High Productivity Additive Technologies: High-Speed Direct Laser Deposition and Non Vacuum Electron Beam Additive Manufacturing

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ABSTRACT

The article is devoted to the development of a new class of industrial machines, based on additive technologies. The most productive methods are considered – high-speed direct laser deposition and Non Vacuum Electron Beam Additive Manufacturing. The main design features and operating principle is described. The possibility of obtaining high-quality metal products using the developed equipment is demonstrated.

1 INTRODUCTION

Currently the additive manufacturing technologies are widely developed in all industrialized countries [1-4]. Using this technology instead of the traditional casting and machining technology can significantly reduce the material consumption of production and labor costs. They also allow to obtain products with preset operating characteristics. Currently it brought to the practical application of technology based on selective laser melting (SLM) of metal powders [5]. This method allows to obtain the details with small size and complicated configuration. The disadvantage of this method is low productivity. Thus in this series most large machine SLM 500 provides productivity up to 40 g/hour for titanium powder [6].

The main trend in the development of additive technology is increasing their productivity, while maintaining the required quality of manufactured products. formation occurs at feeding the material into the area under cultivation beam technologies of cultivation, where product formation occurs at feeding the material (powder or wire) into the area of cultivation under heating source (laser or electron beam), which providing heating and melting of metal, have a greater capacity [7-9]. The use these technologies offers a reduction in material costs and a decrease in manufacturing time compared with SLM (up to 80%).

The article presents the results of research in the field of machine design for additive manufacturing -Equipment for the realization of high-speed laser direct deposition (Institute of Laser and Welding Technologies, SPbPU, Russia) [3,8]and equipment Non Vacuum Electron Beam Additive Manufacturing (IW, Leibniz Universität, Germany).

2 HIGH-SPEED DIRECT LASER DEPOSITION

Technology of high-speed direct laser deposition (HSDLD) is one of most prospective technologies of additive manufacturing [4], which is developing at present [3,7,10]. Using this technology, product is formed from gas-powder jet, feed coaxial or lateral to laser beam, directly in the growing area, performing the controlled heating and incomplete melting of the powder particles, and heating the bedding. Productivity improvements of growth process requires increase of the laser power and speed of the cladding head motion regarding product. Modern high-power lasers, like fiber and diode, allow creating installations with growing productivity up to several kilograms per hour. For the implementation HSDLD process robots Fanuc used. This is a principal difference from the majority of the additive equipment, in which is used guiding bars. Fig 1 shows experimental equipment of Institute of laser and welding technologies.

Fig. 1 High-speed direct laser deposition equipment.

Laboratory bench using 5kW fiber laser LS-5, powder feeder with feeding rate up to 3 kg/h, high precision robot for cladding head movement, 2D rotation unit for product manipulation, chamber with Ar atmosphere and control system. In experiments of direct laser deposition, a number of parameters were ranged: laser power, laser beam spot size, linear velocity, layer height, powder and transport gas feed rates, nozzle geometry and inclination angle, nozzle standoff distance. The use of industrial robots allows to increase the number of degrees of freedom. And it allows increase the volume of the chamber up to several cubic meters without significant rising in price on equipment. Lateral and coaxial nozzles of different design are used for formed gas powder jets formation (fig.2).

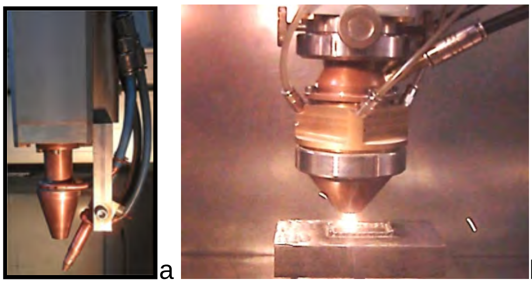

Fig. 2 Lateral (a) and coaxial (b) technological nozzle.

Technological head with lateral nozzle is not symmetrical with respect to the direction of motion when used roll building process depends on the direction of movement. Therefore, when using heads with lateral nozzle, growing should be carried out without changing of the tool movement direction relative to the product. Gas-powder jet formed in this nozzle has a simple structure is symmetrical with respect to the channel axis. It provides a fairly wide range of sustainable growing in the upper half of the jet. Technological head with coaxial nozzle is characterized by independent growing parameters on the direction of tool movement. Direct laser deposition technology is a complex and multifactorial process with a large number of parameters, which affect the result. The mathematical model was built, which had shown one possible way to get stable process with such productivity of growing process [10].

For all tested materials porosity of samples, produced by HSDLD, less than 0,05 vol.%, there are no cracking and non-metallic inclusions. Mechanical tests, made with series of 5 samples, shown, that properties of material which produced by DLD is on the level of rolled metal for steels and Ni-based alloys (table 2), and on the level of forged metal for Ti-based alloys.

State of material	$\sigma_{0,2}$, MPa	σ_B, MPa	δ, %
DLD	488±5	865±10	27,8±1,4
Rolled	414-758	827-1103	30-60
Annealed	414-655	827-1034	30-60
Casted	310	590	25

Tab. 2 Mechanical properties of Inconel 625

As a result of theoretical and experimental investigations samples of different geometry were prepared using coaxial nozzle and side nozzle. Fig.3 shows samples from nickel based alloys [11] – components of turbofan engine.

Fig. 3 Components of part of turbofan engine.

