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ARTICLE

Microstructure and Mechanical Properties of Laser Repaired TC4 Titanium Alloy

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Abstract: Laser Additive Manufacturing (LAM) was employed to fabricate repaired specimens with wrought TC4 as the substrate and TC4 powders with low oxygen (O≤0.13wt%) as the cladding materials. The microstructure and mechanical properties of TC4 specimens fabricated by LAM and wrought billet were investigated comparatively. The results show that the macrostructure of the laser repaired specimen can be divided into three domains, including wrought substrate zone (SZ), heat affected zone (HAZ) and laser deposited zone (LDZ). The LDZ microhardness is equal to that of the SZ basically. And the HAZ microhardness is higher than that of both the LDZ and SZ slightly. The results of room temperature tensile test show that the strength and ductility of the wrought specimen are slightly higher than that of the laser repaired specimens. Meanwhile, the strength of the laser repaired specimen with repair ratio of 40% (i.e. area fraction of the LDZ on the transverse section of tensile specimen within gauge part is 40%)is slightly lower than that of 50% repaired specimen, but the ductility is higher than the latter. Therefore it is favorable to match the strength and ductility of the wrought substrate with the LDZ with low oxygen TC4 powders as the cladding materials, so as to improve the comprehensive properties of laser repaired TC4 titanium alloy. The wrought specimen tensile fracture presents a typical ductile characteristic, and the repaired specimen shows a complex fractograph. From the LDZ to the SZ, the tensile fracture presents a successive transformation from cleavage step to dimple fracture. It can be seen that there is a good corresponding relationship between the fracture morphology and the microstructure of the tensile specimens.

Key words: laser repair; titanium alloy; microstructure; mechanical properties; fracture mechanism

TC4 is a kind of α+β titanium alloys with medium strength, containing 6wt% Al which is a stable element of α phase, and 4wt% V which is a β stable element. It is widely employed to fabricate engine fans, compressor disks, blades and heavy load components due to its excellent comprehensive service performances in the field of aeronautic and astronautic industries[1,2]. Mis-machining damage occurring during the productive process and foreign object damage encountered in the service process become the problems ought to be faced with the increasing of application amount of titanium alloy components of new aircraft. It is urgent to develop new repair techniques to reverse huge losses both on economy and delivery time resulted from the damage of high value components.

Traditional repair techniques, such as brazing, argon arc welding, thermal spraying and electric discharge machining, are usually used to repair the surface defects or the defects with simple shapes. In addition, the heat-input and heat affected zone in the damaged components during welding such as TIG welding is large, which may cause a large residual stress and distortion and low mechanical properties for the final repaired components[3]. In recent years, based on the Laser Additive Manufacturing (LAM) process, an advanced solid free form fabrication, a new advanced repair technique, laser repair (LR), has been developed. Since LAM has been employed to fabricate fully dense and three

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dimensions components with high performance and complex structure, if we set the mis-machining or damaged components as the substrate, and build up worn sections of metal components, the geometrical properties and mechanical properties of the mis-machined or damaged components could be restored. Compared with the traditional repairing techniques, LR has the advantages of high automation, controllable heat input introduced into the damaged components, metallurgical bonding between the repaired zone and the body part, and reasonable repairing cost[4-7]. It has been gradually applied to repair the mis-machining or damaged components. In Germany, the Fraunhofer Institute of Laser Technology has repaired the damaged blades of titanium blisks with LR. They found that the laser deposited zone (LDZ) microstructure was fully dense with no oxidation since the process was performed in a sealed chamber filled with pure argon gas. In addition, the heat-input in the damaged components during the LR process was less, which caused less distortion compared with TIG welding. Finally, repaired parts with excellent performance could be obtained[8]. In China, Weidong Huang et al[3,7], State Key Laboratory of Solidification Processing of Northwestern Polytechnical University, had launched the LAM and LR research. Results show that there is a dense metallurgical bond between the LDZ and the substrate. The LDZ microstructure is composed of primary columnar β grains within which exist $\alpha+\beta$ Widmannstatten structures. The results of hardness and room temperature tensile test show that the LDZ hardness is higher than that of the wrought matrix; meanwhile, the plasticity of the LAMed specimens is lower than that of the wrought specimens. Therefore, the LDZ and the wrought matrix can be treated as a combination of “strong+weak”[9,10]. But, currently, about the relationship between the failure behavior and the microstructure of LRed TC4 titanium alloy in tensile test is rarely reported.

