3D Complex Structures through Layer Plastic Deposition Designed for Carbon Material Impregnation

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DOI: 10.13111/2066-8201.2018.10.3.6

Received: 03 May 2018/ Accepted: 18 June 2018/ Published: September 2018

***6th International Workshop on Numerical Modelling in Aerospace Sciences, NMAS 2018**,*
16 - 17 May 2018, Bucharest, Romania, (held at INCAS, B-dul Iuliu Maniu 220, sector 6)
Section 3 – Modelling of structural problems in aerospace airframes

***Abstract:** The paper aims to demonstrate the capability of LPD – Layer Plastic Deposition 3D printing technique to build complex structures for special purposes such us impregnation with carbon materials. It proposes to push the limits of LPD machines in order to achieve both structural integrity and complexity of the 3D print. Main applicability focus on bioengineering - developing new, lightweight implants and also airspace/automotive industry.*

***Key Words:** rapid prototyping, CAD/CAM/CAE, layer plastic deposition, 3D structures*

1. INTRODUCTION

A new technology, using new materials specially designed for complex geometries, extensively used in research-development and innovation area will be presented in this paper. Firstly we'll provide an overview of basic principles for a rapid prototyping technology, materials and capabilities.

In the following we refer to the additive manufacturing (FA) with the deposit of material filaments known as FDM (Fused Deposition Modeling-the name of the company owning American Stratasys, www.stratasys.com, the leading manufacturer of machines based on this principle of forming the layers of material) or FFF (Fused Filament Fabrication-the name given by the developers of machines designed as an initiative of the RepRap, www.reprap.org).

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We have focused our attention on this process, taking into account growth of installed machines (the current trend especially by spreading low-cost machines assembled from kits or built by enthusiasts. This development has been in progress since 2009, a year in which the patent of Scott Crump (co-founder of Stratasys) for FDM has expired, which has led to a real avalanche of new 3D print models, as well as an increase in the types of applications that use objects manufactured by this process.

The implementation of this technology took place at the Nanostructurated Materials Research Laboratory of the National Research & Development Institute for Non-Ferrous and Rare Metals-IMNR, Pantelimon, Romania.

We installed the LPD equipment in 2017 observing that the yearly/annual demand for LPD services is constantly increasing.

We expect the interest in thermoplastic material parts follows the same strong ascending demand curve.

Since 2017, Nanostructurated Materials Research Laboratory of the National Research & Development Institute for Non-Ferrous and Rare Metals-IMNR works to identify product applications and introduce our systems within the manufacturing industry.

With the purchase of this new LPD-based system, IMNR stays among the leading suppliers who are willing to explore AM (Additive Manufacturing) and the breakthroughs it holds for innovative companies. The ZORTRAX M200 system uses LPD to additively manufacture parts layer-by-layer.

A range of thermoplastic materials is available, including Z-ABS, Z-ULTRAT, Z-GLASS, Z-HIPS, Z-PCABS, Z-PETG, Z-ESD, Z-ASA Pro, Z-PLA Pro. 3D printed parts have excellent mechanical properties and corrosion resistance, low specific weight, and some thermoplastic materials under development and testing provide good biocompatibility.

2. INNOVATIVE TECHNOLOGY: THERMOPLASTIC PARTS DIRECTLY FROM CAD DATA

Manufacturers of 3D printers and filaments for SMB (small and medium-sized businesses) market and rapid prototyping work for industries, including robotics and automation, architecture, industrial design, engineering, aviation, industrial automation. Zortrax machines work with dedicated software, firmware and filaments.

Zortrax Z-SUITE software is created specifically for Zortrax machines. Z-SUITE allows to open a .stl, .obj or .dxf file and set printing preferences. It is the only 3D printing software in which users are able to convert 2D files into 3D models and cut models directly in Z-SUITE software. It is dedicated for both Windows and Mac users. Zortrax developed an application for storing and downloading 3D models - the Zortrax Library. It is available in both Z-SUITE and online.

We use SOLIDWORKS® Premium 2018 x64 SP 2.0 - 3D mechanical CAD and/or Simulation software, in order to generate the complex part design.

Stereolithography is a three-dimensional printing process that makes a solid object from a computer image. The process, also called rapid prototyping, creates parts using a faceted mesh representation in STL files.

It is possible to import STL files with up to 500,000 facets (~ 24 MB for binary format .STL files and ~ 138 MB for ASCII format .STL files).

For surface and solid .STL file imports, there are warnings that conversion may take a long time and you are given the ability to cancel the import.

