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Influence of Layer Thickness and Infill Density on the Impact Strength of Carbon Particle and Polylactic Acid (CP/PLA) Composite

Hiyam Adil Habeeb[1], Ahmed Hadi Abood[2], Ahmed Esmael Mohan[3]
[1]*Technical Collage/ Al-mussaib, Al-Furat Al-Awsat Technical University, Babylon, Iraq*
E-mail: hiyamadil84@atu.edu.iq
[2]*Technical Collage/ Al-mussaib, Al-Furat Al-Awsat Technical University, Babylon, Iraq*
E-mail: com.ahmd@atu.edu.iq
[3]*Technical Collage/ Al-mussaib, Al-Furat Al-Awsat Technical University, Babylon, Iraq*
E-mail: com.ms.ahmad@atu.edu.iq

Abstract-This investigation presents a new perspective on the different parameters used to manufacture various objects. The technology of additive manufacturing for thermoplastic material prototypes was applied for the infused deposition technique. This study focused on the impact of layer thickness and infill density on the mechanical characteristics of specimens of polylactic acid (PLA) and carbon particle/PLA composite (CP/PLA). The test of Izod impact was conducted on the specimens. In accordance with ISO standards, test specimens were created by various layer thicknesses (0.01, 0.02 and 0.03 cm) with various infill densities by using a PLA and CP/PLA composite. A system of 3D printing and the impact strengths were verified for other factors, including part orientation, infill density, shell thickness and print speed. Increasing the thickness of layers from 0.01 to 0.03 cm positively affects the mechanical characteristics, whereas the impact force of the specimen increases with the increase in infill density. The best PLA specimens' impact strength was determined at 0.01 cm as a thickness of layer. This work aimed to improve the impact property of PLA by blending with various materials. PLA neat showed the highest impact strength (23.33 kJ/m^2). When 65 wt% CP was added to the CP/PLA, the impact strength was 14.166 kJ/m^2.

Keywords: *3D printing, Polylactic acid (PLA), CP/PLA composite, Layer thickness, infill density, Impact strength.*

1 Introduction

Additive manufacturing (AM) or three dimension (3D) printing is demarcated as a machinery to produce 3D parts by gathering the printable materials by their layers. From all the 3D printing technologies, the one that is more prevalence to the public is Fused Deposition Modelling (FDM) because of the large number of companies that develop this kind of printers and its relative low cost. Fused deposition modelling (FDM) was widely adopted since the end of the last century [1]. The demand for 3D parts increases annually, a development that could be called the beginning of the commercialisation of 3D printing. The working principle of FDM technology involves feeding the liquefier with filament with the assistance of a motor. Then, the melted material constructs a thin layer on layer until the designed part is finished [2].

The popularity of FDM resulted from its simplicity and flexibility for end users. The Replicating Rapid Prototyper (RepRap) was introduced after the expiration of the FDM patent. Two RepRap versions, namely, 'Darwin' and 'Mendel', were initially available, with the latter approximately half the price and weight of the former. Additionally, RepRap technology provides the end user full control over the built parts, which is opposite to the commercial FDM technology [3]. The technology provides an open-source system that is available free, and the operator has an option to create 3D parts with cheap price. Considerable research on FDM method's performance has been carried out by manipulating the factors of process to assess the influence of a mechanical engineering perspective. In order to print an object using the FDM technology there is a need to determine certain number of printer factors. Since the quality of the final product is affect by the majority of these factors it is of relevance to know which, among them, are the most affects [4]. Products and composites Products Created by two or more products (filaments) with various physical and chemical characteristics, but the actual elements in the finished product remain distinct and independent. [5]. The advancement of FDM's filament materials (filaments) is also one of the critical parts that various research groups have extensively studied. Scientists explored the impact of processing factors on regular specimens to identify filament materials like nylon, acrylonitrile, polylactic acid thermoplastic (PLA) and butadiene styrene (ABS) in the initial step of FDM. Polylactic acid (PLA) is a rarely used consumable material in FDM technology [6][7]. As time passed, various materials with different foreign agents like powders of alumina (Al) and iron (Fe) were investigated for the reinforced thermoplastic matrix [8].

