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# Characteristics of Hybrid Pla and Carbon-Pla in Different Laminates Formations

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***Abstract.*** *The multi-extruder printer allows to printing of different materials into one product. This paper experimented on multi-material lamination using PLA with rigid characteristics and Carbon-PLA with elastic characteristics. The flexural and shore hardness test was chosen to understand how two different materials affect each other. The results show that the different lamination performances affect the flexural strength. The highest flexural strength from 3 laminations was the CPC of 53.33 MPa, this is 3.03% lower than the PLA only and 37.9% higher than Carbon-PLA only. From the 2 laminate specimens the PC laminates achieved the highest flexural strength of 73.07 MPa, the value is 5.4% higher than the PLA only and 50.01% higher than Carbon-PLA only. The shore hardness value showed no significant changes between the lamination and 1 material only. It was also proved that lamination formation can increase the flexural strength or lead to detrimental results. This finding enables the designer of multi-material 3D printing to consider the formation of materials.*

***Keywords:*** *3D printed lamination; Additive Manufacturing; flexural test; Multi Material 3D printing*

## 1. Introduction

The advancement of 3D printing technology led to the machine's improvement in past decades. 3D printing with an extrusion system known as Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) is the most popular type of 3D printer. The wide selection of thermoplastic materials is able to make complex products with inexpensive filaments [1–4]. The ease of manufacture made it well spread of purpose from sports, hobby, aerospace, and energy [5–8].

Previously, the 3D printing process was limited to only 1 material at a time with limited options of materials primarily acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA)[9]. The development of multi-extruder printing on FDM allows to printing of more than one material. This system significantly improves the capability of FDM by combining 2 materials with different properties with customized parameters. The wide range of material availability expands the opportunity to mix many materials into a single printed object [1], [10]. Combining the 2 materials

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with different mechanical properties is expected to have a better combination of mechanical properties [8].

Specifically, the multi-material 3D printer features more than one nozzle extruder such as Flashforge Creator Pro 2. This printer is equipped with 2 nozzles with 2 X-axis carriage, with this feature it can protect the workpiece from oozed material from previous extruder. With dual carriage extruder system also allows the user to print duplicate or symmetrical objects at once making printing time shorter [11].

PLA material is one of the popular materials for 3D printing. Low melting value and bio-degradable characteristics make this material favorable amongst 3D printer users [12], [13]. However, with the ease of processing, PLA has major drawbacks. This material has brittle characteristics therefore this material needs to be improved. One of the improvements from PLA is the Carbon-PLA. This material is a mix of PLA and carbon particles. With the carbon particle existence, the PLA becomes elastic.

Several studies about multi-material 3D printing have been done. PLA, PET, and TPU were printed on the interfacial sequence and then tested in a tensile test using an FDM printer. The tensile test resulted in the breakage on the material boundary interface and the material still has interfacial performance even small value [14]. Another study about the multi-material interface in 3D printers using the material jet binding 3D printer. In this recent study using a material jet binding 3D printer can improve the interfacial performance, some of the specimen breakage in the middle of specimens [15]. Study about hybrid laminates from 3D printing technology by combining PLA FDM and resin photopolymer. The laminates go through various characterizations resulting in the performance of hybrid laminates depending on the constituent material type [16]. However, the study about multi-material 3D printing extrusion-based laminates still not many works found. Specifically, some following questions appear when comes to multi-material hybrid lamination manufactured on FDM 3D printers. Is it possible to manufacture laminates with only 1 multi-material FDM printer? How about the performance of multi-material FDM printed hybrid laminates? From those questions, this paper employs an experimental study of hybrid laminates from an FDM printer. The flexural and shore hardness tests to gain information on the bonding and performance between 2 various materials in various laminate formations.

## 2. Methods

### 2.1. Methodology

In this study, the material PLA (P) and Carbon-PLA (C) combined in different lamination formations. The two different materials if printed layer by layer have different adhesive characteristics compared with the same material. The different formations of lamination are expected to have better mechanical properties than the single material. To achieve the best lamination formation, 4 types of specimens were proposed as shown in Table 1.

