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The Effect of the Combination of PLA, PP, and ABS Filaments on Flexural Strength in FDM 3D Printing

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***Abstract*—3D printing of fused deposition modeling (FDM) technique is one of the most widely used nowadays. One disadvantage of this method is that the printed product has low strength to the fact that the product is developed layer by layer. This research aims to combine PLA, PP, and ABS and determine which results in the highest flexural strength. A Cartesian 3D printer printed specimens according to the ASTM D790 standard. Then, specimens were tested using a universal testing machine. An optic microscope was used to observe the fracture area. The results showed that the combination of PLA-ABS increased flexural strength up to 33.12 MPa. While PLA-PP, PLA-PP-ABS and PP-ABS resulted in a flexural strength of less than half PLA-ABS one, they were 14.90, 14.59 and 12.10 MPa, respectively. All alloy combinations except PLA-ABS were delaminated during the bending test. Delamination causes a decrease in the flexural strength of a specimen.**

Keywords: 3D Printer, ABS, PLA, PP, Bending Strength.

I.INTRODUCTION

FDM (fused deposition modeling) is one of the general principles in additive manufacturing methods that are often used in prototype modeling in production and manufacturing processes. It also applicable to manufacture aircraft components, especially composites made of components [1], [2]. The basic concept of the FDM manufacturing process is to melt raw materials and shape them to build new shapes. The material is a filament placed in a coil, pulled by a driving wheel, fed into a temperature-controlled nozzle head and heated to semi-liquid [3].

Based on their composition, filaments are divided into two categories: single filaments and compound filaments or multiple materials. The single filament is made entirely of polymer compounds without adding additive solutions. Every single filament type has inherent characteristics and mechanical properties. The intrinsic properties of pure polymers cannot accommodate the need for mechanical properties for a particular product. This problem requires researchers and the industry to continue developing polymer filaments suitable for commercial needs. One of the steps that can be taken to improve the mechanical properties of a filament is to combine several filaments. This process eventually leads to the alloy filament A novelty and rarely seen 3D printing using 3 filaments at once.

Most of the FDM 3D printing technique uses polymers as the fed filament, such as PP, PLA, ABS. Polypropylene (PP) is a semi-crystalline thermoplastic polymer derived from propene, a relatively inexpensive by-product of the oil refining process [4]. As propene is inexpensive, virgin PP is relatively cheap when compared to other virgin materials. PolyLactic Acid (PLA) filament is a polymer resulting from the fermentation of plant sources such as sugar cane, taro, and cornstarch. It considers as green filament [5]. ABS (Acrylonitrile Butadiene Styrene) was one of the first plastics to be used with industrial 3D printers. Many years later, ABS is still a very popular material thanks to its low cost and good mechanical properties [6]. When printed as a single filament, PLA has higher strength compare to ABS [7] Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) filaments are the most widely used thermoplastics as the printable materials for FDM processes [8].

Lopes has researched a mixture of PLA, TPU, and PET filament materials [9] Multi-material 3D research focuses on the bulkhead boundaries of different filaments formed in different material zones. The boundary is well demonstrated by the emergence of rupture in these zones. Thus combining (PLA-TPU and PLA-PET), a more pronounced decrease in Young's modulus and tensile strength was obtained [10].

Research on the joining of filaments between ABS and PLA shows a reasonably good flexural strength value with a mixed composition (20%-80%) with a UTS value of 21.4 MPa. As for the flexural strength test, pure PLA filament has a flexural strength value of 17.90 MPa, while pure ABS filament has a flexural strength value of 19.24 MPa. The joining of filaments between ABS and PLA (sandwich) has a flexural strength value of 19.11 MPa with a difference of 0.13 MPa compared to the highest flexural strength value, pure ABS. In addition, using PLA minimised environmental pollution[11]

The study on FDM 3D used PP (polypropylene) based. Various parameters were tested on the samples. The sample with 0° orientation is the one that shows the best performance. The thickness of the layer has little effect on the mechanical performance of the sample. The infill angle has a linear effect on the mechanical properties. The use of fibre as reinforcement is also affect in 3D printing. Therefore, this process is superior to conventional for producing small series of parts/ components [12]

There is no previous research has examined the joining of three PLA, PP, and ABS filaments using the layer-by-layer method. In this case, it is interesting to study because the three filament materials have the potential to produce solid and flexible materials. This research aims to determine the effect of the combination on the bending test results of PLA, PP, and ABS filaments.

