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Study on Microstructure and Properties of LZ50 Axle Steel Repaired by Laser Additive Remanufacturing

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Abstract. ER308L stainless steel welding wire was used for laser repair of LZ50 train axle steel sample. A large number of defects, such as microcracks, pore shrinkage and porosity, can be found in the re-manufacturing sample. A wave-like structure was formed at the boundary of the fusion zone between the augmented repair material and the base material, and the structure in this zone was consist of about 83% martensite and about 17% austenite, In the ER308L stainless steel welding wire repair zone, columnar equiaxed crystals with different lengths and morphology were formed, all of which pointed to the center of the molten pool. After repair, the tensile strength of the specimens decreased from 601.34MPa to 427.81MPa, and the elongation decreased from 16% to 5%, The fracture mode was a combination of ductile fracture and brittle fracture.

Keywords: ER308L; Laser additive re-manufacturing; LZ50 axle steel.

1. Introduction

The axle material of the Electric Multiple Units (EMU) train is LZ50 steel, which is characterized by low surface hardness and easy damage. When the damage depth of the axle of the EMU train exceeds 0.1mm, the axle needs to be scrapped, which leads to the increase of the operation cost of the train. Therefore, a repair technique is urgently needed to extend its service life. Traditional methods such as welding, although the cost is low and the technology is mature, but there are some shortcomings such as large heat affected zone, large residual stress and large deformation. Laser additive manufacturing technology is an emerging repair technology, which has the advantages of high energy density, controllable heat input, adjustable additive filler composition, small heat-affected zone, small deformation and residual stress after repair and high surface quality[1]. Laser additive technology has been widely used in the remanufacturing of machine parts and has a broad application prospect in the field of repair[2]. BenjaminGraf[3] et al. carried out laser additive remanufacturing restoration on the pre-slotted stainless steel and titanium alloy samples, and focused on the influence of grooves of different sizes on the morphology and structure after repairing. It was found that the side of V-shaped and U-shaped grooves with a certain Angle had better metallurgical fusion with the substrate, while the repair effect of U-shaped grooves with vertical side was not ideal, the U-slot was not fully filled and repaired.

The main content of this paper is to use ER308L stainless steel wire as additive material for laser additive remanufacturing repair of ZL50 steel samples, study the feasibility of laser additive technology of train axle, test and comparative analysis of the sample structure and performance after additive remanufacturing.

2. Materials and experiments

2.1. Materials

LZ50 axle steel is used for the experiments. The samples are Standard tensile test specimens, the diameter is 10mm and the length is 100mm. The filler used for laser additive remanufacturing is ER308L stainless steel welding wire with a diameter of 1.2mm, the composition of the welding wire is shown in Table 2.

Table 1 Chemical composition of ZL50 axle steel (mass fraction, wt.%)

Fe	C	Si	Mn	P	S	Cr	Ni	V	Cu	Ti
Bal	0.47	0.15	0.70	0.025	0.015	0.30	0.30	0.02	0.30	0.02

Table 2 Chemical composition of ER308 stainless steel welding wire (Mass fraction, wt.%)

Fe	C	Si	Mn	P	S	Cr	Ni
Bal	0.03	0.65	2.5	0.03	0.03	18.0	9.0

2.2. Experiments

A Wire Electrical Discharge Machining is used to cut notches on the samples, and the size of the trapezoidal groove is shown in Figure 1. The laser additive remanufacturing tests were performed on the CWX-3000 continuous fiber laser with the laser power of 4500w, spot diameter of 0.3mm, scanning speed and defocus of 3m/min and +5mm, respectively. Coaxial blowing protection is adopted, the pure argon gas flow is 7L/min, and the wire feeding Angle and speed are 30° and 2m/min respectively.