Table 1. Laminates and thickness formation.

| Type | Formation | Thickness (mm) |
|---|---|---|
| A | P | 3 |
| A | C | 3 |
| B | P/C/P | 1/1/1 |
| B | C/P/C | 1/1/1 |
| C | P/C | 1.5/1.5 |

The mechanical properties of the specimens were assessed through flexural tests and shore hardness tests. The flexural test was chosen to understand the laminates bonding between different materials under flexural load. The stacking sequence on hybrid laminates will have different characteristics depending on the locations of rigid and soft material under compression and tensile load in flexural testing [17], [18]. The flexural test specimens were designed according to ASTM D790 – 03. Then the specimens were analyzed at a microscopic level. The shore hardness test evaluates the hardness of each specimen related to the flexural modulus. The type of specimen is illustrated in Figure 1(a).

### 2.2. Materials

PLA is a well-known and widely used material in the 3D printing industry. In this research, the PLA is used due to its biodegradable features and the material comes from renewable sources. The PLA filaments from esun PLA+ materials are used as the control specimen and will be combined with the Carbon-PLA in different laminar formations [19]. The second material is the Carbon-PLA filaments from the Creality CR-Carbon Series. This material is a mix of PLA with short carbon fiber to improve the hardness, durability, and rigidity [20]. The properties of both materials are available in Table 2.

Table 2. Properties of PLA and Carbon-PLA Materials

| | Esun PLA+ | Creality CR-Carbon Series |
|---|---|---|
| Properties | Value | Value |
| Filament diameter | 1.75 mm | 1.75 mm |
| Printing temperature | 210 – 230˚C | 195 – 220˚C |
| Density (g/cm$^3$) | 1.23 | - |
| Tensile strength (MPa) | 63 | 49 |
| Flexural strength (MPa) | 74 | - |
| Elongation at break (%) | 20 | - |

### 2.3. Specimen Preparation

All the specimens were printed on Flashforge Creator Pro 2 with an independent dual extruder printer system (IDEX). The dual extruder system allows us to print different materials into one specimen [11]. The IDEX system made the calibration more precise due to different carriage on each extruder. Both of the extruders adopted the direct drive extrusion that push the filament directly into the nozzle. The printer featured a build volume of 200 × 148 × 150 mm, 0.4 mm nozzle diameter, allowed printing speed of 30-100 mm/s, and print precision ± 0.2 mm.

The printing process of the specimens with several provisions. The specimens were printed in groups of 3 of each type with the same orientation. Wall line count at 9999999 to achieve linear path with tensile force direction. The same extruder uses the same material. Post-processing only cuts the extra material left from the extruder.

The slicer software used in this study was from Ultimaker Cura. The parameters of the printing for both materials were almost identical, the difference was in the printing temperature and

