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EFFECTS OF BUILDING CONDITION ON THE TENSILE PROPERTY OF FFF TIMBERFILL PARTS

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ABSTRACT
This paper presents a study of mechanical properties of Fused Deposition Modeling (FDM) rapid prototyping processed material Timberfill. In this study, four important process parameters such as layer thickness, density, printing velocity, and orientation are considered. Experiments are conducted based on L27 Taguchi orthogonal array for the design of experiment (DOE) in order to reduce experimental runs. Finally, the influence of parameters on the responses such as Young modulus parameters, elastic limit, elastic elongation, maximum tension, breaking stress and elongation at break of test specimen are studied. The validity of the models is tested using analysis of variance (ANOVA). The layer height has a practically linear tendency, increasing the value of the tension maximum when the layer height is higher. A maximum value of 585 MPa / kg has been obtained and a minimum of 505 MPa / kg.
Keywords: Additive manufacturing, Fused Deposition Modeling, Tensile, Timberfill

1. INTRODUCTION
AM technologies encompass the set of relatively new production techniques in which products are produced by joining (adding) materials rather than subtracting (removing) them [1]. 3D printing is a generic term used to define any kind of additive or layered manufacturing process, that is, a group of techniques used to obtain final parts or prototypes in a short period from a digital design by progressive addition of a raw material [2]. On the other hand using these technologies in order to achieve certain product specifications is not a simple task. Some AM technologies have their own software that helps users to set few building parameters, with any or little quantitative information, according to cost and surface finish. Also, manufacturers often avoid information data about mechanical behavior of AM processed materials. In order to build functional end-use parts using these technologies it is needed to know how different building parameters affect the mechanical behavior of parts [3]. Of all possible technologies through which 3D printers can perform the manufacturing process, fused filament fabrication (FFF), also known as fused deposition modelling (FDM) is the most extended one. In FDM, the raw material in the form of solid filament wire is made to pass through the extrusion head where it is heated to a semi-liquid state and deposited with a nozzle on the build platform one layer at a time [4] as shown in Fig 1.

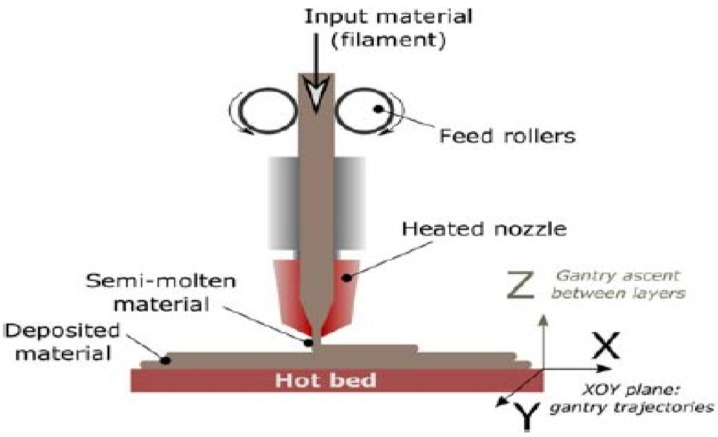

Figure 1 schematic for FDM process [3]

Since mechanical properties are important for functional parts, it is absolutely essential to study influence of various process parameters on mechanical properties so that improvement can be made through selection of best settings [5].
The present study focuses on assessment of mechanical properties viz. tensile strength of part fabricated using fused deposition modelling (FDM) technology. In addition, effect of each process parameter on mechanical property is analyzed.

2. MATERIAL AND METHOD

2.1. Utilized material

Currently, there are many different materials available on the market for FDM 3-D printing including ABS, Nylon, polycarbonate, high-density polyethylene, high impact polystyrene, PLA (poly-lactic acid), and others [6]. In order to these materials majority for ABS and PLA lots of researches have been done due to different properties [7-10]. In this study Timberfill material is chosen based on its abilities and characterizations that it can be used in 3D printing easily, that it allows a high quality of printing even in tricky details and an excellent lamination of the printed object. This material has a purely purpose aesthetic, that of imitating objects with a wood aspect, due to its composition of polymers biodegradable combined with wood fibers. Technical information is shown in table 1.

Table 1. Technical information of Timberfill material

Material density	$1.28\ g/cm^3$	Working Temperature	$170-185\ °C$
Tensile strength	$33.5\ MPa$	Nozzle Diameter	$Min\ 0.4\ mm$
Tensile modulus	$2800\ MPa$	Speed of printing	$20-30\ mm/s$

2.2. Determination of factors and levels

The determined parameters and levels of printing processes for the specimens are layer height (0.2, 0.3, 0.4 mm), fill density (25, 50, 75 %), velocity (30, 35, 40 mm/min), and orientation (OX, 45X, OZ) by nozzle diameter recommended 0.5 mm. For the analysis of the most influential parameters in the mechanical properties of the object it will be necessary to create an experimental design (DOE) and in order to reduce the number of experiments it has been decided to use the L27 Taguchi orthogonal array method.

