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# THE FDM 3D PRINTING APPLICATION FOR ORTHOPEDIC SPLINTS

BY

**CHITARIU DRAGOŞ, MUNTEANU ADRIANA*, SEGHEDIN NICOLAIE and CARATA EUGEN**

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Machines Manufacturing and Industrial Management,

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**Abstract.** The problem addressed in the paper is to identify and investigate the manufacture of hand prosthesis using Fused Deposition Modelling (FDM) technology. This technology offers easy manufacturing complex geometry parts like the items found in medical applications. The research highlight’s some specific aspects of 3D printing, there are presented two different FDM techniques using two different printers in order to print the same hand prosthesis.

**Keywords:** 3D printing fused deposition modelling, temporary hand prosthesis.

## 1. Introduction

3D printing is a trend in development; it includes a wide variety of a wide variety of methods and technologies from plastic extrusion, to polymer jetting, to laser sintering. 3D printing is an additive manufacturing technology, opposed to traditional machining technology that mechanically cuts, removes material from a blank block in order to obtain the finished workpiece (Novakova-Marcincinova, 2012), (Stratasys, 2012).

*Corresponding author; *e-mail:* adycypmunteanu@yahoo..com

Currently there are many different 3D printing processes in use, with various materials and printing parameters.

In industrial practice, in the last years, are commercially available as 3D printing technologies: Stereolitography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), Solid Ground Curing (SGC) and Ink Jet printing Techniques (Munteanu , 2015), (Rapidreadytech, 2015), (Brock, 2000)

Fused deposition modelling (FDM); this is a special application of plastic extrusion. This method of processing can use a variety of polymers and is a manufacturing process that creates through successive layers a three-dimensional object from plastic. Of all rapid prototyping techniques, the fused deposition modelling is an additive manufacturing technology based on diffusion welding; beads of heated plastic are joined building the object layer by layer (Novakova-Marcincinova, 2012), (Munteanu , 2015).

In the case of FDM technology different companies call the same process by different names, Stratasys uses the term Fused Deposition Modeling (FDM), 3D Systems uses the term plastic jet printing, and the RepRap community uses the term fused filament fabrication (FFF) (Bamatt, 2015). Most people recognize the FDM than plastic jet printing or fused filament fabrication. The processes use an extruder head to create objects and inthis case the basic materials are: Acrylonitrile Butadiene Styrene (ABS), polyamide, polycarbonate, polyethylene and polypropylene (Munteanu, 2015), (Rapidreadytech, 2015), (Barnatt, 2015), (3dhubs, 2015).

## 2. FDM Application

FDM technology is an easy solution that allows freedom of design and high accuracy for the product. This technology is currently used in industrial engineering, especially for rapid prototyping, in medical field for printing body parts, also in the artistic field for creation of various shape and profiles (Munteanu, 2015).

The paper presents experimental results of 3D printing of temporary hand prosthesis used for supporting and immobilizing of broken bones, mainly hand bones. The purpose was to see how feasible would be to use 3D printer in the medical field, namely to create a temporary prosthetic hand.

There are situations when fitting a simple splint is sufficient providing real support only one side of the lesion (minor fracture, sprain etc.). Gypsum or more precisely "a cast unit" ensures complete immobilization (360$^o$) fractured limb. Its role is to prevent the bone fragments to move. The device consists of two plaster layers: one soft (thick wool) which is applied directly to the skin that wraps over moist gauze soaked in plaster, which will stiffen forming rigid layer, after it dries (Full drying: one - two days).

The use of cast orthopaedic splints has a series of disadvantages as: if it fitted too tight may affect the blood supply if fitted too wide doesn't fulfil the purpose. Also the removal of the cast isn't without difficulties and unpleasantness.

Due to the nature of the cast, the limb is unreachable during the treatment and affects the skin that could lead to dermatological complications but the most common problems are itching, rashes (Munteanu, 2015), (healthcare.utah.edu, 2015).

In the case of children other limitations are the weight, which can be considerable, thus restricting movement.

Many of these disadvantages (the aesthetic appearance, the hygiene problem, the weight, the itching, the reduced mobility) can be eliminated or diminished by using a device more easily from fabrication point of view; with small weight, more versatile, which does not require a long time for the installation and the removal (Munteanu, 2015),

The first design model is suitable in the case of a bone dislocation or displacement. Such versatility is assured by its multidimensionality (can be used for a great number of patients), has a high attainability for different limb dimension, provided by elastic attachments and the use of rivets permit to modify suitable the dimensions in an appropriate field (Fig. 1.).