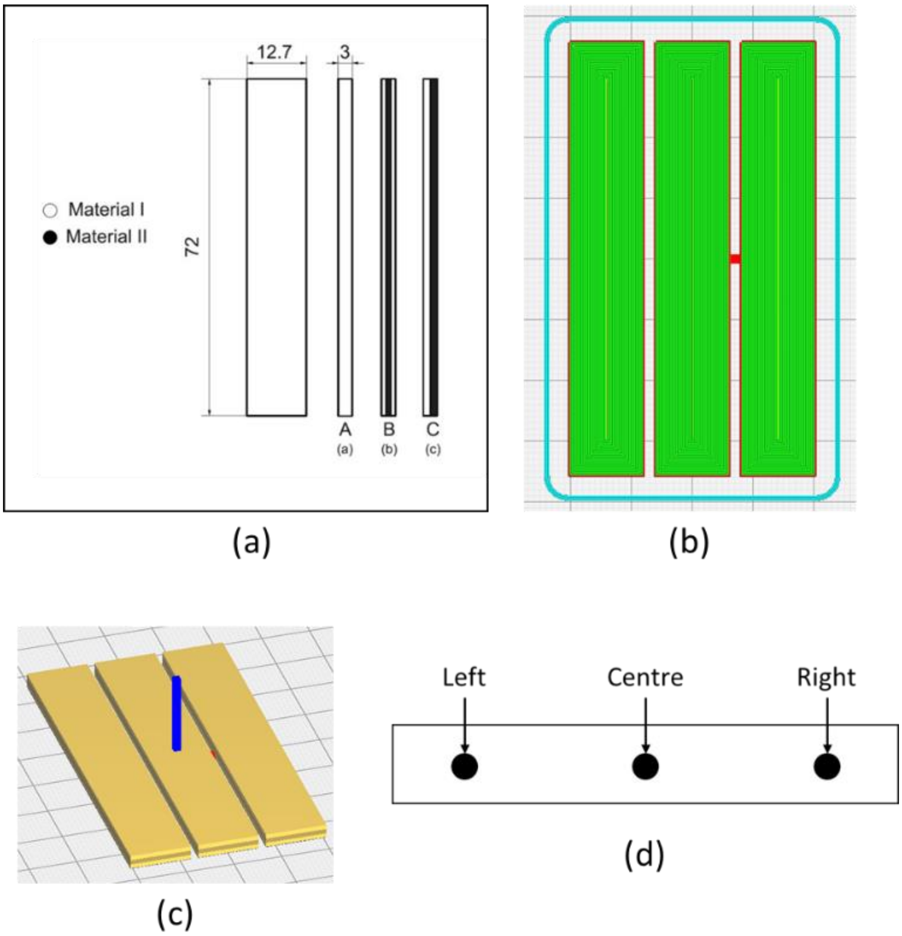


Figure 1. Experiment specimen (a) flexural specimens with Type – A, B, and C laminates, (b) toolpath of printed specimens, (c) printing orientation of the specimens, and (d) location of Shore hardness test.

material flow. In the dual material printing the parameter of the prime tower and ooze shield need to be enabled. The prime tower ensured the material flow before printing and the ooze shield served as protection from oozed material after switching the extruder. The fixed parameter is shown in Table 3, printing toolpath and orientation are shown in Figures 1(b) and 1(c).

Table 3. General printing parameters

| Parameters | Value |
|---|---|
| **Quality** | |
| Layer height | 0.1 mm |
| Line width | 0.4 mm |
| **Walls** | |
| Wall line count | 99999999 |
| Z seam alignment | Sharpest corner |
| | |
| **Material** | |
| Printing temperature | PLA : 200 ˚C<br>Carbon-PLA : 210 ˚C |
| Flow | PLA: 100%<br>Carbon-PLA: 110% |
| Build plate temperature | Not heated |
| **Speed** | |
| Print speed | 50 mm/s |
| **Travel** | |
| Retraction distance | 4 mm |
| **Build plate adhesion** | |
| Type | Skirt |
| Skirt line count | 3 |
| Skirt distance | 3 mm |
| **Dual extrusion** | |
| Prime tower | Enable |
| Tower size | 10 mm |
| Ooze shield | Enable |
| Ooze shield distance | 4 mm |

### 2.4. Testing Procedure

The flexural test was conducted according to ASTM D790-03 to the effect of different laminate formations under the flexural force [21]. The 3-point flexural test was used in this study. The speed of testing was chosen at 2 mm/min. The distance between the span was 48 mm and the width was 12.7 mm. When the specimen underwent the testing a Dinolite digital microscope was used to observe the crack from the side. The flexural force and modulus can be calculated using the Equation (1) and (2). The universal tensile machine from Carson with a 50 kN load cell was used in this study.

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

$$E_B = L^3P/4bd^3D \quad (2)$$

Where:

$\sigma_f$ = flexural stress on the outer laminates at midpoint, MPa.

$E_B$ = modulus of elasticity in bending, GPa.

D = maximum deflection of the center of the beam, mm.

P = load at a given point on the load-deflection curve, N.

L = support span, mm.

b = width of beam tested, mm.

d = depth of the beam tested, mm.

The shore hardness test was chosen commonly for vinyl polymers. The ball indenter pressed the specimens under a spring load and converted them into a scale ranging from 0 to 100. The Shore D was chosen because, with the Shore A test, the scale number was more than 100. The test was carried out using the Shore D hardness tester from Ayuqi Each specimen was tested on 3 different points locations along the same specimens, the location can be seen in Figure 1(d).

## 3. Results and Discussion

The mechanical properties of the specimens are shown in Table 4. The maximum flexural stress and modulus values are shown in Figure 2. The results show how the small number of different materials on these materials have an impact on max load and displacements.

