Search for plastics with piezo optic properties

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Abstract. The work is devoted to the search for plastics used in 3D printing, which have pronounced piezo optic properties. A review of the works devoted to the study of various characteristics of plastics is performed. It is established that there is currently no data on the piezoelectric properties of consumables for 3D printing. The various brands of plastics widely represented on the market are analyzed. Between them, those that transmit light well were selected. Experimental studies of widely available transparent plastics were performed. The photoelasticity method is used in the work. Several grades of plastics with birefringence have been identified. In the future, it is planned to use these materials for printing models of nodal points of spatial structures on a 3D printer in order to obtain stress fields in them.

1. Introduction

Through the application of the appropriate technical support, it is possible to solve almost any problems on the models, those are associated with ensuring the reliability of structures and objects as a whole. The use of modeling in construction science allows to make a research in a shorter time than when analyzing field samples, and, in some cases, is the only possible way. Modeling allows you to effectively solve a large number of complex problems: to identify, with minimal material, labor and cost, a real picture of the efforts distribution in all characteristic sections and nodal interfaces of structural elements; to analyze the stress state of a complex structure instead of an analytical calculation, when it is difficult to use methods of structural mechanics and elasticity theory; to check the correctness of the hypotheses underlying the analytical calculation; to clarify the design scheme of the structure; to determine the nature of the destruction and the breaking load; to estimate the real margin of safety of the structure; to establish the influence of various factors on the work. For the new complex structures, the research can be carried out according to the following scheme: the mathematical modeling or research of a small-scale model using computer programs; the study of a large-scale model; the full-scale tests of the structure or its individual units and elements with the practical use of either physical, analog, or mathematical modeling using polarization-optical methods or holographic models. There are several modeling methods - the creation of physical models of objects, the subject-mathematical and logical-mathematical modeling.

Currently, there is a number of piezo optic materials that are used in the method of photoelasticity for the models manufacturing in order to study the stress state of structural elements and assemblies [1]. Epoxy resin and plexiglass grade E2 are the best of those that are available to us today. At the same time, E2 grade plexiglass has been discontinued, and the manufacture of models made of epoxy...
resin is associated with technological difficulties (it requires a room equipped with an exhaust hood, heating the material with a blowtorch to eliminate residual stress). Modern building structures imply the presence of nodes of complex configuration, to study the stress state of which, the application of photoelasticity is very important. But, due to their complex configuration, it is difficult to make models of such units from Plexiglas grade E2 or epoxy resin. In the last decade, the 3D printing has been widely distributed in various branches of science. Given all of the above, the idea of using 3D printers for the manufacture of three-dimensional samples arose [2]. And this, in turn, required the exploratory research to identify plastics with piezoelectric properties. Available publications allow you to get acquainted with the overview of plastics used in 3D printing, as well as with the technology of their manufacture [3-6]. There are a number of studies devoted to the determination of the mechanical properties of products made of ABS plastic [7,8] and the acoustic properties of plastics [9]. There are works aimed at studying of the influence of printing speed and heat treatment on the strength characteristics [10,11], improving the surface quality of parts [12]. The scientific papers [13-18] considered the physicomechanical, rheological, and fireproof properties of thermoplastic compositions based on polycarbonate and polyamide. The analysis of publications devoted to the study of various properties and characteristics of plastics used in 3D printing allows us to conclude that there is no data on the piezo optic characteristics of new plastics. Moreover, there is no mention in the open press that certain consumables for a 3D printer have the property of birefringence.

2. Relevance of work
Currently, there is no data on the piezoelectric properties of plastics used in 3D printing. The work is devoted to the identification of transparent plastics with piezo optic characteristics.

3. Objective
Experimentally determine those of the plastics used in 3D printing, which have pronounced piezo optic properties.

4. Research objectives
1. An overview of the plastics available on the market for 3D printing.
2. Analysis of the properties of plastics in terms of their transparency.
3. Identification among transparent plastics of those that have high piezoelectric sensitivity.

5. Types and characteristics of plastic for 3D printers.
Plastic is a generic name for several types of thermoplastics, polyamides, nylons and similar materials used in bulk printing on specialized printers. Upon heating and pressure, plastic forms the desired shape and solidifies upon cooling [19].

For different types of products, they choose the most suitable material for technical specifications. These can be complex technical details for mechanisms and simple household goods. Next, we will consider the most famous and sought-after plastic brands for three-dimensional printing.

5.1. PLA plastic.
The main components in the composition of PLA-plastic are sugarcane and corn, which indicates its complete environmental friendliness. By raising or lowering the level of lactic acid in production, various polymer properties are obtained, thereby expanding the scope of its application. Final products have a good sliding surface, so PLA plastic is used to print plain bearings. There is only one drawback of PLA plastic, it is its fragility. The average life of a plastic product is 20 years, subject to all storage standards [20].

5.2. ABS plastic.
ABS plastic for 3D printing is one of the most common plastics. The material is practically odorless and does not contain toxic substances. It has a strong structure with good elasticity; these properties
rightly classify it as an impact-resistant group. ABS plastic tolerates the aggressive effects of various lubricants, gasoline, acids, alkalis. But, usually, ABS plastic has an opaque structure, which limits its use in this research work [20].

