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INFLUENCE OF INTERNAL GEOMETRI ON MECHANICAL PROPERTIES OF 3D PRINTED POLYLACTIC ACID (PLA) MATERIAL

Sigit Tri Wicaksono*, Hosta Ardhyananta, Arif Imbang Pambudi
*Materials and Metallurgical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember Surabaya (ITS)
Jl. Teknik Industri, Kampus ITS Sukolilo Surabaya 60111 Indonesia

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ABSTRACT

Three dimensional (3D) printing technologies have been developed within recent decades and have been demanding for today practical application because of its advantages such as low cost production and easy and simple to use. However, there are still weaknesses in the printing result and processing, including the process efficiency, limited resolution especially for complex design of resulted product, and optimization of the mechanical properties of the filaments used. This study aimed to analyze the effect of variations in the internal geometry on the mechanical properties of 3D printed object using PLA materials. The printed object varied by geometrical shapes and thickness of each geometry. Internal shape geometry used is a triangle and honeycomb, with variations in the size of each symmetry axis of the goemetry are 4.5 mm and 9 mm, and the thickness variation between objects are 1 mm and 2 mm. Test results show that the best performance obtained by measuring its tensile and flexural strength is the sampel with triangle geometry of 9 mm geometrical size and 2 mm of thickness. The tensile strength and flexural strength values of the object are 59.2996 MPa and 123 MPa respectively.

KEYWORDS: 3D Printing, internal geometry, Polylactic Acid, mechanical properties

INTRODUCTION

Generally, there are two types of prototyping method base on the steps of processing methods, bottom-up and top-down prototyping. The bottom-up method mean the printing process started from nothing to become a bulk product of printed prototype. The top-down method use a reverse method at which a printed prototype resulted from a bulk precursor materials. Both of prototyping method have been developed widely [1,2]. Three-dimensional (3D) printing is one of the most versatile and revolutionary additive manufacturing (AM) techniques to create 3D objects with unique structure and diverse properties. 3DP is possibly categorized as bottom-up or top-down prototyping methods depend on the precursor materials used. Presently, there are various techniques or method of printing such as fused deposition modeling (FDM), stereo lithography apparatus (SLA), continuous liquid interface production (CLIP), digital light processing (DLP) and selective laser sintering (SLS) have been developed to form stereoscopic objects with complex architecture. In the late 1980s, S. Scott Crump developed FDM 3D printer and it was commercialized by Stratasys in 1990 [3]. Now, FDM become the most applicable 3D printing method, because of the ease of use, low operational costs, and environmentally friendly. These advantages enhance the development of a wide range of prototype products and manufacturing processes in various industries for various applications. The development of printing three dimensional objects cannot be separated from the development of various software designs that allows creating three dimensional objects and printing them using a 3D printer machine. Commonly design software used before printing three dimensional objects are Solid work and Inventor. The application of the design allows users to create three dimensional objects with a specific format and then convert it in stereo lithography format that can be applied to three dimensional object printing software. On the other hand, results products using FDM 3D printing typically has mechanical properties that are not better than the injection molding process because there is a weak point between the layers. As well as the depreciation happened by the thermoplastic material when the cooling process [3, 4].

In research process and refinement of FDM, of course there are many variables and parameters with the aim of producing three dimensional objects with good results and the level of accuracy approaching its original design and can be applied as the design expected. These variables include the type of printer used, printer dimensional