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3 NON VACUUM ELECTRON BEAM ADDITIVE MANUFACTURING

The use of electron beam (EB) in the atmosphere in additive equipment as a heating source not represented. Therefore, theoretical and experimental studies of the possibility to use the electron beam in the atmosphere for additive manufacturing is of great scientific and practical interest. Application EBAM (electron beam additive manufacturing) can work with the wire, and also with different materials such as steel, titanium, aluminum, copper and other [12,13].

Experiments on the additive production with the electron beam in an atmosphere held at the welding installation NVEB PTR NV-EBW 25-175 Institute of Material Science (IW) in the Leibniz University of Hannover. This setting has the following characteristics: maximum power of the electron beam of 24.5 kV, maximum current 140 mA and an accelerating voltage of 175 kV. Setup for the NVEBW shown on Fig.4.

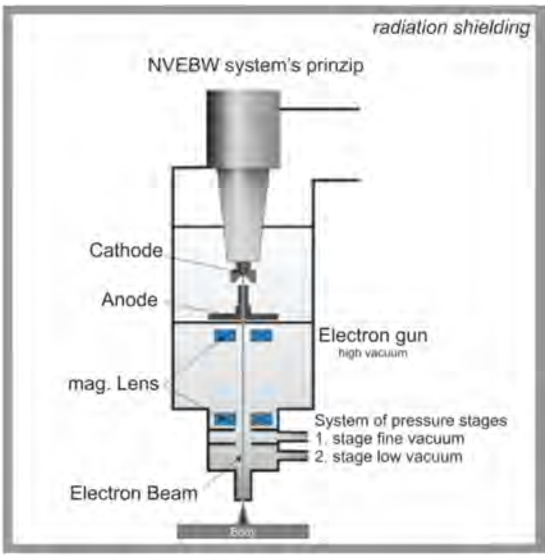
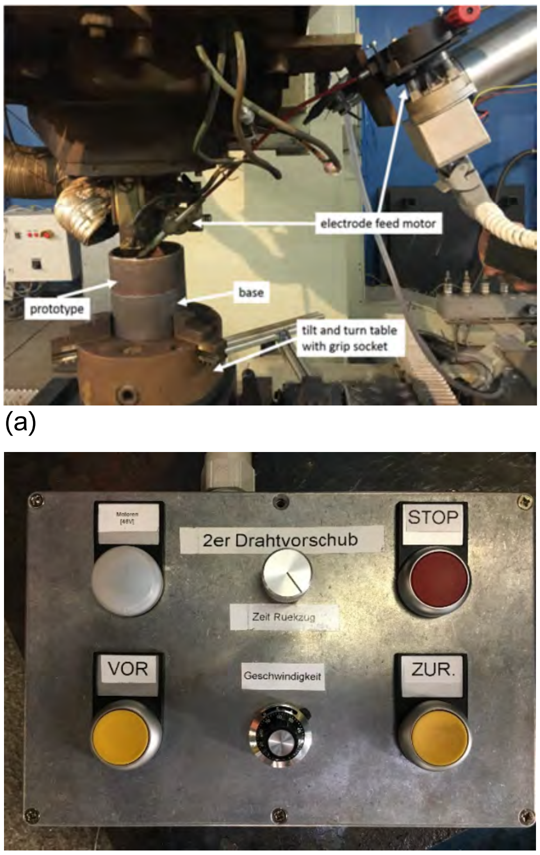


Fig. 4 Setup NVEB PTR NV-EBW 25-175 equipment.

This equipment has following design features: there is an opening for the outlet of the electron beam into the atmosphere, through which there is a constant suction of air into the vacuum system. Use of the powder material is not possible, so the metal wire was selected for testing. Wire feed device was constructed with the possibility of control the feed rate. During the experiments, the substrate for growing was fixed in the rotator at a controlled rate, and the wire was fed into the beam. Optimized setting for AM process with wire feed control are shown in Figure 5.

As the shape for growing axisymmetric shape of the part is selected. EB-gun moved only vertically without changing the wire feeding position, relative to the growth direction. The process was conducted in a continuous mode. Position the wire angle was selected ahead. Such a supply position of the wire leads to less formation of porosity in the material structure [14]. As a grown material Cu-based wire with diameter 1mm was used.

As a result, during the experimental studies tube-like construction from copper wire of 250 mm height and wall thickness of 3 mm was constructed on optimized equipment for Non vacuum electron beam additive manufacturing (Fig. 6).



(a)

(b)

Fig. 5 a) Optimized setting for the process NVEB-AM and b) remote control for wire feed.

Growing process occurred 60 minutes, the the process productivity was 1.9 kg / hour. According to the test results this setting has the potential additive manufacturing using wire as the grown material.

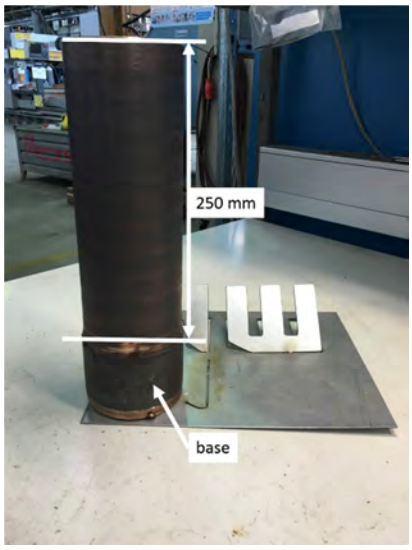


Fig.6. Tube-like construction from copper wire.

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