D. Fabricability of SX Nickel-Base Alloy Deposits by Direct Laser Deposition

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Introduction

Single crystal (SX) nickel-base superalloys have been used in high-temperature gas turbines as blades and vanes in order to increase the operating temperature and, in turn, to improve the overall efficiency of the gas turbines. The economic benefit is tremendous for the repair and reshaping of damaged SX gas turbine components as well as for salvaging the surface defects in as-cast parts by laser processing. Laser Engineered Net Shaping (LENS) is a solid freeform fabrication process which is able to fabricate complex prototypes in near-net shape, leading to significant time and machining cost savings. The LENS process also shows potential for precision repair in SX components. This work is undertaken to study this feasibility and the effects of processing variables on the fabricability of SX nickel-base alloy deposits by LENS processing.

Technical Approach

A typical commercial SX nickel-base superalloy, the CMSX-4 alloy, was chosen as the SX substrate alloy. The nominal composition of this alloy is Ni-9Co-6.5Cr-5.6Al-1Ti-6W-6.5Ta-3Re-0.6Mo-0.1Hf (in wt%). Two nickel-base alloy powders were used in this investigation. One was the CMSX-4 alloy powder, the other was a Ni_3Al-based IC221W alloy powder with a nominal composition of Ni-8.0Al-7.7Cr-3.0Zr-0.003B (in wt%). Different sets of processing parameters were chosen to investigate their effects on the propensity for equiaxed stray grain formation and the solidification cracking susceptibility. Single- and multi-track deposits and multi-layer wall shaped deposits (up to 30 layers) were produced for different purposes in the study. Light optical microscopy (LOM), scanning electron microscopy (SEM) coupled with an X-ray energy-dispersive spectrometer (EDS), and X-ray diffraction (XRD) were used for microstructure analysis.

Results and Discussion

The microstructures of single-track deposits made at a laser power (P) of 450 W and 5, 10, 15 mm/s traverse speeds (with the same powder feed rate of 0.037 g/s) showed that the region of equiaxed stray grains becomes larger as the traverse speed increases, suggesting that the propensity for stray-grain formation increases with increasing processing speed under the experimental conditions. This can be explained from the following two aspects. First, from the analyses of the thermal field (temperature gradient, G) and dendrite growth velocity (V), a simple relationship between the G/V ratio and the processing parameters (P, V_b, T_0) was derived for the laser processing. It was found that an increase in the beam traverse-speed (V_b) decreases the G/V ratio, leading to an increased extent of constitutional cooling (CS). Therefore, the increased extent of CS associated with the higher processing speeds resulted in the increase in the propensity for stray grain formation. Secondly, the interaction time between the laser beam and the material decreases with the increase in the traverse speed, thus reducing the temperature of the melt pool and hence the melting of the powder particles. The partially melted powder particles in the melt pool can increase the nuclei density and act as heterogeneous nucleation sites for equiaxed grains that form on the surface, thus promoting the formation of stray grains. The processing velocity also influences the solidification cracking susceptibility of the nickel-base alloy deposits. The susceptibility to solidification cracking increased as the traverse speed was increased during processing. This can be attributed to the increased thermal stresses resulting from a higher cooling rate associated with the high processing speed.

`Further experiments and similar analyses for other parameters demonstrated that the combination of a relatively low processing velocity and a reasonably low laser power should be advantageous for producing SX deposits free of stray grains and cracks. Any preheat of the substrate will lead to a decreased G/V ratio, thus promoting the stray grain formation. Therefore, preheating of the substrate for the purpose of reducing the cracking susceptibility should be avoided in order to fabricate SX alloy deposits. On the basis of the above experiments and analyses, SX deposits consisting of multi-layer overlapped tracks and of wall-shaped multi-layer single tracks were successfully produced.

Conclusion

The processing parameters influenced the SX fabricability from both the propensity for stray grain formation and the solidification cracking susceptibility. A simple relationship between the G/V ratio and the processing parameters (P, V_b, T_0) was derived, which can be used qualitatively to guide the proper selection of processing conditions to maintain the columnar dendritic growth during the laser deposition. As a general rule, the combination of a relatively low processing velocity and a reasonably low laser power is advantageous for producing SX deposits free of stray grains and cracks. It is important to perform automatic control over the laser power during the LENS processing of SX deposits of multiple layers in order to maintain the SX growth conditions.