Comparative study on the wood-based PLA fabricated by compression molding and additive manufacturing

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Abstract

Additive manufacturing namely 3-Dimensional (3D) printing and its feeding materials are increasingly used for producing customized products. Fused Deposition Modelling (FDM) in conventional 3D printers is a cost-effective solution. This is due to the low cost of the machine and various size selections. Although the machine cost is reasonable, the filament material is a higher cost. In general, the current filament is priced about 4 times more than granulated plastic. Moreover, the special filament containing wood powder shows a high cost of approximately 20 times that of pellets. This work proposes a comparative study of the components obtained from different processes. Compression molding and no-mold techniques were used. A previous design, nozzle from extrusion concept, was also used for fabricating the specimens. PLA and wood-based PLA were carried out to produce the testing samples. The results showed that parts obtained from the compressive mold showed low tensile strength. It was indicated that the residue voids were significantly affected by its strength. Taking into account the 3D printed parts, the articles from the designed extruder present a higher strength than the results derived from the conventional 3D printer and compression machine. On the other side, it was found that the moving direction of the nozzle (raster angle) affected directly the maximum tensile strength. Furthermore, the neat PLA had higher stress than the wood-composite materials used for all fabrication methods. However, in the case of using an extrusion device, it represented the enhancing of mechanical strength, which was caused by the homogeneous texture of polymers melting in a hot barrel. In terms of fabrication cost, the molding technique showed the highest cost even though the feeding material has the lowest cost. A similar cost was found for providing parts from the conventional printer and our design nozzle. However, a pellet-based extruder would be printed the sample filled 15%wt, conventional but the 3D printer is unavailable. Furthermore, recycled materials or waste of 3D printed parts can be utilized by using a conceptual extruder.

Keywords: Additive manufacturing, Fused deposition modelling, Wood composite, Pellet-based extruder
1. Introduction

Currently, Additive Manufacturing (AM) and 3-Dimensional (3D) printing are rapidly growing. Many varieties of materials such as plastics, metals, alloys and bio-materials are applied for supporting AM. Thermoplastics have been widely used in Fused Deposition Modelling (FDM), which is an important type of AM. Other forms of thermoplastics, in particular, the molding process, is often comparatively studied. The difference of investment costs and mechanical strength is an interesting point. The molding process, especially injection molding, will always give an advantage of mechanical property over 3D printing [1-7].

Acrylonitrile butadiene styrene (ABS) was experimentally investigated, which was prepared by injection molding and 3D printing. It was found that in almost all cases injected parts exhibited enhanced mechanical strength which resulted from the higher material compaction [8]. Another result confirmed that the tensile strength of a printed part was lower than those of an injected part by approximately 50% and the other mechanical properties were reduced as well [9]. Processing parameters of 3D printing, infill patterns or part density, was one of reducing parameter which destroys 3D printed parts [10].

However, the cost of parts obtained from an injection molding process was more than several times higher than that of 3D printed parts. The investment cost depended on a variety of parameters e.g., machine, mold design and manufacturing, the number of products and energy consumption etc. The cost was greatly increased in the case of parts having a complex geometry. Normally, the supplied materials for a molded article were pellets or granulate, which were low cost in respect of the filaments of a 3D printer. A secondary process of filament extruding was necessary. Thus, the number of plastic selections was limited. Also, the special filaments, the material filling wood particles, had a very high cost. Previous work achieved the preparation of a wood composite which had a lower-cost material [11]. However, the obtained material always presents as brittle in nature and it may give in the granulate form of a high-wood content.

The above mentioned indicated that a compression molding technique was an alternative method to be considered in terms of investment cost and the low-cost of materials. Because compression molding was a low-cost process and the plastic materials were supplied in the form of small granulates. A further approach, from current literature, combining a 3D printer combining with an extrusion concept was another interesting development [12-15]. This way is usually called the pellet-based 3D printer. The machine was introduced to conveniently use pellets for solving unsuitable forms of feeding material. A 3D printer based on an extrusion machine was proposed to perform the high viscosity of polyether-ether-ketone (PEEK) [12]. A pellet-based printer was also applied for making large scale printed parts [13].

This work was designing and constructing a pellet-based extruder to eliminate the high cost of 3D printed materials. Our machine can use granulates as material to be used in compression molding. A further advantage was that it was also applied to a wood composite which is a special type of printing material. A comparison of plastic formed by compression molding, traditional 3D printing and pellet-based extrusion was investigated in this work. The wood contents and printing orientations were also characterized in detail.

2. Materials and methods

For reducing variations of material properties, polylactic acid (PLA) from the same source was used throughout this work. It was mixed by loading it into a twin-screw extruder. The barrel and die temperature of 200°C and 180°C were controlled for melting material and maintaining it in a molten state. The melting polymer was cooled in a water bath and collected by the rolling machine as depicted in Figure 1. All wood-powder material was kindly supported from the Thai Hevea Wood Association. The varying of particle sizes was determined by screening with a sieve shaker to ensure the particle sizes were in the range of 106-425 μm. Parawood powder and PLA were compounded by twin screw extruder machine in wood content ranges of 5%-wt-15%-wt. The wood filament was divided into 2 categories.
The first, filament form, was directly used for the traditional 3D printer as in Figure 2. The second one was chopped into granulate approximately 3-5 mm and carried out for compression molding and pellet-based 3D printer.