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capacity object to be printed, 3D printing software, and variety of travel speed, thickness, operating temperature, also the number of layers with specified thickness. In addition to the influence of the type of printer in FDM method, filament material which is used as a filler for printing three dimensional objects is certainly has different characteristic in mechanical and physical properties, thus enabling objects has different results of different filament material. Generally filament used came from a thermoplastic materials type polylactic acid (PLA) [5]. Next conditions that influence the objects results are the internal geometry design and dimensions of the object to be printed. FDM 3D printing works on the principle of layering with a bottom up process when printing the object. It can affect the quality of the prints three dimensional objects, considering each object has a different size and design geometry with a certain degree of difficulty. Several authors have conducted research on influence of the internal geometry on the mechanical properties produced. The study compared the samples with geometric stripes, circles, and honeycomb. There is still a lack of research, namely the use of printer type and too much direction of orientation, making internal geometry variable that would be observed will be affected by printing orientation [6]. Another researchers previously conducted research on the effect of variations in the internal geometry on the mechanical properties of the sample printout 3D printer engine. The printer used in the study was the common commercial printers sold in the market. However, there is still a shortage of such research, because the internal geometry at varying are line and honeycomb shape formed with the option of infill geometry parameters of the object to be printed, so that the size and thickness of the object cannot vary. Starting from these conditions, more specific research on the effect of the internal geometry of the mechanical properties of materials used in the 3D printer engine needs to be done. Moreover, the choice of commercial printers is also an option in order to determine the performance and opportunities of its application on a large scale. The study will analyze the results of the mechanical properties of objects FDM 3D printing is influenced by the type of filament material, internal geometry design and dimensions ratio. Data from the study is expected to be a reference or consideration in making three dimensional objects using FDM 3D printing.

MATERIALS AND METHODS

In this study, the type of printer used is Prusa i3. Print application used is Cura software version 14.09 and samples designed to be printed using Inventor software. Tensile test and flexural test samples are based on ASTM standard D638 and ASTM D790. Sample design shown in Figures 2 and 3.

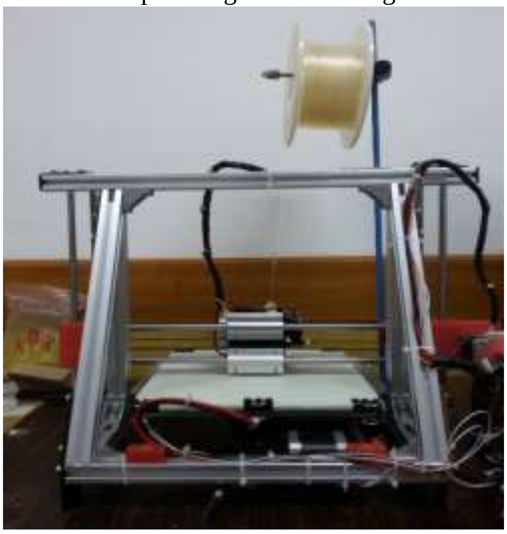

Figure 1. 3D printer used in the study

A. Design and printing of test samples using a 3D Printer

The design process begins with creating objects in 2D using AutoCAD software. *.dwg* files from AutoCAD then opened using Inventor software to be transformed into three dimensional forms and stored in *.stl* file format. Three dimensional files verified consist of 3D *.stl* and *.gcode* file. Both files then opened using Cura software version 14.09. Upon completion of 3D printers in the pre-heat, then the sample is ready to be printed.

B. Mechanical and morphological test

Printed three dimensional tensile and flexural samples then tested. The mechanical testing is according to ASTM D638 and ASTM D790 standart. Sample results of mechanical tests later prepared to be tested again using a Scanning Electron Microscope (SEM). SEM test carried out to observe morphology of the broken area that resulting after the mechanical test.

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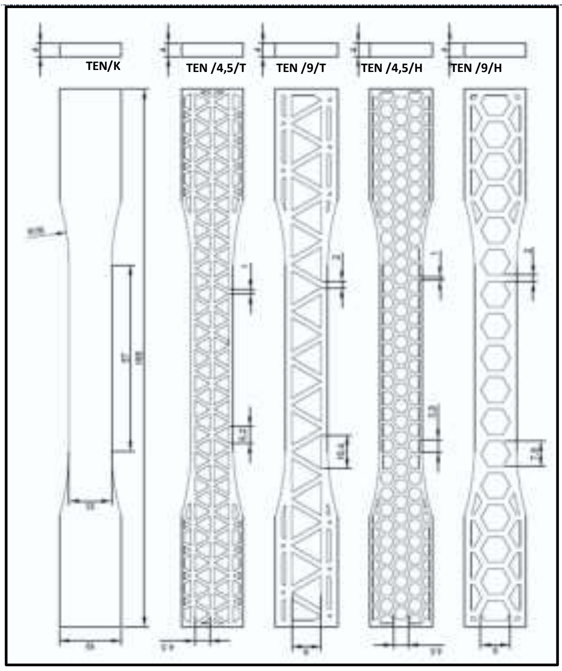