The unit of measurement can be assigned to a model for both import and export.

This new technology is used in top domains of engineering and medicine, both for civil and military purposes.

The most advanced engineering entities, such as National Aeronautics and Space Administration (NASA), use the AM (additive manufacturing) machines, having a special division dedicated for research in AM.

3. THE MECHANICAL UNIT PRINCIPLES OF THE LPD MACHINE

The mechanical unit contains the following components:

1. Mobile building platform
2. Thermoplastic wire
3. Rollers
4. Heated nozzle
5. Structure (if necessary, a supporting structure is also printed to allow overhangs)

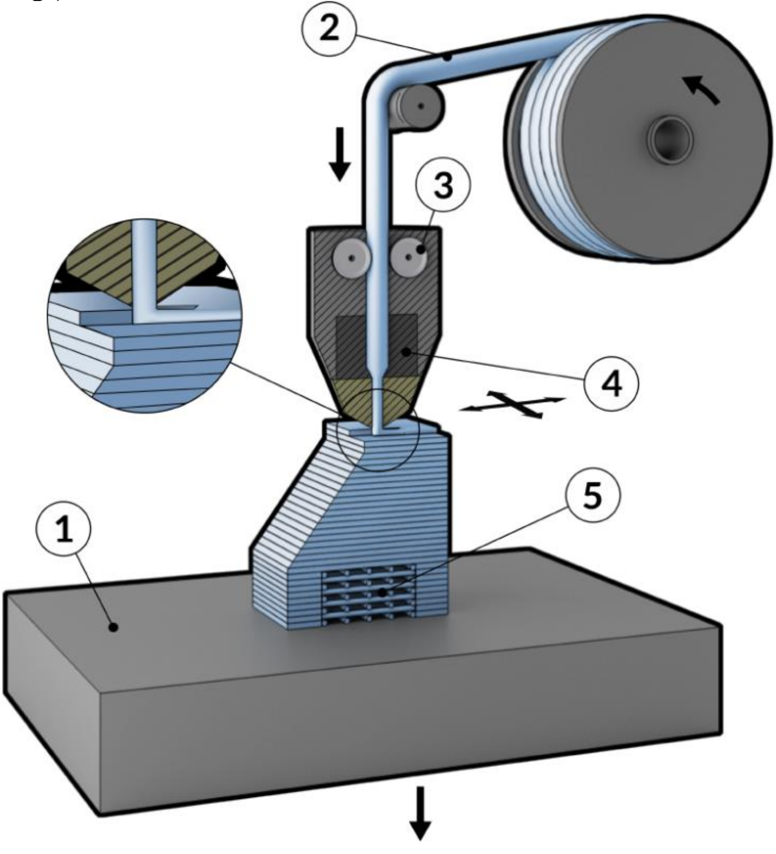

Fig. 1 – Fused Filament Fabrication (FFF) is a relatively new method of rapid prototyping (also known as FDM) which works by laying down consecutive layers of material at high temperatures, allowing the adjacent layers to cool and bond together before the next layer is deposited [1]

The Zortrax M200 unit features the following characteristics:

Printing

Technology LPD (Layer Plastic Deposition),

Layer resolution 90-390 microns,

Minimal wall thickness 400 microns,
Platform levelling Automatic platform points height measurement.

3D printer
Build volume 200 x 200 x 180mm (7.9 x 7.9 x 7.1 in),
Material container Spool,
Material diameter 1.75 mm (0.069 in),
Nozzle diameter 0.4 mm (0.016 in),
Support Mechanically removed - printed from the same material as the model,
Extruder Single,
Connectivity SD card (included),
Materials M Series dedicated materials (recommended),
External materials Applicable.

Temperature
Maximum printing temperature (extruder),
290° C (554° F),
Build platform Heated,
Maximum platform temperature,
105° C (221° F),
Ambient operation temperature,
20° - 30° C (68°-86° F),
Storage temperature 0° - 35° C (32°-95° F).

Electrical
AC input 110 V ~ 4 A 50/60 Hz 240 V ~ 1.7 A 50/60 Hz,
Maximum power consumption,
200 W,

Software
Software bundle Z-SUITE,
Supported file types .stl, .obj, .dxf, .3mf,
Supported operating systems,
Mac OS X / Windows 7 and newer versions.

Physical dimensions
Without spool 350 x 360 x 505 mm (13.8 x 14.2 x 19.9 in),
With spool 350 x 440 x 505 mm (13.8 x 17.3 x 19.9 in),
Shipping box 460 x 470 x 570 mm (18.1 x 18.5 x 22.4 in) 25 kg (55.1 lbs).