Table 4. Mechanical properties comparison from each value.

| Mechanical Properties | Laminates | | | | | |
|---|---|---|---|---|---|---|
| | PLA | Carbon-PLA | PCP | CPC | PC | CP |
| Max flexural stress (MPa) | 69.29 | 48.71 | 67.19 | 53.33 | 73.07 | 54.59 |
| Max flexural strain (mm/mm) | 0.0659 | 0.0822 | 0.0525 | 0.0801 | 0.0865 | 0.0482 |
| Flexural modulus (GPa) | 3.64 | 4.52 | 4.17 | 4.68 | 4.40 | 4.45 |
| Shore Hardness (D) | 51.50 | 47.50 | 50.83 | 48.50 | 50.33 | 50.50 |

The Type – A results on PLA sustained a larger amount of flexural strength at 69.29 MPa than the Carbon-PLA at 48.71 MPa. Subsequently, for the strain, the PLA has a lower value of 0.0659 and the Carbon-PLA of 0.0822. According to the flexural modulus, the PLA was more brittle at 3.64 GPa than the Carbon-PLA at 4.52 GPa. Figure 4(a) shows the differences in the flexural fracture. The PLA fracture was visible with an open crack while the Carbon-PLA did not have any visible crack however the load decreased just after the peak load. These results indicate that the Carbon-PLA has more flexibility than the PLA.

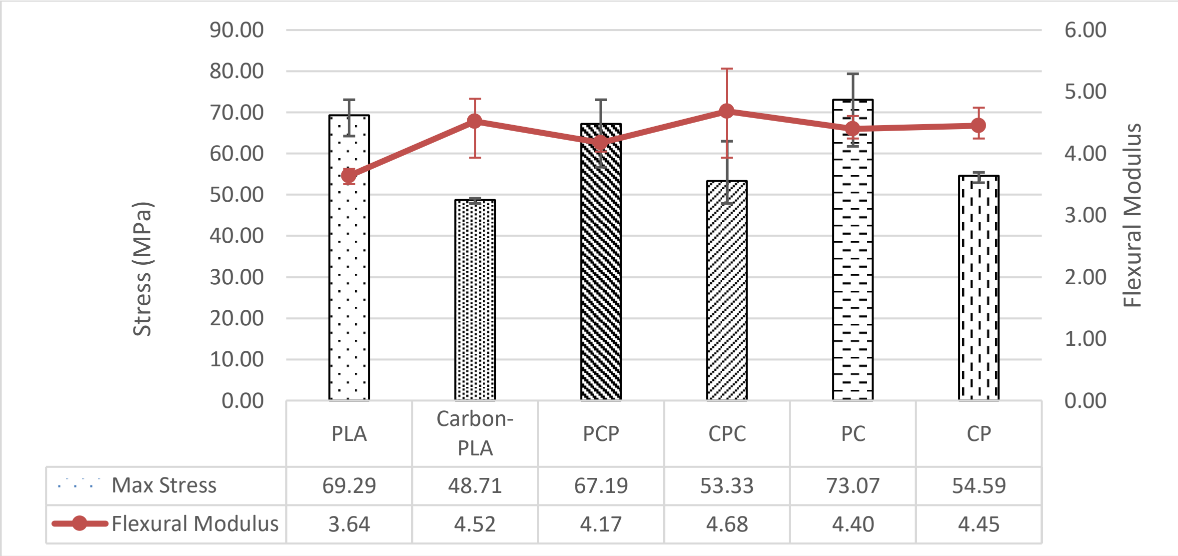


Figure 2. Flexural stress and modulus from the specimens.

Eventually, the Type–-B specimens for the PCP samples obtained 67.19 MPa of flexural strength with maximum strain at 0.0525. The flexural modulus achieved at 4.17 GPa, was slightly increased than the only PLA specimen. These results were affected by the 2 laminates of Carbon-PLA with each 1 mm thickness. The CPC specimens sustained a flexural strength of 53.33 MPa and a maximum strain slightly lower than the Carbon-PLA at 0.0801. The flexural modulus results were the highest among the other laminates at 4.68 GPa. This was due to the carbon-PLA characteristics dominating the laminates. By looking at Figure 4(c) and 4(d) the PCP specimens have visible failure under the bending load although the CPC did not have visible failure. The white area on the CPC represents the plastic deformation of the laminates under bending load. The white area phenomenon also happened in a previous study, this white area occurred by the deformation and debonding between the printed layer [16]. The debonding of the laminates almost occurred with any type of hybrid lamination. This was caused by a large shear force happening on the interface between two layers or different material that received tensile and compression load during flexural test [22].

