Mechanical characterization of additive manufactured samples from biodegradable materials

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Abstract. One of the biggest challenges facing engineers and designers in the field of additive manufacturing is to constantly develop and promote new products to meet the increasingly varied and demanding needs of customers. They must also "navigate" through a wide variety of technologies and materials available in order to determine the most appropriate solution for their application. The best and easiest way to determine if a particular technology or material is right for an application is to study and understand its behavior. This paper aims to mechanical characterize 3D printed samples from biodegradable materials through tensile, bending, and impact tests but also by determining the mechanical behavior in the dynamic regime and the tribological behavior (friction coefficient and wear). For the obtained results during the tensile test were performed a statistical analysis of the technological parameters' influence on the output parameters (tensile strength, strain, and modulus of elasticity) and it has been developed and the optimization of these ones. The studied biodegradable thermoplastics were bioFilament Linen, bioFilament Silk and Fiber Wood which according to the highlighted results can be used in various fields of activity and can easily replacing polymers from fossil resources such as flexible filaments, high impact polystyrene, polypropylene, polypropylene reinforced with short glass fibers, polymers reinforced with metal or wood powder.

1. Introduction
Additive manufacturing offers a number of advantages compared to the other two major groups of manufacturing techniques, namely formative manufacturing (injection molding, stamping, forging and casting) and subtractive manufacturing (CNC - Computer Numerical Control, drilling and turning). This modern technology offers the possibility to print parts with complex geometries and cavities, which would raise problems for other technologies for obtaining products. Also, this is a friendly, simple, clean and economical method that can be used even in confined spaces (offices, research laboratories). Another advantage is that it facilitates rapid verification and development of prototypes and low-volume production parts, [1, 2].
Like any other technology, 3D printing has limitations, one of the biggest being the inability to produce parts with properties equivalent to those made by subtractive or formative techniques because 3D printing produces parts that are not fully dense. Another disadvantage is that the obtained parts often show small variations due to the differentiated cooling or deformations that occur during the solidification of the deposited layers, [1, 3].

The most popular prototyping technology is the FDM one (Fusion Deposition Modeling), a term used and registered by Stratasys more than two decades ago, this American manufacturer of 3D printers still continuing to revolutionize this industry. FDM technology involves prototyping by extruding solid thermoplastic material (filament), which is pushed through a heated nozzle which is melting the material until it becomes a strong viscous fluid. Then, the printer deposits a complete layer on a printing platform following a predetermined path, after that the printing platform moves down with a layer height and the process is repeated until the desired model is built in its entirety, [1, 3].

The FDM printing process depends on a large number of parameters, which can be grouped into three representative categories related to extruder geometry (nozzle diameter, filament diameter), processing (temperature of the molten material; construction platform temperature, printing speed) and structure (layer thickness, filling type, filling density, number of layers, raster angle, the gap between deposited filaments, gap width, pattern), [1, 4-6].

The plastics materials used in 3D printing, the FDM method, are varied and due to their functional characteristics, they can be used in a wide range of applications, from toys to functional parts used in the field of industrial or medical engineering, [3].

But the excessive use of nonbiodegradable polymeric materials (which come in various forms and whose industry is larger than the steel, copper, and aluminium combined industry) in recent decades has led to an accelerated increase in the amount of waste that when not stored properly and recycled become a threat to the environment and to the health of all living beings. To support the global idea of greening, measures have begun to be taken, one of these is the use of biodegradable products in as many areas of activity as possible. In this sense, biodegradable polymers have begun to be developed that require detailed studies in order to determine and understand their characteristics, thus helping to select the applications in which they can be used, [3].

2. Materials and methods
The prototyping of samples necessary for the mechanical, thermal and structural determinations was performed on a series of biodegradable materials selected according to their utility and the possibility of substituting nonbiodegradable synthetic plastics. The biodegradable materials in the form of filaments used in the paper study were bioFila Linen, bioFila Silk and Fiber Wood. The filaments from bioFila Linen are completely biodegradable, but also more resistant than other biodegradable materials, also the filament are characterized by a texture reminiscent of linen cloth, thus being ideal for projects which require a natural look. The bioFila Silk is completely biodegradable, the filament is characterized by a fine and shiny texture, reminiscent of silk, thus being ideal for interior decoration projects (such as lamps or vases). These two filament types are produced by the twoBEars company in Vielank, Germany, [7]. Fiber Wood filament is produced using natural wood and marketed by Fiberlogy (Brzezie, Poland), [8].

