Experimental Test for Elastic and Mechanical Evaluation of ABS Plastic Used in 3D Printing

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Low-volume production components represent a possibility to create prototypes from the same process and materials that someone use for the final product and to bring new products to market instead of waiting for final components to arrive from the machine shop. Additive FDM create geometrical products through the deposition of ABS (Acrylonitrile-Butadiene-Styrene) filaments layer by layer satisfying this necessity. Since the specialized literature offers little information on the properties of such plastic materials, in this paper the authors present some experimental procedures in order to evaluate the elastic and mechanical properties of such a plastic material. The specimens have been printed on a 3D "ULTIMAKER –2" printer.

Keywords: Acrylonitrile-Butadiene-Styrene, Fused Deposition Modeling, 3D printing, integrated software home manufaturing

The term "Rapid Prototyping" (or RP) is used in various industries to describe a rapid process of creating an assembly or parts in stage of "prototype". In other words, the emphasis is on rapid processing of a prototype model on which subsequent models and ultimately the final product will be derived. In the context of "product development", the term "Rapid Prototyping" was widely used to describe technologies that have created physical prototypes from digital models [1].

Additive manufacturing has grown from manufacturing plastic parts, which has a history of over 30 years. Moving towards the metal parts relevant to engineering products and high-tech industries was made through the years around '95, therefore current concerns in this area focuses on metal additive manufacturing technologies which are similar with manufacture plastic parts [2].

Traditional manufacturing processes require careful and detailed geometric shapes that make up the piece in order to determine the order in which to achieve and to know what tools and machinery fundamental tools can be achieved.

Fused Deposition Modeling (FDM) is an additive manufacturing process that uses production-grade thermoplastic materials to produce both prototypes and end-use products. FDM parts are ideal for form, fit and function testing due to the fact that they are able to withstand rigorous testing without shrinking, warping, or moisture absorption.

Additive manufacturing and implicit FDM, requires details on basic dimensions of the piece, understanding how the machine works and materials that are used in the process.

The large use of FDM components starting from the aerospace industry to consumer and medical applications on one hand in conjunction with the low speed of manufacturing in complex geometries on the other hand leads to the use of these components in niche area (pioneering field). This technology is very suitable for finite components production such as: automotive plastic components (rollers, pistons, small cranes etc.). This procedure is more convenient in situations where a small part of a subassembly must be replaced instead of purchasing it from suppliers, which usually sells assemblies and not individual components. For instance, in case of company, which performs the service for home appliances, which deals with thousands of products manufactured by different suppliers, it is much faster and cheaper to print small parts (e.g. buttons, small bodies etc.). Therefore, instead of waiting the part to come from the supplier and to pay for transport, which, in some cases is more expensive than the part itself, the part could be printed locally, using the supplier 3D model. What is expected in the future, together with widely uses of 3D printing and diversifying the material used, that new type of businesses to appear. The expected new product will be the 3D model itself, in case of spare parts or even small toys or games. In this case, the market potential is huge and the same selling infrastructure as software might be used, by downloading and printing the product.

Experimental part

Materials and methods

Current standards for this technology only define the terminology for additive manufacturing processes [5, 6]. The .stl or .obj file types were converted to .gcode using Cura software provided by Ultimaker [7-9]. The geometric shapes were created using 3D software supplied by Autodesk [10-12]. Furthermore, the 3D model might be obtained by 3D scanning, using under development low-cost technology (e.g. Kinect) or other products. The .stl file could be provided from a PLM (Product Lifecycle Management) or 3D modeling software, or downloaded from 3D store.

