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ELECTRON BEAM ADDITIVE MANUFACTURING OF METAL PRODUCTS AS A PROCESS OF NONSTATIONARY METALLURGY: MATERIALS AND FEATURES

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Additive manufacturing (AM) is a technology that allows the formation of various products by gradually adding thin layers of materials [1]. This approach to product formation allows to produce complex or non-standard parts of the required shape and size without the need for expensive tools for machining and reduces the need for many traditional processing steps. This also reduces material costs, which is extremely cost-effective. For these reasons, AM is now a new paradigm for the development and manufacture of products for the aerospace, medical and other industries. For example, it is possible to produce fuel injectors or balloons for aerospace equipment that previously required multiple component assemblies, as well as lightweight engineering structures that result in significant cost savings. Medical and dental implants manufactured by the means of AM offer significant improvements in biocompatibility and integration of implants into patients [2].

Additive metal manufacturing processes are divided into two categories as defined by ASTM F2792: Directed Energy Deposition and Powder Bed Fusion. Further differentiation is provided depending on the primary heat source, such as laser, electron beam, plasma arc and gas-metal arc sources [1]. The process of electron-beam wire-feed additive manufacturing is the least studied of the above, however, is the most interesting in terms of nonstationary metallurgy due to specific production conditions. The range of materials used in additive manufacturing is very wide and includes structural steels, titanium alloys, nickel alloys, aluminum alloys and others. To study the features of the electron-beam additive manufacturing process, studies of steel 321 and titanium alloy Ti-6Al-4V samples obtained by this method were carried out.

One of the main features of non-stationary metallurgy is directional solidification. This is manifested in the ability of the material to crystallize in the direction of the temperature gradient. In most cases, due to the very rapid cooling and heat removal through the substrate, the main direction of growth of the dendrites in the steel 321 coincides with the direction of the product formation. In the case of titanium alloy, temperature gradient determines the growth direction of the primary β-phase grains. At the same time, the α- or α’-phase is also determined by the process temperature and the cooling rate. Another feature of the studied process is the ability to produce products with mechanical characteristics comparable to cast materials. Thus, steel 321, obtained by the method of non-stationary metallurgy, has a tensile strength equal to 536 MPa, while the literary value corresponds to the range from 510 to 650 MPa. A similar result is observed for the titanium alloy: 896 MPa, with a literary value of 900 to 1200 MPa. It is also worth highlighting the anisotropy of material properties caused by thermal history. For example, the microhardness of titanium alloy samples in the lower and upper parts of the sample differs by 10-15%. Primarily, this is due to a different structural-phase state in these areas and the ratio of the phases α and α’.

Consequently, the main way to control the crystallization process and the properties of the resulting products is to control the temperature conditions, which are determined by the printing mode and cooling rate.

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