3D printing of specific tensile samples (ISO 527 standard) was performed with Raise3D Pro2Plus printing equipment, available at the Laboratory of Fine Mechanics and Nanotechnologies, Faculty of Machine Manufacturing and Industrial Management, "Gheorghe Asachi" Technical University of Iasi.

An experimental factorial research plan (2^3 - eight experiments), ANOVA method and Minitab 17 program was used for the samples prototyping from biodegradable materials. The samples have a dumbbell shape and dimensions according to the previously mentioned standard. Factors that were varied on two levels in the complete experimental plan were the layer thickness (0.1mm and 0.2mm), the infill speed (40mm/s, 80mm/s), and the orientation of the sample on the printing bed (flat and on edge).
The tensile test samples were printed from bioFila Linen, bioFila Silk and Fiber Wood materials. The diameter of the nozzle was 0.4 mm. All samples were printed with three shell layers (rectilinear type), a 100% filling degree, and a grid filling type for the raster area. The temperatures of the extrusion nozzle and of the printing bed for the three used materials were:
- For bioFila Linen filament, the nozzle temperature was 215°C and the printing table temperature 65°C;
- For bioFila Silk filament, the nozzle temperature was 220°C and the printing table temperature 65°C;
- For Fiber Wood filament, the nozzle temperature was 200°C and the printing table temperature 55°C.

For each experiment, three samples were printed to highlight the process stability by calculating the mean and the dispersion for each set of values of the input parameters from the experimental plan. Tensile tests were performed on the Instron 3382 universal test machine, at the "Gheorghe Asachi" Technical University in Iasi, Faculty of Materials Science and Engineering, with a constant transverse speed of 5mm/min according to ISO 527-3: 2003, the distance between the jaws was 115mm, the data acquisition rate being 10Hz and the determinations were performed at room temperature (23°C).

TableCurve3D v.4.0 application was used to optimize the technological parameters for the 3D printed samples from biodegradable materials filaments.

In order to achieve the three-point bending test, three samples were prepared (to demonstrate that the printing process is stable and reproducible) from each biodegradable material. A single test was performed on materials with a deformation greater than 5mm. The distance between the sample placement supports was 60mm, the length of the tested sample 50mm, the thickness 4mm and its width 10mm were determined. A universal test machine WTW 50 was used to determine the bending strength, using a load of 1kN and a load rate of 2mm/min.

The impact-specific samples were printed according to the SR EN ISO 179 standard, with the following dimensions: length 80±2mm, width 10±0.2mm and thickness 4±0.2mm. The test parameters used to determine the impact resistance of the three types of filaments were: speed 2.9 m/s, hammer weight 1.189kg and energy 5J. The temperature at which the tests were performed was 20°C. The printing parameters set for obtaining samples were: printing temperature and printing bed temperature according to the statements made for the tensile test printed samples; infill speed 60mm/s; the deposited layer thickness 0.2mm; type of filling - grid; filling degree 100%; flat orientation of the sample on the printing bed; the temperature inside the printing chamber was 23°C.

The test results are used to select a biodegradable material for an imposed stress, to control the quality and to anticipate how this material will react under the action of different types of forces.

3. Results and discussions

3.1. Tensile strength

For each experiment, three samples were printed to highlight the process stability by calculating the mean and the dispersion of the values for each input parameters values set from the experimental plan. Each test was generated responses regarding the tensile strength, σ[MPa], elongation, ε[%] and modulus of elasticity, E[MPa] of the analysed biodegradable material, calculating for each one the mean value and dispersion. Using the ANOVA method, the influences of the input parameters on the tensile strength, on the elongation and on Young's modulus were determined, which allowed a hierarchy of the influence of these factors.

In table 1, the values of the mechanical characteristics obtained for the two studied materials are shown. The characteristic strength-strain curves for the three biodegradable materials bioFila Linen (experiment number 8), bioFila Silk (experiment number 8) și Fiber Wood (experiment number 4) highlighted the relatively homogeneous behavior of the samples figure 1(a) and figure 1(c), demonstrating the fact that the prototyping process, by the FDM method, was stable and reproducible, the mechanical properties of the materials varying within acceptable limits.

The highest value of tensile strength, σmax, was recorded by bioFila Linen – experiment number 8 (33.05±0.72)MPa followed by the material bioFila Silk - experiment number 8, (26.70±1.24)MPa and the Fiber Wood material with the weakest response (18.04±0.23)MPa, for experiment number 4, with
a decrease in tensile strength over bioFila Linen material of 54%. It should be noted that the best values of tensile strength for all materials are recorded for experiments in which the orientation of the sample was "on edge".