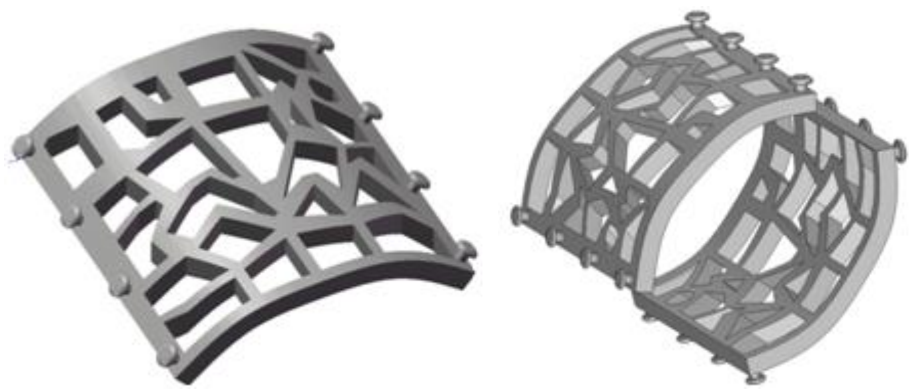


Fig. 1. Temporary hand prosthesis model

The paper presents experimental results of 3D printing of temporary hand prosthesis intended for children. Such versatility is assured by its multidimensionality (can be used for a great number of patients), has a high attainability for different limb dimension, provided by elastic attachments and the use of rivets permit to modify suitable the dimensions in an appropriate field (fig. 1) (Munteanu, 2015),

The material used for the hand prosthesis was ABS (Acrylonitrile-Butadiene-Styren). This material presents good mechanical characteristics impact resistance, good machinability, aesthetic qualities, easy to paint and glue, good strength and stiffness, relatively low cost. The usual applications for this material are machined prototypes, structural components, support blocks, housings, and covers.

## 3. Work methodology

The 3D printer deposits a material such as plastic, wax, or liquid polymer one layer at a time, starting from the base.

In order to obtain 3D printed splint to following steps must be completed:

1. Designing a 3D CAD model of the desired part and saving it into a STL format type;

2. Pre-processing of the STL model in the build-preparation software that slices and positions a 3D CAD file and calculates a path of the printing head for the thermoplastic extrusion the and any necessary support material for gap covering.

Fig. 2 presents a view of the pre-processing stage that indicates the different layers of model and support material.

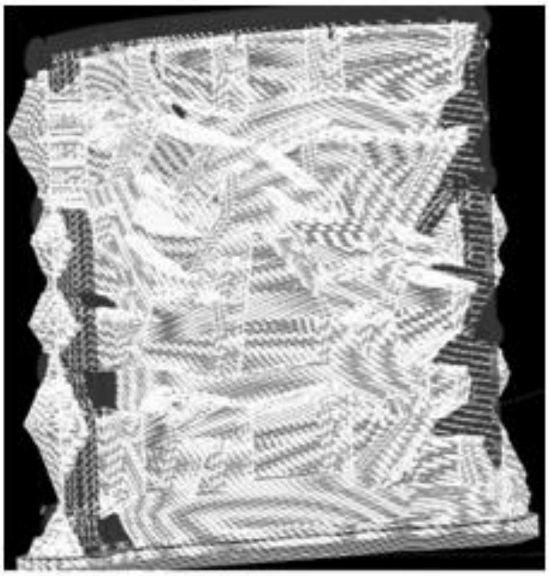


Fig. 2.Pre-processing stage in the case of Insight software for the Fortus 250 3D printer

Fig. 3 presents the sectioned view that indicates model layers, the area with higher density, and support layers the area with lower density.

Also, in this stage parameter that will affect the stiffness/ rigidity of the printed piece are set, slice - layer height, various settings for curves, support settings, fill style of the printed piece, various contours, raster and sparse fill.

Raster width represents the material used to fill in the interior of a layer. This extrusion can be adjusted to fill with negative air gap or positive air gap depending on the density required for the layer.

The sparse high density interior style allows a fill pattern that produces a semi-solid part constructed of interwoven roads that are separated thus conducting to a reduced printing time but lower rigidity than solid material.