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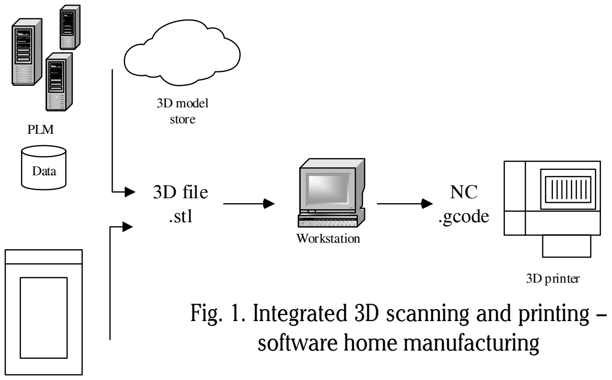

Fig. 1. Integrated 3D scanning and printing – software home manufacturing

The extrusion method functions under the following principle: the extrusion material (filament input) is brought into a semi-solid state and forced through a nozzle to form a filament with a narrower diameter than the diameter of the input filament that will rapidly solidify after the extrusion [3, 4] (fig. 2).

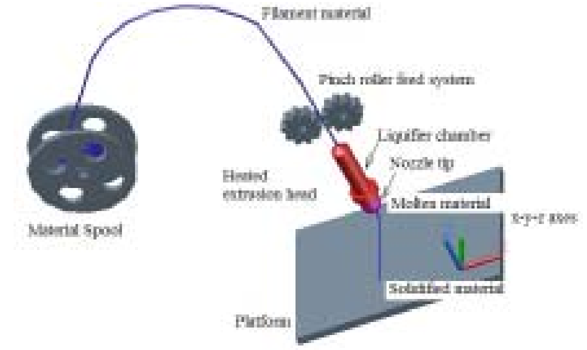

Fig. 2. Schematic of Extrusion-Based Systems [4]

Printing filaments used to be limited to ABS (Acrylonitrile-Butadiene-Styrene), but today there is a wide range of different materials on the market [1]. ABS (Acrylonitrile-Butadiene-Styrene) filament was used to build the objects in experimental part of this article.

Before printing, it is vital that the material is dry. The general printing conditions require heating the plastic material in the extruder to a temperature range of (215-260)°C and the printing baseplate to a range of (90 -115)°C [2].

Extrusion temperature in the experimental parts was 260°C, no rafts were used, while the extrusion speed was kept at 50 mm/s. The technical characteristics of the printing filaments used in the experimental research are: filament diameter 2.85 mm and filament diameter after extrusion 0.3 mm. Because this type of printing process requires a heated base, printing baseplate temperature was set to 115°C [3]. ABS can be used for full functional models. The material is UV resistant and comes closest to the material of real production models.

The specimens were tested in traction and compression through a universal testing machine – INSTRON 8800 (fig. 3). The testing speed was 1mm/min. This machine has a capacity for up to 100 kN, being equipped with hydraulic grips (from the environmental temperature to maximum 1000 C). This machine is equipped with the advanced features of the 8800 digital controller, Console Software and INSTRON's unique fatigue-rated Dynacell load cells [13].

Results and discussions

In order to determine the mechanical (tensile and compressive ultimate stress) and elastic characteristics (Young modulus) of the ABS specimens manufactured on ULTIMAKER printing machine, several experimental tests in traction and compression have been performed, due to the lack of information of these parameters in the technical literature.

Fig. 3. INSTRON 8800 - universal testing machine

In order to carry on tensile tests, according to ASTM D 638 standard, a set of bone specimens (fig. 4) with a length of 25 mm of the calibrating zone and a thickness of 8 mm have been manufactured.

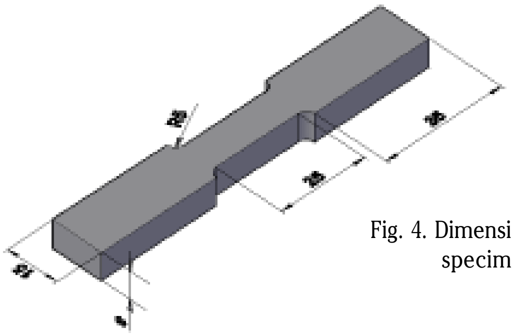

Fig. 4. Dimension of bone specimens

From the graphics depicted below one can conclude that the printing direction has not a great influence on the tensile stress, varying between 67 MPa (in case of horizontal direction) to 70 MPa (in case of vertical direction).