II.MATERIALS AND METHODS

This research is a bending test specimen printing process with ASTM D790 standard.[13] The materials used are PLA, PP, and ABS. The two selected materials were defined as the reference one, which the other will be combined later. In this study, PLA and ABS were selected since it is the most widely used materials in 3D printing technique. PLA and ABS filament specifications are described in Table I and Table II.

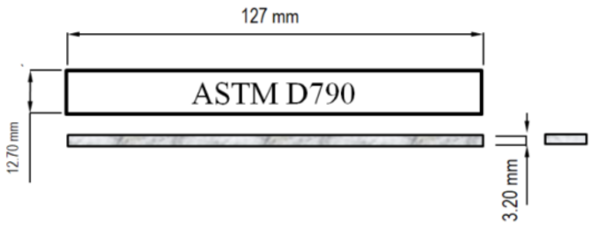


Fig. 1. Bending test.

TABLE I. SPECIFICATION OF PLA

Filament Diameter	1.75 mm [14], [15]
Print Temperature	205-225 °C [11], [15]
Bed Temperature	No heat [14]
Density	1.24 g/cm³ [14]
Tensile Strength	60 MPa [14]
Flexural Strength	55.3 MPa [14]

TABLE II. SPECIFICATION OF ABS

Filament Diameter	1.75 mm [11]
Print Temperature	220-250 °C [11], [16]
Bed Temperature	95-110 °C [11]
Density	1.24 g/cm³ [11]
Tensile Strength	40 MPa [11]
Flexural Strength	75.84 MPa [11]

As the third material, PP filament material is selected. PP is a homopolymer member of polyolefins and one of the most widely used low-density, low-cost semi-crystalline thermoplastics [17]. PP generally has higher tensile, flexural, and compressive strengths and a higher modulus than polyethylene due to the steric interaction of the pendant methyl groups, which results in a polymer chain that is more rigid than polyethylene. PP filament specifications are described in Table III.

TABLE III. SPECIFICATION OF PP

Filament Diameter	1.75 mm [17]
Print Temperature	230-250°C [17]
Bed Temperature	90-100 °C [17]
Density	0.905 g/cm³ [17]
Tensile Strength	33 MPa [17], [18]
Flexural Strength	40 MPa [17], [18]

With the materials listed above, the following combinations were set for evaluation: Three combination represent possible combination of two materials. Then, combination of three materials all together.

- Type-A specimens: PLA-ABS; PLA-PP; PP-ABS.
- Type-B specimens: PLA-PP-ABS

Printing is tailored to the design and variations of the specified material combination. The combination of PLA-ABS, PLA-PP, and PP-ABS has a composition of 50%-50%. The combination of PLA-PP-ABS has a composition of 33.3% each [11]. Three repetitions or replications were printed for 12 specimens in each combination variation.

In order to achieve the target and evaluate the effect of the flexural test on multi-filament 3D printing, it is first necessary to establish some considerations:

- Most of the printing parameters are the same for all the materials (specifically layer height, infill density, build-orientation, number of shells, etc.). The standard 3D printing process does not allow experiencing different printing conditions on each material, and therefore, in order to have an accurate comparison, it is necessary to refine the parameters presented in Table 4, which are considered as default conditions.
- Parameters that can be set for each material are extrusion temperature, print surface temperature, and print speed.

Creality Ender 3 of FDM 3D printer (without modification) was employed for the experimentations. PrusaSlicer 2.3.3 software is software used to set printing parameters on 3D printing machines. Specimens printed with multiple materials, using a single extrusion head. The bending test specimen printing process uses a 3D Printing machine.

TABLE IV: STANDARD 3D MACHINE PARAMETERS

Parameter	Value
Layer Height of two filament (mm)	0.4
Layer Height of three filament (mm)	0.35
Number of Outer Shell Layers	1
Bed Temperature (°C)	70
Build Orientation	X – Y
Extrusion Temperature (°C)	230
Printing Speed (mm/s)	20
Filament Diameter (mm)	1.75
Outer Shell Layers	Vertical
Fan	Disable
Infill Pattern	Line
Infill Density (%)	100

This study's bending test used a three-point universal bending test with a capacity of 1-50 kN and a testing speed of 1 mm/minute. The tools used can be seen in Fig 2. All these samples are tested for their tensile strength.

Furthermore, this study uses a fractography technique to observe faults with an optical microscope. Fractography is the observation of fracture to find out possible voids, porosity, delamination, and others.

Fig. 2. (a-b) Universal bending testing machine HT-2402.

