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ScienceDirect

Physics Procedia 83 (2016) 634 – 646

Physics Procedia

9th International Conference on Photonic Technologies - LANE 2016

Possibility of multi-material laser cladding fabrication of nickel alloy and stainless steel

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Abstract

There are some applications in the industry for multi-material components, including device engineering and multifunctional surface engineering, having to eliminate a brazing or welding technological step. This study investigates the laser cladding process parameters, related single track geometry and quality of multi-material samples. The optimal process parameters for steel were found of 0.21-0.26 J/mm^2 and $0.25 \cdot 10^{-2}$ g/mm under the scanning velocity of 1400-1700 mm/min and powder feeding of 4.2-4.5 g/min. The bimetal thin walls, cylinders and cubes were manufactured within the optimal conditions. The requirements of steel and nickel joining were explored. For the examination, the optical microscopy, SEM, EDX microelement analysis and hardness analysis were involved.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: laser cladding; multi-material; additive manufacturing; bimetal; steel; nickel alloy; Peclet number, thermal power

1. Introduction

The main purpose of engineering technology science is to achieve a predetermined quality of the product with efficient use of production facilities and resources. In these terms, the best efficiency of some engineering structures could be obtained by applying the components combined of several dissimilar materials that fully realize the economic and performance advantages of each material. The most known metal couples are as follows: steel-copper, steel-aluminum, steel-titanium and steel-nickel. For example, the pair of steel-copper (bronze) could be applied as the heat exchangers (due to high conductivity of copper/bronze) or as cam bushing (high tribological properties of

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Peer-review under responsibility of the Bayerisches Laserzentrum GmbH
doi:10.1016/j.phpro.2016.08.066

copper/bronze), the pair of steel-aluminum could be applied as adapters in oxygen regenerators or as details of electrolytic refining equipment (high corrosion resistance of aluminium). Some of the examples are presented in the previous works [1-5].

Choi et al. [6] showed the steel-nickel parts used in light water reactors to connect vessel and generator nozzles to the reactor components. Ramkumar et al. [7] investigated a GTA welding of the nickel superalloy and SS304 for high temperature and corrosive environments applications such as power plants and also studied the weldability of Inconel 718 and AISI 316L [8]. Malakhov et al. [9] studied the explosion weld of nickel and steel plates for application with high temperature and high erosion load in gas turbines.

In this paper, the stainless steel and nickel alloy was chosen because of specific properties of each material: corrosion resistance of structural steel and high-temperature strength of nickel alloy. The definite part is cylindrical Ø20 mm solenoid valve consisted of soft magnetic alloy core and symmetrically located in transversal direction steel and nickel elements. The part is operated in corrosion high temperature environment. The main goal is to eliminate the brazing procedures and the related mechanical edge preparation. In this regard, the multi-material additive manufacturing was involved.

There are some researches on the multi-material additive manufacturing. For example, Liu et al. [3] showed the Selective laser melting of steel-copper bimetallic objects. The authors achieved very good metallurgical bonding even though they make an important note about some technological problems and strong need of correct process parameters. Beal et al. [10] applied the multi-material manufacturing by selective laser melting to produce functionally graded materials in XY-plane using specific powder hopper. The authors investigate the manufacturing process of injection mould made from H13 steel and copper. Yakovlev et al. [11] and Muller et al. [12] studied the multi-material laser cladding of steel 316L and Co-base superalloy from practical and theoretic point of view. Multi-material object manufacturing will meet the problems with geometry, different layer thickness for each material, needs of taking into account the difference in thermal and physical properties. Different aspects of parametric studies of the laser cladding was investigated previously [13-15], the experience of powder-gas flow and preheating was showed in [16]. Gusarov et al. [17] showed the need of input power control to avoid additional residual stresses.

The major goal of the present study was to investigate of the laser-matter interaction process using different approaches. For the study, two powders (stainless steel and nickel superalloy) of industrial use were applied. The subject was connected with the developing of optimal process parameters of laser cladding for both selected materials and fabrication of multi-material (bimetal) samples. The influence of the cladding parameters on the track geometry, microstructures and microhardness was studied. The boundary effect of small of 200 μm of laser beam diameter comparable by order-of-magnitude with powder size (50 μm) was highlighted and the thermodynamic conditions were described.

2. Materials and experimental procedure

2.1. Materials

The stainless steel and nickel superalloy powders materials were used for the study. The stainless steel powder PR-12H18N9T was produced by JSC Polema (Russia), is an austenitic stainless steel with up to 0.12% of carbon, up to 18% of chromium, up to 9% of nickel and up to 0.8% of titanium, similar to AISI321 steel. The element composition is presented in the table 1. The stainless steel powder fraction was of 20 – 63 μm (fig. 1a) with almost spherical particle shape (fig. 3a). Mean powder particle size was 40 μm. Spherical shape factor of the particles is 0.7 based on the statistical analysis software (Occhio S.A., Belgium) using the *Circularity* and *Bluntness* parameters. The measured powder bulk density without taping was 4680 kg/m^3. The steel is well established in the applications with temperatures of -196 °C to 600 °C, weak acid environment (up to 350 °C), for the parts under pressure.

The nickel powder HN71MTYuB was produced by JSC VILS (Russia) is a high-temperature nickel superalloy contains 13-16% of chromium, 2.8-3.2% of molybdenum, 2.35-2.75% of titanium, 1.45-1.8 of aluminum doped with 2% of niobium and 0.01% of cerium. Detailed element composition is presented in table 2. The granulometry of the powder is -70 μm (fig. 1b). Mean powder particle size is 55 μm. The powder presents spherical shape (fig. 3b). Spherical shape factor of the nickel powder particles is 0.8. The measured powder bulk density without taping was 5049 kg/m^3. The typical use of nickel superalloys are the application with high temperatures as turbine parts.