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ANALYSIS OF A 3D PRINTED EYEGLASSES FRAME - EXPERIMENTAL STUDY

Stanciu Anca*1, Bencze Andrei 2

1. University Transilvania of Brașov, Brașov, Romania, anca.stanciu@unitbv.ro
2. University Transilvania of Brașov, Brașov, Romania, andrei.bencze@unitbv.ro
   *Corresponding author: anca.stanciu@unitbv.ro

Abstract: *In this paper is presented a comparative study for an eyeglass frame realized from 3D printed materials (PLA and PETG), as well as from existing eyeglasses frames on the market made of plastic materials, which are the most widespread. For these frames, designed and printed from new materials, made with the help of the Prusa type 3D printer, an optimal weight to strength ratio could be obtained by using a corresponding printed material density. Both the frames that are on the market and the printed ones were subjected to mechanical bending tests, thus having a comparative analysis of the mechanical properties. PLA's benefit as a bio-plastic is its versatility and the fact that it naturally degrades when exposed to the environment. PETG is a material with a unique mixture of qualities, it is readily available and relatively cheap, with a high allowable stress, being easily recycled, transformed into the original resin, and also it is very glossy.*

Keywords: *bending test; eyeglasses frame, 3D printing material, stress, PLA and PETG*

1. INTRODUCTION

Plastic materials are macromolecular synthetic products, used in industry due to the high plasticity and favorable properties of the processed parts, having as advantages: low volumetric mass, good electrical and thermal insulation properties, high resistance to the action of chemical agents, increased capability of processing through multiple technological processes, low price. At the same time, their use is limited, with certain disadvantages: relatively low mechanical properties, non-degradable, which creates serious pollution problems, the properties are not preserved at high temperatures, relatively high expansion coefficients, by burning they release toxic products.

Plastic is also used in the manufacture of eyeglass frames. Eyeglass frames made of plastic are available in a wide variety of designs, shapes and colors. Several types of plastic are available. A big advantage of plastic frames is that they are lightweight and can be found in different shapes and colors.

Poly-lactic acid or PLA is a biodegradable and bioactive thermoplastic derived from renewable sources such as corn starch or sugar cane. It is formed by the polymerization of lactic acid and stands out from conventional plastics due to its exceptional biodegradability and due to the fact that it can be turned into compost.

Another studied material, PETG Print filament, is tougher. It has a very high impact resistance and good flexibility. This filament does not release toxic or irritating vapors when printing. PETG Print has good adhesion between layers, which makes printing extremely easy. Due to the high quality and lack of additives, this filament can be printed in a wide temperature range.

Table 1 presents the comparison between the selected materials, based on [1].

Table1. Comparison of traditional plastic, PLA, PETG [1]

Material properties	Plastic	PLA	PETG
Biodegradability	No	Yes	No
Transparency	Low	High	High
Strength and rigidity	Good	Good	Excellent
Heat resistance	High	Moderate	High
Production source	Fossil fuels (Petrol)	Renewable Sources (Plants)	Fossil fuels (Petrol)
Environmental Impact	Increased carbon footprint	Reduced carbon footprint	Increased carbon footprint

2. EXPERIMENTAL BENDING ANALYSIS OF SELECTED MATERIALS

In the framework of the tests presented in this paper, the mechanical properties [2] for the glasses frames were obtained. Existing plastic frames on the market and frames made with 3D printing, using PLA and PET-G materials, were tested. All the frames were submitted to the bending test.

Figure 1 presents samples of glasses frames subjected to bending test.

Figure 1: Glasses frames and arms subjected to bending test

In the case of bending, the results were obtained automatically in the program used by the bending test machine. This software allowed the statistical calculation of average values for: longitudinal modulus of elasticity E, bending stiffness, admissible stress at maximum load, specific deformation of the specimen, deformation (from the initial value to the maximum value), mechanical work performed (of to the initial value to the maximum), the load at breaking, the stress at breaking, the deformation at breaking, the stress at maximum deformation.

Additionally, a theoretical study (with the Finite Element Models - FEM) was carried out for the 2 printed materials, so that a result can be obtained much faster regarding the changes that appear in the material.

The results for the finite elements analysis and for the tests are presented in Table 2 and Table 3.

Table2. Finite elements model analysis results

Material	PETG	PLA
Maximum deformation [mm] at 10 N applied force	2.19	1.41
Maximum deformation [mm] extrapolated to test maximal load	2.10x67/10= 14.67	1.41x70/10=9.87
Maximum stress [MPa]	5.86	5.87

Table3. Test analysis results

Material	PETG	PLA
Maximum deformation [mm] (linear elastic zone)	15	10
Maximum load [N] (linear elastic zone)	67	70

2.1. FE Model - Geometry

The finite elements model (FEM) pre-processing and post-processing are realized in MSC Patran 2019, while the static linear analysis (SOL 101) is carried out in MSC Nastran 2019.