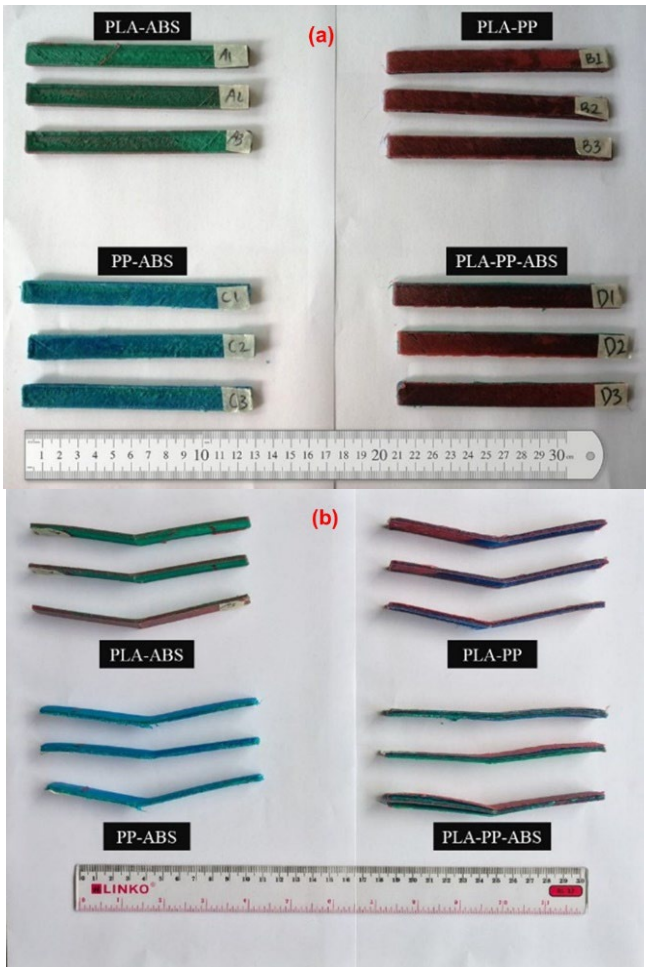


Fig. 3. (a) Results of 3D printing of ASTM D790 and (b) Specimen after bending test.

III. RESULT AND DISCUSSION

The test specimens were printed using a Cartesian type 3D machine with predefined printing parameters. Specimen printing is adjusted to the design and variation of the specified material combination: (i) PLA-ABS, (ii) PLA-PP, (iii) PP-ABS, and (iv) PLA-PP-ABS. The results of the combined filament print are presented in Fig 3a.

The layer-by-layer method requires knowing how long the material is used up for one layer, and the length of the material can be known through the PrusaSlicer software. However, during the printing process, under certain conditions, the length of the material that has been cut can run out before finishing printing one piece. The layer or material has not run out when the print is already one layer, so the material is less or more than one layer.

Test specimens from variations in material combinations are printed using the layer-by-layer method, which means that one specimen has different materials in each layer or is made from alternating materials. Specimens that have undergone a bending test are presented in Fig 3b.

The bending test results are then compared and illustrated in the graph in Fig 4. The sample taken is the third replication sample in each combination variation.

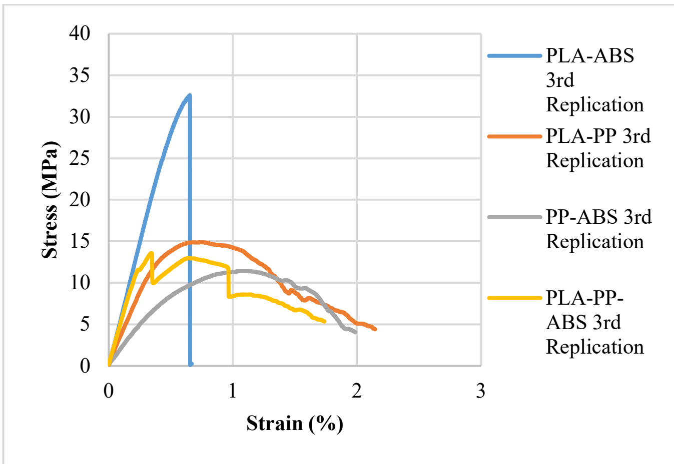


Fig. 4: Stress-strain graph.

The bending test results showed that the PLA-ABS alloy had the highest flexural strength value of the other samples, namely 33.12 MPa. Other alloys containing polypropylene materials, namely PLA-PP, PLA-PP-ABS, and PP-ABS, resulted in a decreasing flexural strength of 14.90, 14.59, and 12.10 MPa, respectively. Based on Fig 4, it can be observed that the PLA-ABS curve differs from the other curves because the PLA-ABS filament incorporation does not experience delamination during the bending test.