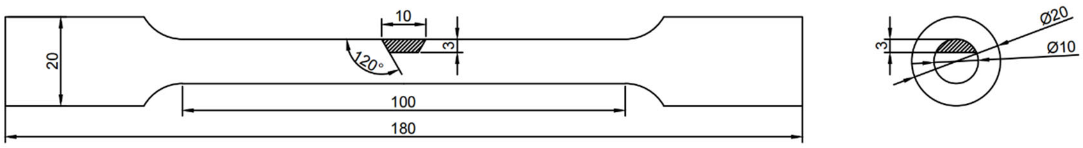

Figure. 1 Schematic diagram of trapezoidal groove size

The hardness test of the cross section of the welded joint was carried out on the HV1000IS Microscopic Vickers hardness tester. The load was 1.96N and the holding time is 10s. DNS-100 universal material testing machine was used to complete the tensile test at room temperature with the tensile speed of 2.00mm /min. The welded joint samples were chemically etched with 4% nitrate alcohol solution and copper chloride etchant (50gCuCl2, 50mlHCl, 100ml anhydrous ethanol). Optical Micrograph (RX50M; OM) for observation.

3. Results and discussion

Fig. 2 shows the structure morphology of LZ50 axle steel. The black flake structure is flake pearlite, the white gridded particles are ferritic, and the black flake pearlite is evenly distributed at the ferritic grain boundary. The volume fraction of pearlite accounts for about 60% of the total matrix. As we all know, there is very little carbon in ferrite, so it can be regarded as pure iron. Because of the large amount of ferrite, it has good toughness.

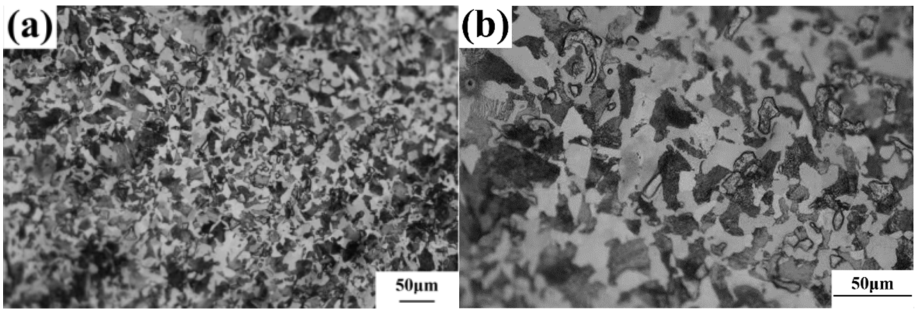

Figure. 2 LZ50 axle steel microstructure

In laser additive remanufacturing process, due to the different thermal properties of the substrate and the filler material, cracks will be generated on the surface repairing area. The welding defects seriously weaken the mechanical properties of the specimen after additive remanufacturing. Cracks are the most common defects in the process of laser wire filling and can be caused by a variety of factors, including mechanical stress, melting impurities and the properties of the material itself. As shown in Figure 3 (a), the surface of LZ50 axle steel after additive remanufacturing was polished to remove excess burrs and oxide layer. there were a large number of welding dents and cracks on the welded surface. In the process of laser additive remanufacturing, a large number of metal oxides are included between layers. It might be the oxide layer on the surface or the oxide layer not cleaned up completely in the laser additive process. In the process of laser melting, pores formed by gas or impurities are included in the molten metal to form a large number of welding defects.

In the process of metal laser additive manufacturing, thermal stress is generated by the formation of temperature gradient of metal materials after heating, and microscopic stress is also caused by phase transformation. As shown in Figure 3 (b), obvious micro-cracks and pores in the repair area lead to serious weak of mechanical properties.

