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球墨铸铁激光熔覆过程多场耦合数值模拟与实验研究

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摘要：球墨铸铁具有良好的强度和韧性，广泛应用于工业领域，但铸造过程中不可避免会产生裂纹、缩松和气孔等缺陷。采用传统工艺修复和强化球墨铸铁工件很难满足使用要求，激光熔覆作为新兴表面强化技术，具有热影响区小、熔覆稀释率可控等特点，可有效减少球墨铸铁表面缺陷。定量化揭示熔覆过程中材料-工艺-组织-性能间的耦合作用机理，可为减少熔覆缺陷提供重要理论依据。本研究建立球墨铸铁基体激光熔覆镍基、钴基粉末过程多场耦合数值模型，考虑光粉作用，熔池表面张力、浮力对液态金属流动的影响，揭示了熔覆温度场、流场和应力场的瞬态演变规律，探讨了多道、多层熔覆过程相关性及熔覆层点蚀失效损伤机理，为建立高质量熔覆层提供理论依据。进行材料学微观表征实验，验证了模型的有效性。计算表明，熔覆最高温度位于光斑中心处，为3130 K，熔池流速呈现中心小、边缘大的特点。残余应力呈“带状”分布。基体与熔覆层耐磨性排序为：Co12熔覆层> IN625熔覆层> QT600基体。

关键词：球墨铸铁；激光熔覆；多场耦合；工艺参数优化

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Multi-field coupling numerical simulation and experimental research on the laser cladding process of nodular cast iron

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Abstract: The nodular cast iron has great strength and toughness, which is widely used in the industrial fields. In the casting process, some defects such as cracks, shrinkage and pores will be inevitably appeared. It is difficult to repair and strengthen the workpieces of nodular cast iron by traditional techniques. As an emerging surface strengthening technology, laser cladding has the characteristics of small heat-affected zone and controllable cladding dilution rate, which can effectively reduce the surface defects of the nodular cast iron. Quantitatively revealing the coupling mechanism between the material-technology-structure-property in the cladding process can provide an important theoretical basis for reducing the cladding defects. In this study, a multi-field coupled numerical model for the laser cladding of nickel-based and cobalt-based powders on the nodular cast iron substrates was established. Considering the light-powder effect and the effect of molten pool surface tension and buoyancy on the flow of liquid metal, the transient evolution law of the temperature field, flow field and stress field of the cladding were revealed. The correlation of multi-track and multi-layer cladding processes, and the damage mechanism of pitting corrosion on the cladding layer were all discussed, which provides a theoretical basis for producing the high-quality cladding layers. The micro- characterization experiments of materials science were carried out to verify the validity of the model. The calculation shows that the maximum temperature of the cladding is located at the center of the spot, which is 3130K. The flow velocity of the molten pool is characterized by the small center and large edges. The residual stress is distributed in a "band-like" distribution. The wear resistance of substrates and cladding layers can be ordered as follows: Co12 cladding layer> IN625 cladding layer> QT600 substrate.

Key words: ductile iron, laser cladding, multi-field coupling, process parameter optimization