Assessment of the deformation and strength properties of parts manufactured using additive technologies, depending on the connection method and operating conditions

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Abstract. The manufacture of dimensional parts on 3D printers with a small working area for printing leads to the need to separate the model into parts, print them separately and join them after the end of printing. The paper considers various ways of joining plastic products obtained by 3D printing methods. Samples were made, parts of which were connected in the process of research in the three considered ways. The tests were carried out in accordance with the requirements of GOST 11262-2014 "Plastics. Tensile tests". The evaluation of the deformation and strength characteristics of the joints at different temperatures (+20°C, -30°C, -50°C) was carried out. It has been established that negative temperatures do not have a negative effect on the deformation and strength characteristics of the joints of parts made of ABS plastic. The results of tensile tests are presented. The use of the technology proposed by the author for joining plastic parts at enterprises engaged in the manufacture and repair of dimensional products will allow expanding the range of products without significant changes in the material and technical base.

1. Introduction

Additive technologies have a huge potential for the production of products in various industries [1-2]. However, their distribution in the repair industry is relatively small and is mainly determined by the technologies that were developed in the second half of the twentieth century for the restoration of metal products. Taking into account the technical leap in the development of 3D printing, attention should be paid not only to the use of these technologies in manufacturing, but also in the repair of equipment [3-4].

Almost any road-building vehicle, automobile and other equipment has plastic products in its design. Moreover, a significant part of these parts is made of ABS plastic [5]. During operation, various kinds of defects may arise, associated with both natural wear and tear and emergency impacts. The most serious are those damages in which there is separation and loss of structural elements.

Restoration of plastic parts by traditional methods is carried out by gluing (used if the broken structural element is preserved), surfacing with filler rods approximately similar in configuration to the lost element, or molding with special compounds [6-7]. But all these methods do not allow you to accurately recreate the required geometry of the part.

The restoration method proposed by the authors consists in making an exact copy of the missing element on a 3D printer and connecting it to the part. The purpose of this work is to determine the...
change in the deformation and strength characteristics of plastic parts manufactured using additive technologies, depending on the connection method and operating conditions.

2. Objects and test procedure
The test specimens were printed on a Magnum Creative 2Pro 3D printer with print modes defined in earlier studies [8]. The material used was ABS-plastic made by REC, brand ABS M5. The samples are two butt-connected plates with a total overall dimension of 220 × 30 × 3 mm. The connection was made in three different ways: hot air welding, organic solvent bonding and 3D welding.

Welding with heated air was carried out at an air flow temperature of 300°C [9]. Air consumption during welding was 250 l/min.

The halves of the samples were glued on a flat surface. The ends of the plates were kept in an organic solvent acetone for 30 seconds, then half of the samples were placed on a glass surface, aligned relative to each other, and glued together with a counter axial force not exceeding 100 N [10].

To carry out the 3D welding process, half of the samples were placed on the printing table of the 3D printer and fixed on it coaxially with clamps. The extrusion temperature was 235°C, the speed of movement of the print head was 10 mm/min. The amount of filler plastic supplied was set by the program and was equal to 60 mm per side. Welding was carried out alternately on both sides. To minimize temperature deformations of the samples, they were heated to 105°C.

To compare the strength characteristics of the joints of plastic parts with solid parts, one-piece (reference) specimens with overall dimensions of 220 × 30 × 3 mm were made.

The appearance of the obtained samples is shown in Figure 1.

(a)

(b)

(c)

(d)

**Figure: 1.** Samples connected by 3D welding (a), glued (b), welded with heated air (c), solid (d)
Since the operating conditions can differ significantly depending on the geographical location, the experiment was carried out at three different temperatures: + 20°C, -30°C, -50°C [8]. To determine the effect of negative temperatures on the strength characteristics of the joints, the samples obtained were divided into three groups. Each of the groups of samples was kept for 30 days at the appropriate temperature. The first group is the control one. Holding temperature + 20°C (room temperature). The second group of samples was placed in a PozisFH-258-1 freezer with a temperature of -30°C (low temperature). The third batch of samples was loaded into a LOIPFT-311-80 cryostat with a temperature of -50°C (extremely low temperature).

After the end of exposure, the samples were tensile tested on a UTS-110M-50 testing machine using the temperature measurement system STI TS 3. The use of this temperature system allows you to provide the required temperature and maintain it during testing.

Tensile tests of plastic samples obtained by 3D printing were carried out in accordance with the requirements of GOST 11262-2017. The speed of movement of the grips of the testing machine during the tests was 2 mm / min.

3. Results and Discussion

Table 1 presents a summary of the test results for all three groups of samples.

| Sample joining method | Ultimate strength, MPa | Elastic modulus, MPa | Relative deformation at destruction, % |
|-----------------------|-----------------------|---------------------|----------------------------------------|
|                       | +20°C | -30°C | -50°C | +20°C | -30°C | -50°C | +20°C | -30°C | -50°C |
| 3D welding            | 16.454 | 39.801 | 29.272 | 548.96 | 781.06 | 454.385 | 3.4 | 4.1 | 7.3 |
| Hot air welding       | 1.794  | 13.65  | 17.521 | 622.38 | 752.69 | 473.925 | 0.3 | 1.6 | 3.45 |
| Gluing                | 11.456 | 22.026 | 23.258 | 445.81 | 725.66 | 514.11  | 2.4 | 2.25 | 4.5  |
| Whole (reference)     | 28.353 | 56.343 | 52.81  | 607.06 | 880.86 | 532.98  | 6.1 | 5.75 | 10.8 |
| samples               |         |       |       |       |       |        |     |     |      |

In figure 2 is a bar graph showing the change in tensile strength for each bonding method as a function of temperature.
Figure 2. Change in tensile strength depending on the method of connection and ambient temperature: a – whole samples; b – hot air welding; c – gluing; d – 3D welding.

The histogram of the change in the elastic modulus at different temperatures, depending on the connection method, is shown in figure 3.

Figure 3. Change in modulus of elasticity in tension depending on the method of connection and ambient temperature: a – whole samples; b – hot air welding; c – gluing; d – 3D welding.
A comparative histogram of changes in the relative elongation of samples depending on the method of connection and temperature is shown in figure 4.

![Figure 4. Change in the relative deformation of the samples under tension depending on the method of connection and the ambient temperature](image)

As follows from the data obtained, negative temperatures generally have a strengthening effect on the joints of plastic parts. The method of joining proposed by the authors is characterized by the highest tensile strength in comparison with traditional joining methods.

4. Conclusion
The obtained test results make it possible to assess the prospects of the method proposed by the authors. An important role is played by the relatively low influence of the human factor on the quality of the resulting welded joint. It can be used in the conditions of repair enterprises. However, to obtain a more complete picture, it is necessary to carry out additional tests, including impact strength.

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