5.3. **SBS plastic.**

SBS plastic is more flexible than ABS. The plastic thread has a flexible structure and is not subject to brittleness and burning, as in PLA plastic. The texture of the material is transparent. Parts made of SBS plastic are completely safe for nature and humans. This material has the so-called “glass effect” due to its full transparency and the absence of turbidity in it after heating with a printer nozzle. Also, this plastic has no shrinkage after heating. In the industry, SBS plastic is used for the manufacture of bottles and transparent glassware, medical devices and shades. This filament is easy to process. The material has all safety certificates for use with food products. Therefore, SBS plastic can be used as a material for children's toys [19].

5.4. **PETG plastic.**

PETG is designed to replace ABS and PLA in the field of 3D printing, in its properties it surpasses these materials, it is a durable material, exceptionally strong and odorless when printing. PETG is many times more durable than ABS and PLA filaments, its density is about 20% higher than that of ABS plastic, and it is also chemically resistant, which indicates the difficulty of processing it with acids, alkalis, acetone. Typically, PETG filament is available in a wide range of translucent colors, and printed shapes are glossy. Therefore, this material is ideal for printing everything that should not break and should be transparent [20].

In the course of work, computer models were created in the KOMPAS-3D program. Models were shaped as plates measuring 100x30x5 mm (figure 1).

![Figure 1. The computer model.](image)

To print computer models on a 3D printer, three types of transparent plastics were used: PLA, SBS and PETG. Transparent plastic of the ABS model is difficult to access, therefore, studies were carried out using the brands of filament, those are widely available. Computer models were printed on a 3D printer, printing of each model took about one hour.

![Figure 2. The scheme of model loading](image)
Samples made on a 3D printer were tested for bending, the loading scheme is shown at figure 2. To obtain the stress fields in the models, the photoelasticity method was used. The tests were carried out with direct transmission on the PPU-7 installation (figure 3).

![Figure 3. PPU-7 installation: L.S. - light source, L.F. - light filter, P - polarizer, A - analyzer, M - model under study, \(\lambda/4\) - quarter-wave plate, L - lens, S – screen.]

5.5. **Photoelasticity**

Photoelasticity is the occurrence of optical anisotropy in initially isotropic solids (including polymers) under the action of mechanical stresses (piezo-optical effect). The photoelasticity method is an experimental method for solving problems in the mechanics of the deformable solids, in which stresses and strains are related by Hooke's law. This method allows you to determine the distribution of stresses (strains) on transparent models in the studied area without using the apparatus of the mathematical theory of elasticity. On the other hand, due to the visibility of optical information, it serves as a good illustration of the solutions obtained in the framework of this theory [1].

5.6. **Isochromes**

Isochromes are lines, those are the geometrical locations of points of the same magnitude of the optical path difference. The isochromic field of the model is most convenient to observe in the circularly polarized light. This field can be obtained both in white and in monochromatic light. In the case of obtaining an isochromic field in white light, the interference fringes with a strictly defined alternation of colors are observed. Singular points or areas with zero optical travel difference are characterized by color, uniform travel, and dark color. To obtain an isochromic field in monochromatic light, the same coloration of the whole field takes place, corresponding to the wavelength of monochromatic light, against which isochroms are observed in the form of alternating dark and light lines. Dark lines correspond to optical path difference values that are multiples of the wavelength. Mica plates serve to obtain circularly polarized light. Using these plates, an interference pattern can be obtained in white and monochromatic light. Obtaining an isochromic field in monochromatic light polarized in a circle is achieved by photographing through the double exposure method [1].

5.7. **Isoclines**

Isoclines are lines that are the geometrical place of points with the same slope of the main sites at the points of the stressed model [1].

5.8. **The pattern of interference bands**

The pattern of interference bands is a regular alternation of areas of increased and decreased light intensity, resulting from the application of coherent light beams, i.e., under conditions of a constant (or regularly changing) phase difference between them.

In the present work, the isocline field was not of interest; therefore, only isochromic fields were obtained [1].

The first tested model was printed from PLA plastic (figure 4). Although the model is transparent, the tests have shown that the PLA filament does not have the piezoelectric properties necessary for the photoelasticity method, which suggests the impossibility of further work with it. The figure 4 shows photographs of the model before loading (figure 4a) and during loading when illuminated with white light at the PPU-7 installation (figure 4b).
The second investigated model was made of SBS plastic. Due to the fact that SBS-plastic has a low stiffness, in comparison with other tested brands of plastic, mechanical deformations occurred under the load necessary to obtain a picture of interference fringes. Despite this, it was experimentally established that this type of filament has poorly expressed piezoelectric properties, but its low stiffness does not allow increasing the load to obtain a more saturated isochromic field. The figure 5 shows photographs of the model after loading (figure 5a) and when testing on the PPU-7 installation (figure 5b).

The PETG plastic model was last investigated. In the course of the experiment, it was found that this material has good piezoelectric properties. Photos of the samples are shown at figure 6 - before loading (figure 6a) and in under loading during transillumination by plane-polarized light (figure 6b).

6. Conclusion
In the course of the work done, a review of the plastics used in 3D printing, those are widely available on the market, was performed. Three types of filament were selected and tested: PLA, SBS and PETG. Empirically, among these three plastics, it was determined one with the highest piezoelectric sensitivity. It turned out to be the PETG plastic. In the future, it is planned to determine the piezoelectric characteristics of this material and its usage for printing models of nodes of complex configuration.
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