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Surface additive manufacturing of Ni-based superalloy/H13 steel system by laser depositing: Microstructure, microhardness and flexural response

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ABSTRACT

The Ni-based superalloy was deposited on the AISI H13 tool steel by laser depositing as a surface additive manufacturing method. The microstructure and microhardness were analysed from the top surface of deposited layer to base metal. And the composition and constituent phases of Ni-based deposited layer were characterized. Furthermore, considering the anisotropy along three orthogonal directions of the system (Ni-based superalloy/H13 steel), the three-points bending test combined with fracture analysis was performed to evaluate the flexural behavior of the system. The results suggest that laser deposited Ni-based superalloy layer has interdendritic eutectic structures and the finely intermixed dendrites with directionality. Corresponding to the order of the deposited layer, transition zone, heat affected zone and the base metal, the average microhardness decreases gradually, which shows a gradient distribution. Moreover, the flexural response of the system is influenced by the type of applied load which determines the stress state of the deposited layer. The flexural capacity of the system can be maximized when the deposited layer is subjected to pure compressive stress. And the flexural ductility of the system is weakened when the tensile stress exists in the deposited layer.

1. Introduction

In the die and mold manufacturing industry, due to combination of high softening resistance and excellent toughness, the Cr-Mo-V hot-working die steels (such as H13 steel) is widely used for making dies, extrusion mandrels, plastic molds, cores, die holder blocks and hot-working punches [1] Based on several related research reports [2–8] and our previous investigation [9], hot-working dies are subjected to severe static or cyclic thermal-mechanical loads during hot forming processes, and local failures (wear, fracture and plastic deformation) at prime locations are important reasons to drastically reduce the service life of the dies. Thus, the local mechanical properties of hot-working dies need to be improved at room and elevated temperature.

As a surface additive manufacturing method, laser depositing (or cladding) is to melt the metallic materials (powders or wires) to form a deposited layer on the surface of a substrate after solidification, which can be used to modify the local properties of dies to further achieve the goals of saving materials and improving performance. Because of a desirable combination of high temperature strength and toughness, oxidation and creep resistance, and high temperature stability [10–12], the Ni-based superalloys have been widely applied for manufacturing the key parts in the field of aerospace, energy and chemical industry, etc. Such as the propulsion components of turbine engine blades, disks, casings and liners; the nuclear power reactors and the turbine engines for power generation [13]. Moreover, the Ni-based superalloys also can be used in the field of the surface strengthening or remanufacturing [14,15]. Prospectively, by laser depositing technology and using Ni-based superalloys as deposited material, it is meaningful to deposit one or more layers of Ni-based superalloys on the local working surfaces of hot-working dies or other important parts, and to further improve the service life of parts under high temperature and pressure load.

Generally, the mechanical properties (such as tensile strength, yield strength and impact toughness, etc.) of laser deposited layer are evaluated by standard tensile test and Charpy impact test [16–19]. However, the ability of the material to resist flexural deformation (i.e. flexural strength) is also one of the most important utility indicators of many mechanical parts [20]. When a mechanical part fabricated or repaired by additive manufacturing methods such as laser depositing is put in actual service conditions, it also acts as a common part to bear the flexural load in different directions. For instance, gas turbines work under high temperature after a long time of serving, rotor, blade and other parts will produce thermal bending, which can lead to gas turbines failure [21]. Under the action of flexural mechanical loads, the rollers, drill pipes, extrusion mandrels and hot-working punches will

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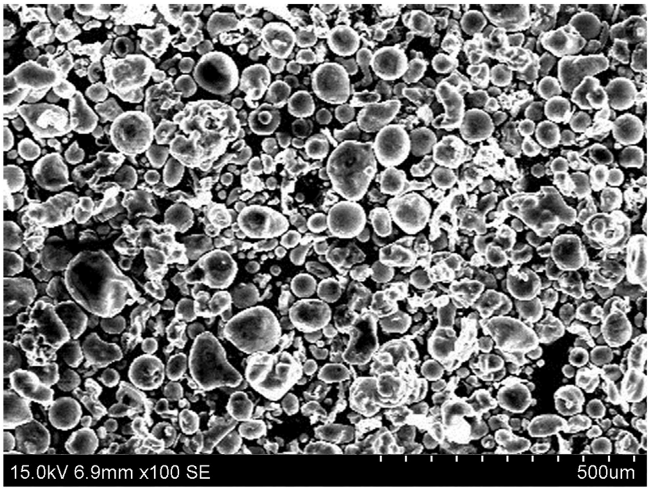

Fig. 1. SEM morphology of Ni-based superalloy powder.

Table 1
Chemical composition of Ni-based powder (wt%).

Elements	C	Ni	Cr	W	Ti	Nb	Al	Si	Co	Fe
Composition	0.09	48.6	21.5	2.75	0.95	1.45	0.05	0.02	0.03	Bal.