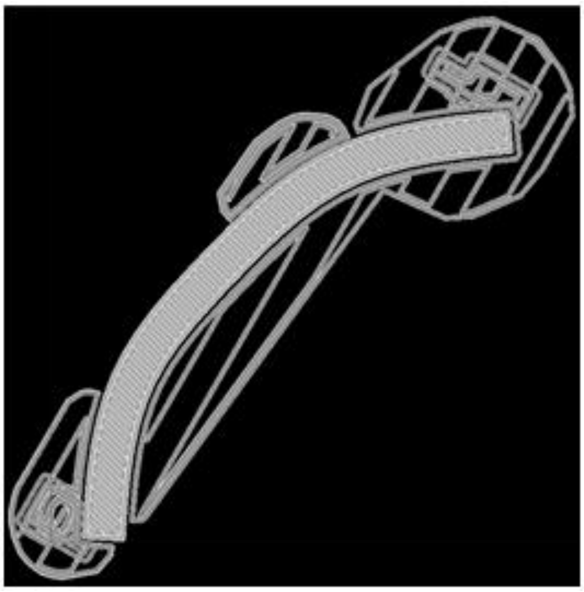


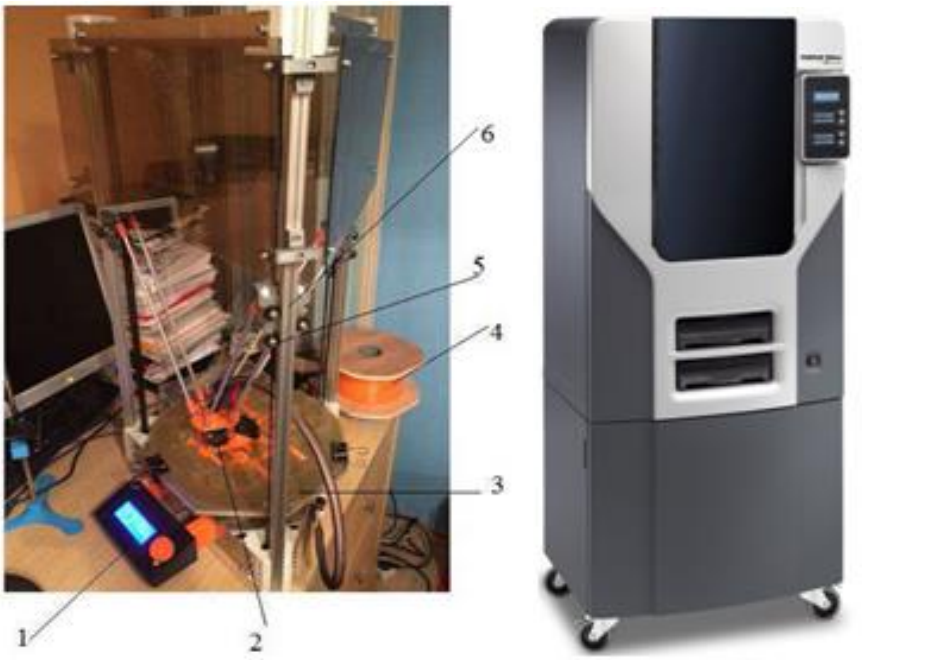
Fig. 3. Sectioned view of the model in the pre-processing stage

4. Production – the printing of the piece when the printer heats the thermoplastic to semi-liquid state and deposits the material along the programmed extrusion path. Automatically, if needed support material is deposited for supporting the hollow areas that sustain the model material that will finally be the part.

5. Post-processing: the user breaks away support material or dissolves it in detergent and water, and the part is ready to use.

In the paper two printers were used to print the two temporary hand prosthesis. The first printer is low price starting kit printer fig. 4.a, the second printer is Fortus 250 printer made by Stratasys.

In the case of the low printer the printing materials used are ABS filament, PLA, NYLON, PETT of 1.75 mm diameter. The maximum printing speed is 150 mm/s but the optimal print speed is between 50-100 mm/s. The minimum thickness layer of printing is 0.1mm but the print optimum layer thickness is 0.2 mm.




a) b)

Fig. 4.a. Low-price 3D printer, b. Fortus 250 printer

The printer has a single full metal nozzle print head (2) of 0.4 mm that supports extrusion temperatures up to 300 degrees. The printing surface is cylindrical type with the base of 300 mm and the height 300 mm. The print bed surface (3) is heated of PEI and withstands temperatures up to 110 degrees. The printed support can be assured by SD Card and from USB and the independent control is assured of LCD display (1). The ABS filament (4) is in the form of a roll, and the motion can be achieved thanks to the linear guide (5), (6).

The parameters used to print the temporary hand prosthesis model are presented in Table 1.

In the case of the Fortus 250 printer uses ABSplus-P430 thermoplastic, the build chamber has the dimensions 254 x 254 x 305 mm. The layer thickness varies between 0.330 mm, 0.254 mm, 0.178 mm.

The printer use two cartridges a support and model cartage. The support is movable material that acts as scaffolding for the model material that is the structure of final 3D part.

