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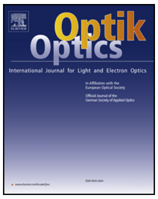

Original research article

Effect of ultrasonic peening on Microstructure and properties of laser rapid forming GH4169

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ABSTRACT

A new hybrid process of laser rapid forming (LRF) assisted by ultrasonic shot peening (LRF-USP) is proposed to improving the tensile and stress rupture properties at laser rapid forming. Based on mechanism analysis of laser rapid forming and ultrasonic shot peening, a processing model of LRF-USP is built. The special experimental equipments were designed and made. Forming experiments on the Nickel-based superalloy powders were conducted with the equipments, and the samples were analyzed by scanning electronic microscopy (SEM) and energy dispersive spectrometer (EDS). The result shows that theoretical model and experimental results are identical well with each other. During LRF-USP, USP can refine grain sizes and eliminate the residual tensile stress produced by LRF, forming a residual plastic field with compressive stresses.

1. Introduction

Laser rapid forming (LRF) is a newly developed and advanced manufacturing technology, which is based upon laser cladding and rapid prototyping technology, LRF can shape the complex structure parts (three-dimensional) directly without pre-processing and/or post-processing [1,2]. During LRF, using a laser beam with a certain energy fabricates parts by scanning melting thin layers of powders in the light of the CAD data. Thus, LRF technology indicates a high potential on the aspect of net-shape forming high property engineering parts, such as complex internal geometries and small volume parts for injection moulding and die casting [3–5].

Although LRF technique have improved considerably recently, there still exist many defects impeding the successful fabrication of high performance metallic parts with excellent microstructures and properties. The reason is that the solidification process of the small high temperature molten pool emerges high temperature gradient and high cooling rate during LRF [6,12]. The defects include delamination, distortion and porosity during this process, but a more important problem is residual tensile stress [7–9]. Since LRF is carried out layer by layer, the residual tensile stress may lead to the formation of microcrack and poor fatigue property [10]. The material properties and part geometry are degraded by the residual tensile stress severely in LRF. The high temperature anneal process is the most effective method of relieving residual stress in LRF. However, during the LRF process, the microcracks will generate due to residual tensile stress superposition before parts forming. Meanwhile, recrystallization takes place in the LRF samples treated by heating, the fine crystalline structure of the LRF samples will be damaged due to high temperature annealing [11]. In order to take best advantage of LRF parts, we present a novel method for improving performance of LRF parts.

In the present paper, we report an approach to the forming of Nickel-based superalloy that exploits LRF-USP to prepare high performance that subsequently defines the size of grain produced by a dendritic refinement process. This approach to forming thin

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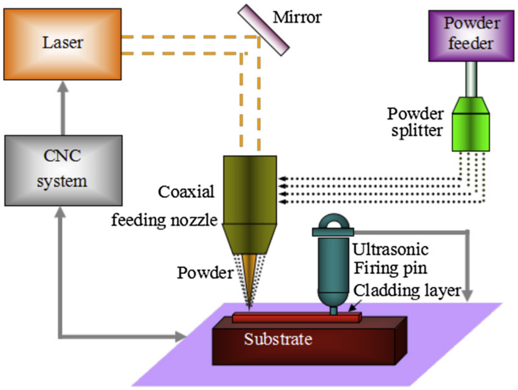

Fig. 1. Schematic diagram of LRF-USP equipment.

wall parts which have fine grain structure and reasonable distribution of residual compressive stress is understood from

previous studies [10,11], and it overcomes the limitation of high temperature annealing. We demonstrated this method with the manufacturing of GH4169 alloy.

2. Experimental details

In this work, the experiments were conducted on a LRF-USP equipment (Fig. 1),which includes a 4 kW Tru-Disk fiber laser, a PAT-AMP406 ultrasonic firing pin, a FARGO-2008 robot working table, a GTV powder feeding system with the powder mass stream in the range of 0.5–50 g/min and an coaxial nozzle with three-beam nozzle alignment. During the forming process, the powders are deposited on the stainless steel substrate by LRF, and ultrasonic firing pin treated the forming layer after LRF, the parts are manufactured after layers on the substrate with 200 mm × 100 mm × 4 mm. The dimension of the LRF-USP samples is designed as 200 mm × 50 mm × 4 mm. The chemical composition of GH4169 powders is shown in Table 1. The processing parameters are illustrated in Table 2.

The samples were machined to prepare the standard tensile and stress rupture testing bars, the shape and size are shown in Fig. 2. The micromorphology and microstructural characteristics were observed by scanning electron microscope (SEM). The model of SEM equipment is JSM-7100 F.

The relation of the fracture surface and the characteristics of microstructure and properties were characterized by scanning electron microscopy (SEM). Energy dispersive X-ray spectrometer(E- DS) was also adopted to analysis elements distribution. The model of DES is INCAx-sight.

3. Results and discussion

3.1. Typical microstructure of LRF-USP GH4169

Fig. 3 reveals microstructure and micro graph of the LRF and LRF-USP GH4169 alloy. For comparison, the microstructure of LRF sample is also included. As shown in Fig. 3a) and b), Adopting optical microscope to observe micrograph at lower magnifications, epitaxial growth features of columnar dendrites along the direction of deposition process layer by layer are displayed clearly during LRF, the reason is that a high laser energy density results in extremely high cooling rate. Other researchers have found similar results in LRF fabrication of 316 L and Inconel 718 [13,14]. The average dendrite spacing is about 8 μm (Fig. 3b) due to the rapid solidification process of LRF, which is an important reason for the superior mechanical properties and defect-free of LRF GH4169 samples. Recrystallization takes place in the LRF sample after USP treatment (Fig. 3c).As compared to the grain size obtained in the LRF, the average grain size after USP treatment is about 5 μm–7 μm, this grain size is relatively refinement. Furthermore, SEM photo of section is investigated the microstructure at a higher magnification, as shown in Fig. 3d. It is apparent that a group of grains are developed.

In Fig. 3c, the long and narrow grains are still clearly revealed to indicate the growth direction of the sample. Meanwhile, there are numerous deposits along direction of grain growth on the sample. In contrast, there was amount of uniformly distributed micron particles at the grain boundaries, the effect of particle reinforcement will be obvious and the intensity of the material reaches its maximum.

Table 1
The chemical composition of GH4169 powders (%).

C	Cr	Mo	Ni	Al	Nb	Ti	B	Si	Mn	P	S	Fe
0.03	18	3.0	52	0.5	4.8	0.81	0.006	0.35	0.35	0.015	0.015	ba1