The FDM process create high controlling on the mechanical characteristics by various printing factors like filaments that using, layer height, layer orientation, shells' number, height between platform and nozzle, etc. This process of production involves the solidification and melting of the materials that cause the generating of stresses of residual, which produced in the material because of the various or the contraction and temperature, which are created throughout the printing [9].

Three factors are manipulated in this work, namely, thickness of layer (mm), infill density (%) and speed of printing (mm/s).

This work focuses on the effect the parameters of FDM on the mechanical characteristics of 3D printed material by utilising PLA neat and the CP/PLA composite. The involved factors in this study were percentage infill 100%,85%,65% and 50% and thickness of layer at 0.1,0.2 and 0.3 mm and printing orientation was 45º[9]. The filaments the used in printing are natural PLA mixed with carbon particles (CP) generates the CP/PLA composite. The print parts will be tested under an impact test machine. All factors will be assessed and the optimal ones will be proposed to obtain the maximum substantial effect on the impact strength

This paper is structured as follows: The section 2 describes about the literaturereviw and detailed of the parameters of FDM and effect it on mechanicals properties, section 3 included the methodology and working. Section 4, explain the results and d iscussion about effect parameters of FDM on mechanicals properties and section 5 including the conclusion.

2- literature survey

Some of academics have studies the process of printing' factors and its influence on the characteristics of the feigning roughness, product, etc. [10] investigated the effect of direction of printing and layer's height on the remaining strain, summing up that the remaining strain is less when utilizing a longitudinal direction (0º) and a layer height is 0.025 cm. However, to date, few studies exist on the performance of low-cost 3D printer regarding their mechanical characteristics. Recently, the mechanical characteristics of utilizing a 3D printer were evaluated by manipulating the thickness of layer, percent infill and orientation of print [12].
Another investigation also explored the impact process factors utilizing RepRap Prusa I3 3D printer by changing other factors, like several factor infill orientation and shell perimeters [13]. The current investigation investigates the impact process factors on the mechanical characteristics by utilising a recently advanced open-source 3D printer utilizing (Repetier-Host V2.0.1) software. Three factors are manipulated, namely, thickness of layer (mm), thickness of shell (mm) and speed of printing (mm/s). The print parts will be tested under an impact test machine. All factors will be assessed and the optimal ones will be proposed to obtain the maximum substantial effect on the impact strength.

3 Methodology

The CP/PLA composite consisting of natural PLA blended with CP in a 35/65 ratio was utilized to identified the mechanical characteristics of 3D printed materials by utilising PLA and composite PLA. These characteristics varied when various factors in slicing and printing were utilised. Thus, this research examined the correlation between fill ratio and height of layer on impact strength. The TEVO model of 3D printer was utilised to print the sample of impact studied in this examination Figure 1. SolidWorks Computer Aided Design (CAD) Technology (Solidworks 2016, Dassault Systems, Waltham, MA United states) modelled the prototypes. ASTM E2298 (ASTM E2298 – standard test for designed and tested Impact Testing of Metallic Materials (2015)) has defined the configuration of the specimen to evaluate the subject matter for Izod pendulum impact testing by swinginging pendulum to a rapid blast. This effect influences the energy consumption of the substance and is a measure of structural resilience [14]. Sample that conforms to ASTM E2298 includes a V-shaped notch that supplies the sample with a tension concentrater. The notch measures the material's tolerance to propagating cracks. The CAD model has been distributed as a normal STL file and submitted to G-code Language, a popular slicer program. A various software has been utilised for slicing the STL files into machine-readable G-code that involved Slic3r and Cura Figure 1. All samples were printed from the extact file of STL. The specimens were also printed and sliced with such settings as the extruder temperature, where all specimens of natural PLA and the CP/PLA composite were printed at a temperature of 200º Figure 2.