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**Table 1.**
*3D Printing Parameters*

| Parameters | | Value for Low cost printer | Value for Fortus 250 printer | Units |
|---|---|---|---|---|
| Printing speed | | 8 0 | Program controlled | [mm/s] |
| Layer thickness | | 0.2 | 0.1778 | [mm] |
| Number of layers | | Program controlled | 353 | - |
| ABS filament | | 1.75 | - | [mm] |
| | Model filament | - | 1.8 | [mm] |
| | Support filament | - | 1.8 | [mm] |
| The extrusion temperature | | 2 70 | Program controlled | [ºC] |
| Base plate temperature | | 110 | - | [ºC] |
| Build Chamber temperature | | - | 80 | [ºC] |
| Part interior style | | Program controlled | Sparse high density | |
| Number of base layers | | Program controlled | 2 | |

Fig. 5.Printed temporary hand prosthesis by Fortus 250 printer

The printer use two cartridges a support and model cartage. The support is movable material that acts as scaffolding for the model material that is the structure of final 3D part.

Fig. 5 presents the printed model from Fortus 250 printer before stage 5 of post-processing that removes the support material.

Fig. 6 presents the final printed temporary hand prosthesis; in the left side is low printer temporary hand prosthesis in the right side is the Fortus 250 printed temporary hand prosthesis.

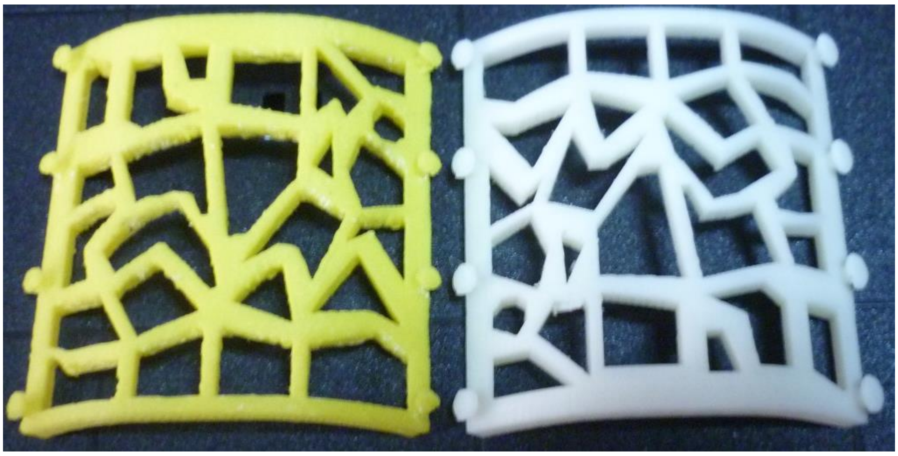

Fig. 6. 3D printed temporary hand prosthesis

The finish of the professional printer is much better; the low printer layer deposits are visible compared to the smooth finish of the professional printer. In order to correctly evaluate the finished product the $R_a$ Roughness was measured in order to compare the two equipment's used in testing. One measurement was made on the directions along the extrusion path and one measurement was made on the transversal direction.

**Table 2**

$R_a$ Roughness of the Printed Temporary Hand Prosthesis

| Direction of measurement | Low price printer | Fortus 250 printer |
|---|---|---|
| Along side extrusion path | 4 - 6[μm] | 1 - 3 [μm] |
| On transversal direction of the extrusion path | 17 - 19 [μm] | 12 - 13 [μm] |

Supplementary the temporary prosthesis is easy and attractive to children, being used a yellow filament, other colours are available and even the usage of different colour layers. The wearing of this temporary hand prosthesis still requires the use of rubber wristbands on the active edges to protect the skin.

## 4. Conclusion

The use of FDM technology can provide real benefits in term of response time and production cost of special customized parts with complex geometry like the items found in medical applications.

In case of the orthopaedic hand prosthesis, FDM technology offers variability and customisations of the model, low manufacturing time and cost, also the technology is easy to learn and apply.

The parameterization of the build-preparation software offers the possibility of varying the stiffness of the printed hand prosthesis offering the right flexibility in the right place according, to the doctor's indications and patient needs. The 3D printed hand prosthesis presented still requires the use of rubber wristbands on the active edges to protect the skin, in the case of the low price printer, but Fortus printed prosthesis the edges are much smoother .

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APLICAREA PRINTARII 3D TIP FDM PENTRU ATELE ORTOPEDICE
(Rezumat)

Problema abordată în lucrare este de a identifica și investiga fabricarea de proteze de mână, tehnologiile moderne de impriumare si anume modelarea 3D folosind metoda FDM (Fused Deposition Modelling). Aceasta tehnologie de fabricație ofera posibilitatea obşinerii ușoare a unor piese u geometrie complexe spre exemplu obiecte gasite in aplicatii medicale. Lucarea punctează câteva aspecte specifice ale metodei de imprimare 3d, fiind prezentate două tehnici diferite, folosind două imprimante FDM diferite pentru a imprima aceeași proteză de mână.