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Ultrasonic Vibration-Assisted Laser Engineered Net Shaping of Inconel 718 Parts: A Feasibility Study

Fuda Ning[a], Yingbin Hu[a], Zhichao Liu[a,b], Weilong Cong[a,]*, Yuzhou Li[a,c], Xinlin Wang[a,b]

[a]*Department of Industrial, Manufacturing, and Systems Engineering, Texas Tech University, Lubbock, Texas, 79409, USA*
[b]*School of Mechanical Engineering, Dalian University of Technology, Dalian, Liaoning, 116024, China*
[c]*School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou, Guangdong, 510006, China*

Abstract

Laser engineered net shaping (LENS) has been applied as a key technology in direct manufacturing or repairing of high added-value metal parts. Recently, many investigations on LENS manufacturing of Inconel 718 parts have been conducted for potential applications of the aircraft turbine component manufacturing or repairing. However, fabrication defects such as pores, cavities, and heterogeneous microstructures always exist in the parts, affecting part qualities and mechanical properties. Therefore, it is crucial to LENS-manufacture Inconel 718 parts in a high-quality and high-efficiency way. Ultrasonic vibration has been introduced into various melting metal solidification processes for process improvements. However, there are no reported investigations on ultrasonic vibration-assisted (UV-A) LENS of Inconel 718 parts. In this paper, for the first time, UV-A LENS is proposed to reduce the fabrication defects of Inconel 718 parts. The experimental investigation is conducted to study the effects of ultrasonic vibration on microstructures and microhardness of the parts fabricated by UV-A LENS and LENS without ultrasonic vibration. The results showed that ultrasonic vibration could reduce the porosity, refine the microstructure with a smaller average grain size, and fragment the detrimental phase with a uniform distribution, thus enhancing the microhardness of the fabricated parts.

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Keywords: Laser engineered net shaping (LENS); Ultrasonic vibration; Inconel 718 alloy; Microstructures; Microhardness

* Corresponding author. Tel.: +1-806-834-6178; fax: +1-806-742-3411.
E-mail address: weilong.cong@ttu.edu

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1. Introduction

Laser additive manufacturing (LAM) has become a competitive method for direct fabrication of metal parts with complex structures, due to its advantages of high power density, excellent stability, and easy controllability [1, 2]. LAM technique is mainly divided into powder bed fusion mode and laser beam deposition mode. Compared with the powder bed fusion additive manufacturing such as selective laser melting (SLM), laser engineered net shaping (LENS), a direct laser beam deposition method, has the advantages of part repairing capability, high powder utilizing efficiency, high part building efficiency, etc. [3]. Thus, LENS has been applied as a key technology in fabricating and repairing functional and high added-value metal parts.

In all the applications of LENS process, a high-energy laser beam is used to create a molten pool on a substrate. In the meantime, the powders are continuously delivered into the molten pool by a flowing inert gas stream through the coaxial nozzles, leading to the increase of molten pool volume. Then the molten pool begins to solidify after the leaving of laser beam radiation. As the deposition head moves along the tracking paths, the first layer is deposited on the substrate. Afterwards, the head ascends one-layer thickness to a new position for the next layer deposition. Similar process will be repeated many times until a designed three-dimensional (3D) structure is built layer by layer.

One of the most relevant and important LENS applications focuses on the aircraft turbine components that are usually manufactured or repaired by nickel-based superalloys [4]. Since these superalloys are expensive and exhibit poor machinability, the utilization of LENS enables the reduction of wasted materials, resulting in the decrease of manufacturing costs and increase of productivity. Inconel 718, a type of precipitation hardening nickel-based superalloy, is the most attractive candidate to manufacture or repair the turbines due to its superior properties such as outstanding corrosion resistance, high fatigue strength, and excellent oxidation resistance at elevated temperatures [5]. Recently, LENS of Inconel 718 has attracted great interests in both industry and academia [6]. Many investigations have been conducted to evaluate the microstructures and mechanical properties of LENS-fabricated Inconel 718 parts [7-11]. However, fabrication defects such as pores, cavities, and heterogeneous microstructures are always induced, which are greatly detrimental to the part qualities and mechanical properties of the LENS-fabricated Inconel 718 parts. Therefore, LENS of Inconel 718 parts in a low-cost, high-efficiency, and high-quality way has become a crucial task.

Ultrasonic vibration has been effectively used in melting metal solidification processes such as casting, arc welding, etc. [12-20]. The direct input of ultrasonic vibration results in many nonlinear effects including acoustic streaming and cavitation. With these effects, ultrasonic vibration can help to reduce porosity, refine the microstructure, and increase the homogeneity of chemical contents. Although heat treatment has been utilized as a standardized post-processing method to additionally reduce the porosity and homogenize the microstructures of additively manufactured components, the influence of ultrasonic vibration on the LENS-fabricated parts prior to heat treatment process is desired to be studied. A previous investigation of the authors was carried out in ultrasonic vibration-assisted (UV-A) LENS manufacturing of 17-4 PH stainless steel parts [21]. The results evidenced the fabricated defects reduction induced by the ultrasonic vibration, leading to the improved tensile properties and microhardness. Similarly, finer microstructure and larger microhardness were also achieved in UV-A laser metal deposition of stainless steel 316L by Chen et al. [22]. In addition, Wu et al. [23] utilized ultrasonic vibration to refine microstructures of the zirconia coatings fabricated by laser cladding and modify the dilution characteristics to enhance the coating bonding strength. However, to the best of the authors' knowledge, there are no reported investigations on UV-A LENS of Inconel 718 parts.

In this paper, UV-A LENS process is utilized to fabricate Inconel 718 parts for the first time, with the purpose to reduce or even eliminate the defects of parts. The experimental investigation is conducted to study the effects of ultrasonic vibration on the part performance in both UV-A LENS and LENS without ultrasonic vibration. Microstructures including porosity, grain size, and featured phases are observed and microhardness of the as-deposited Inconel 718 parts is evaluated.

2. Experimental procedures

2.1. Powder material