纳米改性高强铝合金激光清洗-电弧复合增材制造基础研究

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随着航空航天、轨道交通、新能源汽车等领域的不断创新发展，运载工具的高速、高航程和低能耗需求日益增加，结构同步强化与轻量化逐渐成为研究趋势。因此，轻量化材料的增材制造技术越来越重要。Al-Zn-Mg-Cu(7075)超硬铝合金具有较高的强韧性和耐蚀性，在制造轻量化、大尺寸复杂结构中广泛应用。电弧增材制造(Wire Arc Additive Manufacturing，简称 WAAM)具有成本低、沉积效率高等优点，是增材制造大尺寸工件的理想技术之一。由于高气孔倾向性、高裂纹敏感性和焊后机械性能下降等缺点，超硬铝合金 WAAM 技术仍未突破。针对上述难题，本文提出了纳秒激光清洗-WAAM 新工艺，并结合纳米材料改性技术，采用变极性电弧技术，对激光清洗-WAAM 缺陷、显微组织与力学性能进行了系统分析研究。通过对缺陷和组织性能的分析，发现激光清洗作用、TiC 纳米相改性、变极性电弧模式均能降低气孔率。并且添加了 TiC 纳米改性相的 7075 铝合金（7075NT）电弧增材后基本无裂纹。7075NT 试样的力学性能优于 7075，各项异性系数远低于 7075。热处理后 7075NT 试样的最高抗拉强度可达 450MPa，7075 试样热处理后的最高抗拉强度可达 373MPa。激光清洗主要是通过剔除熔池污染物，从而减少气孔率。纳米改性是通过形成细小的等轴晶达到抑制气孔的效果，并通过细晶强化和第二相强化提高其性能。

关键词：电弧增材制造；激光清洗；气孔率；组织性能

Laser cleaning-arc hybrid additive manufacturing of nano-modified high-strength aluminum alloys

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With the continuous innovation and development of aerospace, rail transit, new energy vehicles and other fields, the demand for high speed, high range and low energy consumption of vehicles is increasing, and the simultaneous strengthening and lightening of structures has gradually become a research trend. Therefore, additive manufacturing techniques for lightweight materials are becoming more and more important. Al-Zn-Mg-Cu (7075) superhard aluminum alloys have high strength, toughness and corrosion resistance, and are widely used in the manufacture of lightweight, large-scale complex structures. Wire Arc Additive Manufacturing (WAAM) has the advantages of low cost and high deposition efficiency, and is one of the ideal technologies for additive manufacturing of large-sized workpieces. Due to the disadvantages of high porosity tendency, high crack susceptibility, and decreased mechanical properties after welding, the WAAM of super-hard aluminum alloys has not yet been broken through. In view of the above problems, this paper proposes a new hybrid nanosecond laser cleaning-WAAM process, combined with nanomaterial modification technology, using variable-polarity arc technology, to analyze the microstructures and changes in the process of laser cleaning-WAAM. Through the analysis of defects and microstructure properties, it was found that laser cleaning, TiC nano-phase modification, and variable-polarity arc mode can reduce the porosity. The 7075 aluminum alloy added with TiC nano-modified phase (7075NT) has no cracks. The mechanical properties of the 7075NT specimen are better than those of 7075, and the anisotropy coefficient is much lower than that of 7075. The highest tensile strength of 7075NT sample after heat treatment can reach 450MPa, and the highest tensile strength of 7075 sample after heat treatment can reach 373MPa. Laser cleaning mainly reduces porosity by removing contaminants from the molten pool. Nano-modification is to achieve the effect of suppressing pores by forming fine equiaxed crystals, and improving its performance through fine-grain strengthening and second-phase strengthening.

Key words: wire arc additive manufacturing; laser cleaning; porosity; microstructure and properties