Table 2
Chemical composition of H13 steel (wt%).

Elements	C	Cr	Si	Mn	Mo	V	Fe
Composition	0.397	4.49	1.39	0.365	1.18	0.876	Bal.

present plastic instability in the actual service. Therefore, the flexural strength and flexural behavior of system (Ni-based superalloy/H13 steel) need to be evaluated through bending test methods.

At present, researches on the flexural performance of a system of Ni base superalloy and H13 steel are less reported. In this paper, Ni-based superalloy was deposited on H13 steel substrate by surface additive manufacturing method of laser depositing. The microstructure and microhardness were analysed from the top surface of deposited layer to base metal. And the composition and constituent phases of Ni-based deposited layer were characterized. The three-points bending test combined with fracture analysis was carried out to estimate the flexural strength and to evaluate the flexural behavior. The purpose of the present research is to investigate the microstructure of Ni-based superalloy/H13 steel system, and to evaluate its mechanical properties, especially the flexural response in different loading directions.

2. Materials and experiment

2.1. Sample preparation by direct laser depositing

Ni-based superalloy spherical powder prepared by plasma rotation electrode method was used as the deposition material. Via sieving analysis, the particles size range is between 150–320 meshes. And Fig. 1 further presents the morphology and particle size of the powder. As-annealed AISI H13 tool steel plates (160 mm × 100 mm × 12 mm) were used as the base metal which was ground, polished and rinsed with acetone to remove the surface oxides and contaminations. The chemical composition of Ni-based powder and H13 steel determined by the fluorescence spectrum and sulfur carbon analysis was provided in Tables 1 and 2. Before laser depositing, the powder was heated to 150 °C for 15 min to remove moisture, and the base metal was heated to 300 °C to avoid cracking. As shown in Fig. 2, the sample preparation experiment was carried out by using a direct laser depositing (DLD) system which mainly consists of a 5 kW transverse-flow continuous wave CO2 laser, four axis numerical control (NC) workbench, continuous powder feeder, chiller (water-cooling unit) and coaxial powder feeding nozzle. The multi-pass deposition path was one-way orthogonal type (laser scanning pattern in Fig. 2), and the main process parameters were selected according to the factory's know-how and were listed as follows: laser power $P = 1.7$ kW, spot diameter $d = 4$ mm, scanning speed $V = 300$ mm/min, powder feeding rate $S = 4.2$ g/min, argon shielding gas flow 10 L/min, hatch spacing $H = 2$ mm.

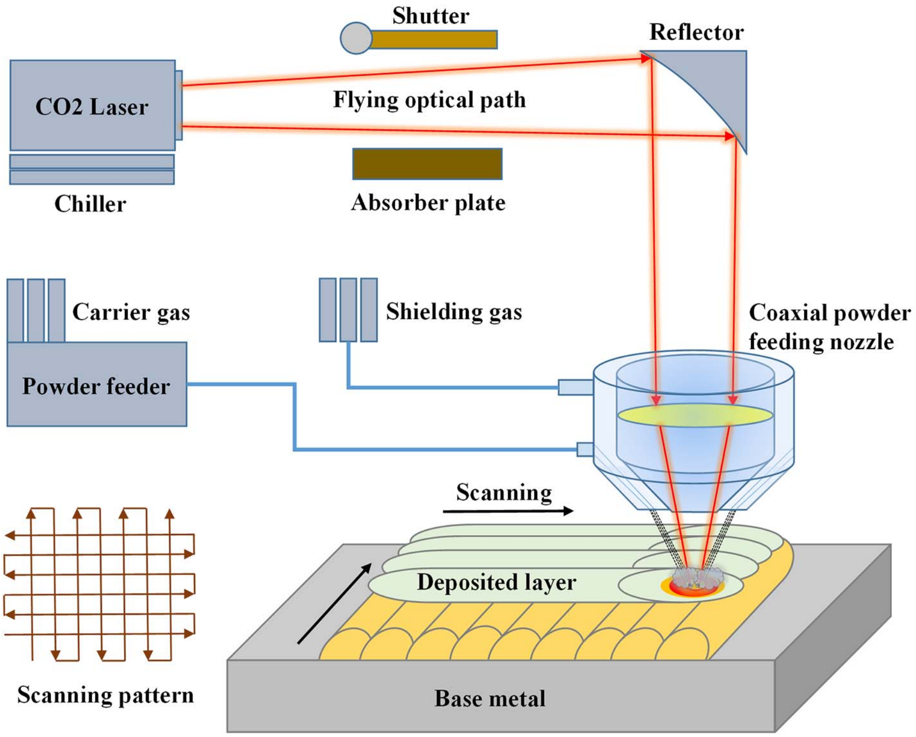

Fig. 2. Schematic of direct laser depositing process.