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ON THE POSSIBILITIES OF USING VARIOUS PLASTICS TYPES FOR 3D PRINTING OF SUBMERGED MARINE DEVICES PARTS

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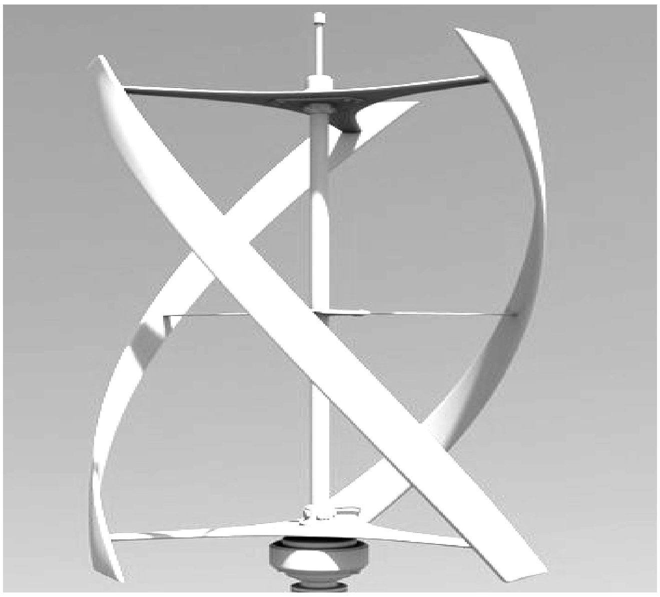
Abstract. *The possibility of using 3D printing technology for the production of parts for the underwater devices operating in the marine environment is considered. It is substantiated that this technology can be effective for small-sized (about meters) parts of complex geometry, which, for example, are included in low-power (possibly modular) installations for collecting clean marine energy, as well as for a variety of ship devices (such as ship stabilizers, steering devices, other parts with complex geometry), etc. Various types of plastics used today for 3D printing are considered, taking into account the need for their operation in the marine environment. It has been established that the best technical and economic indicators of the production process can be achieved using ASA type plastics, and if not to take into account the price factor, the best solutions will be PC-ABS and HIPS type plastics. In general, the most common ABS plastics can show satisfactory results (while the PLA option is not applicable in this case).*

Keywords: *3D printing, additive technologies, types of plastics, marine environment, strength characteristics, chemical stability.*

Introduction.

Today, it is possible to indicate a variety of industries where parts of complex geometry should be used. For example, one such application is the blades of wind power plants with a turbine with a horizontal axis - Fig. 1, a. However, surface complexity is even more evident in vertical axis wind turbines. For example, in Fig. 1, b is shown an installation with helicoid blades, obviously having an extremely complex geometry. The efficiency of using a turbine is largely determined by the accuracy of the blades surface, and in the case of complex geometry, deviations that are difficult to determine visually during a superficial inspection can lead to a drop in the efficiency coefficient by a percents or more (which can be considered significant due to the fact that the coefficient itself is values about 20%).

Obviously, products of such complexity can hardly be manufactured by simple technological operations such as rolling or other methods of steel bending. In this regard, the traditional manufacturing technology for wind turbine blades is their molding from composite materials, and one of the most serious problems in wind energy is the disposal of these parts of the wind turbines. Thus, there are still no known methods for processing wind turbine blades made from composites that are effective from a technical and economic point of view. Today they are simply buried in the ground until future methods for reliably recycling them become available. Thus, it is advisable to search for alternative materials for the manufacture of turbine blades that allow for simpler recycling and are applicable at least in certain special cases when implementing such installations.

a) b)

Figure 1 - Elements of wind energy systems with complex geometry:
a – *for turbines with a horizontal axis*, **b** – *for turbines with a vertical axis*

Further, it should be noted that a fairly promising way to generate clean energy is to place turbines with horizontal and vertical axis under water, in places where there are noticeable horizontal water flows. These can be river beds, but also sea currents on the shelf or in open sea. A number of research works is currently underway to develop new installations for underwater use [1-5]. However, in this case, the material of their blades and other parts with complex geometries imposes additional requirements related to chemical resistance to sea water, UV sun radiation, vibrations and other dynamic mechanical loads.

