Optics and Laser Technology 98 (2018) 326–338

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Effects of process parameters on properties of porous foams formed by laser-assisted melting of steel powder (AISI P21)/foaming agent (ZrH_2) mixture

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ARTICLE INFO

Article history:
Received 1 May 2017
Received in revised form 19 June 2017
Accepted 14 August 2017

Keywords:
Metal powders
Direct energy deposition
Metal foam
Porosity

ABSTRACT

This paper describes the fabrication of lightweight metal foams using the directed energy deposition (DED) method. DED is a highly flexible additive manufacturing process wherein a metal powder mixed with a foaming agent is sprayed while a high-power laser is used to simultaneously melt the powder mixture into layered metal foams. In this study, a mixture of a carbon steel material (P21 powder) and a widely used foaming agent, ZrH_2, is used to fabricate metal foams. The effects of various process parameters, such as the laser power, powder feed rate, powder gas flow rate, and scanning speed, on the deposition characteristics (porosity, pore size, and pore distribution) are investigated. The synthesized metal foams exhibit porosities of 10% or lower, and a mean pore area of $7 \times 10^5\ \mu m^2$. It is observed that the degree of foaming increases in proportion to the laser power to a certain extent. The results also show that the powder feed rate has the most pronounced effect on the porosity of the metal foams, while the powder gas flow rate is the most suitable parameter for adjusting the size of the pores formed within the foams. Further, the scanning speed, which determines the amounts of energy and powder delivered, has a significant effect on the height of the deposits as well as on the properties of the foams. Thus, during the DED process for fabricating metal foams, the pore size and distribution and hence the foam porosity can be tailored by varying the individual process parameters. These findings should be useful as reference data for the design of processes for fabricating porous metallic materials that meet the specific requirements for specialized parts.

1. Introduction

Metal foams are porous materials that contain a large number of pores and are physically characterized by low weight and high sound insulation/absorption, crashworthiness, compression performance, and electromagnetic shielding. In addition, despite their lightweight nature, metal foams maintain their mechanical properties and show high machinability [1,2]. Thanks to these properties, metal foams are used widely in vehicles, airplanes, ships, building projects, power plants, batteries, and biomedicine [3,4].

Conventionally, metal foams have been manufactured by bubbling gas through molten alloys or by stirring a foaming agent into a molten alloy and controlling the pressure while cooling [5–8]. In the powder metallurgy method [9,10], a consolidated metal powder with a particulate foaming agent is heated into the mushy state; then, the foaming agent releases hydrogen and expands the material. In the space holder method [11–13], a ceramic mold from a wax or polymer-foam precursor is burned out, followed by pressure infiltration with a molten metal or metal powder slurry, which is finally sintered. Recently, lotus-type and gasar-type porous metals with many elongated pores and superior mechanical properties compared to those of conventional porous materials have been developed. The fabrication principle of such porous metals is as follows. The differences in solubility between the solid and liquid phases for hydrogen, nitrogen, and oxygen can cause gas bubbles during solidification. Elongated pores can be produced by unidirectional solidification using a water-cooled hearth as the bottom surface of the casting mold [14–16].

Recently, additive manufacturing (AM) of metal foams has been gaining attention owing to its suitability for multiproduct small-scale production [17–19]. In comparison to the conventional