The mesh is done on the median surface of the geometry presented in Figure 2. The median surface is meshed with 2D Shell elements (with hybrid quad4 and tria3 topology) and has a general global element edge length of 1 mm. Plate thickness, defined in the FE properties is 5 mm. Since the material properties are not varying with the thickness, the shell approach is applicable.

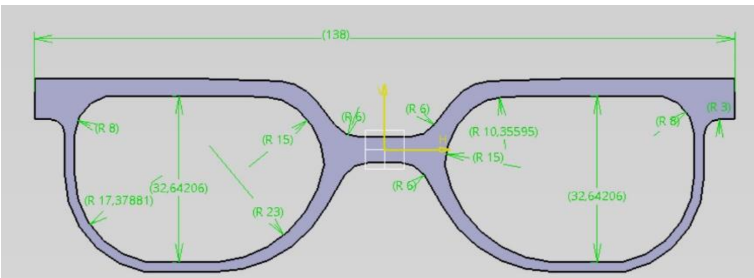


Figure 2: Model geometry

The selected materials are defined as isotropic materials based on the technical sheets provided by the manufacturers:

Prusament PLA / Prusa Polymers, named hereafter PLA

- o Longitudinal elasticity Modulus 2200 MPa
- o Tensile Yield Allowable Strength = 50.8 MPa

Prusament PETG / Prusa Polymers, named hereafter PETG

- o Longitudinal elasticity Modulus 1500 MPa
- o Tensile Yield Allowable Strength = 47.0 MPa

For an improved modelling, the PLA material is defined additionally also as a composite material (laminate material), with a stacking layup of 10 plies of 0.5mm each, with different orientations as presented in the Table 4. The plies at 0 degrees are aligned with the longitudinal direction.

Table4. Layup of the PLA composite material model

Material	Ply orientation in stacking [deg.]
Layup 1	0 / 45 / 0 / -45 / 90 / 90 / 45 / 0 / -45 / 0

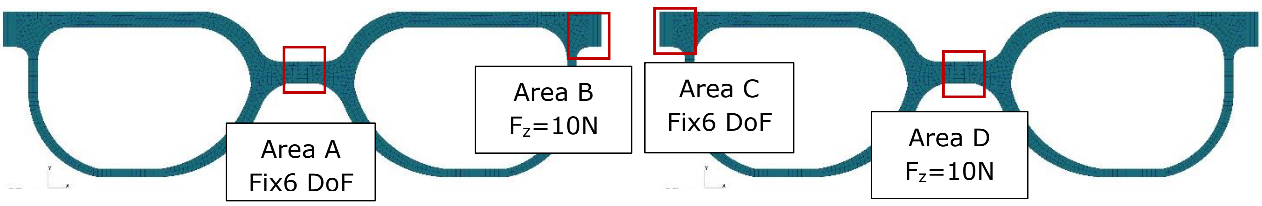
2.2. FE Model - Loads

Two load cases are defined, based on a selection of possible realistic scenarios, considering ear and nose side loading and clamping.

In both selected scenarios, a load of 10 N (equivalent of a force exerted by a 1 kilogram weight) is applied in a specific location as presented in Table 5. Function of the load application point, the model is constricted (movement is restricted for all 6 degrees of freedom) at critical locations, as presented in Figure 3, leading to a conservative analysis.

Table4. Layup of the PLA composite material model

Load Case	Fixations – Blocked DOFs	Fixations – Area (Zone)	Load Value	Load Direction	Load Area (Zone)
1	All 6	nodes in A	9x1.11=10N	negative Z	nodes in B
2	All 6	nodes in C	6*1.66=10N	negative Z	nodes in D



Load case 1 Load case 2

Figure 3: FE Model - Load cases definition

2.3. FE Model - Results

At post-processing stage, the von Mises stresses are extracted for each material and each load case listed above, and the results are summarized in Table 5. The Figures 4, 5 and 6 present typical deformations and stresses for the 2 selected load cases.

Table5. FE Model results

Load Case	Material	Material Definition	Thickness [mm]	Maximum Displacement [mm]	Von Mises Stress Z1/Z2 [MPa]	Allowable Stress [MPa]
1	PETG	Isotrop	5.0	8.03	37.62	47.0
1	PLA	Isotrop	5.0	5.49	37.75	50.8
1	PLA	2D Composite	0.5x10	5.49	30.13	50.8
2	PETG	Isotrop	5.0	18.54	35.97	47.0
2	PLA	Isotrop	5.0	12.65	36.00	50.8
2	PLA	2D Composite	0.5x10	12.65	30.69	50.8