Figure 2. The internal geometry design and dimensions (mm) of tensile test specimens

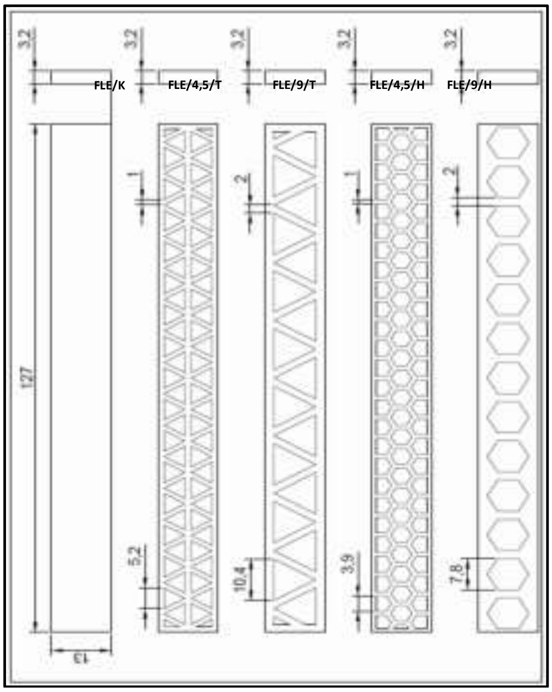

Figure 3. The internal geometry design and dimensions (mm) of flexural test specimens

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RESULTS AND DISCUSSION

A. Tensile test analysis

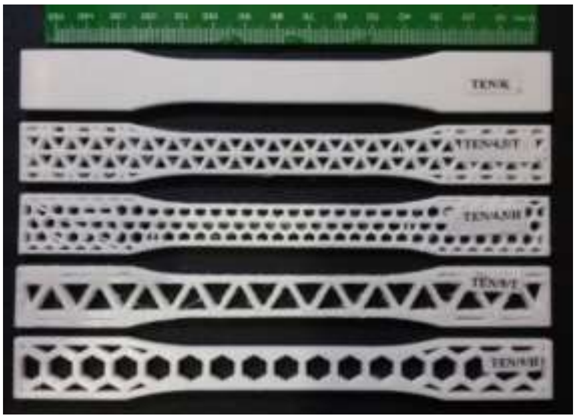

Figure 4. Tensile test sample

Tensile test sample in Figure 4 is formed in accordance with ASTM D638 type I with a nominal thickness of each sample 4 ± 0.4 mm and testing speed 5 mm/min. The tensile test was performed using Shimadzu AG-10TE machine with load capacity 100 kN. Table 1 presents sample data TEN/K compared with datasheet from PLA filament. Samples TEN/K shows ultimate tensile strength nominal is in the range of reference data that is 50.9191 MPa. Based on these data, it is known that printing parameters for printing tensile test samples in accordance with references.

Table 1. Ultimate tensile strength PLA

Sample	Reference PLA Filament	TEN/K
Tensile Strength (MPa)	49 - 56	50,9191

Cross sectional area of each sample is calculated from the cross sectional area of the control sample deminshed with internal geometry area of each variable sample. Broad cross sectional area of sample TEN/K is 52 mm^2. Obtained from the samples product thickness (t = 4 mm) and width (l = 13 mm). While the cross sectional area for sample TEN/4.5/T, TEN/9/T,TEN/4.5/H, and TEN/9/H is 16 mm^2. It is the minimum nominal of cross section area as the divisor of breaking force that is generated when the sample broke [4].

