ON THE PROBLEM OF FORMATION OF DEFECT-FREE PRODUCTS FROM NICKEL-BASED SUPERALLOY OBTAINED BY ELECTRON BEAM ADDITIVE MANUFACTURING*

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Formation of products from nickel-based superalloys by additive manufacturing is an important and urgent tusk [1]. Nowadays for obtaining products with directional or single-crystalline structure substrates from the same material as the additive product itself are used [2]. With the purpose of reduction of expenses on technological process, as a substrate it is possible to apply cheaper material with isomorphic structure. As it is known [3], different approaches in additive manufacturing are characterized by different propensities to defect formation. The most widespread defects in the products obtained by the methods of additive manufacturing processes are the loss of fusible alloying elements, the formation of porosity and non-smelting, cracks and stratification. The last type of defects is most relevant for 3D printing of products on substrates made of a material with chemical composition different from product material. In this work by the wire-feed electron beam additive manufacturing (EBAM) defect-free product in the form of a wall from nickel-based superalloy ZhS6U were obtained on a steel substrate. In earlier works, the authors obtained similar products, but they contained defects in the form of cracks [4]. It should be noted that the EBAM process is characterized by such technological printing parameters as accelerating voltage ($\boldsymbol{U}$, kV), beam current ($\boldsymbol{I}$, mA) and printing velocity ($\boldsymbol{V}$, mm/min) [5]. These parameters can be linked via the heat input:

$$E = \frac{60 \cdot U \cdot I}{1000 \cdot V}. \tag{1}$$

During the work three walls (products marked "1", "2" and "3") were obtained from ZhS6U superalloy on SS304 austenitic steel substrates with different heat input values of 0.37, 0.40 and 2.07 kJ/mm. The first two walls (obtained at lower heat input values) contained cracks, the third wall was defect-free. Since products from superalloys need to be obtained with directional structure, it makes sense to estimate the primary dendrite arm spacing (λ_1, μm - the main structural characteristic in directional solidification). In products with the lowest heat input at the substrate boundary, λ_1^{bottom} = 9.6 μm, and near the product upper surface, λ_1^{top} = 30.5 μm. In case of the largest heat input, λ_1^{bottom} = 7.6 μm and λ_1^{top} = 40 - 50 μm. On this basis, it is possible to calculate the values of temperature gradients at the substrate and the product surface, using the dependence:

$$\lambda_1 = A \cdot (G \cdot R)^{-n}, \tag{2}$$

where A is the coefficient proportional to the solidification interval; n is the dimensionless coefficient; G is the temperature gradient, °C/cm; R is the solidification rate, mm/s. Estimates made taking into account ratio (2) showed that for products "1" and "2" the value of temperature gradient changes from substrate to top in the range from 1493.87 to 9.8 °C/cm. And for article "3" the temperature gradient ranges from 3663.61 to 1.47 °C/cm. Thus, this paper shows that an increase in heat input reduces crack formation, but there is an enlargement of dendritic structure elements. This effect is undesirable for products with directional structure and further research is required to find a compromise solution.

REFERENCES

[1] A. V. Zavodov, N. V. Petrushin, D. V. Zaitsev, “Microstructure and phase composition of ZHS32 superalloy after selective laser melting, vacuum heat treatment and hot isostatic pressing,” Letters on materials, vol. 7 (2), pp. 111-116, 2017.

[2] Yao-Jian Liang, Jia Li, An Li, Xiao-Tong Pang, Hua-Ming Wang, “Solidification path of single-crystal nickel-base superalloys with minor carbon additions under laser rapid directional solidification conditions,” Scripta Materialia 127 (2017) 58–62.

[3] T. DebRoy, H.L. Wei, J.S. Zuback, et. al., “Additive manufacturing of metallic components – Process, structure and properties,” Progress in Materials Science 92 (2018) 112–224.

[4] D. A. Gurianov, S. V. Fortuna, and K. S. Osipovich, “Defects formation features of nickel-based superalloy product obtained by wire-feed electron beam additive manufacturing,” AIP Conference Proceedings 2167, 020125 (2019).

[5] S. Yu. Tarasov, A. V. Filippov, N. L. Savchenko, et. al., “Effect of heat input on phase content, crystalline lattice parameter, and residual strain in wire-feed electron beam additive manufactured 304 stainless steel,” Int J Adv Manuf Technol, volume 99, pages2353–2363(2018)

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