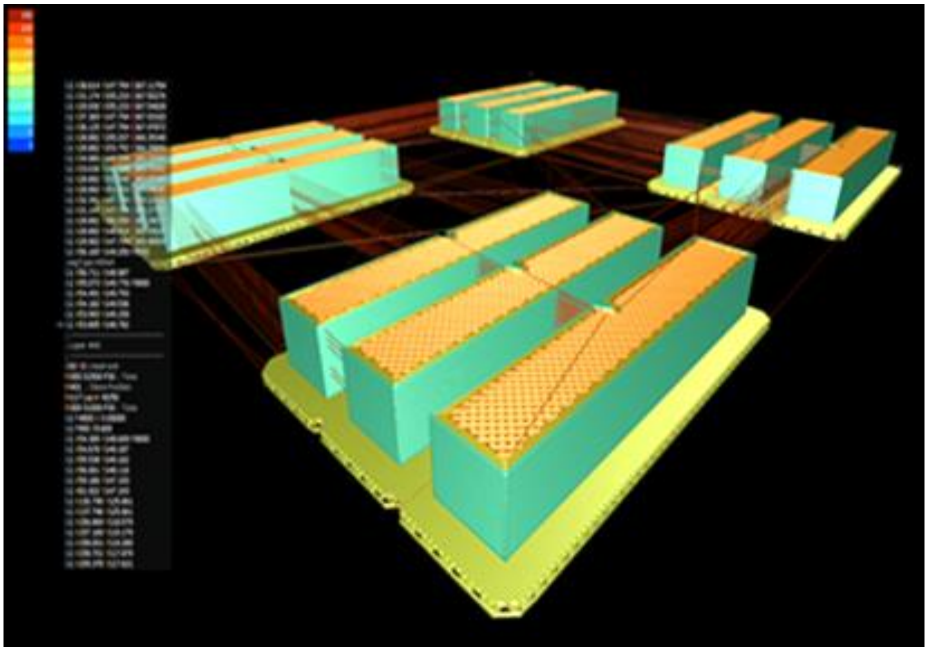


Figure 1: Samples before printing

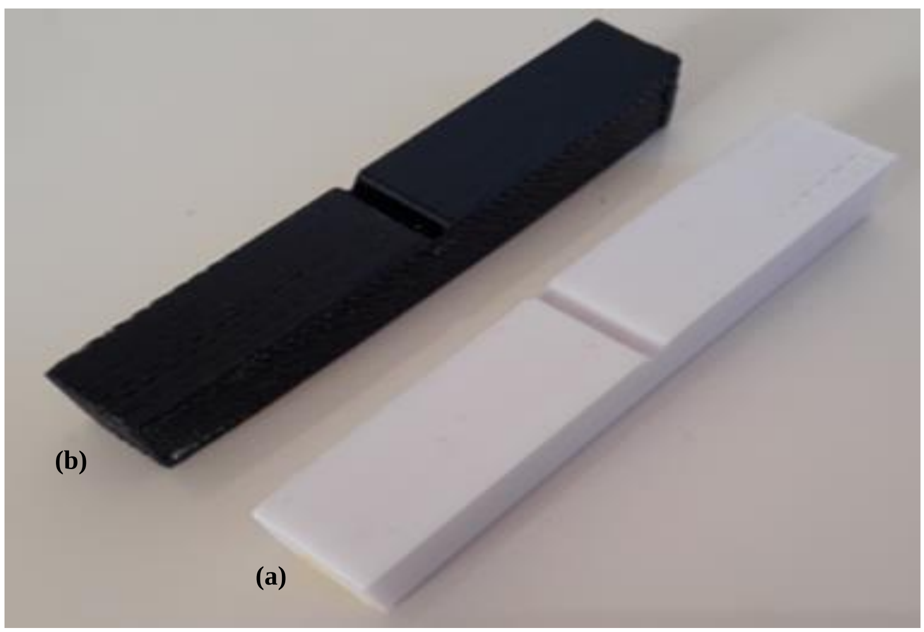


Figure 2: (a) natural PLA sample, (b) CP/PLA composite sample after printing.