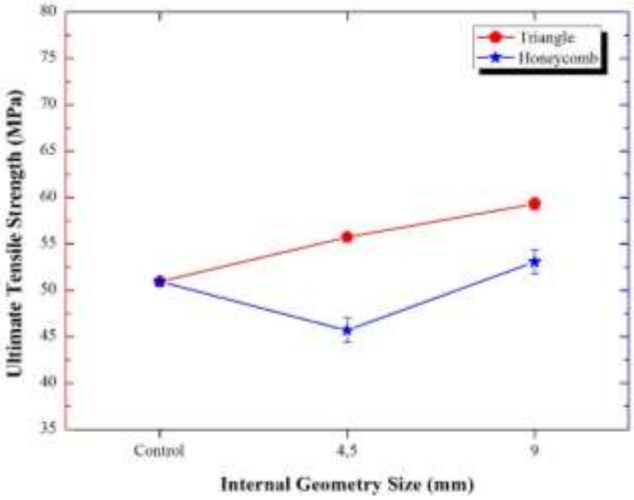

Figure 5. Ultimate tensile strength of tensile test sample

TEN/K or control samples made with the aim to determine the sample quality prints using 3D printer machine, as well as a control variable for comparison of samples with internal geometry variation [7]. Figure 5 presents ultimate tensile strength data of each sample. Sequentially, the ultimate tensile strength values of the samples

TEN/K, TEN/4.5/T, TEN/9/T, TEN/4.5/H, TEN/9/T are 50.9191 MPa, 55.7140 MPa, 59.2996 MPa, 45.6622 MPa, and 53.0172 Mpa respectively. Difference value strengths of each size and geometrical shape are certainly influenced by the selection of various sizes and geometries, as well as the effect of the print process using a 3D printer. [7] The process of printing using a 3D printer got result that layer thickness affects mechanical performance of test sample. This is because influence of internal geometry able to withstand a certain load is different from TEN/K samples [8].

B. SEM analysis for tensile test results

Furthermore to analyze the influence of internal geometry and printing processes samples, fracture morphology was observed using a Scanning Electron Microscope (SEM). Figure 6 displays the images on photomicro of the entire sample area..

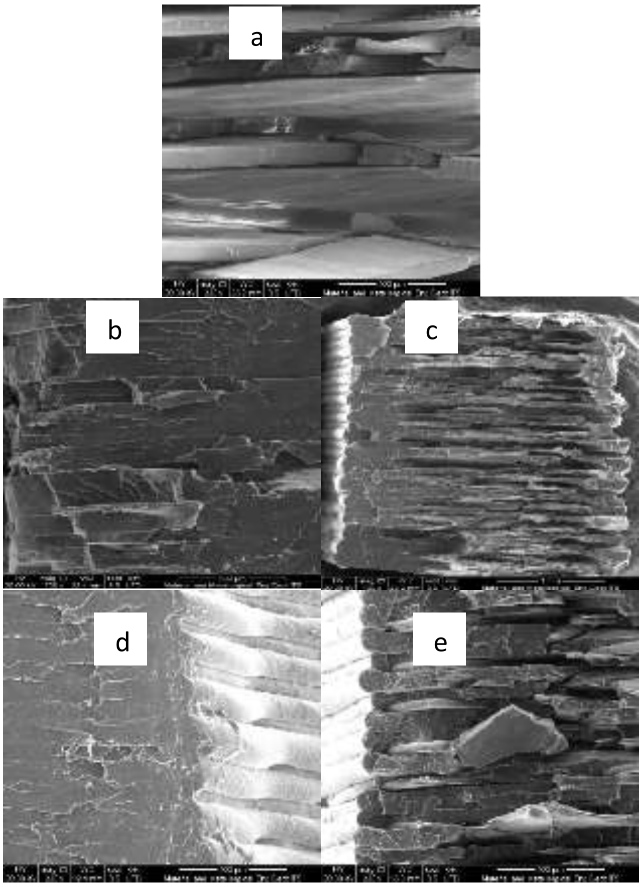

Figure 6. SEM results at 200x magnification for tensile test sample (a)TEN/K, (b)TEN/4,5/T, (c)TEN/9/T, (d)TEN/4,5/H, (e)TEN/9/H

