# Design of ABS Plastic Components through FDM Process for the Quick Replacement of Outworn Parts in a Technological Flow

**NICOLETA ELISABETA PASCU[1], TIBERIU GABRIEL DOBRESCU[2]\*, EMILIA BALAN[2], GABRIEL JIGA[3], VICTOR ADIR[1]**
[1]University Politehnica of Bucharest, Engineering Graphics and Industrial Design Department, 313 Splaiul Independenei, 060042, Bucharest, Romania
[2]University Politehnica of Bucharest, Machine and Production Systems Department, 313 Splaiul Independenei, 060042, Bucharest, Romania
[3]University Politehnica of Bucharest, Strength of Materials Department, 313 Splaiul Independenei, 060042, Bucharest, Romania

*The paper shows the importance of designing an ABS (Acrylonitrile-Butadiene-Styrene) plastic part which will be produced using FDM (Fused Deposition Modeling) technology; it is obtained a product with the same characteristics provided by the operating guide book. Thus, this solution combines both the capacity of the designer as well as the applied technology and can produce similar or improved plastic components, at the same time maintaining the functional characteristics of the work piece. This paper is a plea for the application of 3D printing using FDM technology for manufacturing components (spare parts) out of production, because the technological systems users no longer have other solutions available for replacing outworn plastic parts. 3D printing using FDM technology is a fast option for replacing outworn components, the modeling, simulation and printing time being shorter than the purchase time of a new subassembly or assembly that has been remanufactured and modernized.*

*Keywords: 3D printing, Fused Deposition Modeling, Acrylonitrile-Butadiene-Styrene, support, design*

The current industrial competitiveness requires to obtain new products with high functional parameters through prompt methods. Their geometrical characteristics are based on the full exploitation of the properties of the materials used. This requirement is performed by using new materials and technologies [1, 11]. Simultaneously with the development and usage of new technologies, more advanced in terms of technical characteristics, new issues have emerged regarding the design and the strength of materials used for components or entire products. These issues are closely realated to perform a final product with dimensional precision accuracy, geometric shape accurateness and surface quality precision. All these parameters are imposed by the functional role of the components, the degree of loading and operating conditions.

The use of plastic components in technical systems is a cheap and easy-to-use solution. The component presented and analyzed in this paper (on which all the tests have been carried out) is a support (fig. 1) for the brushes of an electromagnetic coupling with collector brushes (sliding contact) from a reel stand (reel splicer) of a web-fed offset printing machine. The support is of medium complexity (fig. 2); it presents housing with a bolt necessary for hinge jointing the housing with the clamping arm. Designing and producing the part in house is determined by its lack from the market (the part is out-dated, no longer being produced by the original supplier). The technical solution proposed in this paper has resulted from numerous tests of ABS components [13]. Since the strength of the injected plastics material (the original part is obtained by plastic mold injection) is different from that of the 3D printed parts, it is necessary to modify the component in terms of geometrical shape details [2].
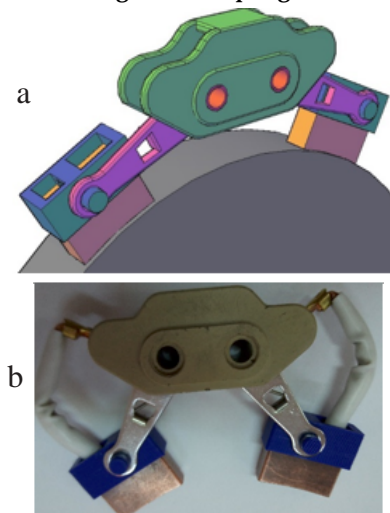


Fig. 1. Double leg brush holder with simply supported brushes (a - geometric 3D model; b - real model)
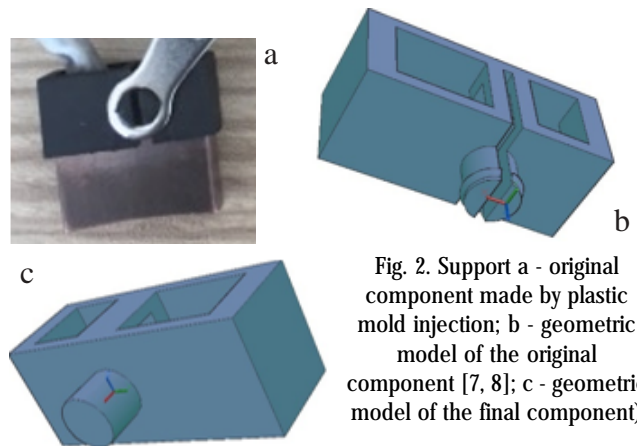