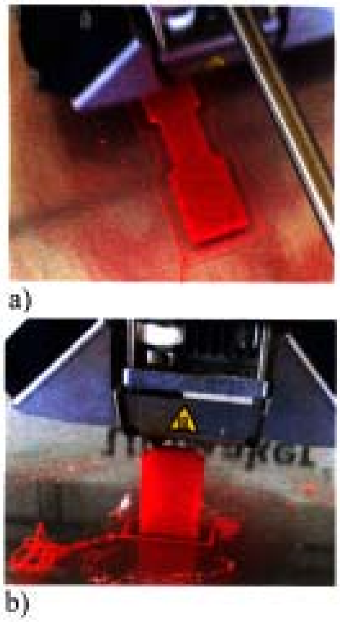

Fig. 5. Printing direction: a) horizontal and b) vertical

In the same time, the same conclusions could be drawn for the printing speed: the ultimate tensile stress vary from 73 MPa – in case of a low printing speed (50 mm/s) to 65 MPa – in case of a high printing speed (100 mm/s). In the zone of small deformations (a tensile strain up to 5%), all the four cases present nearly a same allure. They have a linear behavior until a strain of 5% continuing with a smooth inclination until the fracture, corresponding to a value of approximately 30-35%.

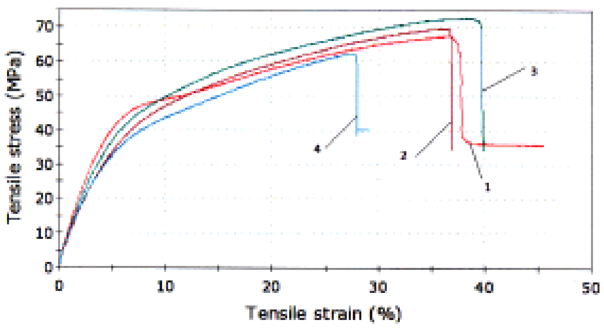

Fig. 6. Stress-strain curves

where:

1) v = 140 [mm/s], horizontal direction of printing;
2) v = 140 [mm/s], vertical direction of printing;
3) v = 50 [mm/s], horizontal direction of printing;
4) v = 50 [mm/s], vertical direction of printing;

In order to strengthen the remarks which could be taken from the graphics depicted in figure 6, supplementary tensile tests have been performed on other bone specimens, with the same cross section dimensions as the previous ones.

The stress-strain curves are plotted in figure 7 and the values of maximum UTS are presented in table 1.

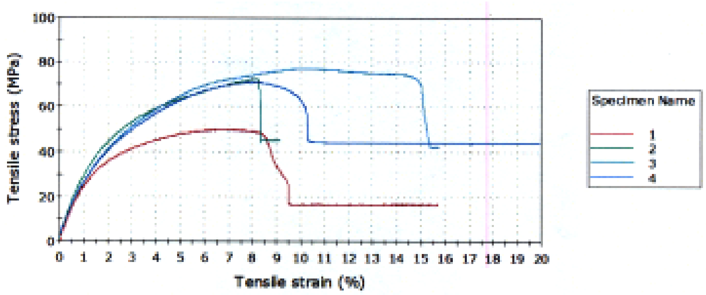

Fig. 7. Stress-strain curves

Table 1

VALUES OF MAXIMUM UTS

Specimen	Ultimate tensile stress [MPa]	Thickness [mm]	Width [mm]	Load at UTS [N]
1	49.68	5.17	10.04	2578.74727
2	72.74	5.00	9.98	3629.91095
3	76.99	5.11	10.06	3957.98683
4	70.22	5.00	9.9	3476.21441

