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Технологии и аддитивное оборудование для изделий из металлических, полимерных и керамических материалов в строительстве

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Аннотация. Актуальность темы исследования обусловлена мировыми тенденциями последних лет к применению новых технологий производства в совершенно различных сферах промышленности. Результаты исследования будут представлены по вопросу основных видов аддитивных технологий, наиболее распространённого оборудования и особенностей, связанных с использованием конкретных материалов. При написании работы в методологическом плане применялся метод анализа совокупности научных трудов, написанных по рассматриваемой теме. Задачи статьи состоят в том, чтобы: изучить основные аддитивные технологии; познакомить читателя с принципами аддитивной технологии; обосновать роль и влияние аддитивных технологий на сферу промышленности.

Ключевые слова: аддитивные технологии, аддитивное оборудование, металлические материалы, полимерные материалы, керамические материалы

Technologies and additive equipment for products made of metal, polymer and ceramic materials for construction

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Abstract. The relevance of the review is due to the global trends of recent years towards the use of new production technologies in completely different areas of industry. The results of the research on the main types of additive technologies, the most common equipment and features associated with the use of specific materials will be presented. In the process of writing the article, the analysis method was used. The analysis of many scientific papers written on the topic under consideration was carried out. The objectives of the article are: to familiarize the reader with the principles of additive technologies; substantiation of the role and influence of additive technologies on education for the construction industry.

Keywords: additive Fabrication, additive equipment, metal materials, polymer materials, ceramic materials

1. Introduction

Different types of materials are located in the basis of the production in the various industries. The issues of using metals and various metal alloys are considered in relation to such areas of production as mechanical engineering, technologies for space objects, etc.

Technologies are gradually developing and improving due to the work of the research scientists [1, 2, 3]. Ceramic products obtained using additive technologies are widely used in medicine, in particular in dentistry, space engineering, etc. Scientists from all over the world and in Russia in particular are also thinking about the application of this material and working with it using additive technology [4]. Also, in dentistry, such a group of materials as polymers has found its application. They are used for the manufacture of preliminary models, surgical templates, caps, etc. Technologies for the manufacture of the products made of polymers are constantly being improved and are subjected to the careful studies [5].

What is additive fabrication? It is a term that describes a special process of manufacturing a part, product or structure. Production is based on the initial creation of a CAD model (CAD - Computer Aided Design - an automated system that performs the functions of design using information technology) and adding material in layers. Between themselves, the applied layers are fixed by solidification or bonding. In another way, additive fabrication can be called 3D technologies.

While traditional manufacturing methods are based on cutting off a piece of material from a common piece (subtractive manufacturing) either on the use of special limiting elements filled with the material and creating the contour of future products (shaping manufacturing), additive manufacturing involves adding material layer by layer. The product is made exclusively on the basis of a digital 3D model, which means that the use of the modern computer programs and CAD systems is obligatorily. The whole process of additive manufacturing is holistic, continuous from product design to its manufacture [6].

2. Materials and methods

The results of the analysis presented in the paper were carried out on the basis of different classifications of additive fabrication.

Two directions in additive technologies can be distinguished, based on the principle of product formation.

- Bed deposition: The material is combined, it is located on the working surface of the technological equipment platform. When the process of manufacturing a part ends, a part of the material remains on the surface, which is not a waste, it can be used to create another part.

- Direct deposition: The material is deposited directly and that is how the element is formed. The element is manufactured in layers, the material is fed to the working platform heated to the required temperature from a device with a distributing tip [3].

Let us list some 3D technologies, highlighting the features of each of them, as well as positive and negative features.

- FDM (Fused Deposition Modeling). The material for the manufacture of the element is a plastic rod, which is passed through a special nozzle and fed into the print head. In the head, the rod is heated and fed to the working surface (the first layer), and then to the product itself. The material supply and the movement of the head and the working surface are controlled by an electronic system. Equipment control algorithms must ensure continuous polymer deposition, so there are limitations for the manufacture of parts with closed cavities. The polymer hardens after application.

Pros: the process is simple, and the equipment is affordable (the printer can be assembled by yourself); low production cost; low cost and availability of raw materials, as well as its great variety.

Cons: after the completion of the manufacture of the part, surface treatment is required; it is not possible to produce several parts in parallel.

- SLM (Selective Laser Melting). Material for manufacturing - powders from various metals and their alloys. Powder particles are melted in a sealed chamber in an inert gas (argon or nitrogen) and then welded together.

Pros: the scope is wide and practically unlimited; it is possible to create products with closed cavities, a large surface area and a small volume.

Cons: significant internal stresses in the part; materials with a high melting point have some limitations in use; expensive equipment and materials for the manufacture of products.