The Type–C specimens were tested on both sides of the specimens to obtain the characteristic of bending load at the ductile and brittle part of the material. The PC specimens mean the PLA material became the outer layer while the Carbon-PLA was the inner layer. This configuration achieved the highest flexural strength of 73.07 MPa and strain at 0.0865. Whilst the flexural modulus is at 4.40 GPa. The Carbon-PLA placed in the inner part absorbed the bending force at the same time the PLA made the material stiffer. Thus, the materials sustained a higher flexural strength without losing their flexibility. When the material inverted became CP the inner layer was PLA and the outer layer was Carbon-PLA resulting lower flexural strength of 54.59 MPa with a flexural strain of 0.0482. The flexural modulus increased slightly at 4.45 GPa. The lower flexural strength and strain due to the PLA was a stiffer material than the Carbon-PLA.

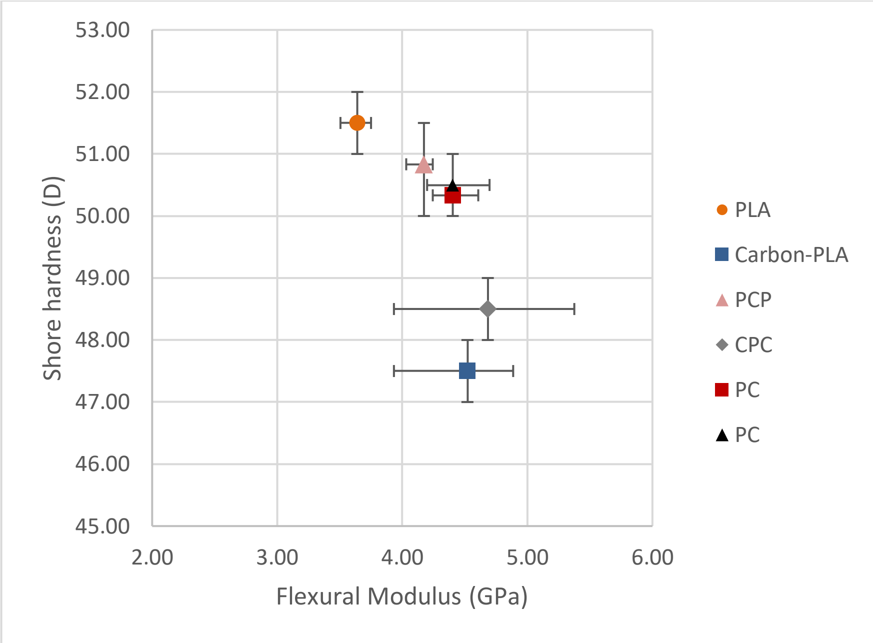


Figure 3. Relation between flexural modulus and Shore hardness.

Hence, it cannot absorb a great amount of the tensile load. Since the Carbon-PLA is more flexible it was easy to stretch while placed in an outer layer under tensile load. From Figure 4(e) the fracture under flexural stress on the PC the larger crack at the PLA laminates whilst the Carbon-PLA laminates only at the outer layer. On the CP specimens shown in Figure 4(f), the failure was in tear form on the outer layer. These hybrid characteristics also proved on hybrid laminates of FDM PLA and photopolymer resin. Since PLA was a non-rigid material compared to the photopolymer resin, higher flexural strength was achieved when the PLA was placed on top of the photopolymer resin [16]. These results indicate the importance of materials that going to receive a bending load. Choosing an incorrect laminate configuration can have detrimental effects rather than improving it.

Table 3 shows results from the Shore hardness. Hardness was measured in the left, center, and right areas of the specimens. A higher value on the Shore hardness indicates the materials have higher hardness with low flexibility [23]. The Shore hardness value is compared with the flexural modulus to understand the relation between the two characteristics. According to a previous study, the hardness of the 3D printed parts depends on the manufacturing process [24]. Figure 3 shows the higher hardness value related to lower flexural modulus, PLA has the lowest flexural modulus of 3.64 GPa with the highest hardness value of 51.50 D. Following the PCP with a flexural modulus of 4.17 GPa with a hardness value of 50.83. While PC and CP resulted in close values of flexural modulus 4.40 and 4.45 GPa with a hardness of 50.33 and 50.50 D respectively. The shore hardness becomes lower significantly on the CPC laminates with a hardness value of 48.50 D and a high flexural modulus of 4.68 GPa. The last is the Carbon-PLA with a hardness value of 47.50 D with flexural modulus of 4.52 GPa. These results represent the existence of Carbon-PLA affecting the durability of the material. Thicker the Carbon-PLA laminates give higher flexibility. This result has a lower value than the previous study, it was caused by the arrangement of the printing process. The previous study showed the hardness of PLA around 77-78 D with 45˚/-45˚ laminates [24]. When the laminates angle changes to 0˚ the hardness properties become lower.