**Table 1.** Experimental results of uniaxial tensile tests of printed samples from bioFila Linen, bioFila Silk and Fiber Wood.

| Exp. no. | Material      | Input parameters | σ_{max} [MPa] | ε [%] | εt [%] | E [MPa] |
|---------|---------------|------------------|---------------|-------|--------|---------|
| 1       | bioFila Linen | 0.1 40 flat      | 27.91±1.56    | 2.45±0.22 | 3.20±0.12 | 1348.65±121.92 |
| 2       | bioFila Linen | 0.1 40 on edge   | 27.98±0.31    | 2.88±0.32 | 3.06±0.18 | 1548.75±29.16 |
| 3       | bioFila Linen | 0.1 80 flat      | 21.15±1.37    | 2.58±0.13 | 4.83±0.20 | 1332.28±19.19 |
| 4       | bioFila Linen | 0.1 80 on edge   | 27.55±0.72    | 2.63±0.11 | 2.93±0.05 | 1548.00±5.14 |
| 5       | bioFila Linen | 0.2 40 flat      | 24.65±0.57    | 3.06±0.38 | 3.36±0.06 | 1413.91±155.54 |
| 6       | bioFila Linen | 0.2 40 on edge   | 32.70±0.81    | 2.66±0.08 | 3.18±0.12 | 1812.90±41.21 |
| 7       | bioFila Linen | 0.2 80 flat      | 24.17±0.64    | 2.66±0.28 | 3.10±0.07 | 1561.92±57.45 |
| 8       | bioFila Linen | 0.2 80 on edge   | 33.05±0.72    | 2.92±0.40 | 3.58±0.58 | 1621.74±179.61 |
| 1       | bioFila Silk  | 0.1 40 flat      | 15.82±1.95    | 4.11±1.03 | 5.04±0.12 | 902.59±22.15  |
| 2       | bioFila Silk  | 0.1 40 on edge   | 24.37±0.37    | 3.53±0.33 | 5.89±0.02 | 1016.75±43.55 |
| 3       | bioFila Silk  | 0.1 80 flat      | 14.85±1.95    | 4.23±1.16 | 4.95±0.09 | 813.96±49.15  |
| 4       | bioFila Silk  | 0.1 80 on edge   | 21.18±2.39    | 4.57±0.62 | 4.91±0.11 | 1045.01±77.30 |
| 5       | bioFila Silk  | 0.2 40 flat      | 11.10±2.08    | 3.07±0.96 | 8.48±0.31 | 815.44±24.81  |
| 6       | bioFila Silk  | 0.2 40 on edge   | 25.97±3.12    | 4.04±1.32 | 5.73±0.15 | 1069.35±66.88 |
| 7       | bioFila Silk  | 0.2 80 flat      | 12.69±2.20    | 3.72±1.38 | 4.48±0.10 | 869.98±24.11  |
| 8       | bioFila Silk  | 0.2 80 on edge   | 26.70±1.24    | 4.13±0.84 | 5.16±0.84 | 1099.83±4.41  |
| 1       | Fiber Wood    | 0.1 40 flat      | 14.70±0.25    | 2.75±0.07 | 3.21±0.12 | 886.83±6.37   |
| 2       | Fiber Wood    | 0.1 40 on edge   | 17.42±0.83    | 2.21±0.14 | 2.88±0.17 | 1100.27±36.39 |
| 3       | Fiber Wood    | 0.1 80 flat      | 14.31±0.14    | 2.55±0.14 | 2.71±0.22 | 879.64±55.36  |
| 4       | Fiber Wood    | 0.1 80 on edge   | 18.04±0.23    | 2.31±0.20 | 2.39±0.15 | 1104.03±49.31 |
| 5       | Fiber Wood    | 0.2 40 flat      | 15.31±0.16    | 2.77±0.14 | 3.14±0.14 | 890.76±18.45  |
| 6       | Fiber Wood    | 0.2 40 on edge   | 16.27±0.19    | 2.38±0.01 | 2.69±0.39 | 1016.89±46.76 |
| 7       | Fiber Wood    | 0.2 80 flat      | 15.14±0.46    | 2.73±0.05 | 3.19±0.08 | 878.88±72.54  |
| 8       | Fiber Wood    | 0.2 80 on edge   | 17.31±0.31    | 2.43±0.13 | 2.92±0.11 | 1577.11±133.85 |