From the image, there are differences in interaction between the resulting layers of three dimensional printing processes in each sample. This condition occurs due to the printing process of each test sample [9]. Seen from the fracture characteristics are flat and without fibers like after withdrawn [10]. Based on the conditions of micrograph results, it is known that results from printing process using a 3D printer machine is not exactly 100% with the initial design. Facts from SEM test results show that size and geometry can affect accuracy of the resulting layer. Too small thickness (1 mm) making layers that have been printed will be depressed by the next layer, and so on. Pressure conditions from layer being printed to finish printed layer causing the layers become flat and widen. Thickness becomes wider than the design dimensions. The condition causes the surface conditions between layers to be different as result of sample with geometry of 4.5 mm. These results make the ability samples measuring geometry 4.5 mm to withstand a tensile load is lower than samples measuring geometry 9 mm. Through the same process, the results of the sample with a size of 9 mm visible geometry are coated with the same size and attached to one another. These conditions make layers between the test samples have same composition and mutually reinforcing. With a good print layer, a sample with internal geometry size 9 mm is able to withstand a tensile load is better than the sample size of 4.5 mm. This is because the sample size of 9 mm can distribute the force with almost the same in each layer.

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C. Flexural test analysis

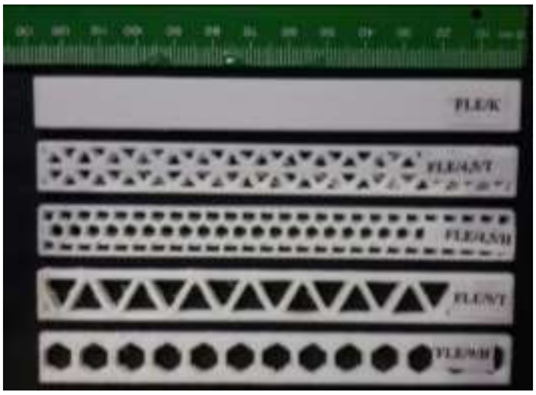

Figure 7. Flexural test sample

Figure 7 is a view of flexural test sample prints using 3D Printers. The sample size was adjusted to the flexural test ASTM D790 standard. The reference data which is used to determine the quality of the sample printout shown in table 2.

Tabel 2. Flexural Strength PLA

Sample	Reference PLA Filament	FLE/K
Flexural Strength (MPa)	80 - 114	88,7880

Samples control, FLE/K has a value of 88.7880 MPa. The value is in the range of reference data. In other words, the sample prints using 3D printer is in accordance with the selected parameter. Flexural strength and deflection data presented in figure 8 and 9. Flexural test is done to determine the flexural strength of PLA material which has varied internal geometry. Testing is done by giving a bending load slowly until the sample reaches fatigue limit. Bending process causing the top surface of the samples experience pressure and the bottom of the sample undergoing a process of tension so that the specimens fractured at the bottom because it is not able to withstand tensile stress [11]. The data results from testing are maximum load and deflection received by the sample. Data then processed and converted into flexural strength and flexural modulus of each sample. Flexural strength is the result of the calculation of force per unit area in the area of the specimen that was broken in the flexural loading [11]. The width of the control sample (FLE/K) is 13 mm, while the sample with the internal geometry variation is 4 mm. This value is used based on a surface in contact with the bending indentor. Figure 8 is flexural strength data of flexural test samples of all the variables. Triangle sample with internal geometry size 4.5 mm has a flexural strength value 92.4760 MPa. Then for a sample of size 9 mm geometries has 123.0021 MPa in flexural strength. Triangle sample with 9 mm size of internal geometry has higher flexural stress compared to samples with internal geometry size 4.5 mm. Next is a sample of honeycomb geometry. Graph shown that samples with internal geometry size 4,5 mm has a bending stress values lower flexural strength than the honeycomb 9 mm. Flexural strength value of each sample honeycomb 4.5 mm and 9 mm respectively are 68.5939 Mpa and 93.0147 MPa. Samples FLE/4.5/H has lower flexural strength value compared with FLE/K samples.