2.3. Experimental setup

There are no regulations regarding the tensile tests of specimens manufactured with additive manufacturing technology, so for the design and testing of the specimens traction has been wanted to follow the Standard ISO-527 Plastics. Specimens have been manufactured using a *Prusa i3* Steel 3D printer with 2.85 mm diameter light wood tone Timberfill. The universal test machine Microtest has been used for tensile tests EM2 / 20 equipped with 25 kN load cell, 50 mm extensometer, Spider and Microtest data acquisition system.

3. RESULTS AND DISCUSSION

All data has been collected and results of each of the specimens in a Microsoft Access database, where they have generated specific reports for each specimen with all its characteristics. For each experiment, batches of 5 test pieces were tested, which subsequently has calculated the average of each of the parameters to study. For the analysis of the results, Minitab 17 software has been used to analyze through Designs of Taguchi experiments. Fig.2 shows the means of the results of influence of parameters.

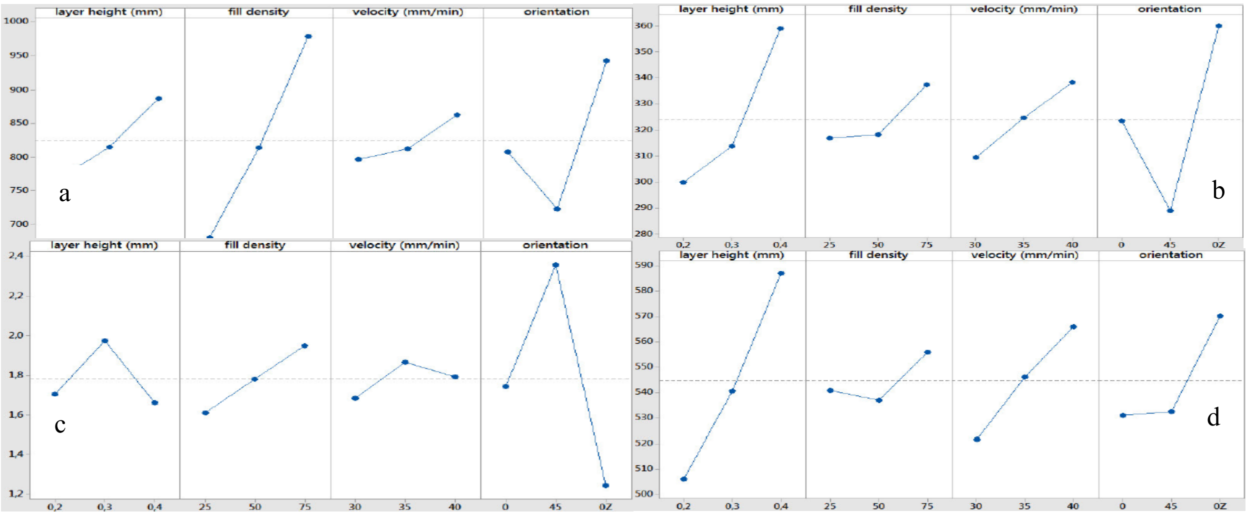

Figure 2: Interaction of the means of the results on: a) Young's Module, b) Elastic Limit, c) Elongation, d) Max Tension

Based on analyze of the result (ANOVA), the parameter with an important influence on the Young's module is the orientation (a). We quickly see that the 45º orientation in OX plane is the worst, presenting values of 725 MPa / kg. While orientation 0 on the OZ plane is the best with values of 950 MPa / kg. 0º orientation in OX plane remains a little below the average of the previous 2, means that the best orientation is clear and indisputable. With a first visual analysis we can deduce that the elastic limit suffers totally different response to Young's module, and consequently, the variables influencing the response will be others. The layer height has a notoriety in the important elastic limit (b). There is no linear trend, because the increase in the value of the output response is much greater when we go from a layer height of 0.3 to 0.4, not when the change is from 0.2 to 0.3. At first change of level is increased the specific elastic limit by approximately 15 MPa / kg. In the second change of level this value has increased by 45 MPa / kg, tripling the result of the first jump. Indeed, orientation has a great influence, although this time it does so different; is the orientation at 45º in the OX plane which has a greater elongation and the 0º in OZ plane the one with the lowest elongation value (c). The maximum tension has a response mostly influenced by layer height and orientation, the others being 2 less influenced variables. The layer height has a practically linear tendency, increasing the value of the tension maximum when the layer height is higher (d). A maximum value of 585 MPa / kg has been obtained and a minimum of 505 MPa / kg.

4. CONCLUSION

After the analysis and discussion of all the obtained results, the conclusions are enunciated the most influential parameters in the properties studied. The most influential parameters are orientation, layer height, fill density, and speed respectively. Following table indicates the conclusion of optimal parameters on responses in summary:

Table 2: Distribution of the responses according to parameters

Response	Influential Parameter
Tensile Strength	Layer height: 0.4 Orientation: 0 in OZ
Elastic Elongation	Orientation: 45 in OX Increasing the Fill Density
Young's Module	Orientation 0 in OZ Increasing the Fill Density
Maximum Tension	Increasing the Speed

The amount of material used has much more weight than the manufacturing time in the cost function.

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