Application of numerical simulation systems when using composite materials used in additive production

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Abstract. Composite materials are widely used in modern production processes. Polymer composite materials, especially from the ABS group with different physical and mechanical properties have great potential in the field of electronic industry. To date, additive technologies are actively used, which requires a new approach to modeling the physical properties of various polymers, passing into a new state at the time of homogenization. For products made of polymeric materials with the use of additive technologies is characterized by the dependence of the final mechanical properties not only on the design, but also on the technological modes of manufacture, as in the manufacturing process is formed by a complex spatial structure of the layers, which leads to heterogeneity of the properties of different parts of the product. The structure of polymers is related to the properties of the final product and the level of quality.

1. Introduction

Now, enterprises and organizations of the radio-electronic industry have maintained a positive pace of development of production and scientific and technical activities. That involves the use of new technologies in production.

Commercial operation of electronic equipment often occurs under the influence of various external factors. To produce products from composite materials, it is necessary to use numerical simulation systems when using composite materials used in additive manufacturing to save resources and reduce the time for testing. In order to avoid emergency situations during the operation of the equipment, it is necessary to simulate the external environment considering the properties of composite materials [1,2].

2. Application of systems of numerical simulation considering polymers

Now, for a wide range of products, the procedure for selecting production technologies is used. For additive manufacturing, it is also necessary to consider the polymers used in the production of figure 1 [1,3].

The classical approach, based on the use of averaged material parameters in the design of the product and not considering the anisotropy of the material properties in different areas of the product, leads to the fact that the final product has characteristics different from those required. In addition, this approach involves the laying of large reserve factors, which in turn leads to an increase in the mass of the final product and a significant increase in material consumption [3,4].
Layer-by-layer synthesis or additive manufacturing refers to the process of manufacturing products based on digital prototypes. The construction takes place layer by layer. This fact significantly distinguishes additive technologies from traditional ones, which implied the process of cutting off excess material. The use of additive technologies radically changes the production process itself. In this case, the construction procedure can be any: top-down or bottom-up. The use of different in their properties and composition of materials and suitable technologies allows to obtain models with different physical characteristics and capabilities. Figure 1 shows the additive manufacturing process.

![Additive Manufacturing Process Diagram](image)

Figure 1. Application of additive technologies in production.

Application of this technology for production Complex Elements is Economically advantageous in small-scale production, compared to Traditional technologies such as Injection Molding and allows to achieve significant strength indices, table 1.

| Material                     | Tensile strength (MPa) | Tensile strength per unit mass (MPa) |
|------------------------------|------------------------|-------------------------------------|
| Aluminum alloy               | 1.0                    | 1.0                                 |
| Steel                        | 5.0                    | 1.7                                 |
| Poly-n-phenyleneterephthalamide | 5.4                  | 10.0                                |
| Polymers                     | 5.8                    | 15.0                                |
| Ceramic threads              | 25                     | 50                                  |

The number of polymers used in additive production considered in the composite materials 45 of the ABS group.

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Establishes mandatory requirements of specification, each of which must be strictly adhered to: Temperature, strength, modulus, and so polymer must be greater than or equal to the relevant number specified in the technical specification. If at least one requirement of the technical specification is not met, the polymer is not suitable for filamentation

\[
1 \text{ (true)} = TF1 \geq TK1 \\
1 \text{ (true)} = TF2 \geq TK2 \\
1 \text{ (true)} = TF3 \geq TK3 \\
1 \text{ (true)} = TF4 \geq TK4 \\
1 \text{ (true)} = TF5 \geq TK5 
\]

Where TF is the requirement for the polymer, TK - requirements specification.

If the polymer meets all the requirements of TK, then set 5 logical 1 (true). If at least one requirement is not met, at least one logical 0 will appear.

Apply the logical operation "N", which will set 0. "N" =1(true) if all operands are equal to one.
"N" =0(false) if at least one operand is zero.
\[ C_F = \bigcap_{i=1}^{n} a = 1 \]

\[ a_i = \begin{cases} 
0, & \text{if } x_i < x_{0i} \\
1, & \text{if } x_i \geq x_{0i} 
\end{cases} \]

\( x_{0i} \) - i requirement of TK; 
\( x_i \) - characteristics of the polymer corresponding to the i-th requirement TK. Operation implemented in the cell of "fit polymer".

**Table 2.** Materials and areas of application.

| Polymer name | Tensile strength MPa | Bending strength MPa | Elasticity module MPa | The temperature of deformation beginning at 1.82 MPa in 0°C | Softening temperature on Vika at 5 kg/m2 in 0°C | Polymer is suitable (true) or unusable (false) |
|--------------|----------------------|----------------------|-----------------------|-------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| ABS          | The truth            | The truth            | The truth             | Lie                                                          | The truth                                    | Lie                                           |
| ASA          | The truth            | The truth            | The truth             | The truth                                                    | The truth                                    | The truth                                    |

There are three possible situations:

\[ a_1 = \text{no suitable polymer in the group. } TK \leq \text{Polymer} \]

\[ a_2 = \text{only one suitable polymer in the polymer group.} \]

\[ a_3 = \text{several suitable polymers in the group. } F_1 \geq F_2 \]

The field of selection of suitable polymer is simulated on physical properties. The data were recorded in Excel Files that are used for input into FE programs such as Abaqus Unified FEA. Input data for Abaqus were directed to stress and plastic deformation analysis in different temperature environments. The areas of nominal stresses in different temperature modes are determined. That allows to predict for what temperature modes the body of REA, executed from various composite materials is intended.