A plastic filament is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. Typically there is a precision- controlled drive that pushes the filament into the nozzle.

The nozzle is heated to melt the material. The thermoplastics are heated well above their glass transition temperature and then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism.

The nozzle follows a tool-path controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear design, although other mechanical designs such as deltabot have been employed.

Fig. 2 – Zortrax M200 – compact unit

4. STRUCTURE 3D DESIGN

The following table is only a short list, because new filaments with increased mechanical, physical and thermal properties are constantly developing.

Table 1 – Categories of filaments that can be used with Zortrax M200

1			LAYER THICKNESS (mm)				
2	**Nr.**	**MATERIAL**	**0,09**	**0,14**	**0,19**	**0,29**	**0,39**
3	**1**	Z-ABS	green	green	green	green	green
4	**2**	Z-GLASS	red	green	green	green	red
5	**3**	Z-HIPS	green	green	green	green	red
6	**4**	Z-PCABS	red	green	green	red	red
7	**5**	Z-PETG	red	green	green	red	red
8	**6**	Z-ULTRAT	green	green	green	green	red
9	**7**	Z-ESD	green	green	green	red	red
10	**8**	Z-PLA Pro	green	green	green	green	red
11	**9**	Z-ASA Pro	green	green	green	red	red

LEGEND:

green	AVAILABLE
red	NOT AVAILABLE

These categories offer a unique combination of properties for many engineering applications.

Thermoplastic wires are materials characterized by high impact resistance, which gives to models a uniform surface texture. That all-purpose material allows to 3D print elements requiring durability, such as end-use parts, which, after continued use, keep their initial shape over time. With thermoplastic wires, objects with properties comparable to those of models manufactured could be produced using injection molding technology, including functional prototypes, test casings, and mechanical parts. Thermoplastic wires allow testing tailor-made projects in unlimited ways, in one of twenty-two shades. [2]

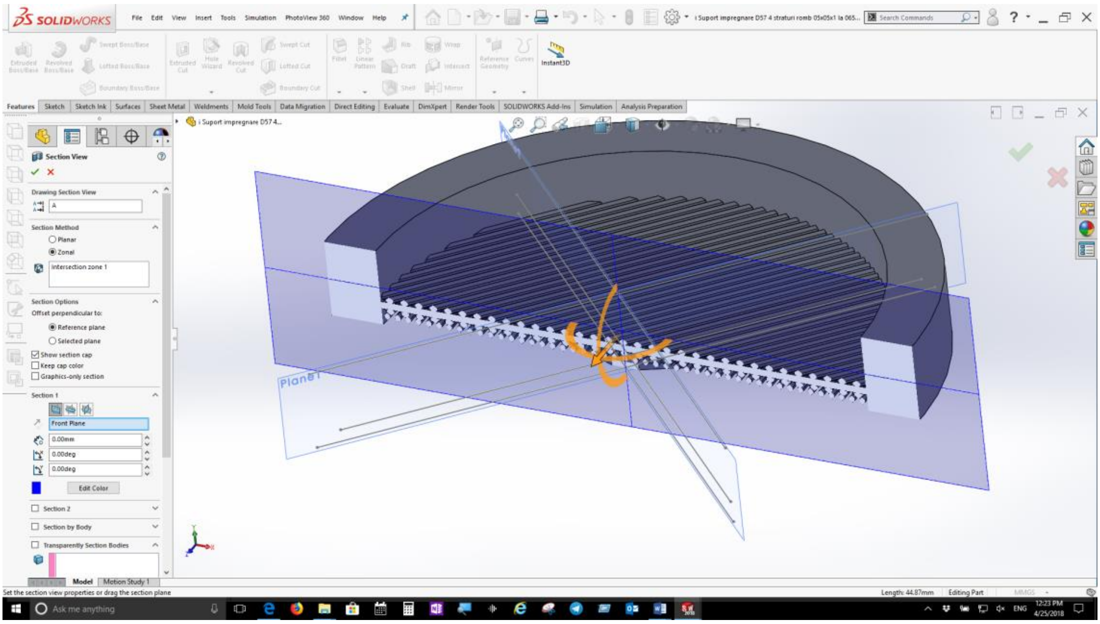

Fig. 3 – SolidWorks 2018 Premium design of scaffold structure

Stereolithography machines are 3D printers that can build any volume shape as a series of slices. Ultimately these machines require a series of closed 2D contours that are filled in with solidified material as the layers are fused together.