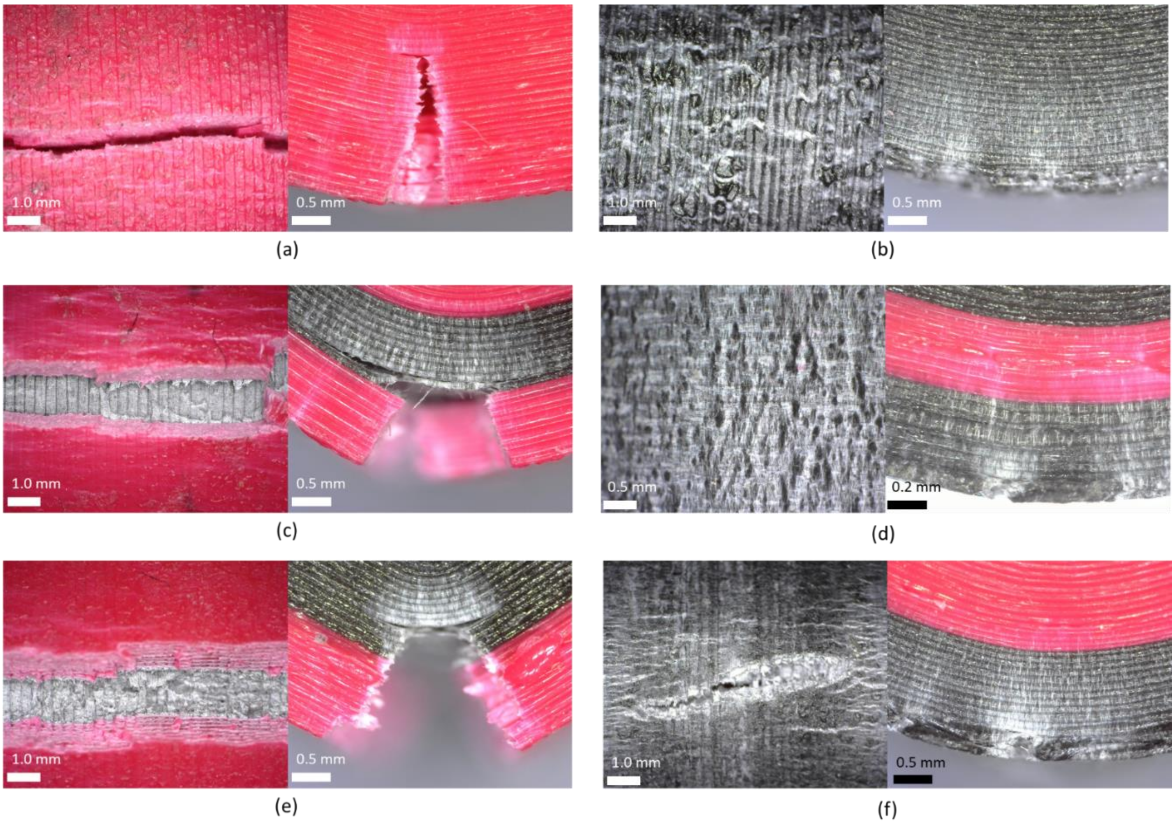


Figure 4. The flexural fracture from the bottom (left) and wall side (right) of (a) PLA, (b) Carbon-PLA, (c) PCP, (d) CPC, (e) PC, and (f) CP.

## 4. Conclusions

A series of flexural, Shore Hardness, and density tests have been carried out to characterize 3D-printed multi-material laminates. It was proven that multi-material laminates made from FDM 3D printing were possible to make. The formation of laminates affects the stress on the outer layer under flexural force. If the inner layer is a softer material, it can absorb the stress and the outer layer holds the rigidity of the specimens, thus higher stress is required until fracture. It was proven in PC with 73.07 mPa flexural stress and CPC with 53.33 mPa flexural stress, the outer layer of the laminates was Carbon-PLA with flexible characteristics while the rigid PLA materials were in the outer or middle layer. The presence of flexible material results in greater durability. It was presented on the flexural modulus and shore hardness results. According to the results, the best laminates by flexural modulus and shore hardness relation were CPC (4.68 GPa and 48.50 D).

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