Carbon particles have been chosen as CP parts can be designed to use the characteristics of CP composites, but such parts may also have an impacting load; this knowledge is therefore highly useful, and although CP is known to be the worst fiber reinforcement for resist the impact-load [15].
[16] investigated the impacts of three dimensional-print impact sample that contained v-notches one or the other printed with the parts or machined post- printing. The present investigation also examined the printing the sample impacts in various factors on the plate of build [16]. Of PLA, the thickness of the sheet demonstrated a substantial gap in impact resistance and the test written and milled v-notch displayed statistically negligible variations in impact resistance. Additional investigations were

conducted to analyse the impact strength of various 3D printed materials with FDM printing methods [14]. Researchers have investigated the performance of 3-D printing of functionally graded layers of multimaterials like PLA and composites, and it was confirmed that at interface boundaries, the layers could have porosity and some void spaces that might become a main cause for their poor character. In fact, the structural nature of the sample has affected the mechanical strength of the multimaterial printed components [17]. Impact load failure modes involve fibre fracture, fiber pull-out, fiber / matrix debonding, longitudinal matrix fracturing, interlaminar matrix breaking and delamination of splitting [18]. The key energy absorption mechanisms in compositesmaterials to impact loading are interlaminary flexure and shear deformations. Carbon particles are widely utilized in the manufacture of composite as mechanical replacements of materials due to their low mass, rigidity, resilience and high individual modules [19]. The strength characteristics of carbon fibre composites rely largely on mechanical characteristics.

The impact of material characteristics represents their capability to absorb and disperse energies for measuring the strength of a material under impact or shock loading. Impact strength (J/m^2) is calculated utilising the energy absorbed by impact testing by dividing the cross-section area at the fracture, as expressed in the next formula [7]:

$$Impact\ strenth\ (Gc) = \frac{U_c}{A_c}\ (1)$$

Whereas:
Gc: Material's impact strength (J/m^2).
Uc: Energy of impact (J).
Ac: Specimen's cross-sectional area (m^2).

PLA filament and the CP/PLA composite were utilized to construct the specimens. The extrusion degree temperatures, extrusion speed and other parameters were fixed, as demonstrated in Table 1. During the experimental work, these factors were stay without any change. Specimens with three of thicknesses' layer (0.01, 0.02 and 0.03 cm) were created by 3D printing of PLA and the CP/PLA composite tested for impact strengths. The constructed specimens were loaded till breaking. Nine samples of each PLA neat and CP/PLA composite were printed using the same printing parameters (100% infill density; 0.01, 0.02 and 0.03 cm layer heights; and 50 mm/s printing speed). All samples were printed as 45° part orientation.

Tabel 1. Parameters that were set as Constant in this study

Fixed parameter	**Tevo printer**
Print density	100%
Shell option	Top and bottom 3 layers
Perimeter/outer wall	3

Support material	Yes
Fill angle	45°
Rectilinear	Print pattern

Other parameters that were changed during printing include the different layers, infill densities and materials, as demonstrated in Table 2. The effects of these factors on impact testing were examined. The thickness of the layer is called as the height of the slide dumped from the nozzle. The thickness of layer parameter is utilized to assess the impact that thin or thick layers create on the results' quality [4]. Nine samples for each material, PLA neat and CP/PLA composite were printed under similar conditions (0.2 mm layer height; 50%, 65%, 85% and 100% infill densities; and 50 mm/s printing speed). All samples were printed at 45° part orientation. The impact test was performed in depending with the ISO 180 standard.

Tabel 2. Variable parameters used in this study

parameter	Tevo printer
Layer height	0.1, 0.2, 0.3 mm
Infill density	50%, 65%, 85%, 100%
Filament material	PLA and CP/PLA composite