**note:** (t) - layer thickness; s - infill speed; s_o – sample orientation.

Analysing the dispersion of the results for the three samples, for each material, it can be concluded that the material Fiber Wood, figure 1(c) has the lowest dispersion, followed by bioFila Linen, figure 1(a) and bioFila Silk figure 1(b).
According to the obtained results regarding the strain at break ($\varepsilon_{\text{max}}$) of the printed samples from the studied biodegradable materials, it was found that the material that showed the most rigid behavior was the Fiber Wood biopolymer (2.21±0.14)%. The material with the highest elasticity was bioFila Silk with a strain value of (4.13±0.84)%. The total elongation ($\varepsilon_t$) also reaches the highest value in the case of the bioFila Silk material - experiment number 5, (8.4±0.31)%, and the lowest value was again recorded by the most fragile material, Fiber Wood, the experiment number 2, (2.28±0.17)%.  

The elasticity modulus of the analysed polymers is higher for the “on edge” oriented samples during the prototyping process. Its highest values are presented by the materials Fiber Wood and bioFila Linen, approximately 1600MPa, which reveals that these two materials are more rigid than the other material analysed, the bioFila Silk approximate 1100MPa, which deforms more because it has the modulus of elasticity smaller.

![Figure 1](image)

**Figure 1.** Strain-strength curve of materials: (a) bioFila Linen, experiment no. 8; (b) bioFila Silk, experiment no. 6; (c) Fiber Wood, experiment no. 4

In the case of bioFila Silk material, it can be easily observed that after the elastic zone it has a different behavior that can be associated with the fact that the printed layer begins to yield progressively, in this plastic area appears permanent deformation, followed by complete yielding of the material. The printed materials bioFila Linen, figure 1(a), and Fiber Wood, figure 1(c) are characterized by curves specific to brittle plastics, fragile because the breaking, the release takes place without the “necking” of the samples.

The mechanical properties obtained for the studied materials are comparable to those of synthetic materials (Flexible - tensile strength 26-43MPa, HIPS (High Impact Polystyrene) - tensile strength
32MPa, PP (Polypropylene) - tensile strength 32MPa, Metal Filled - tensile strength 20-30MPa, etc.), [9], so that they can be used in various industrial fields and not only.

3.2. The influence of technological parameters on tensile behavior

The influence of the technological parameters on the mechanical behavior of the printed samples was made only for the bioFila Linen material because for it the best results in tensile and impact tests were obtained.

Table 2 shows the results of the ANOVA analysis for the factors that influence the mechanical responses obtained following the uniaxial tensile testing of the samples from the bioFila Linen. The greatest and statistically significant influence (p=0.001) is given by the orientation of the sample (F=100.17), followed by the thickness of the deposited layer (p=0.007 and F=26.96). Infilling speed has no statistically significant influence (p> 0.05). The greatest and statistically significant influence on the modulus of elasticity, E (p=0.022) is given by the sample orientation (F=13.13), followed by the thickness of the deposited layer (p=0.05 and F=6.87). Infilling speed has no statistically significant influences because p> 0.05. None of the factors has a statistically significant influence on the ε strain, the value of p is over 0.05.

| Parameter          | Tensile strength | Modulus of elasticity | Strain     |
|--------------------|-----------------|-----------------------|------------|
|                    | Fisher-Value    | Probability of Fisher value, p-value | Fisher-Value    | Probability of Fisher value, p-value | Fisher-Value    | Probability of Fisher value, p-value |
| Sample orientation | 100.17          | 0.001                 | 13.13      | 0.022              | 0.84           | 0.411                        |
| Infill speed       | 0.67            | 0.458                 | 0.06       | 0.815              | 0.75           | 0.436                        |
| Layer thickness    | 26.96           | 0.007                 | 6.87       | 0.05               | 0.18           | 0.695                        |

Figure 2 presents the main effects of the factors on tensile strength, modulus of elasticity and strain. The tensile strength (main value of the model 27.39MPa) is higher for the samples placed „on edge” and those for which the thickness of the deposited layer is large (0.2 mm). The reduced infilling speed (40mm/s) ensures a higher tensile strength. The elasticity modulus (mean value of the model 1536.01MPa) is higher for the samples oriented „on edge” and those that were printed at a greater layer thickness (0.2mm). The low filling speed (40mm/s) ensures a higher modulus of elasticity. The strain value (mean value of the model 3.4%) is higher for samples made at high print speeds (80mm/s) and with thinner deposition layers (0.1mm). The strain increases for the samples deposited in a „flat” direction on the printing bed.
3.3. Optimization of technological parameters in order to maximize mechanical responses

The optimization criteria are to maximize tensile strength, modulus of elasticity and strain. The same material is presented as for the influence of technological parameters for the same reasons mentioned previously. To maximize tensile strength, quantitative technological parameters were selected: infill speed, $s$ [mm/min], and printing layer thickness, $t$ [mm]. The printing direction was considered "on edge", for which, according to the analysis of the factors influence, the best results for the tensile strength emerged.