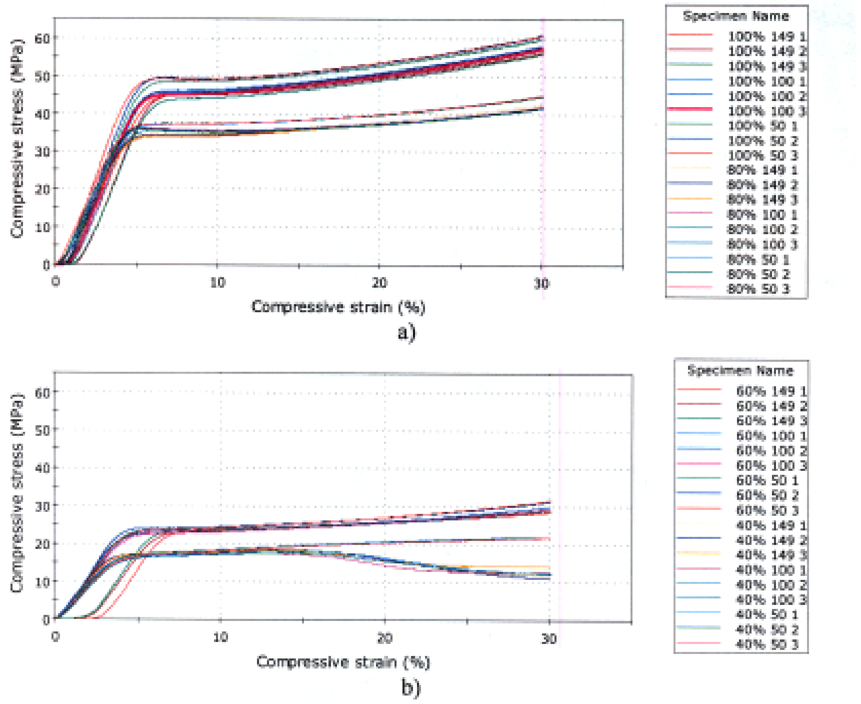

Fig. 8. Compressive stress variation with respect to compressive strain

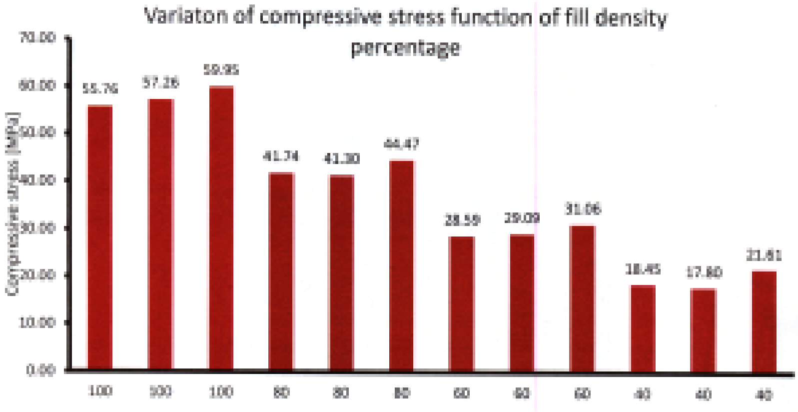

Fig. 9. Compressive stress variation function of fill density

Concerning the compressive tests, according to D 695 standard, a set of cubic samples of 20 mm have been manufactured. To put in evidence the influence of deposition parameters upon the specimens, the deposition speed as well as the density (degree of filling), have been varied.

In that sense, five sets of specimens with densities ranging from 100 to 40, with a ratio of 20% densities have been performed. For each sample of constant density, three different speeds have been taken into consideration:

