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INFLUENCE OF DESIGN FACTORS ON THE STRENGTH OF BENDING 3D-PRINTED ELEMENTS

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Abstract. The main methods of mechanical testing of composite materials include: determination of the strength of the material in tension, bending, torsion, compression, impact loads, etc. This article presents the methodology and results of tests for the bending strength of structural elements made of ABS plastic manufactured using 3D printing. The shape of the cross-section of the test specimens-beams and the percentage of filling their internal cavity with the specified polymer material were selected as design factors that are predicted to have an impact on the output parameter. The most optimal configuration was established and the dependence of the strength on the change in the specified variable factors was determined.

Keywords: polymers, 3D printing, ABS-plastic, strength, bending, short-term loading, destruction.

Introduction. Due to the low modulus of elasticity of polymeric materials, they are effective in structures where their high-strength properties and the small influence of their deformability are used to the maximum. Polymer materials and plastics used in construction make it possible to save metal, wood, glass, cement and other traditional materials. The main areas of effective use of plastic structures in buildings and structures are to reduce their mass, improve the transportation of light enclosing structures and increase resistance to aggressive external environments. Construction structures using plastics, multi-layer rectilinear or curved enclosing panels, spatial forms of single and double curvature (domes, shells, etc.), as well as transparent enclosing panels are effective.

Moreover, one of the progressive areas that actively uses polymer materials, including for building structures, is additive manufacturing, which ensures the production of three-dimensional solid products from an automated digital file using 3D printing. Considering the demand and widespread use of products manufactured by 3D printing as structural elements, studying their strength properties under load and optimization of their parameters are the important and relevant scientific task.

Analysis of recent researchs and publications. The main methods of mechanical testing of composite materials include in: determining the strength of the material in tension, bending, torsion, compression, under shock loads etc. All these types of tests are carried out before the destruction of the test sample. In addition, there are other methods of mechanical tests, which include in wear tests, studies on the change in shape and size of composite materials, fatigue strength tests, etc. [1].

In addition, in contrast to full-scale experiments, numerical experiments are often carried out with the help of either mathematical [2, 3] or computer modeling with the use of various existing software complexes [4-7].

The accumulated experience of creating structures from polymer composite materials indicates an increased spread of such parameters as stiffness and strength, which is due to the instability of the initial components, deviations in the execution of technological processes, etc. These factors are taken into account by the introduction of an additional safety factor when determining the calculated load, the value of which depends on the coefficient of variation of the mechanical properties of products made of composite materials. Thus, a high-quality selection of methods of mechanical testing of composite materials and improvement of testing methods will allow to predict with high reliability the main mechanisms of destruction and strength of composite materials.

Materials and methods of research. For the research, ABS plastic was used to manufacture samples-beams, which is known with its strength, durability and resistance to high temperatures. The tests were conducted at the Department of Metal, Wooden, and Plastic Structures as part of the work of the scientific circle.The solution to the task of developing a methodology for conducting a bending strength test, as well as preparing relevant samples made with the help of 3D printing, was chosen. According to the results of the literature review, 2 series of samples were formed, which differ in the shape of the cross-section: rectangular (series 1) and T-beams (series 2).

According to the requirements [8, 9] and [10], as well as the technical characteristics of the 3D printer used for their production, the standard samples had dimensions 10x10mm, length – 200mm.

Taking into account the use of additive technologies for the manufacture of test samples, it is possible to adjust the degree of filling of the internal cavity of the beams to save materials and determine the optimal amount of filling to ensure the necessary bending strength. Thus, 3 variations of the filling percentage of the internal cavity of the experimental sample were chosen: 10%, 50%, 100% [10]. Each series included 6 samples, for each filling percentage, 2 identical twin specimens were made to establish the average bending strength between them.

The advantages of the material include in an optimal combination of elasticity and strength, and the disadvantages are some nuances during use like odor and shrinkage.

Research results. The tests were carried out on a PROFLINE hydraulic press with load capacity 10 tons. A device with a loading tip and supports was placed on the test machine. Their convergence were taken place at a constant speed.