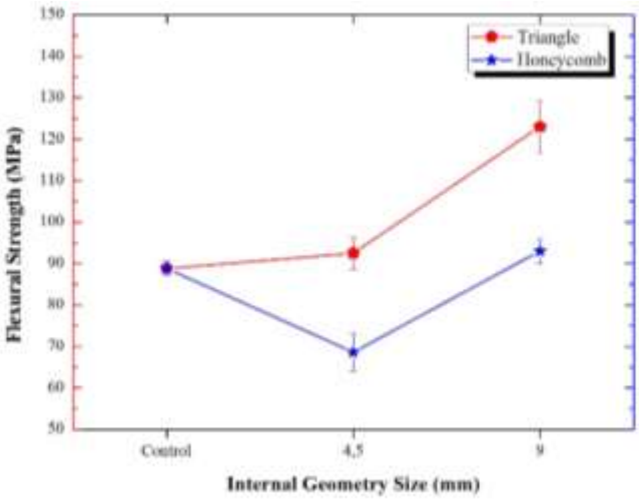

Figure 8. Flexural strength of flexural tensile test sample

Characteristics of the test rod while receiving treatment can be explained by normal stress equation. Where the normal stress denoted (σ), (M) is bending moment in cross section, then distance from neutral axis to cross section is noted in (y), and (I) is the moment of inertia of the test rod. Using modulus equation, tension occurs on the x axis is equal to multiple between the modulus and elongation occurring on the x axis. Normal stres varies with the y distance from neutral surface. So in neutral condition, generated torque is zero. The outer layer of the rod coordinate y is denoted by the symbol c, so normal stress that work will be divided by the value of Z, which is the quotient between the I/c, also called section modulus.

D. SEM analysis for flexural test results

Micrograph at figure 10 is the result of SEM image at 200x magnification. From five samples tested, only three samples were broken, as in the picture. Visible part that receives the compressive stress in the control samples experienced tearing but not yet broken. Similarly, the image b is FLE/9/T sampled with an image taken from side spot specimens. It seems clear that the fracture is fibrous, showing that the fracture patterns of sample look like fracture from ductile material. It is also seen that the constituent layers of printed sample depressed and out of the pattern. Then the sample FLE/9/H has a fracture pattern similar to micrograph results of tensile test sample, but the layers more smooth and thin. Control sample looked torn but not yet broken. While the crack propagation direction from honeycomb samples clearly visible starting from pressure area on the upper surface of the specimen. Referring to the test results, it can be analyzed that internal geometry variations affect the flexural strength of flexural test sample. Flexural test samples with variation of internal geometry explain interaction between layers formed with difference in the size of geometry provides ability to accept different loads [5]. Interaction between layers of sample 9 mm in geometry size are better than the sample with a size of 4.5 mm geometry due to inter layers formed and can be mutually reinforcing such a compositing effect [5,12].

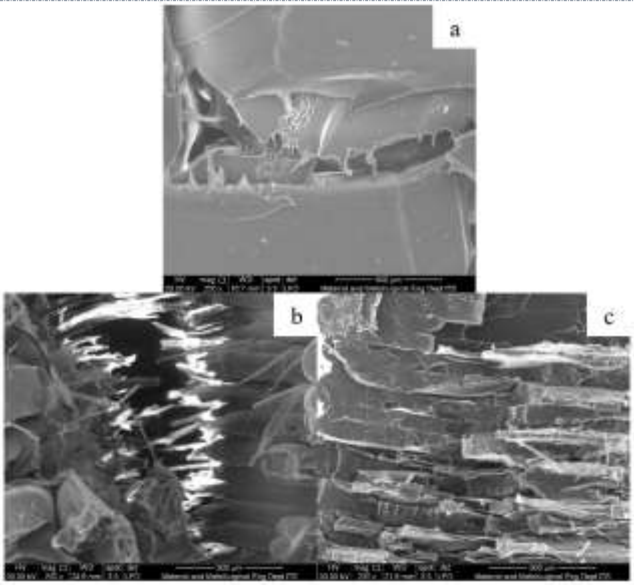

Figure 10. SEM results at 200x magnification for flexural test sample (a)FLE/K, (b)FLE/9/T, (c)FLE/9/H