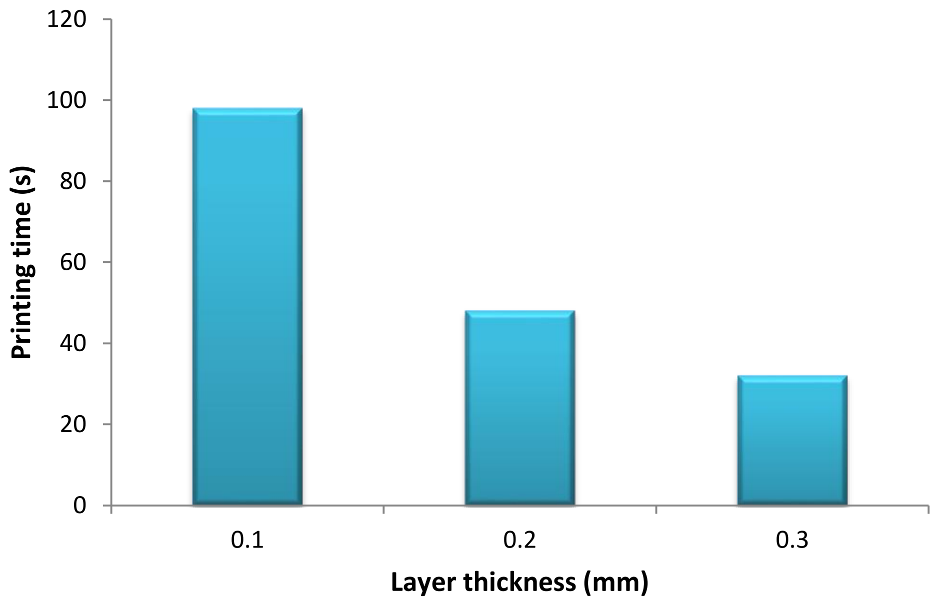
4 Result and Discussion

All 36 samples of CP/PLA composite and natural PLA have been made-up utilizing the machine of 3D, and the impact test was conducted. The mean values of impact strength were gained using Equation (1) at different layer heights and infill densities. The results show the greatest impact strength were at natural PLA, the greatest impact strength of natural PLA is obtained at layer height= 0.01 cm, which was 23.33 KJ/m^2, whereas the lowest impact strength is obtained at layer height= 0.03 cm, which was 16.25 KJ/m^2 Table 2. The layer height =0.02 cm for natural PLA indicated an impact strength of 17.5 kJ/m^2. Table III lists the impact strength for different layer thicknesses. The forth column in Table 3 presents the impact test's results and impact strength measurements for various layer thicknesses (0.1, 0.2 and 0.3 mm). For the calculated values, a low layer thickness can lead to a high impact strength. Specimens were imprinted at an angle of 45 °, where the rectangular filaments have been directed to the direction of loading, and the strongest manufacturing is to the direction of loading. Throughout the tests of impact, specimens were subjected to axial pressure due to the construction admixture that could cause single layers to slide along till breaking the specimen.

Tabel 3. Average impact strength of natural pla material

No. of tests	Thickness of Layer (cm)	Printing time (min)	Average impact strength of PLA (KJ/m^2)	Average Impact strength of CP/PLA composite (KJ/m^2)
3 samples	0.01	98	23.33	14.166
3 samples	0.02	48	17.5	13.333
3 samples	0.03	32	16.25	12.5

The average impact strength of natural PLA, as demonstrated in figure 3, indicates that the min. PLA impact strength is 16.25 kJ/ m^2, whereas the maximum impact strength is 23.33 kJ/m^2. The test results suggest that the 3D-printed PLA specimens' impacted strength improved with the reducing thickenss of the layer.



Figuer 3 Relationship between layer thickness and impact strength.

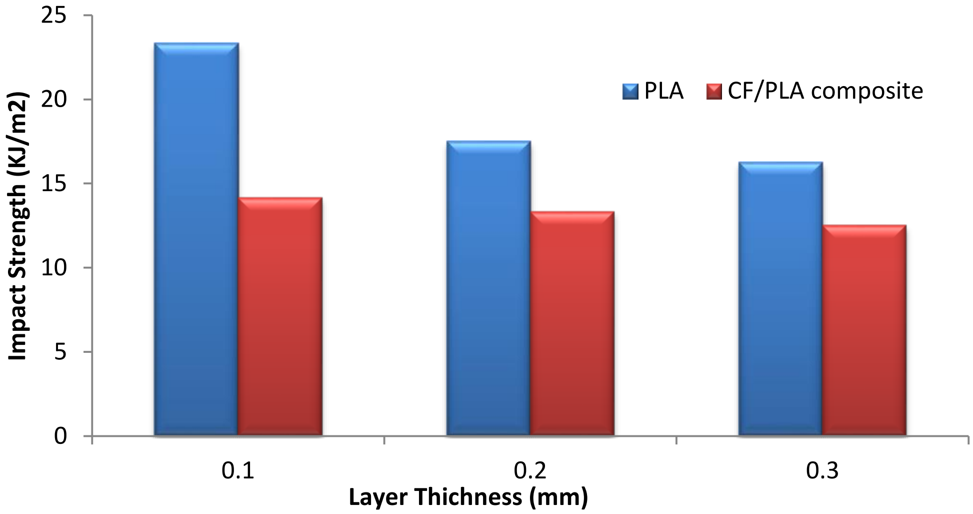


Figure 4 Correlation between layer thickness and printing time.