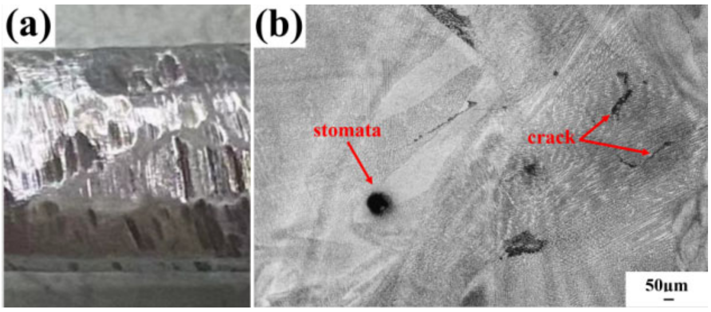

Figure. 3 Remanufacturing area, (a) the macro morphology (b) the microstructure

As shown in Fig. 4 (a) the microstructure of the recrystallization zone after laser additive remanufacturing. It showed obvious spray-like structure without obvious fusion line. The lower part is the heat affected zone of the substrate, and the area near the fusion zone is the coarse crystal zone, it is "overheated zone". The peak temperature of this zone is very high, which promotes the growth of austenite grains. The spark shape structure should be the mixing zone of ER308 material and ZL50 axle steel. with laser heated, two kinds of molten metals are mixed to form a spark shape structure. It is assumed that 50% ER308 and 50% ZL50 respectively exist in the spray structure, cooling speed is 1000°C/s for the simulation. As shown in Figure 4 (b), carbon and other elements in steel are diffused in austenite, so that the chemical components in austenite are evenly distributed, which promotes the formation of cryptocrystalline martensite. The organization of the spark shape area is about 83% martensite and 17% austenite, and martensite usually extends from one side of austenite to the other side. Normally, the maximum size of sheet martensite is determined by the size of the austenite grain, which will become larger if the austenite grain is larger.

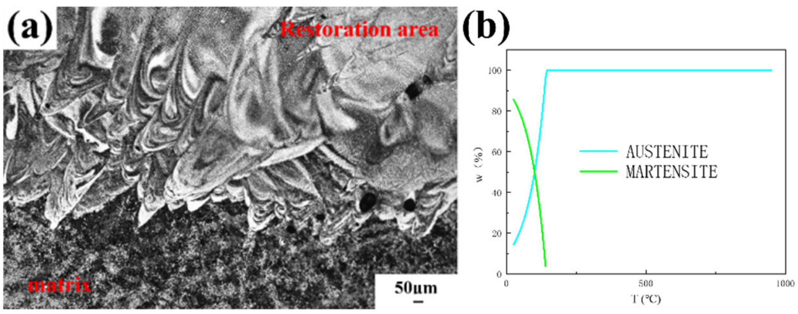

Figure. 4 Morphology of the remanufacturing area, (a) recrystallization area (b) non-equilibrium phase diagram

In the process of laser additive remanufacturing, complex heating process and thermal cycle mode lead to complex phase transition and microstructure evolution in the remanufactured area[2], and it mainly consists of martensite crystals, such as planar crystal, columnar crystal and dendrite. The main factors affecting the microstructure of the remanufacturing area include alloying element composition, interfacial energy, temperature gradient and solidification rate[4]. Fig. 5 shows the microstructure near two adjacent laser additive remanufacturing layers. The interlaminar zone is a kind of planar crystal. As shown in Figure 5, columnar crystals with different lengths and morphologies are formed, all of which point to the center of the molten pool. The reason is the direction of heat flow affects the direction of grain growth. At the beginning, heat is dissipated to the matrix, and the maximum temperature gradient is perpendicular to the interface of the molten pool, as well as the direction of heat flow. The heat dissipation of the repair layer is caused by the previous repair layer. As a result, as the distance from the interface increase, the temperature gradient decreases gradually, while the solidification rate increases gradually, the plane boundary becomes unstable, and columnar crystals of different lengths and shapes are formed. The accelerated crystallization rate will form multi-directional crystals, and the microstructure is gradually refined. Thus improving the properties of materials[5].