The radius of the tip (r_1) and the edges of the supports (r_2) (Fig. 1) have the following dimensions in mm:

– $r_1 = (5 \pm 0.1)$;

– $r_2 = (2.0 \pm 0.2)$.

Before testing, in the middle third of the length of the sample, the width of the sample were measured with an error of ±0.1 mm and the thickness – with an error of ±0.02 mm. Before the test, the samples were conditioned according to the requirements [11] for at least 16 hours at a temperature of (23±2)°C and a relative humidity of (50±5)%. The tests were conducted under the same conditions. The distance between the supports were taken as (15...17)h (Fig. 1). The loading of the sample was carried out in the middle of the span between the supports smoothly, without jolts.

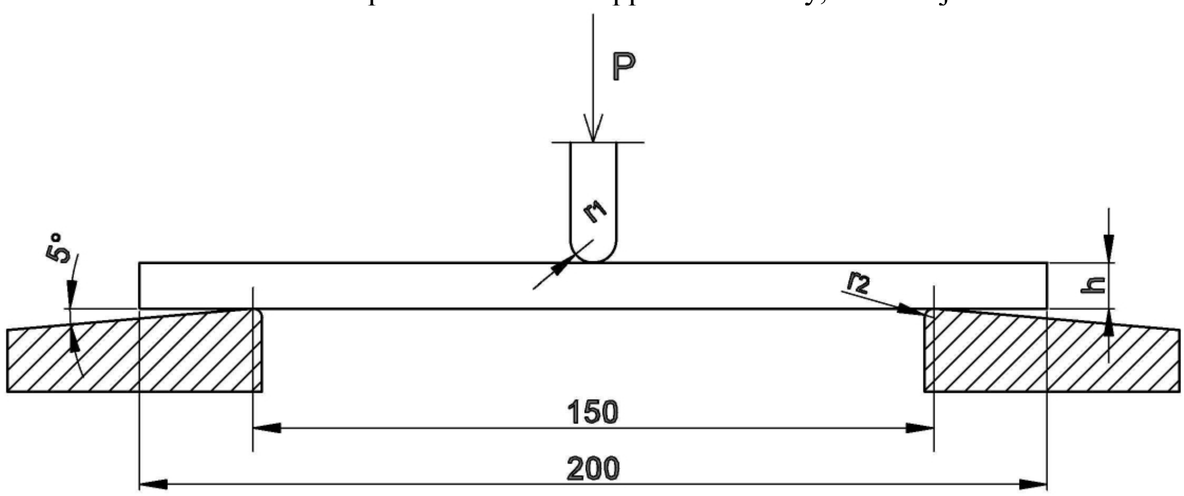

Figure 1. Scheme of loaded sample

After testing, the ultimate strength was determined for each sample. The processed results are presented in Table 1.

Table 1 – Test results of prototypes

Percentage of filling	Type of section	P_{max}, N	σ, N/mm
20%	■	159	35,8
	T	318	254,16
50%	■	954	214,7
	T	477	381,2
70%	■	954	214,7
	T	636	508,3

The nature of the fracture of the test specimens is shown in Fig. 2.

Fig. 2. Destruction of prototypes

A graphical interpretation of the research results is shown in Fig. 3.