For the FDM technique, the time was reduced since this technique based on the part's direction that impacts its height. Villalpando and Urbanik (2011) predicted that building time significantly reduces because less material is placed. Figure 4 illustrates the interaction between the thickness of layer and building time for the FDM method. Column 5 in Table 3 presents the impact strength with various layers thicknesses of CP / PLA composite. Columns 4 and 5 in Table 4 report the effects of the impact check and the measurement of mean impact strength for various thicknesses of layer (0.01, 0.02 and 0.03 cm). The avg. CP / PLA composite impact strength is shown in column 5 in table 3. With the reducing thickness of layer, the test findings on impact strength of the 3D-printed PLA samples were increased. The great impact strength was 14.166 KJ / m^2 at layer height =0.01 cm and the low impact strength was achieved at layer height =0.03 cm, which was 12.5 KJ/m^2. Table 3 also indicates that the average impact strength is directly proportional to the layer height. Increasing the distance between layers (0.1, 0.2 and 0.3) leads to a decrease in the impact strength because this distance positively compatible with layer height, increase one of them lead to increase the second one. Therefore, the impact of the natural PLA decreases. The reason is that the powers of adhesion and cohesion between the layers are low. Wide layer thickness, voids / porosity spaces and low adhesivity across various layers. Advantage of a wide thickness of voids found in successive layers the weak mechanical characteristics of 3-D printed dual material composite can be induced. The adhesive strength among the various layers was weak because of the fairly large number of voids [6]. When the compare between the results in tables 3 at column 4 and 5, impact values shown that the impact values of natural PLA greatest from impact values of CP/PLA composite, characteristics of the carbon fibre, and fibre/matrix adhesion. More work was performed to explore the susceptibility of carbon particle composites to effects. The effect of carbon particle size on the impact resistant of carbon particle composites [19] was studied by Ozkan et al. They found that the form of size material utilized had little influence on impact resistant, but that impact resistance decreased with a rise in carbon particles inside the composite. The adding of fibres into a ductile matrix of polymer produces the material brittle, which decreases the impact resistance [20]. The other direct parameters impact of 3D printing on impact strength is the infill density of materials. This research used four percentages to print the samples at 50%, 65%, 85% and 100% infill densities. Table 4 presents the results of the different infill densities for CP/PLA composite and the natural PLA.

Tabel 4. average strength impact of composite materials as cp/pla and natural pla

No. of tests	Layer height (mm)	Infill density (%)	Average impact strength of PLA(KJ/m^2)	Average impact strength of CP/PLA composite (KJ/m^2)	Printin g time (min)
3 samples	0.2	100	17.5	13.333	48
3 samples	0.2	85	16.04	12.08	43
3 samples	0.2	65	15	10.833	39
3 samples	0.2	50	13.75	10	35

Table 4 illustrates the results of impact strength for the CP/PLA composite and PLA in which increasing the infill density percentage increased the impact values. When the samples were printed at 100% infill, 100% solid materials without a gap between the layers fortify the samples and generate high impact. The infill density determines whether or not the parts could be formed in hollow or solid form by regulating the per cent infill. The infill is set to 100%, indicating that it is fully solid. However, the gap of air between the extruded filament cannot be identified because during the phases of layer formation some of the extruded filament, extrude as small and thick layers that called the positive or negative air gaps. The highest impact values for PLA and CP/PLA composite are 17.5 and 13.333 KJ/m^2, respectively, when the infill density is 100%. The lowest impact strengths for PLA and CP/PLA composite of 50% infill density are 13.75 and 10 KJ/m^2, respectively. Therefore, all specimens were printed with settings of 50%, 65%, 85% and 100% infill (figure 5). This trend impacts the part as the air gap is a substantial factor of contributing to strength [21]. Time of printing is directly proportional to the infill density (Table 4). Thus, with a high infill percentage, printing takes considerable time to produce the samples. Conversely, a low time of printing has a low infill percentage. It suggests the introduction of CP into the PLA / CP has decreased the effect power of molecular bonding and could have led to lower peak and break power and other physical characteristics. However this reduced composite strength may not even be visible depending on the requirement in multimaterial manufacturing for specific multilayer components generated with 3D printing based on the position of the layers deposited saa[22].