- SLA (Stereolithography). The material for manufacturing is a polymer in the form of a photopolymer resin. The working surface is immersed in a tank with a liquid photopolymer resin. Point lasers light from below on areas that, according to the 3D model, must be hardened to create the first layer. Further, the working surface rises by the thickness of the second layer, and the resin flows under the hardened layer. The operation is repeated according to the data for the second layer. Iterations are carried out until the part is finished.

Pros: the process of manufacturing is carried out by very thin layers due to that it is possible to achieve its high accuracy; the surface of the part does not require mechanical processing.

Cons: the necessity of the additional ultraviolet irradiation of the finished part to increase the strength of the product; products come out quite fragile; expensive equipment and printing materials.

3. Results and discussions

The feedstock for manufacturing using many of the additive fabrication technologies is presented in the form of a powder - a bulk material with a characteristic particle size up to 100 microns.

The general requirement for all powders is the shape of particles which should represent a sphere. This shape is the most acceptable due to the more compact filling of a certain volume and the minimum material resistance in the supply system in comparison with others.

In the industry, various methods are used to obtain powder, for example, plasma spraying of a rapidly rotating billet. One of the most common is the PREP method (plasma centrifugal spraying of a rotating billet), the advantages of which include obtaining dense gas-free particles of spherical shape [6].

Let us talk directly about equipment for working with metal raw materials. Certain requirements are imposed on metal powders: the chemical composition must be uniform, a certain bulk density, shape and particle size distribution. The «Granule» type plant of PJSC "Elektromekhanika" (figure 1) makes it possible to obtain a powder with a particle size of 20-70 microns, the content of gas elements is low, also the chemical composition of the resulting powder can be different, for example, heat-resistant nickel alloys, titanium, molybdenum, intermetallic compounds.

Figure 1. The «Granule» equipment works according to the PREP method.

The powder production technology has the following stages:

- creating a vacuum in the spray chamber;

- filling the volume of the spray chamber with a mixture of argon and helium;
- loading on the billet drums;
- clamping the workpiece to the drums with a roller;
- acceleration of the workpiece to the operating speed;
- turning on the plasma torch;
- setting the working gap between the end face of the workpiece and the plasma torch;
- start of the spraying process;
- longitudinal movement of the sprayed workpiece;
- cinder length control;
- stop the rotation of the workpiece;
- cinder dumping [6].

The powder is formed in the spray chamber, where a plasma torch and mechanisms for its movement are installed on the rolling door. Opposite the plasma torch, on the other side of the spray chamber, a drive unit is installed, inside it are the drums with an electric drive and a mechanism for moving the workpiece.

The equipment of the «Granule» type has an optical measurement of the gap between the end face of the workpiece and the plasma torch is carried out. The optical camera (figure 2) is directed to the spray area, it processes signals proportional to the radiation energy, and then transmits the information to the computer. There, the received data is processed, and a visual representation of the gap is carried out.

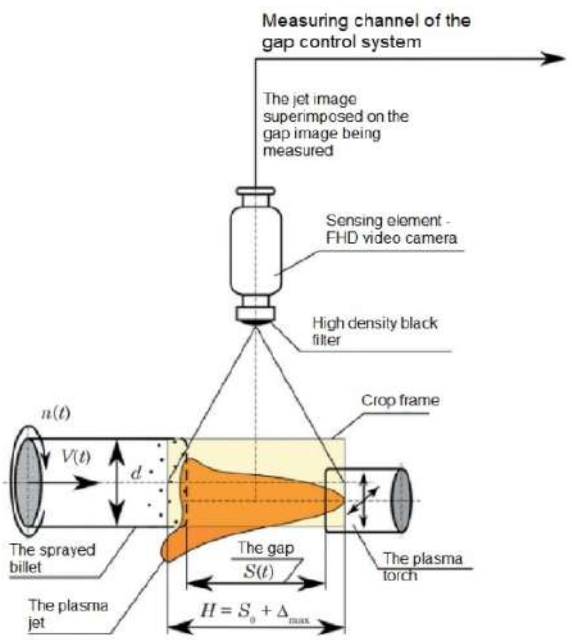

Figure 2. Signal processing by an optical camera.

The requirements for the parameters of the technological process determine the intensity of spraying the workpiece. It is also important to ensure the constancy of the value of the gap S(t) between the plasma torch and the workpiece in the plasma jet. This condition is fulfilled by the control loop for the longitudinal feed rate of the workpiece.

Powders from nickel-based heat-resistant alloys of the grades ЭП741 НП, ЭП962 П, ЭИ698 П, ЭП962 НП, ЭП975 П, Inconel 625M and the others, titanium alloys, TiAl intermetallic compounds, molybdenum were obtained on the «Granule» equipment (figure 3) [6].