In the specimen, the alloy is perfectly laminated. However, after the three-point bending, the specimen experienced delamination. Delamination is one of the critical damage models that occur in laminated composites [19]. Delamination occurs due to several factors, such as high interlaminar stresses at the corners, stress concentrations at the crack site, or other damage to the laminate.

Fig 3b shows that the alloy that does not experience delamination after the three-point bending test is only PLA-ABS alloy. PLA-PP, PP-ABS, and PLA-PP-ABS alloys are delaminated in different shapes, although the 3D prints are all bonded to the laminate well. Fig 5 compares delaminated and not delaminated specimens after the three-point bending test.

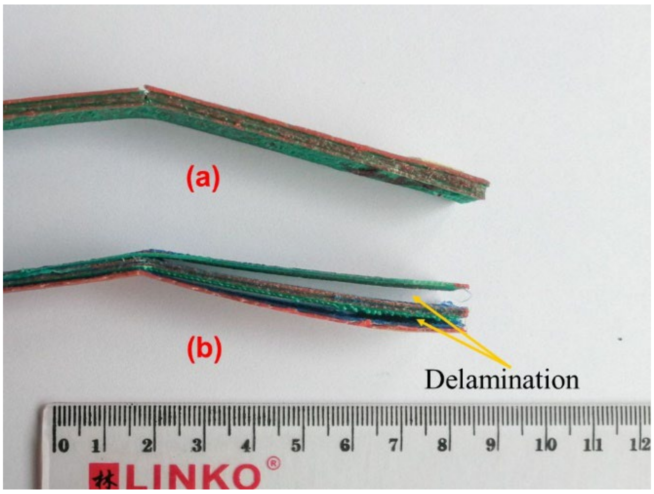
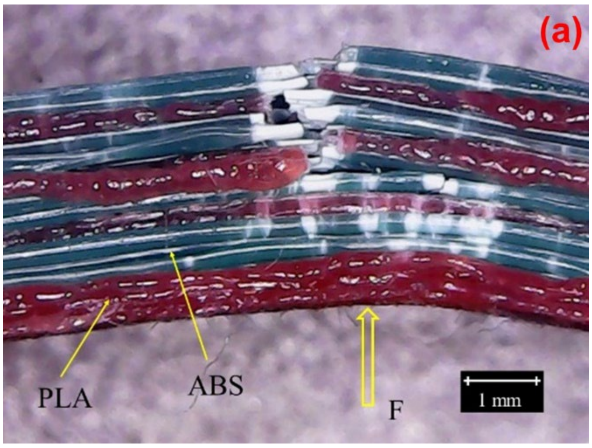
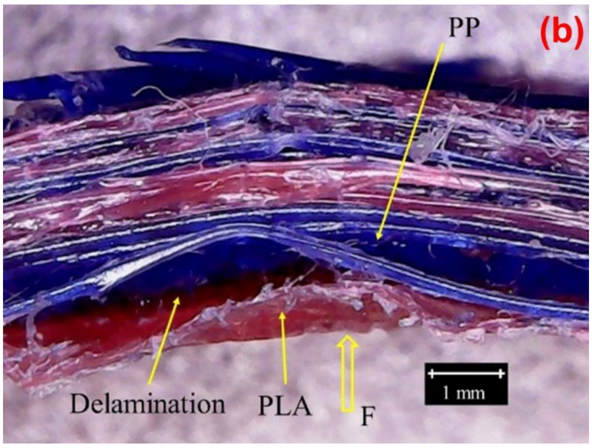
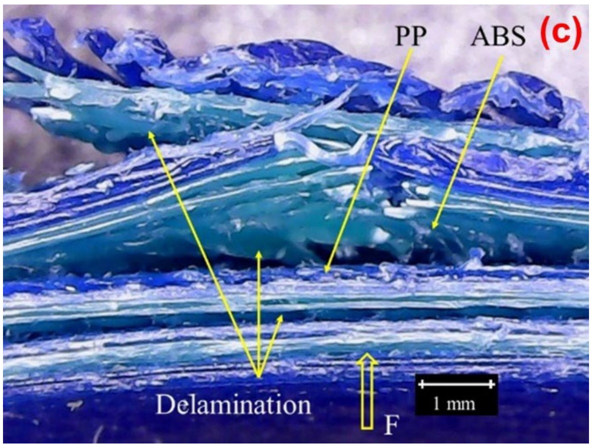


Fig. 5. (a) PLA-ABS alloy specimen and (b) PLA-PP-ABS alloy specimen.