Fig. 2. Support a - original component made by plastic mold injection; b - geometric model of the original component [7, 8]; c - geometric model of the final component)

For a better understanding of the importance of the support in the assembly, figure 3 shows the technological sketch of a reel stand, three-arm version, where: 1 - bed of the assembly; 2 - spindle of the three-arm device; 3 - arm; 4 - clamping device (with tapered form) for the paper reel; 5 - drive belt of the paper reel (it is required to maintain a constant value of the rewind speed of the paper reel); 6 - paper strip.
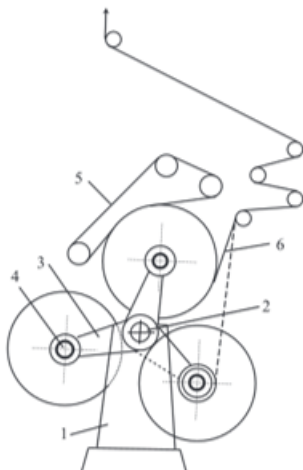
*\* email: tibidobrescu@yahoo.com*
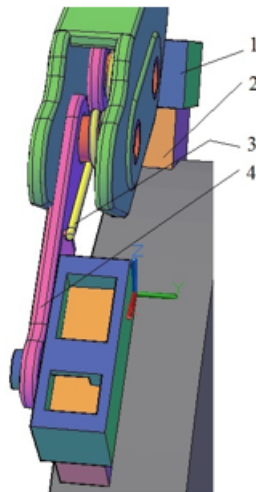
Fig. 3. Reel stand, three-arm version [3]



Fig. 4. Electromagnetic coupling with collector brushes

The double leg brush holder in figure 1b may wear prematurely for the following reasons: the collector has a increased radial play and the brushes rub over in their bearing (bolt) or the springs that press on the arm are too strong (fig. 4). The elements shown in figure 4 are: 1 - support to be 3D printed; 2 - brush; 3 - torsional spring; 4 - arm supporting the brush holder.

## Experimental part
### Materials and methods

Designed components were produced on a Creality 3D CR-10 printer [4] with open frame and heated printing table, with the following characteristics: working space on the X axis - 300 mm, on the Y axis -300 mm and on the Z axis - 400 mm; printing speed: normal: 80 mm/s, max: 200 mm/s. The output diameter of the thread in the print nozzle is 0.4 mm. The software used to generate the machine code is Simplify 3D [5, 10].

The material used for the experiment was limited to ABS because the original part obtained by plastic mold injection was made out of ABS. The ABS filament used has the diameter of the blue filament 1.75 ± 0.10 [mm] [6]. The extrusion temperature in the experimental components was 250° C for nozzle temperature and 80° C for build plate temperature. The degree of filling for parts obtained through printing was set to 100%. The components were printed on the platform in a horizontal position as shown in figure 5.



Fig. 5. Printing parts (horizontal position)

Table 1 shows the printing process characteristics used for all the printed sets.

Table 2 shows the details about the printing time ($t_p$), the length of the filament consumed ($l_f$), the mass of filament consumed ($m_f$) and the cost of the filament consumed ($c_f$) for the horizontal printed ABS support.

**Table 1**
CHARACTERISTICS OF THE PRINTING PROCESS

| Parameter | ABS |
|---|---|
| Nozzle | 0.4 [mm] |
| Layer Height | 0.1 [mm] |
| Profile | Normal |
| Wall Thickness | 1 [mm] |
| Top/Bottom Thickness | 0.8 [mm] |
| Infill Density | 100 % |
| Print Speed | 45 [mm/s] |
| Travel Speed | 120 [mm/s] |
| Support Placement | Everywhere |
| Build Plate Adhesion Type | Skirt |

## Results and discussions

In order to perform a static simulation on the bolt one must determine the forces and moments applied on the bolt during operation. For this reason, a graphical representation of the assembly double leg brush holder with simply supported brushes (fig. 6a), was performed.