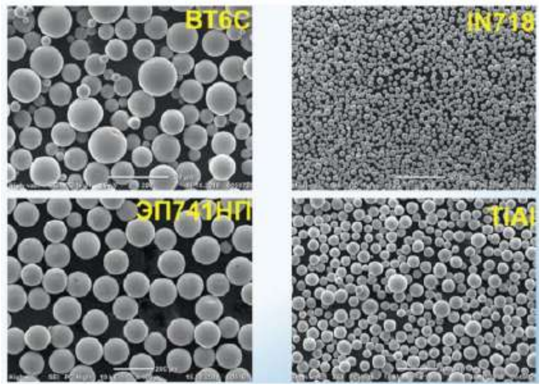

Figure 3. Nickel-based powders ЭП741 НП, titanium alloys TiAl, and others, obtained on the «Granule-2500» equipment.

Let's move on to the process of manufacturing the elements. PJSC «Elektromekhanika» manufactures «SLS-1» equipment (figure 4), which operates using the technology of selective laser melting (SLM) of metallic titanium, nickel powders and powders from other alloys.

Figure 4. The «SLS-1» equipment.

Laser radiation is generated by an ytterbium fiber complex with a power of 1000 W. Rotary mirrors carry out high-speed ray deflection. The table of the «SLS-1» installation is a load-bearing structure consisting of a supporting frame, a dosing hopper, mechanisms for dosed powder supply, leveling with a set of knives, and vertical movement of the substrate. The table is located in the working chamber, which is also equipped with actuators, infrared heaters, and a video camera. In addition, a vacuum station is installed in the working chamber, which provides a constant vacuum in the chamber and pumps argon to cool the gaseous medium and remove evaporation products. The working chamber is equipped with a gas purification system [6].

When the feedstock is a polymer, 3D printing is based on the transfer of the material into a viscous-fluid state, which is achieved by raising the temperature to certain parameters that are different for each type of polymer. As already noted, temperature is one of the key parameters in the implementation of 3D printing. Temperature conditions during printing are constantly changing both for the working platform and for the environment around the printed element.

Consider extrusion 3D printing with polymeric materials (FDM). The physical processes that occur during extrusion 3D printing are shown in figure 5 [5].

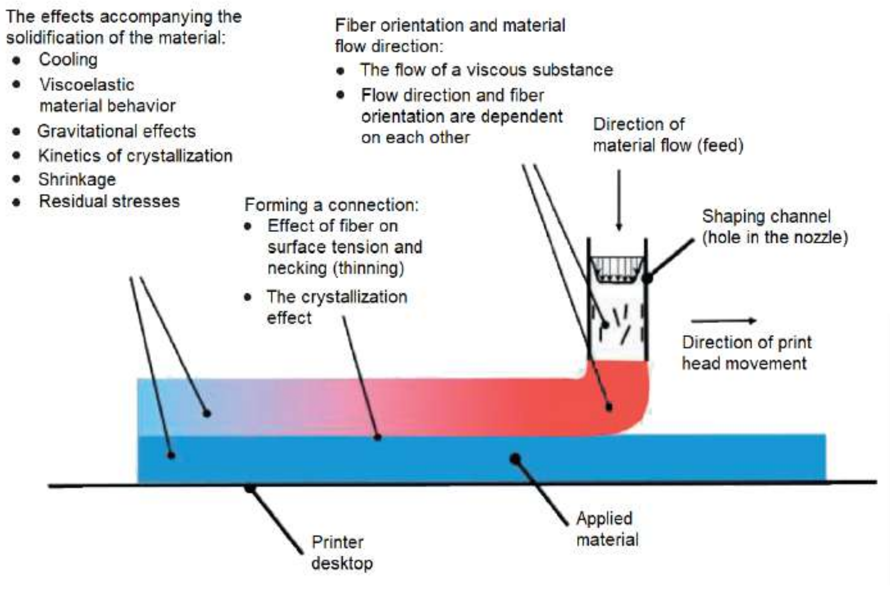

Figure 5. Extrusion 3D printing processes.

A standard 3D printer for printing using FDM technology consists of a body with guides and stepper motors fixed on it, as well as control electronics (figure 6). The printing process itself takes place on the desktop. The extruder or print head is controlled by algorithms and moves in the vertical and horizontal planes along the trajectory set by the computer-aided design system. The most often used coordinate system is Descartes in the form of a three-dimensional space with the X, Y, Z axes. The so-called delta robots use a cylindrical coordinate system [8].