A natural file format for such a machine would be a series of closed polygons corresponding to different Z-values.

However, since it is possible to vary the layer thicknesses for a faster though less precise build, it was easier to define the model to be built as a closed polyhedron that can be sliced at the necessary horizontal levels.

The STL file format appears capable of defining a polyhedron with any polygonal facet, but in practice it is only ever used for triangles, which means that much of the syntax of the ASCII protocol is superfluous.

To properly form a 3D volume, the surface represented by any STL files must be closed and connected, where every edge is part of exactly two triangles, and not self-intersecting. Since the STL syntax does not enforce this property, it can be ignored for applications where the closeness does not matter.

The closeness only matters insofar as the software that slices the triangles requires it to ensure that the resulting 2D polygons are closed.

Sometimes such software can be written to clean up small discrepancies by moving vertices that are close together so that they coincide. The results are not predictable, but it is often sufficient. [3]

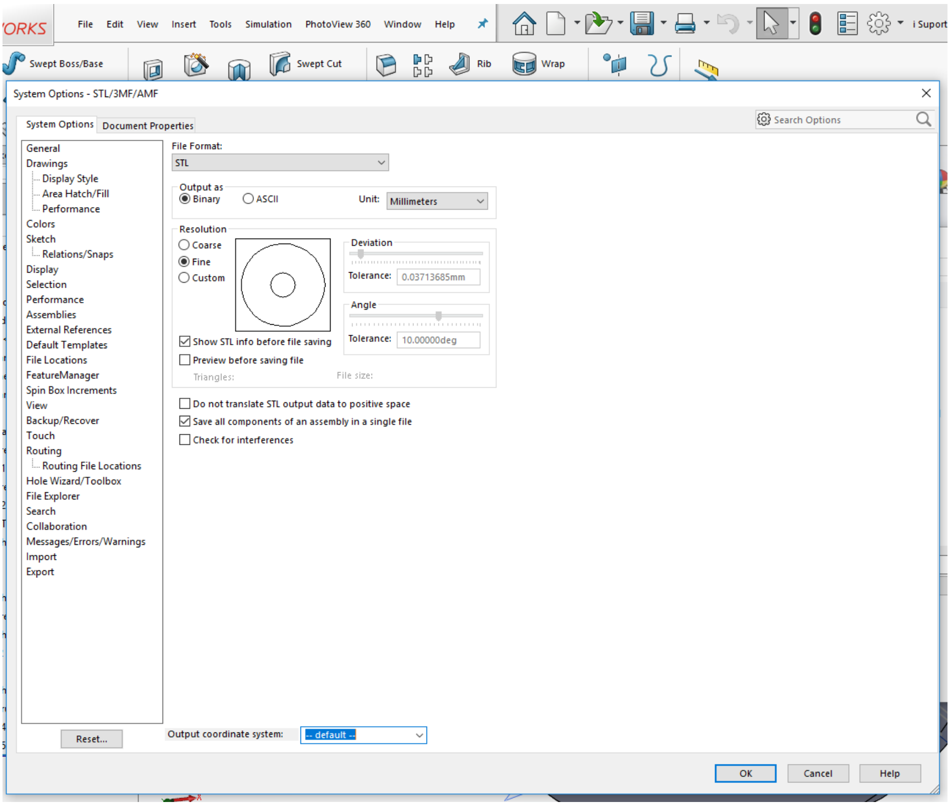

Fig. 4 – STL/3MF/AMF system option settings

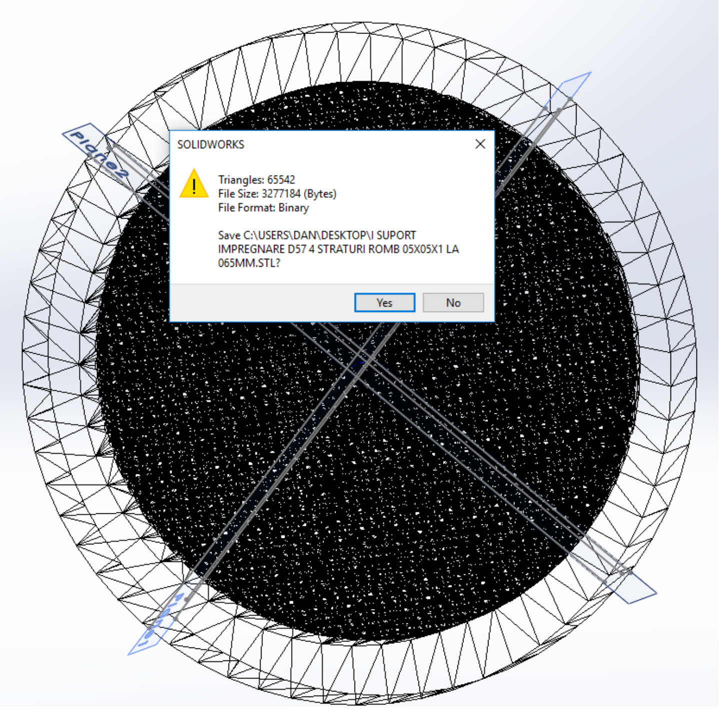

Fig. 5 – STL conversion showing number of triangles generated (66542)

5. 3D LAYER PLASTIC DEPOSITION RESULTS

Combined with traditional scanning techniques, the rapid technologies (prototyping and tooling) can be used as instruments for better (three-dimensional) visualization and simulation of structural behavior of a design.

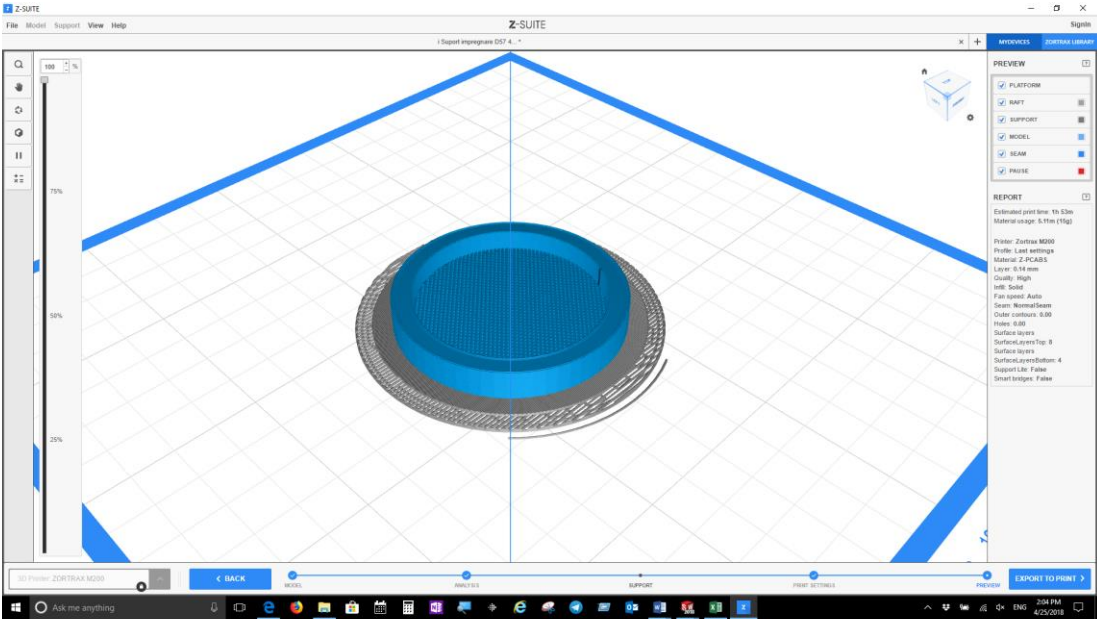

Fig. 6 – Parametric model in 3D CAD – STL imported and positioned on the LPD machine plate

With the aid of editable support feature, it is possible to take the full control over the model's automatically generated support. It creates the possibility to easily add, remove, change their positions and size using three different types of support (point, face and edge). Also, it offers the advantage to create offsets for more precise and effortless removal.