In table 3, graph (a) is represented the plan obtained by regression. The correlation coefficient is very good $R^2=0.99$, the deviations from the experimental points are very small.

Table 3. Results regarding the optimization of the technological parameters in the case of the printed samples from bioFila Linen.

| Parameter | The regression equation | $R^2$ | Error [%] | Optimum |
|-----------|-------------------------|-------|-----------|---------|
| $\sigma$  | $\sigma = 23.1 + 50 \cdot t - 0.00375 \cdot s$, [MPa] | 0.99  | 32.95MPa  | 0.76 0.2 40 |
| $E$       | $E = 1523.36 + 1689.45 \cdot t - 2.4 \cdot s$, [MPa] | 0.88  | 1765.25MPa | 2.63 0.2 40 |
| $\varepsilon$ | $\varepsilon = 2.41 + 3.85 \cdot t + 0.0034 \cdot s$, [%] | 0.7  | 3.45% 3.58 | 0.2 80 |
The regression equation for (a) tensile strength, (b) modulus of elasticity, (c) strain of bioFila Linen samples when printed „on edge”.

Note: σ - tensile strength [MPa]; E - modulus of elasticity; ε - strain; R² - correlation coefficient.

The equation that approximates the influence of the layer thickness, t, and of the infilling speed, s, on the tensile strength is presented in table 3, whose maximum in the field of experiments is for t=0.2mm and s=40mm/s. For these parameters and „on edge” orientation of the sample on the printing bed we obtain σ=32.95MPa. The deviation from the experimental data in this case is 0.76%.

For the elasticity modulus the bioFila Linen material, the best values resulted when the printing was considered „on edge”. Table 3, graphic (b) shows the regression equation of the plane which represents the influence of the infilling speed and the layer thickness on the modulus of elasticity at 3D printed samples placed „on edge”. The regression equation for the elasticity modulus (R²=0.88) is presented in table 3, whose maximum in the field of experiments is for t=0.2mm and s=40mm/min. For these parameters and „on edge” printing is obtained E=1765.25MPa, with an error of 2.63% compared to the experimental data.

For strain, the best results came out for the input factor, „on edge” sample orientation. The equation of the plane is for R²=0.7 being represented in table 3, graph (c), whose maximum in the field of experiments is for t=0.2mm and s=80mm/s. For these parameters and „on edge” printing we obtain ε=3.45%. The error compared to the experimental data is 3.58%.

3.4. Bending strength
Before starting the bending test, certain conditions have been established according to the literature. Thus, it was considered that for materials with the maximum arrow greater than 5mm, the results obtained cannot be taken into account because are not proper for this type of test. Following the bending test of samples, an arrow of less than 5mm was recorded for two of the three studied biodegradable materials, namely for, bioFila Linen, figure 3(a) and Fiber Wood, figure 3(b).
The highest mean value of bending strength was recorded by the bioFila Linen material with 
(32.75±1.3)MPa followed by the Fiber Wood material which recorded a mean value of 
(24.56±8.35)MPa. Regarding the deformation of the two materials, the most deformable material at 
bending was Fiber Wood with a maximum arrow value of (3.03±0.24)mm, followed by the 
biodegradable material bioFila Linen with a slightly lower value (2.83±0.11)mm.

The bioFila Silk material, figure 4, according to the characteristic bending test curve, is not suitable 
for this type of test as it does not yield easily under the action of a progressive load, to the fact that it is 
an elastoplastic material.

Conventional plastics that can be successfully replaced by the two materials suitable for this type of 
base mechanical test are polypropylene (approx. 26MPa), polypropylene reinforced with short glass 
fibers (approx. 8MPa), [10], polymeric materials reinforced with metal and wood powder, [9], etc.

3.5. Impact strength
Impact strength determination of the samples from bioFila Linen, bioFila Silk and Fiber Wood 
materials, by Charpy method, was realized in accordance with the SR EN ISO 179 standard, with the
with the purpose of observing their impact behavior. The obtained results during the are presented in table 4.