It should be noted that parts with complex surface geometry may be necessary not only for power plant turbines, but also for other underwater devices that interact with water flows. For example, these could be ship propellers, rudders and thrusters, stabilizers (passive and active), structures such as floating buoys, etc.

Thus, it is necessary to analyze the possibility of using other technological processes for the production of parts with complex surface geometries, depending on the various features of such parts (primarily their size), as well as operating conditions (the main interest in this work is focused on application in underwater marine devices).

Main text

The main assumption that will be substantiated in this work is the possibility of using 3D printing technology to create parts that operate in underwater marine conditions.

The obvious and main advantage of three-dimensional printing as a technological process is the ability to realize solid bodies of arbitrary, almost any complex shape, subject to sufficiently high accuracy.

From a technological point of view, the creation of parts from composites requires a number of actions, of which the following can be distinguished:

- preliminary preparation of appropriate forms that implement the same complex geometry, which is a difficult task; when 3D printing, no preforms are needed;
- filling forms with reinforcing elements that form the strength frame of the product (in the case of 3D printing, production is carried out in one stage, which is simpler from an organizational point of view);
- filling the remaining volume of the part with a binder mixture.

The last stage is especially difficult to perform, which requires, for example, the vacuum infusion method. The strength of the resulting final product depends on the quality of this process. Obviously, when performing 3D printing, there are no difficult steps to perform, except for heating the plastic above its melting point.

Also, since in comparison with the formation of composite parts, the layer-by-layer production process is much simpler to implement, therefore it can be automated in a much better way. Today 3D printing devices operate in an almost fully automatic mode (with the exception of the possibility of unexpected breakdowns or disruptions in the technological process caused by significant external factors). To the contrary, the share of manual work in the formation of composite objects (especially very large ones) is still quite high.

An important disadvantage of the volumetric plastic printing method is the relatively small overall size of the manufactured products. Thus, it is currently not possible to cheaply produce parts larger than 1-2 meters in size. Typical sizes of parts that can be produced with using printer machines, accessible to a wide range of consumers, are shown in Table. 1 [6].

Table 1 - Parameters of available industrial 3D printers

Brand	Product	Build Size	Country	Price, $
Modix	BIG-Meter V4	1010x1010x1010 mm	Israel	13,500
CreatBot	F1000	1000x1000x1000 mm	China	29,999
BigRep	BigRep ONE v4	1005x1005x1005 mm	Germany	30,000
3D Platform	400 Series WORKBENCH XTREME	1000x1500x700 mm	United States	49,999
Tractus3D	T3500	1000dx2100mm	Netherlands	59,000
The Industry	MAGNUM	1500x1200x1200 mm	Sweden	135,000
MASSIVit 3D	Massive 10000	1420x1110x1500 mm	Israel	upon request
Modix	MAMA	2000x5000x1000 mm	Israel	upon request

From the above list, the Tractus3D model deserves most attention, which allows to print products with a length of 2.1 m and a radius of 1 m, which is well suited for the case of a shape close to cylindrical (such as, for example, a turbine rotor with a vertical axis - Fig. 1, b). As it is seen, the estimated price of the hardware (59 thousand dollars) is quite affordable in terms of the fixed assets of production (it is implied that the hardware is used in business processes for the regular production of the blades for energy generators or similar devices).

An important disadvantage, as it may seem, is the small sizes of the products provided by average-cost printers, which are extremely far from the values of hundreds meters, which are necessary, for example, for the production of blades for modern wind turbines. However, in fact, this circumstance only indicates the scope of 3D printing, which is limited to small installations of low (about kilowatts) power. Such installations can meet the energy needs of small business and private households, and can also be united into arrays, collectively delivering quite competitive electrical power.

The small sizes of parts made from plastic also solve the problem of their (probably) insufficient mechanical strength when making products tens of meters long (even without seam joints), and also larger ones obtained by thermal bonding of separately printed blocks. Solid plastic products with sizes of about meters are able to provide the required reliability and endurance in relation to mechanical loads acting integrally on the entire product. At the same time, the overall strength of a 100 m long blade made of plastic can be questionable and requires detailed calculations for an accurate assessment.