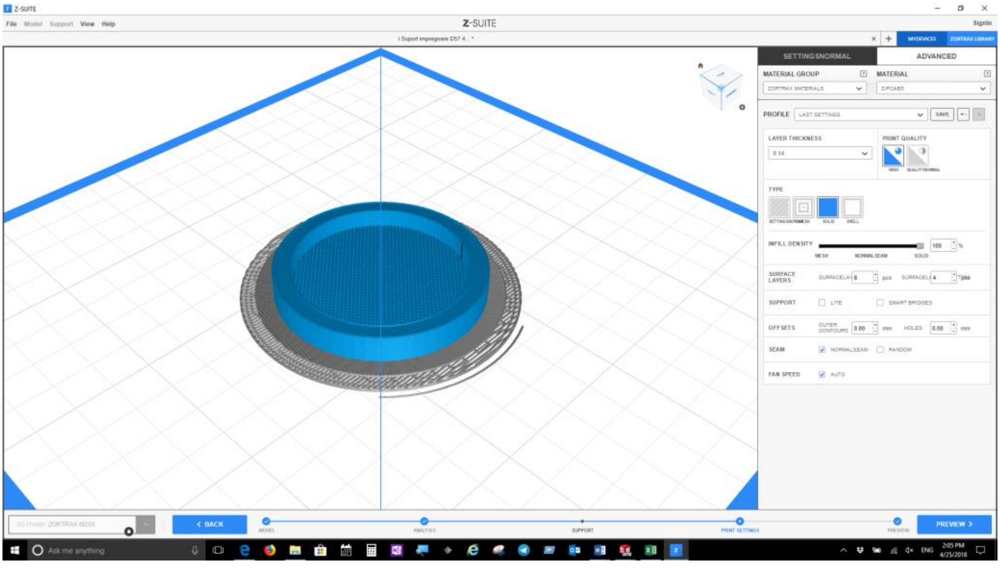

Fig. 7 – Print settings window allows users to choose from a variety of options (layer thickness, infill density, surface layers, etc.)

With the aid of auto mesh repair Z-SUITE detects and repairs all defects in model's mesh. Automatic fixing takes place during loading and greatly reduces the risk of failed prints.

Fig. 8 – Final part with fine layers extracted from the base plate

6. USES OF CAD AND RAPID PROTOTYPING IN MECHATRONICS, BIOMEDICAL AND AEROSPACE ENGINEERING

Main advantages of the rapid prototyping technology:

- no tooling or part-specific tools required,
- no tool path generation or design of EDM electrodes necessary,
- plastic parts created directly in one step,
- simple, fully automatic operation,
- complex geometries such as freeforms, deep slots and conformal cooling channels can be produced without additional effort,
- no unused material during process, giving minimal waste.

FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing.

Rapid prototyping facilitates iterative testing, and for very short runs, rapid manufacturing can be a relatively inexpensive alternative. [4]

FDM uses the thermoplastics PLA, ABS, ABSi, polyphenylsulfone (PPSF), polycarbonate (PC), PETG and also Ultem 9085 among others.

These materials are used for their heat resistance properties. Ultem 9085 also exhibits fire retardancy making it suitable for aerospace and aviation applications.

FDM is also used in prototyping scaffolds for medical tissue engineering applications. [5]

Mechanical Properties	Metric	English	Test Method
Tensile Strength	32.60 MPa	4730 psi	ISO 527:1998
Breaking Stress	30.70 MPa	4450 psi	ISO 527:1998
Elongation at max Tensile Stress	3.78%	3.78%	ISO 527:1998
Elongation at Break	4.87%	4.87%	ISO 527:1998
Bending Stress	54.00 MPa	7830 psi	ISO 178:2011
Flexural Modulus	1.85 GPa	268 ksi	ISO 178:2011
Izod Impact, Notched	5.26 kJ/m^2	2.50 $ft\text{-}lb/in^2$	ISO 180:2004
Thermal Properties	**Metric**	**English**	**Test Method**
Glass Transition Temperature	106.40° C	224° F	ISO 11357-3:2014
Other Properties	**Metric**	**English**	**Test Method**
Melt Flow Rate	43.88 g/10 min Load 5 kg Temperature 260° C	0.0968 lb/10 min Load 11 lb Temperature 500° F	ISO 1133:2006
Specific Density	1.179 g/cm^3	9.84 lb/gal	ISO 1183-3:2003
Shore Hardness (D)	73.4	73.4	ISO 868:1998

Fig. 9 – Mechanical properties of Z-ULTRAT thermoplastic filaments

7. CONCLUSIONS

Thermoplastic filaments are versatile materials perfect for 3D printing prototypes which can be used in thorough tests before starting the production processes. It exhibits a high level of hardness, allowing completing durable prints without compromises on their quality. With these materials, boldest models can acquire a unique, smooth, semi mat surface and they resemble the elements manufactured with mass production plastics, therefore, imitating the complete consumer products or end-use parts. These materials are also fully suited for creating prototypes of mechanical parts or casing elements for performance tests.

ACKNOLEDGEMENT

This work was supported by the national project **ctr. PN 18070301/ 2018** Emerging Technologies for advanced non-ferrous Material Development with high added value - EMERNEF- Contracting Authority: Ministry of Research and Innovation, Romania.

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