The forces exerted by the connecting element on the bolt were represented as in figure 6b. The forces acting on the bolt were represented in figure 6c.
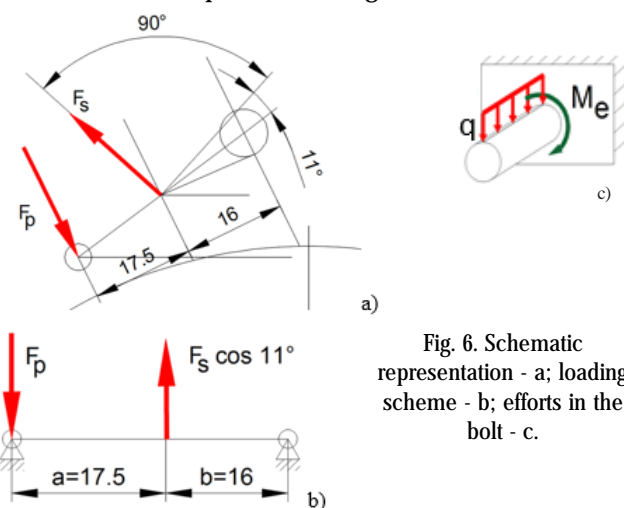


Fig. 6. Schematic representation - a; loading scheme - b; efforts in the bolt - c.

From the catalogue data of double leg brush holder with simply supported brushes, the brush pressure $p_b$ and the brush area S are extracted (relation1).

$$p_b = 225 \frac{cN}{cm^2} = 0.0225\,MPa\,;\quad S = 60 \cdot 6,1 = 122\,mm^2 \qquad (1)$$

$$p_b = \frac{F_p}{S} \qquad (2)$$

Taking into account relations (1) and (2) results the relation (3).

$$F_p = p_b \cdot S = 0.0225 \frac{N}{mm^2} \cdot 122\,mm^2 = 2.745\,N \quad (3)$$

where $F_p$ represents the pressing force.

Following the scheme in figure 6 b it can be concluded that the component acting perpendicular to the arm will be: $F_S \cos 11°$:

$$F_S \cos 11° = F_p \frac{a+b}{b} = 2.745 \cdot \frac{33.5}{16} = 5.854\,N \qquad (4)$$

In figure 6c are represented: $M_{eq}$ - the equivalent moment and q - the uniform distributed load exerted on the bolt.

| Part | Infill Density | $t_p$ [min] | $l_f$ [mm] | $m_f$ [g] | $c_f$ [RON] |
|---|---|---|---|---|---|
| The initial model - fig. 2 b) | 100 % | 25 | 343.9 | 1.03 | 0.28 |
| The final model - fig. 2 c) | 100 % | 25 | 364 | 1.09 | 0.30 |

**Table 2**
ABS PRINT SUPPORT DETAILS

Following suitable calculations, q and $M_{eq}$ were determined:

$$q = \frac{F_s}{\ell} = \frac{5.854}{2} = 2.927 \frac{N}{mm} \quad (5)$$

$$M_{eq} = \sqrt{M_i^2 + M_t^2} = \sqrt{(F_s \cdot a)^2 + \left(\frac{q\ell^2}{2}\right)^2} =$$

$$= \sqrt{102.44^2 + 5.854^2} = 102.6 \, Nmm \quad (6)$$

Finally, $\sigma_{max}$ resulted as:

$$\sigma_{max} = \frac{M_{eq}}{W_y} = \frac{32 M_{eq}}{\pi d_b^3} = \frac{102.6 \cdot 32}{\pi \cdot 4.5^3} = 11.47 \, MPa \quad (7)$$

where $\sigma_{max}$ represents the normal stress, $d_b$ - the bolt diameter (4.5 mm) and $\sigma_\alpha = 44$ MPa (the allowable stress for the ABS material).

The terms in relation (6) $M_i$ - thebending moment exerted by the arm of the lever on the bolt, $M_t$ - the twisting moment in the bolt given by the spring force and $M_{eq}$ - the equivalent moment determined by the maximum shear stress theory. Taking into account the analytical values obtained for q and $M_{eq}$, the static analysis will be performed using a simulation software.

Tests were performed to highlight the behavior of the joint in the bolt in terms of elastic or plastic deformation. To establish the model of the structure the solid elements with 6 degrees of freedom per node, of the tetrahedron type, and hexahedral elements with 3 degrees of freedom per node (translations on X, Y, Z axes) were used. The two types of elements have considered the two versions of the geometric model: version 1 - figure 2b and version 2 - figure 2c. Making only a single zone for applying the uniform distributed pressure is justified by the worst case scenario. For the static analysis of the bolt support, the uniformly distributed pressure load distribution on the surface of the entire contact area between bolt and bar and the equivalent moment resulted.
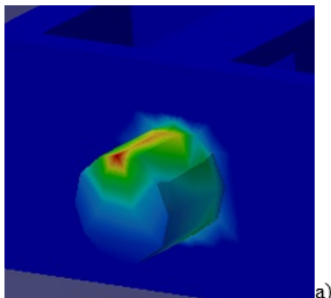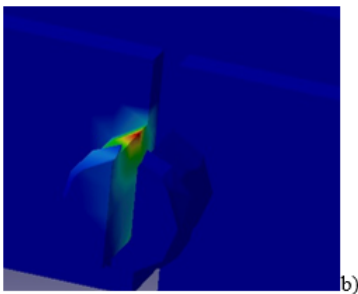