For successful use of composite materials, it is necessary to consider the Farewell scheme of the inner part of the head Additive installation.
Figure 2. Structure of the polymer filamentation process.

Phase 1. There is an incoming cold polymer. Its properties have not yet changed from heating, so its resistance to movement is determined by friction against the wall.

Phase 2. Green. In this part, the polymer is already somewhat heated by the walls and its mechanical properties deteriorate, but the fluidity is not yet manifested.

Phase 3. The temperature becomes higher and the plastic deformation of the bar begins. Under pressure, it is distributed to the sides, forming a piston.

Phase 4. In this zone, the polymer must be melted to the center, that is, completely. Otherwise, if the nozzle is not suitable molten core, there is uneven extrusion of plastic. This phenomenon was well observed with a polymer of 1.7-1.8 mm and a nozzle diameter of 1 mm, at a polymer feed rate of 490-900 mm / min.

Section 5 - flow compression zone the shape and length of this section is not too important-the smaller the length of this section, the better.

Section 6. The end of the nozzle. The tip is up to 0.45 mm. This is the area with the greatest resistance, so its length greatly affects the resistance. With a length of 0.45 mm and a nozzle diameter of 0.25 mm, as it turned out, 48% of the total resistance accounted for this area. It should be borne in mind that the lengthening of this section leads not only to a decrease in speed, but also has a smoothing effect on the polymer supply, reducing bloating at high speeds. Strength parameters are shown in table 3.

Table 3. The performance of polymers and melt flow index.

| Polymer          | Temperature interval Processing K | The conditions determining melting Load, H | Temperatures, K | Operating temperature range, K | The energy of activating the viscous current, kJ/mol |
|------------------|----------------------------------|------------------------------------------|----------------|-------------------------------|---------------------------------|
| AbsPolymer (TU 6-05-1587-84) | 483-524 | 217.1 | 484 | 229-339 | 45 |
Of the variety of polymers for use at high temperatures suitable ABS polymers with additives of materials to increase the melting point.

3. Simulation of physical loads
Based on the data on the temperature regimes of polymers used in additive manufacturing, simulation of mechanical deformation of polymers was carried out.

From the position of the theory of rates of chemical reactions, the process of creep was considered and a formula for the rate of deformation of metals was proposed by V. Kaushman, and a similar formula for the rate of deformation of polymers was proposed by A. Alexandrov.

\[ \varepsilon = \varepsilon_0 \exp\left[-\frac{Q_0 - \alpha \sigma}{RT}\right] \]

Where is \( \varepsilon_0 \) - frequency factor; \( Q_0 \) - the energy of activation of the creep process; \( \alpha \) - constant, characterizing the activation volume, \( RT \) - the average value of specific kinetic energy.

At present, inelastic deformation plastic for crystalline bodies and forced elastic for polymers is considered as a process occurring in time under the influence of stresses with the participation of thermal fluctuations, figure 3.

Figure 3. The calculation of the maximum loads at different temperatures of polymer articles, produced by layer-by-layer synthesis.

The joint load on the product of the digital model, calculated at the output of this scheme, characterizes the expected probability of obtaining each result of operation under temperature conditions [8]. That, depending on the material can withstand the load from 10-550 N/mm².

These calculations are aimed at reducing the level of defects based on the stages of plasticization were developed and implemented corrective actions to change the temperature regimes in the process.
documentation. Implementation of corrective actions made it possible to achieve statistically controlled behavior of the process, set to the middle of the tolerance field figure [5,6,7].

References
[1] Chabanenko A V and Yastrebov A P 2018 Quality Assurance of Hull Elements of Radio-Electronic Equipment by Means of Control System IEEE International Conference "Quality Management, Transport and Information Security, Information Technologies" (IT&QM&IS) pp 394-8
[2] Chabanenko A V, Frolova E A, Balashov V M and Smirnova M S 2018 Electrodynamic analysis of materials for the antenna elements IOP Conf. Ser.: Mater. Sci. Eng. 450 022009
[3] Batkovskiy A M, Kalachikhin P A, Semenova E G, Fomina A V and Balashov V M 2018 Conficuration of enterprise networks Entrepreneurship and Sustainability Issues
[4] Batkovskiy A M, Nesterov V A, Semenova E G, Sudakov V A and Fomina A V 2017 Developing intelligent decision support systems in multi-criteria problems of administrative-territorial formations infrastructure projects assessment Journal of Applied Economic Sciences
[5] Maiorov E E, Prokopenko V T, Mashek A C, Tsygankova G A, Kurlov A V, Khokhlova M V, Kirik D I and Kapralov D D 2018 Experimental study of metrological characteristics of the automated interferometric system for measuring the surface shape of diffusely reflecting objects Measurement Techniques 10 1016-21
[6] Chabanenko A V, Semenova E G, Smirnova V O, Smirnov A O and Rozhkov N N 2018 Quality Assurance of Additive Production through the System of Control of Layer Synthesis Questions of radio electronics 10 75-9
[7] Chabanenko A V 2018 Quality management of case elements of REA RIA Standards and Quality 2 90-4
[8] Nazarevich S A, Rozhkov N N and Polyakov S L 2016 Models for assessing the quality of core and innovative products of enterprises Questions of radio electronics 6 40-6