CONCLUSION

Based on test results and data analysis in this study, the conclusion is :

1. Printing process parameter for 3D objects with triangle and honeycomb internal geometry variations using polylactic acid filament is suitable with the criteria of printed polylactic acid material.
2. The mechanical properties of specimen are strongly depend on internal geometry designed within the specimen strusture.
3. Tensile and flexural test is obtained from the object with tirangle geometry with geometrical size 9 mm and 2 mm thickness between objects. The tensile strength value of the object is 59.2996 MPa and flexural strength values is 123 Mpa

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REFERENCES

[1] Shih-Hsuan Chiu, Sigit Tri Wicaksono, Kun-Ting Chen, Chiu-Yen Chen, "Mechanical and thermal properties of photopolymer/CB (carbon black) nanocomposite for rapid prototyping", Rapid Prototyping Journal 21/3 (2015) 262–269.

[2] Shih-Hsuan Chiu, Ivan Ivan, Cheng-Lung Wu, Kun-Ting Chen, Sigit Tri Wicaksono, Hitoshi Takagi, "Mechanical properties of urethane diacrylate/ bamboo powder composite fabricated by rapid prototyping system", Rapid Prototyping Journal 22/4 (2016) 676–683.

[3] Zixiang Weng, Jianlei Wang, T. Senthil, Lixin Wu, "Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing," Materials and Design 102, 276 – 283, 2016.

[4] Melenka, Garret W., Cheung B.K.O., Schofiled, J.S., dwason, M.R., Carey, J.P., "Evaluation and Prediction of the Tensile Properties of Continuous Fiber-Reinforced 3D Printed Structures," Composites Structure 153, 866 – 875, 2016.

[5] Li, Nanya, Li, Yingguang, Liu, Shuting, "Rapid Prototyping of Continuous Carbon Fiber Reinforced Polylactic Acid Composites by 3D Printing," Journal of Materials Processing Technology, 2016.

[6] Tomislav Galeta, Pero Raos, Josip Stojsic, Ivana Paksi, "Influence of Structure on Mechanical Properties of 3D Printed Objects," Procedia Engineering 149, 100 – 104, 2016.

[7] O.S. Carneiro, A.F. Silva, R. Gomes, "Fused Deposition Modeling with Polypropylene," Materials and Design Journal, 768 – 776, 2015.

[8] Ebel E., sinnemann T, "Fabrication of FDM 3D Object with ABS and PLA and Determination of Their Mechanical Properties," Rtejournal, vol. 2014. (urn:nbn:de:0009-2-38722).
[9] Arghavan Farzadi, "Effect of layer printing delay on mechanical properties and dimensional accuracy of 3D printed porous prototypes in bone tissue engineering," Ceramic International 41, 8320 – 8330, 2015.
[10] V.S. Giita Silverajah, Nor Azowa Ibrahim, Norhazlin zainuddin, "Mechanical, Thermal, and Morphological Properties of Polylactic Acid/Epoxidized Palm Olein Blend," Molecules, 17, 11729 – 1747, 2012.
[11] Shah, Vishu. 1998. Handbook of Plastics Testing 2nd Edition. USA : John Wiley & Sons Inc.
[12] Shih-Hsuan Chiu, Sigit Tri Wicaksono, Kun-Ting Chen and Sheng-Hong Pong, "Morphology and properties of a photopolymer/clay nanocomposite prepared by a rapid prototyping system", Sci Eng Compos Mater 2014; 21(2): 205–210.

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