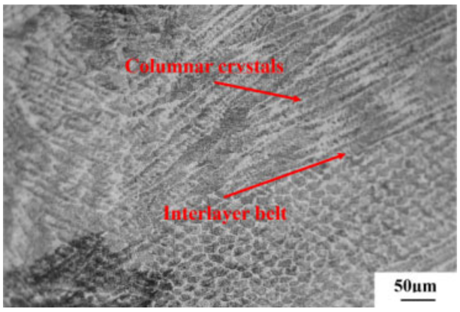

Figure. 5 The microstructure of the laser remanufacturing area

As shown in Figure 6, the hardness test data is measured with a distance of 0.3mm along the direction perpendicular to the laser additive remanufacturing direction. The hardness value of the base material is about 150~250 HV, with an average value of 176.8HV. The Vickers hardness of the remanufacturing area is roughly between 500 and 600, and its average value is about 534.8HV. The higher hardness value in this area is due to the martensite formed at a high cooling rate [6]. There is a large gap between the hardness of the base material and the remanufacturing area. In practical use, due to the high hardness gap will weak the mechanical properties.

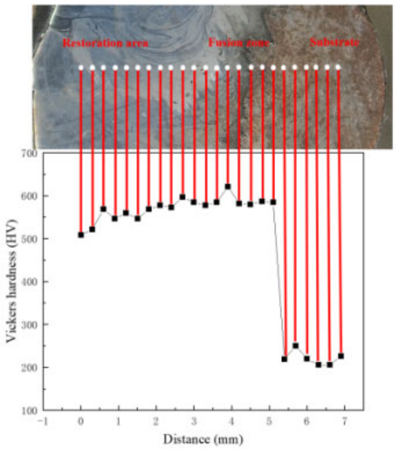

Figure. 6 hardness profile

Figure 7 (a) shows the tensile curve of LZ50 axle steel. It can be seen, after the fracture of elastic stage, yield stage, strengthening stage and neck stage, the yield strength of remanufacturing sample increased from 359.95MPa to 401.07MPa, and the tensile yield limit of remanufacturing sample increased by 11.4% than that of original sample, and the tensile strength decreased from 601.34MPa to 427.81MPa, and the elongation decreased from 16% to 5%. The main reasons are: cracks, pores and other welding defects in the materials, the surface of the remanufacturing sample is not smooth enough and the caused residual stress in the samples. Cracks first appear from the defects in the remanufacturing zone without obvious plastic deformation, and then the cracks extend to the base metal and fracture occurs. As shown in Figure 7 (b), for the fracture morphology of the remanufacturing sample, tear ridge and cleavage step can be observed. The fracture mode of the sample is a combination of ductile fracture and brittle fracture.

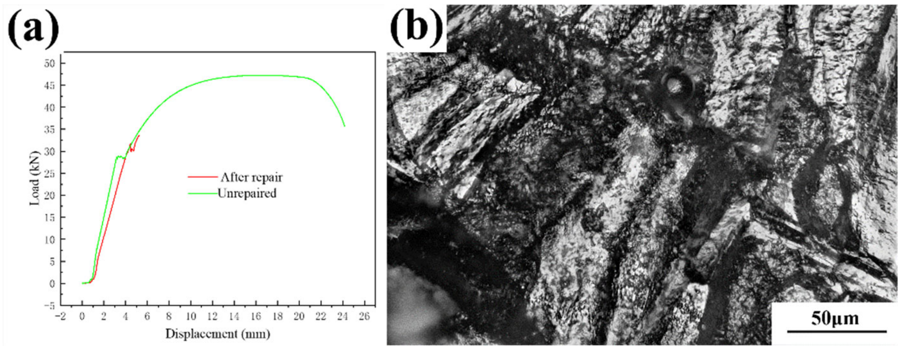

Figure. 7 Tensile curve and stretch section, (a) Tensile curve and. (b) Stretch section

4. Conclusion

The microstructure and properties of laser additive remanufacturing ZL50 axle steel were studied. The conclusions are as follows:

(1) In the process of laser additive remanufacturing, a large number of pores, cracks and other defects are formed in the remanufacturing area.

(2) Columnar equiaxed crystals with different lengths and morphologies were formed in the laser additive remanufacturing area, all of which pointed to the center of the molten pool, because the direction of heat flow affected the direction of grain growth.

(3) The tensile yield limit of repaired sample increased by 11.4%, the tensile strength decreased from 601.34MPa to 427.81MPa, and the elongation decreased from 16% to 5%.

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