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3D printing of polymer matrix composites for space: A review and promises

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Abstract

Today scientists try to present technologies that can help in solving social issues. Three-dimensional printing methods are currently manufactured products for all industries. This paper provides an overview of the creation of high-temperature polymer composite materials by three-dimensional printing technology for space applications. Additive technologies make it possible to find a balance between the required physical and mechanical properties and at the same time to ease construction, which can significantly reduce the cost of manufacturing products in comparison with traditional materials and methods of processing.
To increase the physicomechanical properties and operating temperature of high-temperature plastics, composite materials are created with the addition of dispersed and fibrous fillers. The most common fillers are carbon and fiberglass.

Keywords: 3D printing, additive manufacturing, composite material, space;

1. Introduction

Additive technologies for the production of products containing polymeric materials are considered to be fast-growing, due to their technological simplicity, good quality of the products obtained (compared to polymer products obtained by classical technologies) and wide range of applications. Recent developments have been actively carried out to create new high-temperature polymer composite materials using additive technologies for space applications.

The requirements for the physical and technical properties of products and operating conditions significantly limit the use of traditional materials in the space industry, primarily due to high operating temperatures.

The development of new materials and methods for their processing is one of the priority areas for the development of modern materials science, inextricably linked with the development of new technologies for producing materials of new quality with a new set of operational properties.

2. Methods

Research work on the technology development and the creation of three-dimensional printing equipment (3DP) with high-temperature polymer composite materials is actively gaining popularity today. Previously, printing with such materials was carried out according to the technology of electron beam melting (EBM) [11] and selective laser sintering (SLS). Pre-processing of three-dimensional models is carried out using commercial software MAGICS RP (Materialize NV, Leuven, Belgium). The main advantage of these technologies is printing at high temperatures.

With the growing popularity of creating high-temperature composite materials, a new equipment for processing them is being developed.

Three-dimensional printing with high-temperature plastics by surfacing modeling (FDM) is gaining popularity [3, 14, 12]. For printing with high-temperature plastics, 3D printers with an extrusion temperature of up to 500 ° C [19, 7] and also printing at room temperature with the usage of reactive extrusion [15, 17] are being developed.

To improve the performance of plastics and to expand the application of FDM technology, Continuous Scaled Manufacturing (CSM) technology has been developed [13]. The incorporation of continuous fiber into a polymer composite by the CSM method is a new and promising innovation in creating a new generation of composite materials with unique properties. However, the anisotropy of properties narrows the scope of such a material [8], so this is both an advantage and a disadvantage of products made from such composite materials.

3. High performance composites

High-temperature polymers are polymers suitable for continuous operation at temperatures above 150 ° C [5]. Composite materials based on these plastics are suitable for use as critical parts in various industries.

The group of these polymers includes: polyimide (PI), polyetherketone ether ketone ketone (PEKEKK), polycarbonate (PC), polyether ether ketone (PEEK), polyetherimide (PEI), polyphenyl sulfone (PPS), polysulfone (PSU) and others. The main properties of plastics are shown in table 1 [9].

Table 1. Properties of unfilled high temperature plastics

Thermoplastic type	Density, g/cm^2	σ^+, MPa	E^+, MPa	Notched Izod, J/m
PI	1.43	120	3700	43
PEKEKK	1.31	120	4600	60
PC	1.20	69	2380	95
PEEK	1.3	220	4000	86
PEI	1.27	105	3000	53
PPS	1.36	82	3800-4300	69
PSU	1.24	80	2480-2600	80

A number of requirements arise for high-temperature plastics for use in space conditions, namely: resistance to low temperatures, fire resistance, radiation resistance, physical and mechanical strength.

The best way to increase the strength characteristics of plastics is fiber reinforcement [2]. The main method of manufacturing such composites is the introduction of various fibers into the polymer matrix. The most common fibers used for hardening polymers are carbon, glass, and aramid fibers [1, 10].

Existing work on the creation of filled polymers indicates an increase in physical and technical properties without a significant change in the cost of production, which is also relevant. Upon receipt of products carried out by the method of additive technologies with the correct selection of modes, it is possible to obtain the orientation of the fibers in the product, which leads to improved properties of the material in a given direction [4]. One of the important characteristics affecting the properties of the composite is the fiber length. The longer the fiber is, the higher the strength characteristics are. The adhesion of the matrix and the filler is the main reason of this strengthening. The fiber orientation during three-dimensional printing is also important [6]. When forming a product with a distribution of fiber stacking during printing in the direction other than stretching, a less effective increase in mechanical properties is observed.

The radiation effect on polymer systems is a well-known field, and studies of the mechanical properties of polymers after gamma radiation remain a subject of great interest. The percentage of air gap in the product can greatly affect radiation chemistry, since the material has less free oxygen. Currently, space applications of plastics such as acrylbutadiene styrene (ABS), polylactide (PLA), and Nylon-6 have been studied [18]. However, research in this area is still relevant.

During 3D printing in a zero-burst experiment (3DPrint), the FDM printer was developed by Made In Space (MIS) and launched in September 2014 [16]. This printer performs polylactide (PLA) printing due to its low extrusion temperature and non-toxicity. Printing with high-temperature plastics in space has not been carried out at the moment, which can be potentially interesting, because approximately 28.6% of parts requiring replacement during a space mission are plastics and composites [20].

4. Conclusion

Traditional materials such as aluminum, steel, gold have a lot of weight when creating spacecraft. Materials such as plastic, by their nature, do not have much weight; 3DP can significantly help us reduce costs: saving mass for spacecraft, as well as creating more ergonomic designs. The introduction of new technologies for space applications is not so fast, and space missions are very long. However, the potential savings in mass and time that 3DP can offer are extremely beneficial, therefore, there is a huge advantage in the development of additive technologies for space applications.

Currently, polymers are used for small spacecraft, such as CubeSats, it is necessary to develop new high-temperature composite materials to increase the life of these devices.

On the whole, the current state of research in the field of 3D printing with high-temperature polymer composites is still at an initial stage, despite the identification of some general laws of the formation of the structure and properties of products in 3D printing.

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