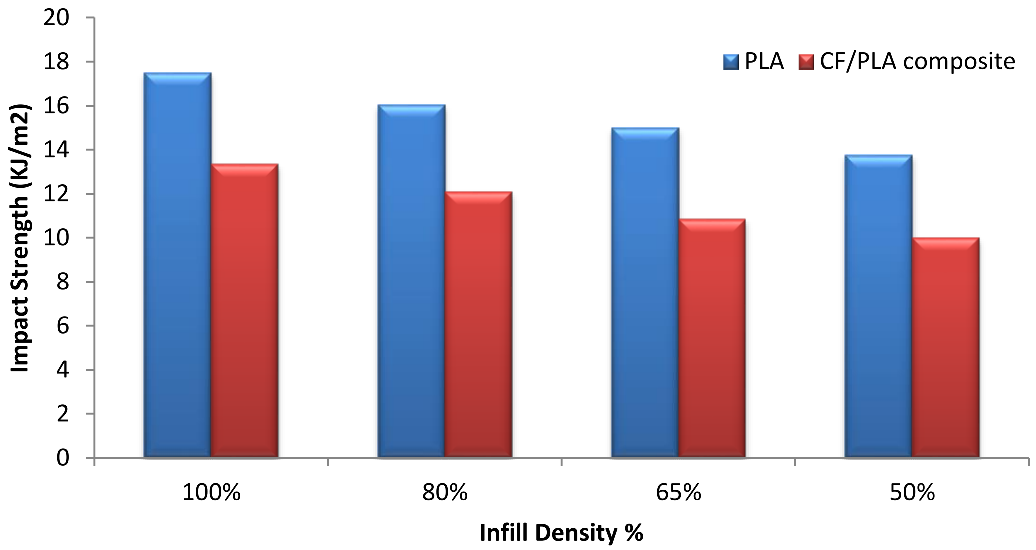


Figure 5 Relationship between infill density and impact strength

5 Conclusion

This research demonstrates the efficiency of layer infill density and thickening as two of the parameters affecting the FDM process on the properties of the part, on the strength of impact. PLA 's standard sample experiments and the CP / PLA composite were conducted on standard environment and specification in 3D printing machines. FDM segment strength is distinguished by process parameters of 'layer thickness' and 'infill density.' The analysis shows that the smallest thickness of layer has the highest impact strength, and a high density of infill produces great impact strength.

With a layer thickness increase greater than 0.01 cm, a low impact strength increases. The printing time of the specimens decreases with the increasing layer thickness. This paper focused on the impact resistance of natural PLA and CP/PLA composites printed using a commercially available desktop 3D printer.

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Hiyam Adil Habeeb was born in Babylon City, Iraq. She finished her BS in Foundation of Technical Education at Technical College Al-Mussaib, Babylon, Iraq, in the field of Machinery Equipment Techniques Engineering and MSc at Universiti Teknikal Malaysia Melaka (UTeM), Malacca, Malaysia, in the field of Mechanical Engineering & Applied Mechanics.

Ahmed Hadi Abood. was born in Babylon City, Iraq. He finished his BS in Foundation of Technical Education at university of mosul, mosul, Iraq, in the field of Materials Engineering and MSc at Muddil Technical University, Bagdad, in the field of Mechanical Engineering / Materials.

Ahmed Esmael Mohan was born in Babylon City, Iraq. He finished his BS in Foundation of Technical Education at Technical College Al-Mussaib, Babylon, Iraq, in the field of Pump Equipment Engineering and MSc at Universiti Teknikal Malaysia Melaka (UTeM), Malacca, Malaysia, in the field of Mechanical Engineering & Applied Mechanics.