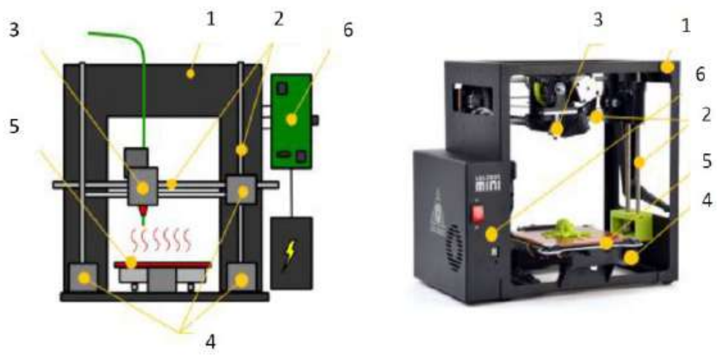

Figure 6. Scheme of the FDM 3D printer device: 1 - case, 2 - guides fixed on it, 3 - print head, 4 - stepper motors, 5 - desktop; 6 - control electronics.

Strong bonds, crystal and band structures, as well as other unique properties - all this leads to the widespread use of ceramic materials in various industries: from the jewelry and medical industries to the aviation and nuclear industries. Additive fabrication reduces scrap rates and increases production flexibility with ceramic materials, which can be produced quickly and with high precision due to advanced technology.

Let us have a look at the «AF-200 Universal» printer, a development of the Russian company LLC «Additive Fabrication». The 3D printer works on SLA technology, it is also accompanied by the company's own software and auxiliary equipment: a device for preparing a ceramic suspension and a furnace for heat treatment of the product obtained after printing. The production cycle for manufacturing a detail on the «AF-200 Universal» printer is shown in figure 7.

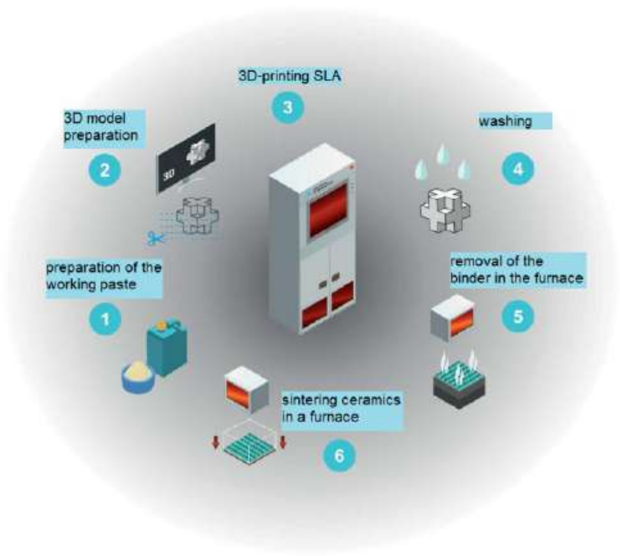

Figure 7. The production cycle of manufacturing a detail on the «AF-200 Universal» printer.

Let us take a closer look at step 3 of figure 7.

The material supply system and distributing knifes apply the ceramic slurry evenly onto the transfer ribbon. The construction of the object is carried out in layers "from the bottom to the top" on the working platform. To grow the product, the platform is lowered onto the surface of the ceramic paste, not reaching it by 20-100 microns (the gap is equal to the thickness of the printed layer). There is a laser under the transfer ribbon that illuminates the layer of the product. After that, the platform rises up. Operations continue until the part is completed. The created objects can be of various shapes and have a rather complex geometry; examples of ceramic products made using the SLA technology are shown in figure 8 [4].

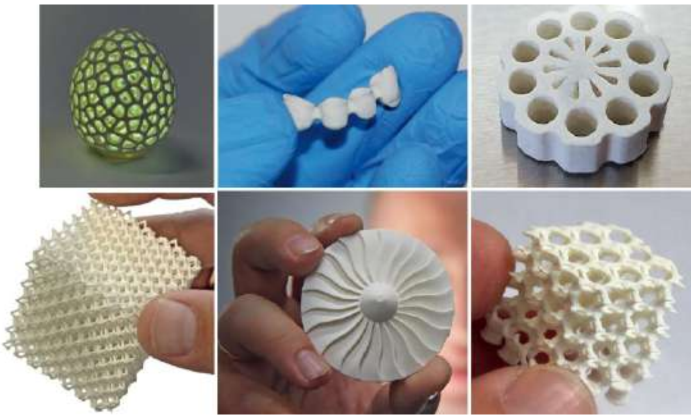

Figure 8. The examples of ceramic products made using SLA technology.

4. Conclusions & recommendations

Additive fabrication is becoming more and more common in various industries these days. It should be understood that additive fabrication technologies are not simple, which means that to working with these technologies requires qualified specialists who are ready to constantly develop in the chosen area.

It is necessary to attract young professionals from various industries, as well as managers at various levels to introduce technologies in fabrication. The advantage of additive technologies lies in the variety of raw materials, technologies and equipment, which allows the use of 3D printing in various industries. The economic component of the issue may become a limitation, this aspect requires a more detailed consideration, analysis and evaluation of the benefits of investing in personnel training, the purchase of equipment and the introduction of technology in general.

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