to construct the manufacturing cloud data center and process the machining parameters synchronously. Basing on the laser hybrid machining centers with embedded sensors, this study also has developed their human-machine interfaces to cooperate with these machine tools and sensors, as well as to analyze the machining big data capturing from all sensors. Figures 7-8 respectively demonstrate the developed monitor interfaces that show the captured machining data in the processes of laser cladding and PBF. The integration system of the human-machine interfaces is shown in Fig. 9, and a developed APP for the real-time alert mechanisms is presented in Fig. 10.

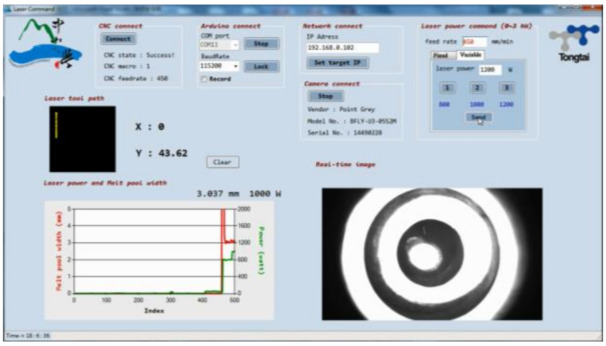

Fig.7. Monitor interface in laser cladding processes

Fig.8. Monitor interface in PBF processes

Fig.9. Integration system of the human-machine interfaces

Fig.10. APP for the real-time alert mechanisms

4. Experiments and verification of laser hybrid AM **processes**

This study utilizes a laser AM hybrid DED machine center (AMH-350) and two laser AM PBF machine centers (AMP-160, AMP25), which all are made by the Tongtai Machine & Tool Co., Ltd., to conduct the experiments and verification of laser hybrid AM processes. Figure 11 shows a lobe-cam reducer used as an example for implementing experiments and exhibitions. Figures 12-13 demonstrate the DED machining processes and an experimental result of the roller disc, a component in the lobe-cam reducer, after DED machining processes, respectively. Figures 14-16 respectively reveal the PBF machining processes and two experimental results: one is a compound of lobe-cams, which is also a component in the lobe-cam reducer, and the other is a shrouded centrifugal impeller after PBF machining processes.

Fig.11. A lobe-cam reducer

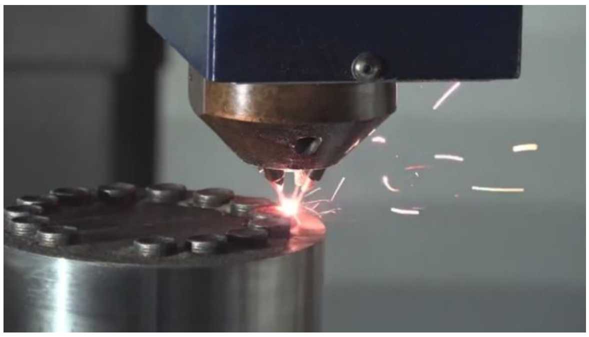

Fig.12. DED machining processes

Fig.13. A roller disc after DED machining processes

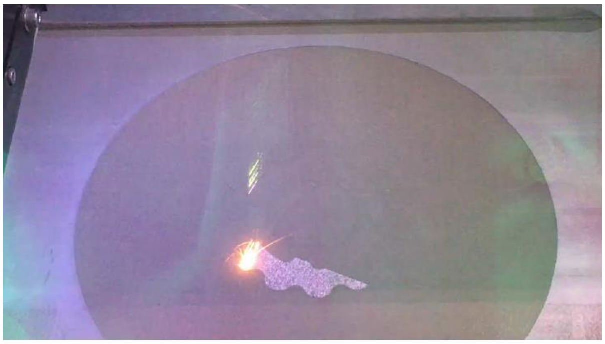

Fig.14. PBF machining processes

Fig.15. A compound of lobe-cams after PBF machining processes

Fig.16. A shrouded centrifugal impeller after PBF machining processes

5. Conclusions

This study has successfully developed and constructed the cyber-physical system that can be cooperated with the laser AM machine centers. The CPS embedded in the laser AM machines aims at DED and PBF machining processes and can provide the numerical models for engineering analysis and simulation before machining processes. It can also provide real-time monitor and alert functions by muti-machines internet. All the machining data recorded in the manufacturing processes will be uploaded to the set-up cloud data center for further investigation and application.

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