Fig. 7. Static analysis

In the static analysis, very low values for the displacements on all three directions were obtained in both cases considered in figures 7a and b. These values were obtained with $M_{eq}$ - the equivalent moment and q - the uniform distributed load. Figure 7 shows the state of the contact stresses between the bolt and the arm, highlighting with red the areas with maximum contact strains corresponding to the contact area.

Since the mathematical calculations as well as the data obtained in the static analysis indicated a high strength of the bolt in both cases (fig. 2b and c) the decision to print both versions of the support was made.

In the first phase of the tests the support with the initial shape of the ABS fixing element was performed (fig. 8 a). As a result of mechanical stress (ABS material has relatively high stiffness), the wall of the support has succumbed because it has only 1 [mm] in width (fig. 5) [6]. As a result of this test, the use of the support with this specific geometry was removed. No further tests were necessary, the result being highly conclusive (fig. 9).
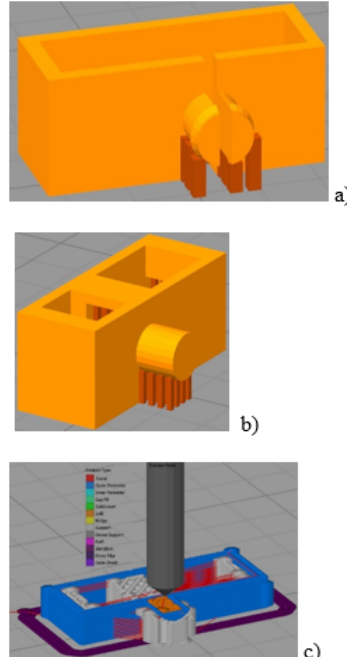


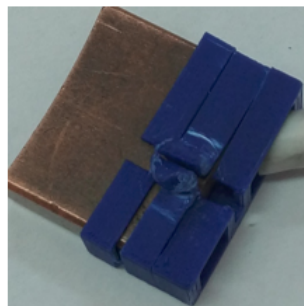Fig. 8a-c. Models represented in the Simplify 3D software [5]


Fig. 9. Outworn support

In the second phase of the tests, the ABS material was retained and the constructive forms were changed, the bolt being no longer split and having a diameter of 4 mm and the wall of the support increasing to a thickness of 1.2 mm. After repeated pressing on the bolt with high frequency it was observed that the wall maintained its structural integrity (fig. 10).


Fig. 10. The final version of the support

**Conclusions**

This paper highlighted the importance of the design stages for a brush holder obtained by 3D printing. The brush holder is a component part of an electromagnetic coupling with collector brushes.

The horizontal printed support of ABS material with the manufacturer's geometry cannot be used because it

damages rapidly. The support from ABS material printed horizontally with full bolt has the highest strength to cyclic stresses.

The conclusion of this study is that the optimal variant from a constructive and economical point of view is the solution proposed by the new shaped design shown in figure 2 c. Printing this variant on the 3D printing machine is optimal. This conclusion was obtained by comparing and taking into account the values presented in the static analysis.

It was taken into account that the need to replace the component was urgent for the company. Web-fed offset printing machine which includes the reel stand was used continuously (24 h/ 7 days / week) in the technological flow.

The reel stand is the assembly that holds the paper reels on which the magazine will be printed performed.

The component designed and 3D printed resisted on the web-fed offset printing machine for 120 days. During this time a total print run of about 18,000,000 magazines were printed.

During this time the component resisted to the imposed loading and was not damaged. Its removal from the technological flow was imposed due to the acquisition by the user of another reel stand. Therefore, the part fulfilled the role for which it was designed, namely [9]: it kept the manufacturing process up and running during the entire waiting time for the delivery of a new piece of equipment.

However, one cannot affirm that this 3D printed version can be compared to the version obtained by plastic mold injection, the latter being superior in terms of productivity, but not in terms of final cost of parts (plastic mold injection to suppliers) [12]. Through a simple calculation of material consumption and energy invested, the final cost of the support would be 0.50 RON (3D printing). But when the component is no longer produced, 3D printing is the easiest method of manufacture.

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