推力室模拟结构件的激光熔化沉积成形研究

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摘 要 推力室具有变径回转空腔、内流道、多筋搭接等典型结构特征。若采用传统机械加工方法存在生产周期长、加工成本高、加工效率低、结合性能差、材料浪费严重等问题。如采用激光增材制造，用水平分层法直接堆积，大倾角部分的熔池易产生塌陷，内流道部分热积累严重、筋与薄壁连接处易产生凹凸缺陷、双层薄壁内表面黏粉严重、筋板成形较困难，难以得到合格的产品。为提升推力室整体成形质量和打印精度，本文基于机器人8轴离线编程仿真软件，对多结构特征的推力室成形工艺进行了研究。将“推力室模拟件”划分为变径空腔成形区域、内流道成形区域和多筋搭接成形区域，分别提出了“水平分层，法向堆积”、“基于基体母线的曲面分层”、“水平分层，法向堆积”方法对各区域进行分步组合成形。建立了筋壁搭接简化模型，并通过T型搭接试验验证了可行性，最终完成了“推力室模拟件”的整体成形。实验结果表明：采用“水平分层，法向堆积”方法可根据变径空腔几何模型实时调节变位机倾角，使光束轴向与加工位置侧面切线始终保持一致，实现了上下层无错位堆积；采用“基于基体母线的曲面分层”方法，内流道沿曲面母线的平滑成形，有效地避免了能量局部积累、成形表面形貌差、成形过程中粉末过熔化等问题；采用“水平分层，斜向堆积”方法，可有效的解决多筋搭接区域堆积时熔覆头与已成型部分的干涉、筋与薄壁连接处凹凸缺陷等问题。检测结果表明：成形件表面平整，尺寸误差在9％以内，壁厚稳定在2.25mm左右，三种成形区域的显微组织整体均匀致密，硬度和强度总体保持稳定。

关键词： 激光增材制造；变径空腔结构；内流道结构；多筋搭接结构

Study on laser melting deposition forming of thrust chamber simulated structural parts

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Abstract The thruster has typical structure characteristics such as cavities with variable diameters, inner flow channels and connecting ribs. Serious problems will arise if traditional methods were used directly, such as long production cycle, high processing cost, low processing efficiency, poor binding performance, serious material waste and so on. There are also many issues to be solved if horizontal layering method of additive manufacturing is applied for direct deposition. For example, the melt pool of part with large angle is easy to collapse. The heat accumulation of the inner flow channel is serious. Concave and convex defects are produced at the junction of the rib and the thin wall. Severe sticky powders problem occurs on the inner surface of double thin-walled parts. The rib is hard to form. To sum up, it is difficult to get qualified products using traditional methods and horizontal layering method of additive manufacturing. In order to improve the overall forming quality and printing accuracy of thrusters, we study the forming process of thrusters with multiple structures based on the programming simulation software of 8-axis robot. The thruster simulator is divided into 3 parts: cavities with variable diameters forming region, inner runner channels forming region and multi-rib connecting region. Methods are proposed for each region respectively such as horizontally layering while normally depositing, curved surface layering based on generatrix and oblique directional dislocation layering. The rib-thin wall lap model is established while the feasibility is verified by T-shape lap test. Finally, the whole forming of thruster simulator is completed. The experimental results show that horizontally layering while normally depositing method can adjust the angle of positioner synchronously according to the geometric model of cavities with variable diameters, so the axial direction of the laser beam is always consistent with the tangent line of the machining position, which help to achieve stacking without dislocation and effectively overcome the collapse of melt pool. Curved surface layering based on generatrix method can fabricate inner flow channels that form smoothly along the generatrix, which effectively avoid the problems such as energy local energy accumulation, poor surface morphology and powders over-melting during the forming process. Oblique directional dislocation layering method can effectively solve the problems such as the interference between the cladding head and the formed part, concave and convex defects at the junction of the rib and the thin wall. The results show that the surface of parts is smooth, the size error is less than 9%, and the thickness of the wall is stable at about 2.25mm. The microstructure of three forming regions is uniform and compact with stable hardness and strength.

Key words: laser additive manufacturing; variable diameter cavity structure; Inner runner structure; multi-rib connecting structure