![Figure 1. Twin screw extruder when rolling filament.](image1)

![Figure 2. Shredding composite materials (a) chopped machine (b) composite material.](image2)

In the compression molding process, aluminum foil was laid on the bottom and the top of the mold cavity. Each composite was weighed and then placed between aluminum foils. All samples were compressed under a pressure of 15 MPa and a mold temperature of 190ºC for 15 minutes. The polymer sheets were punched as the geometry of ASTM D638 specification which is shown in Figure 3. In the printing process, the dumbbell shape of ASTM D638 was also built up in 3 directions as in Figure 4. The obtained samples were used for evaluating the mechanical properties by using Universal Testing Machine (UTM, COMETECH Model LRK-20). According to ASTM D638 procedure, a dumbbell-shaped testing sample was installed between the grips with a gauge length of 50 mm and 5 mm/min of crosshead speed was also set. The raw data from five specimens of each condition was collected to find the average value and the standard deviation.
Figure 3. Cut the workpiece from the extrusion sheet.

Figure 4. Different orientation directions (a) 0 degree (parallel to force) (b) ±45 degree (c) 90 degree (Perpendicular to force).

3. Results and discussions

3.1 Effect of forming processes
The tensile properties of different types of plastics fabricated using FDM and compression molding are presented in Figure 5. There was shown a significant difference between compression molding and additive manufacturing. Molded articles presented lower tensile strength and gave better elongations. Generally, samples from the molding process are compressed using high pressure which promotes a strong and stiff polymer material. However, the short-compressed stroke of the open flash mold caused insufficient pressure to release air in the raw material. Hence, the air bubbles which occurred inside the test sample [9,10] are presented in Figure 6(a). This reason led to the lower failure strength. The short-cycle time of polymer melts in the molding process also resulted in the stretchability of materials. In additive manufacturing, heated positions promoted an excellent diffusion of polymer chains leading to a stronger bonding strength. A slight difference between a traditional 3D printer and a pellet extruder
was observed. This pellet-based extruder was stronger than traditional 3D printer due to better cross-layer diffusion as shown in Figure 6(b) and (c). However, the part of pellet extruder had a lower flexibility caused by the chain scission of polymer melt in a barrel.

![Image](image1)

**Figure 5.** Mechanical property comparison between compression molding and additive manufacturing processes (a) maximum tensile strength (b) elongation at break.

![Image](image2)

**Figure 6.** Composite surface fabricating in different processes (a) compression molding (b) traditional 3D printer (c) pellet-based AM.

### 3.2 Effect of parawood contents

Figure 7(a) and (b) show the results of wood composites which composed of parawood flour and PLA. The maximum tensile strength decreased as wood content was added. In contrast, material elongation showed better effects (except for the traditional 3D printer). This observation can be explained by the fact that an increase of wooden power gradually decreased the polymer area which supported the applied force. However, the nature soft of wood attributed to the stretchability of the composite materials. Surprisingly, in the case of a pellet-based extruder, stronger strength than those of a conventional printer was found. It can be interpreted that the long-heated barrel induced the cumulative heat of melting polymer. This led to an excellent molecular diffusion higher than the results obtained from the traditional 3D printer. The unexpected result was found that the maximum strength and elongation became more pronounced in case wood filling 15%wt. As considered the pellet-based mechanism, the slow-rotating screw in the heated barrel contributed to the good dispersion and distribution of wood particle and plastic matrix.
3.3 Effect of filled orientation
The three filling paths, which were compared to compression molding, are presented in Figure 8. The corresponding results presented the higher strength of FDM techniques as mention earlier. This difference in tensile strength of the orientations can be explained by the arrangement of the filling path in the specimens. The 0 degrees, parallel to the applied force, was presented the highest strength. As the raster angle increased, it showed a reduction in mechanical failure, especially for a 90-degree orientation. This was due to the influence of molecular orientation and bonding strength. As considered the AM techniques, it can be explained by two parameters i.e., polymer diffusion and surface roughness. Normally, the diffusion depth of the polymer molecular promoted the strength of the material, while the surface roughness destroyed it properties. In the case of 0 angles (parallel to force direction), a pellet-based extruder showed an improvement in tensile strength. This observation was due to the high-temperature pellet-based AM inducing better diffusion. It meant that the diffusion effect (pellet-based extruder) governed the roughness effect (traditional printer). For a 90-degree arrangement, a traditional 3D printer displayed good maximum tensile strength. This result indicated that the surface roughness of apart from a pellet-based extruder was more affected by the reduction of tensile properties. In the middle angle of 45 degrees, the two effects from roughness and diffusion were similarly found.

Figure 7. Effect of parawood content on the mechanical properties for varying forming processes (a) maximum tensile strength (b) elongation at break.
4. Conclusion
This study presents the comparative performances between a compression molded article and two types of AM parts. It can be seen that AM parts showed good strength above the compression molding technique. This was from the homogenous texture of the fabricating parts. The obtained results indicated that an increase of rubber-wood powder tends to decrease the maximum tensile strength of all introduced processes. Surprisingly, the stretchability of parts obtained from a pellet-based extruder was close to the molded part. However, the effect of filling orientation was evidently presented both for the traditional 3D printer and pellet-based extruder. Our design, the nozzle motivated from the extrusion process, could supply low-costing material in the form of neat pellet and wood-plastic composites. While the mechanical strength was higher than that of a compression molded part. A further advantage of this extrusion-based concept was that it could provide the same complex shapes as a traditional 3D printer. Moreover, it could use recycled materials.

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Figure 8. Effect of filling orientation of additive manufacturing (a) maximum tensile strength (b) elongation at break.
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