Table 4. Mean values of the Charpy strength for printed samples from Extrudr GreenTec and Extrudr BDP Pearl.

| Material     | Sample | Sample dimensions [mm] | Impact strength (kJ/ m²) (mean values) |
|--------------|--------|------------------------|----------------------------------------|
|              |        | length                 | width                                  |
| bioFila Linen| 1      | 36.7                   | 100.4                                  | 11.13                                  |
|              | 2      | 36.8                   | 100.4                                  | 10.71                                  | 10.92± 0.3*                             |
|              | 3      | 36.0                   | 100.5                                  | 14.47                                  |
| bioFila Silk | 1      | 36.5                   | 99.9                                   | 9.30                                   |
|              | 2      | 36.3                   | 99.8                                   | 8.19                                   | 8.75± 0.78*                             |
|              | 3      | 36.9                   | 100.0                                  | 4.97                                   |
| Fiber Wood   | 1      | 36.4                   | 101.1                                  | 8.06                                   |
|              | 2      | 36.2                   | 100.4                                  | 9.33                                   | 8.7± 0.9*                               |
|              | 3      | 37.2                   | 100.8                                  | 6.02                                   |

*mean value achieved between the impact strength of two samples, sample three being excluded from the study due to the very large difference in the value obtained for the impact strength (difference probably caused by possible temperature variations during printing)

The best value of impact resistance was recorded by the bioFila Linen material (10.92±0.3)kJ/m², followed by the bioFila Silk material (8.75±0.78)kJ/m² and at a small difference Fiber Wood material (8.7±0.9)kJ/m². The recorded values for impact resistance are quite low compared to other biodegradable materials, for example, PLA the most widely used biodegradable material, this one has an impact resistance of about 38kJ/m², [11]. According to the literature, the presence of lignin and/or natural vegetable fibers (a substance that confers hardness) decreases the impact resistance of polymers or composites materials, [12, 13], thus explaining the obtained values. The viscoelastic hardness is explained by the fact that the lignin molecule is a complex molecule which in its turn is made up of three other complex molecules and which, depending on an external deforming cause, tries to shorten the chemical bonds between them so that the lignin molecule to occupy the same volume.

From the analysis of the graph presented in figure 5, the variations of the mean values of the impact resistance can be observed but also the standard deviations calculated for each material. The mean value of the impact resistance deviations is ±0.66kJ/m².

Figure 5. Impact strength diagram of the printed samples made of biodegradable filaments.
It can be noticed that the bioFila Silk and Fiber Wood materials show almost identical behavior in this type of test, with almost identical values of impact resistance.

The bioFila Linen, bioFila Silk and Fiber Wood materials can successfully replace, according to the obtained values during the impact resistance determinations, materials that also have in their composition lignin and/or natural fibres but also polymers reinforced with glass microfibers or metal powders, [9, 14].

4. Conclusions
Additive manufacturing offers the possibility to obtain parts that find their applicability in various fields, whether it is a prototype or a functional product/part. The best way to determine if a particular material is suitable for an application is to study and understand its behavior.

Samples obtained using FDM three-dimensional printing technology are significantly influenced by process parameters that can be controlled directly or indirectly before the model printing. Selecting the optimal printing parameters is quite difficult, if the aim is to obtain a part/product with mechanical characteristics as high as possible.

The following conclusions can be drawn from the analysis of tensile tests:
- tensile strength is the mechanical property often used to evaluate the usefulness of the product manufactured by prototyping, and not only. Thus, the best values of tensile strength were obtained for “on edge” oriented samples. The values of the tensile strength in the case of the “flat” orientation of the sample, varied/decreased compared to the other type of sample orientation by up to 50%;
- “flat” oriented samples have a more fragile behavior, offering lower strain results;
- the best mechanical behavior was highlighted by the bioFila Linen biodegradable material, and the weakest results were obtained for the Fiber Wood printed samples;
- also, at the moment of the mechanical determinations, the material interruptions must be taken into account, due to the layer’s adhesion lack, which has a significant effect on the general resistance of the sample.

The mechanical properties obtained for the studied materials are comparable to those of synthetic materials such as Flexible filaments - 26-43MPa tensile strength, HIPS - 32MPa tensile strength, PP - 32MPa tensile strength, Metal Filled - 20-30MPa tensile strength, but also with those of other plastics that have in their composition lignin and natural fibers, glass microfibers or metal powders (valid for impact resistance), so they can be used in various industrial fields and beyond.

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