In the present paper LAM has been employed to fabricate repaired specimens with wrought TC4 as the substrate and TC4 powders with low oxygen (O≤0.13wt%) as the cladding materials. The microstructure and mechanical properties of TC4 specimens fabricated by LAM and wrought billet were investigated comparatively.

1 Experiment

The experiments were performed on a LAM system typed LSF-IIIB, established by State Key Laboratory of Solidification Processing, which consisted of a 4 kW continuous wave CO_2 laser, a five-axis numerical control working table, a powder feeder with a coaxial nozzle and a chamber filled with pure argon gas, etc. The substrate was wrought TC4 alloy. The wrought substrate is composed of duplex microstructure as shown in Fig.1. The TC4 powders prepared by plasma rotating electrode with the size of –100 mesh were employed as the cladding materials. The chemical composition of the substrate and the cladding powders are listed in Table 1. The powders were dried in a vacuum oven for 2 h at (120±10) °C. The processing parameters of LR are shown in Table 2.

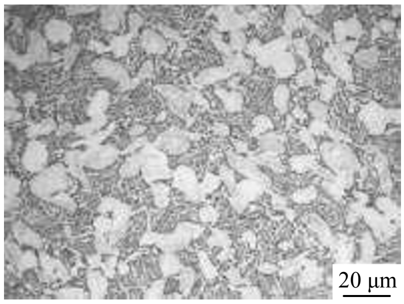

Fig.1 Microstructure of the TC4 wrought substrate

Before the LR experiment, the wrought billet of TC4 alloy was machined to obtain specimens with a prefabricated surface defect, as shown in Fig.2a (solid line shows the specimen with surface defect, dot line shows the LRed tensile specimen). Then, the surface to be repaired was polished by abrasive papers and cleaned by acetone. The LAM technique with mutually perpendicular scanning path was employed to accomplish the LRed specimens and the height of LDZ was about 5 mm. The LRed specimens are shown in Fig.2b. The LRed TC4 alloy specimens were machined into the standard tensile specimens and the repair ratio was set to 40% and 50%. Fig.3 shows the geometric figure of a tensile bar. The tensile properties were tested on a German electronic tensile testing machine ZWICK according to GB/T228-2010 specification. After tensile failure, the 40% repaired specimen was sectioned and got a cross-section at the farthest position from the fracture within the gauge length for microstructural observation. The microstructure of the LRed specimens was revealed using the etchant of 10 mL HF+30 mL HNO_3+50 mL H_2O, and examined by an OLYMPUSGX71 optical microscope. The microhardness of the LRed specimens from the LDZ to the substrate zone (SZ) was further tested by a Duramin-A300 microhardness tester with the load of 0.5 kg. The tensile fracture of the wrought and LRed specimens was observed by a TESCAN VEGAⅡ LMH scanning electron microscope.

Table 1 Chemical composition of the TC4 powders and the wrought substrate (wt%)

	Al	V	Fe	O	C	N	H	Bal.
Powders	6.10	4.20	0.12	0.08	0.01	0.015	0.009	Ti
Substrate	6.42	3.88	0.20	0.16	0.02	0.01	0.010	Ti

Table 2 Experiment parameters of the LR process

Laser powder/W	Scanning velocity/ $mm\cdot s^{-1}$	Laser spot diameter/ mm	Powder feeding rate/ $g\cdot min^{-1}$	$\triangle Z$/ mm	Overlap rate/%
2200	10	2	5	0.3	40, 50