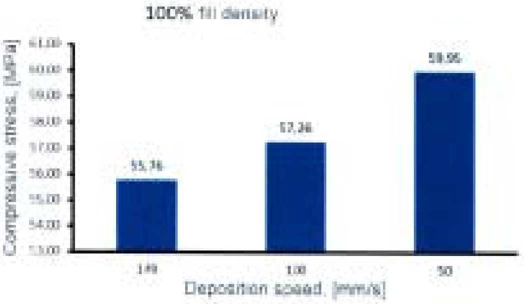

Fig. 10. Compressive stress variation for a 100% fill density

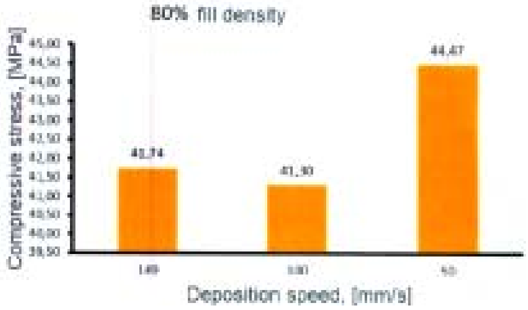

Fig. 11. Compressive stress variation for a 80% fill density

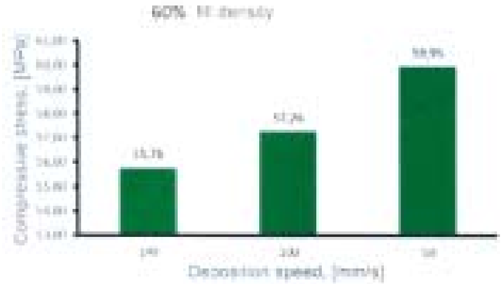

Fig. 12. Compressive stress variation for 60% fill density

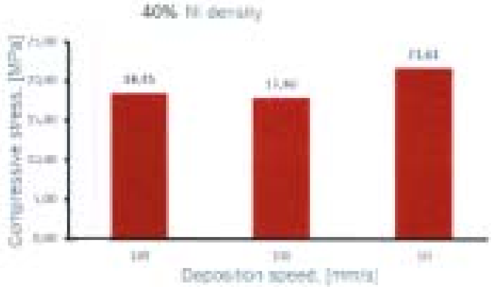

Fig. 13. Compressive stress variation for 40% fill density

Fig. 14. Swelling in volume

Fig. 15. Specimen swelling

140 mm/s, 100 mm/s respectively 50 mm/s resulting in a number of 36 specimens.

In figure 8 (a and b) are represented, cumulatively, the compressive stress variation curves (σ) as function of the compressive strain (ε) as results of the performed tests.

Analyzing the plots depicted in figures 8 and 9 one can conclude that specimens having a fill density equal to 100% are significantly higher concerning the mechanical behaviour compared to those having a lower fill density.

Analyzing the plots depicted in fig. 10-13 one can remark that for a lower deposition speed (50 mm/s) the mechanical characteristics are higher compared to those obtained for a higher deposition speed.

Analyzing the physical aspect of the tested samples one can conclude that:

- with decreasing the specimens fill density it is observed a diminition of compressive strains (fig. 8);
- for 100% and 80% fill densities a specimen uniform swelling in volume is observed (fig. 13);
- with a decrease of the fill density, the specimen swelling becomes more and more prominent towards the specimen basis, i.e. the zone from where the printing platform deposition starts (fig. 14).

Conclusions

With a wide range of FDM materials available, any application can be tackled. Material changes can be made quickly and easily with low maintenance costs making for a great ROI. So, we foreseen two core appliances, one for companies (e.g. spare parts) and one for home users. The first company appliance could be easily integrated with Product Lifecycle Management - PLM or Enterprise Resource Planning-ERP system, which could store and provide 3D models. The second appliance is the subject of *integrated software home manufacturing,* which aims to give the home users an end-to-end software and hardware technology to manufacture home appliance parts (broken parts, toys etc.).

The Filament Deposition Method represents a prominent form of rapid prototyping, suitable for rapid manufacturing. Rapid prototyping facilitates iterative testing being a relatively inexpensive alternative. Since FDM uses the thermoplastics ABS, the components made from such materials are used for their heat resistance properties. Due to the high interest in medicine, FDM is also used in prototyping scaffolds for medical tissue engineering applications.

Real production thermoplastics are stable and have no appreciable warpage, shrinkage, or moisture absorption, like the resins (and powders) in competitive processes. Because thermoplastics are environmentally stable, part accuracy (or tolerance) does not change with ambient conditions or time. This enables FDM parts to be among the most dimensionally accurate.

An important conclusion drawn from this paper is the fact that the filament deposition (vertical or horizontal) as well as the fill density affect in a very low manner the elastic and mechanical characteristics. Since the low speed of deposition is more appropriate for the achievement of a final product, this method is preferable in case of products with complicated geometrical shapes.

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