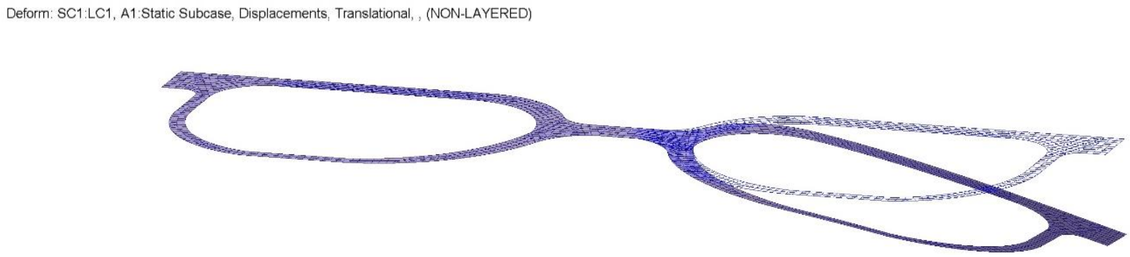


Figure 4: Deformation – Load Case 1 (side and isometric view), PLA material, 2D isotropic

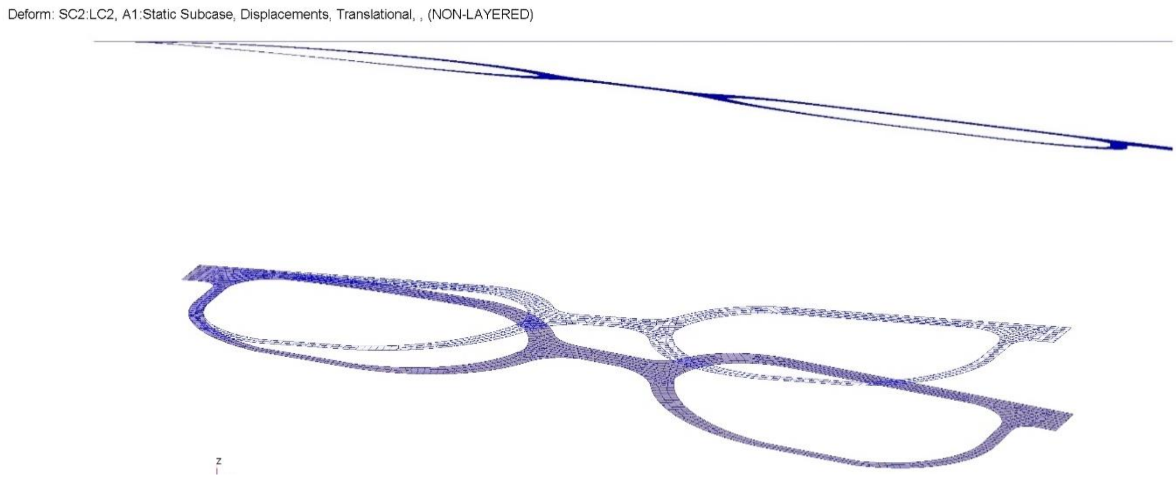


Figure 5: Deformation – Load case 2(side and isometric view), PLA material, 2D isotropic

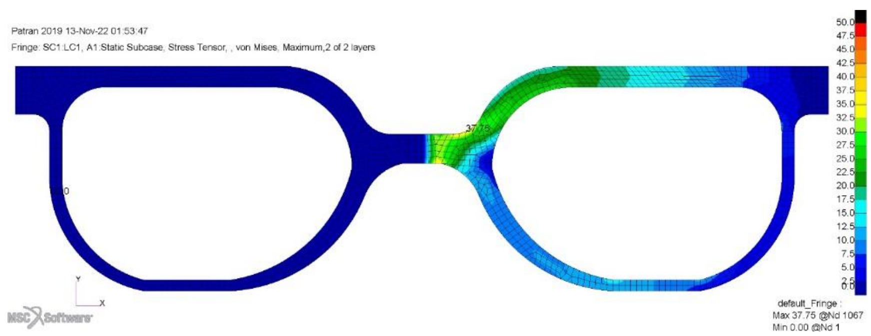


Figure 6: Von Mises Stress – Load Case 1, PLA material, 2D isotropic

3. CONCLUSIONS

The eyeglass frames, both made of plastic materials and printed with the help of the 3D printer, were subjected to the bending test, thus obtaining their mechanical properties (Yield tension allowable Fty, Longitudinal Elasticity Modulus E, Strain and Stress).

Finite element method (FEM) analysis is a complex process, which involves going through some well-defined stages. Another important aspect is to have the technical sheet of the material, so that depending on its structure, the product can be analyzed, thus replacing the experimental analysis, reducing the time required, as well as the consumption of materials.

Also, care must be taken not to exceed the admissible yield stress, because above this value, the material enters the yield zone and residual deformations occur, possibly causing cracks between the layers.

Both quantitatively and qualitatively, the solutions offered by the finite element method are close to the real behavior of the piece, but depend to a great extent on the modeling and solving capabilities offered by the used software.

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