The phenomenon of specimen delamination during the three-point bending test can be seen in the stress-strain test graph presented in Fig 4. The line fluctuations in the curve graph can be caused by poor interfacial bonding (delamination) between the filament layers in the specimen [20]–[23]. Delamination can be seen clearly in Fig 6, a micro photo of the specimen alloy fracture.







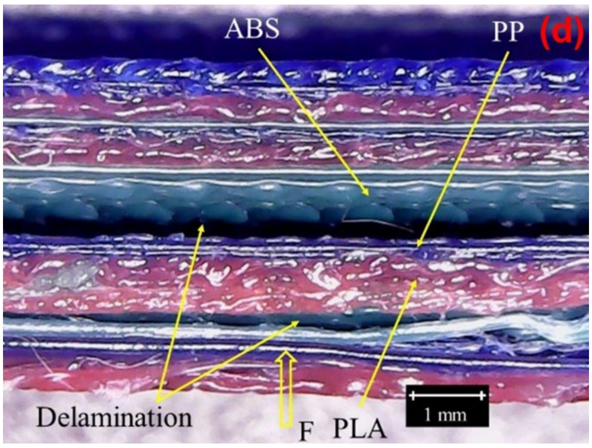


Fig. 6. Micro-photo of (a) PLA-ABS (b) PLA-PP (c) PP-ABS and (d) PLA-PP-ABS

A. PLA-ABS Specimens

The bonding of the PLA-ABS specimens occurs laminarly, not atomically (co-polymerisation). Lamination is a combination of two or more layers by bonding. Generally, this technique is carried out with materials such as plastic by melting the plastic onto the product [24]. The defects, such as shrinkage and warping, occur due to the difference in melting temperature between ABS and PLA. Temperature changing during the printing process. Fig 6a is a micro photo of the fracture experienced by the PLA-ABS specimen.

B. PLA-PP Specimens

The delamination of this alloy is seen in the first and second layers, namely the PLA and PP filaments, which in this section is also the part exposed to bending loads. Fig 6b is a micro photo of the delamination experienced by the PLA-PP specimen. The occurrence of delamination during the three-point bending test can reduce the value of flexural strength.[25]–[27]

C. PP-ABS Specimens

The PP-ABS specimens experienced almost similar delamination phenomena in each replication after the three-point bending test. The delamination that occurs in this combination can be seen in Fig 6c.

D. PLA-PP-ABS Specimens

Specimens using three filaments, namely PLA-PP-ABS, also experienced delamination in three replications. Fig 6d is a micro photo of the delamination of three replications of the PLA-PP-ABS alloy. The delamination in this combination is caused by the different melting temperatures of the three PLA, PP, and ABS filaments. Specimens made of PP-ABS experienced delamination. PP and ABS filaments in this alloy well bond because of the different melting temperatures between the two filaments. The printing temperature must be kept stable during the process to get more optimal bonding results [21].

In Fig 4, the stress-strain graph of the bending test, the curve of the PLA-PP-ABS alloy experiences significant fluctuations compared to the other three alloys. It confirms that the PLA-PP-ABS combination specimen experienced the greatest delamination during the three-point bending test. The bending stress results have the second lowest average of the other three specimens, namely 14.59 MPa with a standard deviation of ± 5.24. Despite experiencing large delamination, the flexural strength value of this alloy is not the lowest. It may be due to the addition of ABS filament, which has high flexural strength and elongation before breaking when combined with PLA.

CONCLUSIONS

Observations following the experimentations of combining PLA, PP, and ABS have been carried out using FDM 3D printing technique. Based on the research results, the combination of PLA-ABS with layer-by-layer method has the highest average value of flexural strength with a value of 33.12 MPa. The combination of PLA-PP with layer by-layer method has the second-highest average flexural strength value with a value of 14.90 MPa. The combination of PP-ABS with layer-by-layer method has the lowest average flexural strength value with a value of 12.10 MPa. Delamination occurs when the specimen is tested for bending. 45-degree fracturing occurred in all replications in the lower layer during testing. The combination of PLA-PP-ABS alloy has the second lowest average flexural strength value with a value of 14.59 MPa. Combination of PLA-ABS alloy did not experience delamination and resulted in ductile fracture. While, combination of PLA-PP-ABS experienced the greatest delamination during the bending test. Therefore, it is suggested to apply combination of PLA-ABS for the best bending strength, less delamination, and ductile.

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CONFLICT OF INTEREST

There is no conflict of interest.

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