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http://dx.doi.org/10.1016/j.optlastec.2017.08.008
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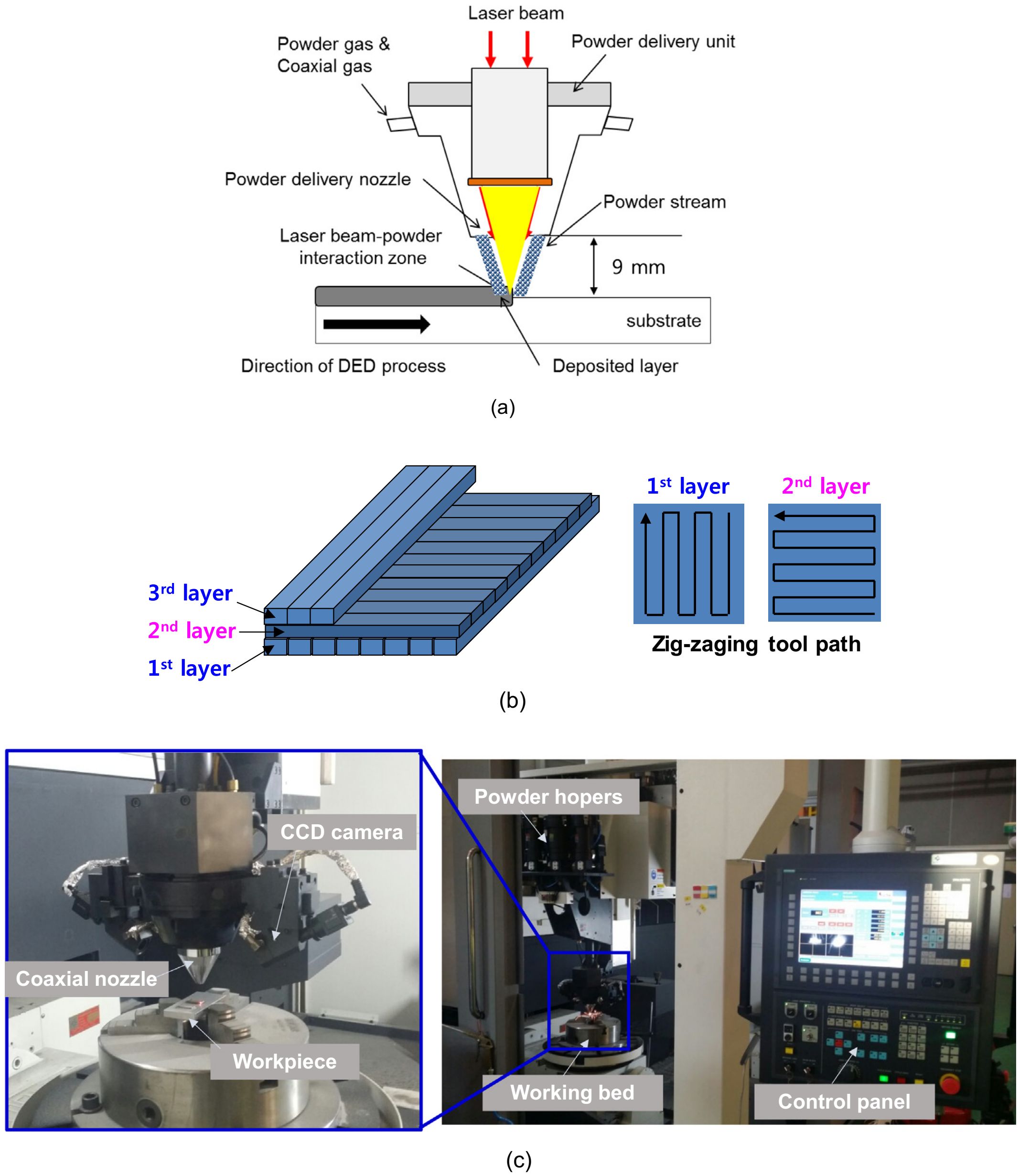

Fig. 1. (a) Schematic diagram of the laser metal deposition with the coaxial powder feeder, (b) DED machine, MX3, developed by Insstek Co., Ltd., and (c) tool path.

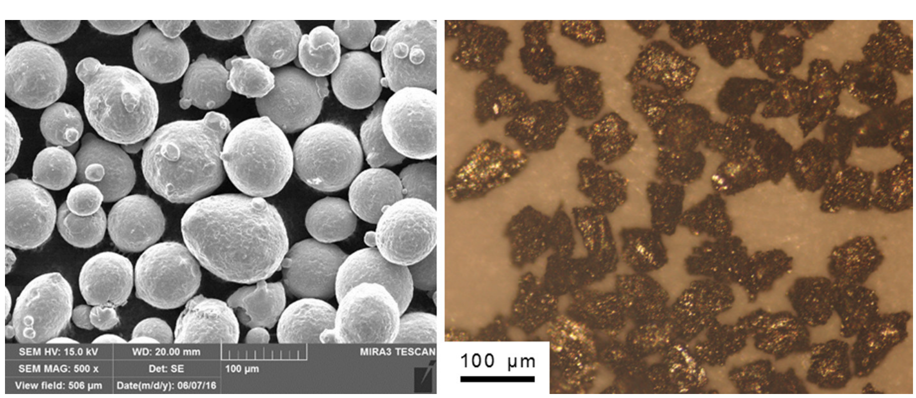

Fig. 2. Microscopy images of powder P21 (left) and foaming agent ZrH_2 (right).