An important advantage of plastic products is the ease of disposal – the most important factor that calls into question the overall environmental efficiency of existing wind generators. The shredding of plastic products followed by secondary melting and extrusion of plastic filament is a process that can be carried out on an industrial scale for all types of plastic (although, of course, it should be noted that some types of plastic, such as ABS, are recycled at much more many places compared to PET-G products). It should be remembered that effective processing procedures have not yet been created for composite materials.

Moving to the specific choice of the plastic type, it should be noted that the most suitable for use in marine conditions is ABS (acroleinitrile butadiene styrene), which is also widely available on sale and is one of the standard materials for 3D printing. An important feature of ABS plastic is the strong recommendation for printing in a closed chamber, which reduces thermal deformation in the product, prevents cracking and so-called delamination (when different layers applied over time peel off from one another) during shrinkage. This feature is also observed in plastics such as Nylon and HIPS, which are quite promising (for the purposes of implementing the power elements of the marine devices structures). An important advantage of ASA (acrylonitrile styrene acrylate) plastics is their increased resistance to ultraviolet radiation and aggressive chemical substances, which can be very useful when producing parts for use in aggressive salty marine environments. At the same time, the mechanical characteristics of this type of plastic are not inferior to ABS, but can even exceed it in some applications.

The most widely used, cheap and easy to process, plastic PLA is not suitable for the conditions of the problem under consideration, since it does not have high strength and has a low melting point. This leads to that even at 60 Celsius that is actually achievable in marine conditions (for onsurface elements under tropical sailing conditions) this plastic may be subject to deformation.

Another HIPS (high impact polystyrene) plastic option is positioned as highly durable and suitable for shock loads. It, also like ABS, has good thermal stability, which causes significant shrinkage during the production of the part. Consequently, it requires increased manufacturing process parameters that do not allow significant temperature differences between different points of the product.

PET-G plastics provide high strength along with ease of processing. The characteristics of these types of plastic, as well as several other types, are given in Table 2.

Table 2 - Characteristics of various plastics types for 3D printing of submerged marine devices parts

Type of plastic	PLA	ABS	PET-G	HIPS	ASA.	PC-ABS	Nylon
Mechanical strength	Low	High	Average	Very high	High	Very high	High
Chemical stability	Low	Average	High	Average	High	Average	High
UV stability	Low	Average	Average	Average	High	Average	High
Heat stability	Low	High	High	High	High	High	High
Shrinkage	Small	High	Small	High	High	Average	High
Difficulty in post-processing	High	Low / acetone	Average	Low / limonene	Low / acetone	Low	Low / mechanical
Price	Low	Low	Average	Low	Average	High	High
Applicability for marine device parts	Doesn't fit	Fits good	Fits	Fits good	Fits very good	Fits good	Fits good

Summary and conclusions.

It was established that ASA plastic has the best balanced characteristics (if to include the price factor). In the case when the price factor is not decisive (for example, if it is not considered mass production of the parts, but piece production, for development work), then PC-ABS and HIPS plastic options may be more preferable. These options provide excellent mechanical characteristics of strength, resistance to external factors of the marine environment, and are also easy to process, which also allows them to be manufactured into larger parts (this issue requires additional research, due to the fact that parts of marine devices are periodically exposed to significant external loads). In any case, for the implementation of parts for a variety of small modular installations (about meters in size), the option of 3D printing using the specified types of plastics is extremely promising (for all the material selection factors).

In case of the limited availability of plastics types (for example, due to the limited capabilities of the 3D printer model used), the extremely common ABS plastic can provide quite acceptable characteristics of strength and resistance to various negative environmental factors. This type of plastic, in particular, is successfully used by home users of 3D printers, as well as by small companies to produce the hulls of light boats, which, as practice shows, serve for many years, requiring only occasional minor maintenance (which is easy to carry out due to the described properties of this type of plastic). All of the above types of plastic are subject to recycling, however, in the case of ABS plastic, the list of organizations that accept it for recycling is much wider than for some other options (for example, PET-G).

Thus, in general, it is possible to argue that the use of 3D printing for the production of parts for submerged marine devices is quite promising and can be considered as the main technological process for the mass production of relevant products.

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