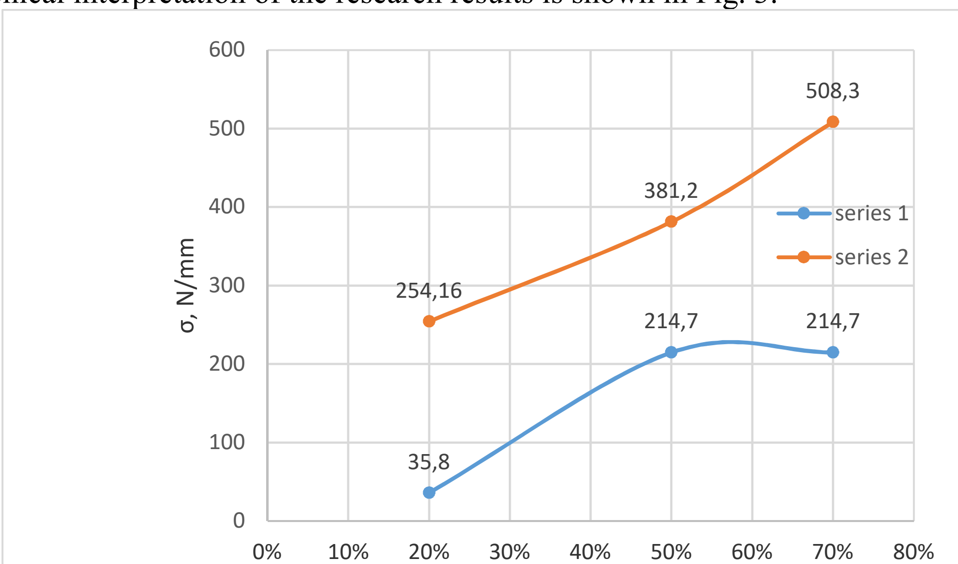

Fig. 3. Diagram of the dependence of the limit strength of samples on the initial factors

During the analysis of the obtained results, it was found that the best strength characteristics were shown by the T-section, namely its ultimate strength compared to the rectangular one when the section is filled with 20% plastic is 85%, when filled with 50% – 43%, and when filled with 70% – 57%.

The influence of the percentage of filling the section with plastic on the strength of the experimental samples was also analyzed. Thus, the maximum increase in the strength of rectangular section samples occurred when the section was filled with 50% plastic, with 70% filling no increase in strength was observed. For T-section samples, on the contrary, the greatest strength was shown by beams with the maximum percentage of filling the section with plastic, with 20% filling they made a difference of 33%, and with 50% filling – 25%.

Conclusions. Based on the results of the given data, the following conclusions can be presented:

1. The T-shaped cross-section was found to be more effective than the rectangular one when working on bending under the same conditions.
2. The percentage of filling of the internal cavity of the sample correlates with the shape of the cross-section of the sample, which is a more significant design factor among the proposed ones.

Among the prospects for further research are the analysis and comparison of the obtained results, as well as the manufacture and testing of 3 series of samples under the action of repeated loads of different levels.

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ВПЛИВ КОНСТРУКТИВНИХ ЧИННИКІВ НА МІЦНІСТЬ ЗГИНАЛЬНИХ 3D-ДРУКОВАНИХ ЕЛЕМЕНТІВ

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Анотація. До основних методів механічних випробувань композиційних матеріалів належать: визначення міцності матеріалу при розтягу, згині, крученні, ударних навантаженнях, стиску та ін. В даній статті представлено методику проведення та результати експериментальних досліджень щодо визначення міцності при згині конструкційних елементів з пластику ABS, виготовлених за допомогою 3D друку. В якості конструктивних чинників, що прогнозовано мають вплив на вихідний параметр, обрано форму поперечного перерізу дослідних зразків-балок та відсоток заповнення їхньої внутрішньої порожнини зазначеним полімерним матеріалом. Розроблено 2 серії дослідних зразків, що відрізняються за формою поперечного перерізу (1 серія – прямокутний переріз, 2 серія – тавровий переріз), встановлено відповідні розміри та схему випробування згідно вимог нормативних документів. Означено варіювання відсотка заповнення внутрішньої порожнини дослідних елементів полімерним матеріалом, а саме 10%, 50% та 100%. Описано алгоритм виконання випробувань за дії статичного короткочасного навантаження. Наведені прогнозовані схеми й критерії руйнування зразків, а також умови припинення виконання випробувань. В ході аналізу отриманих результатів встановлено, що кращі міцнісні характеристики показав тавровий переріз. Також було проаналізовано вплив відсотка заповнення перерізу пластиком на міцність дослідних зразків. Відсоток заповнення внутрішньої порожнини зразка корелює з формою перерізу зразка, що є більш значущим конструктивним фактором серед запропонованих. Серед перспектив подальших досліджень – аналіз і порівняння отриманих результатів, а також виготовлення і випробування 3 серій зразків під дією повторюваних навантажень різного рівня.

Ключові слова: полімери, 3D друк, ABS-пластик, міцність, згин, короткочасне навантаження, руйнування.