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Investigation of blended rPET/HPDE and the effect of wall line count using FDM process on mechanical and tribological properties

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ABSTRACT

Fused Deposition Modelling (FDM) is the most common 3D printing method, which the mechanical properties and wear performance can be affected by various printing parameters and the addition of recycled materials. Therefore, this study aims to support sustainable use of recycled materials by investigating the effect of wall line count of blended recycled polyethylene terephthalate /high density polyethylene (rPET/HDPE) on mechanical and tribological properties using FDM process. The ratios of rPET:HDPE used in this work was 5:95 and blended using extrusion process to fabricate the 3D filament. Then, thermal analysis and surface morphology were examined to observe the compatibility of these blended materials. Moreover, the mechanical and wear performance of 3D-printed samples with 5, 10, and 15 wall line counts were evaluated using tensile and reciprocating wear test, respectively. It shows that the addition of 5% rPET into HDPE produced a higher melting temperature compared to pure HDPE. In terms of mechanical properties, the 10 wall line counts exhibit the best mechanical and tribological properties. The 10 wall line counts produced two times higher tensile strength and better wear resistance compared to the 5 and 15 wall line counts. Overall, the results show that varying wall line counts can affect the mechanical and tribological properties.

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1.0 INTRODUCTION

Additive manufacturing or AM are commonly referred to as 3D printing, which is considered as a revolutionary approach for improving industrial production that capable of producing lighter and stronger 3D-printed part with complex geometries. Additive manufacturing is a method that involves layer-by-layer production with incorporating various materials such as plastic, liquid resin, and powder based on the specific 3D printing machine (Jandyal et al., 2022). Among different types of additive manufacturing machines, FDM has been commonly known 3D printing machine for affordability and versatility of manufacturing wide range of thermoplastics (Danut Mazurchevici et al., 2020). FDM technology works by creating the part layer-by-layer by melting and extruding the filaments made of thermoplastic through a moving nozzle. The nozzle is driven by a computer-controlled system along a path that is presented by the 3D model of the part that is being 3D-printed. As the nozzle moves, a small layer of the molten thermoplastic is deposited onto the build platform. The build platform is lowered by one layer height after this layer is set down, and the procedure is repeated until the complete portion is built (Daminabo et al., 2020).

There are many types of thermoplastic are used in FDM technology, with each material offering different properties suited for varying applications. The most common material used in FDM technology is Polylactic Acid (PLA). PLA material is favourable among users due to the biodegradability and environmentally friendly properties, which makes it a preferable choice for FDM applications (Tümer & Erbil, 2021). Other materials such as Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG), and Polycarbonate (PC) are common for fabricating 3D-printed part (Zaidi & Gawhari. 2024). Furthermore, the use of various materials has shown advancement in FDM technology, leading to the incorporation of recycled materials in 3D filaments. A study by Hasan et al. (2024) utilizes recycled PLA for evaluating the durability of 3D-printed spur gears using FDM process. The tribological properties of recycled and pure PLA were evaluated to assess the wear resistance and frictional behaviour. According to the study, the recycled PLA have the lowest in tribological performance with pure PLA. However, it is still considered as a viable alternative for sustainable manufacturing.

Meanwhile, a previous investigation conducted by Singh et al. (2020) that uses recycled waste HDPE and reinforced with various fillers. The methodology involves pure waste HDPE and reinforced waste HDPE with silicon carbide (SiC) and aluminum oxide (Al_2O_3), which 3D-printed using FDM process with an aim to observe the tribological properties. The findings stated that pure waste HDPE indicates the lowest tribological performance due to low hardness and high wear rate, in comparison with the addition of fillers. Despite the prior research that use various recycled materials, recycled Polyethylene Terephthalate (rPET) or waste plastic bottles has not been addressed using the FDM technology, focusing on its mechanical and tribological properties. Hence, the use of rPET in FDM technology is crucial for improving sustainability of materials and reducing plastic pollution.

In addition, printing parameters plays a major role that can affect the mechanical and tribological properties of 3D-printed parts using FDM technology. Various printing parameters such as layer height, nozzle temperature, infill pattern, and infill density. A study by Norani et al., (2020) investigate the most optimal 3D printing parameters from the FDM process in terms of tribological properties. The study analyzes the friction and wear coefficient properties of ABS polymer using response surface methodology (RSM). The methodology involves varying infill patterns used in this study. It was found that varying infill patterns significantly affect the coefficient of friction (CoF) and wear rate. The results showed that the layer height of 0.10 mm, a nozzle temperature of 234 °C, and using a triangular flip infill pattern demonstrated the optimal wear resistance and lowest COF due to better load distribution. Another study by Hanon et al., (2019) examined the tribological properties of ABS and PLA at various printing temperatures. The temperature varied from low at 190 – 195 °C, optimal at 200 – 205 °C, and maximum at 215 – 220 °C. Based on the results, it indicates that printing temperature can affect the tribological properties. The ABS material exhibits lower CoF results than PLA at all three temperatures ranges.

According to these previous studies, it shows varying printing parameters and incorporating recycled materials can influence the mechanical and tribological properties of 3D-printed parts using FDM process. This research provides a unique perspective on using recycled materials in combination with varying wall line count to develop high wear resistance of 3D-printed parts, offering a sustainable and cost-effective alternative in comparison to the traditional manufacturing methods. The existing literature has indicated printing parameters such as layer height, nozzle temperature, infill pattern, and infill density can affect the strength, wear resistance, and toughness of 3D-printed FDM parts. In addition, the incorporation of rPET is lacking in evaluating the mechanical and tribological properties, which is due to focus on common 3D printing materials such as PLA, ABS, or TPU. Therefore, this study aims to address the gap by evaluating the printing parameter of wall line count and the addition of rPET with HDPE can affect the mechanical strength and wear performance of 3D-printed parts. The interactions of the wall line count with 3D-printed rPET/HDPE parts are expected to produce high wear resistance 3D-printed parts and provide a sustainable production process of using recycled materials.

2.0 EXPERIMENTAL PROCEDURE

In this work, the waste plastic bottles or rPET was collected from cafeteria around UTeM and residential areas in Ayer Keroh, Melaka while the HDPE pellets was supplied by Lotte Chemical Titan Sdn Bhd. Then, the collected rPET was cleaned with running water to remove any dirt and then dried under natural sunlight. The dried rPET was cut into strips and crushed using a crushing machine. After the crushing process, both rPET and HDPE pellets were dried in a drying oven for 5 hours at 80 ℃ to remove moisture. In order to fabricate the 3D filament, the rPET and HDPE mixture was required. Hence, both materials were manually mixed based on the composition, shown in Table 1.

Table 1: The composition of rPET/HDPE for 3D filament fabrication.

Sample ID	**rPET/HDPE (100 g)**	**rPET (g)**	**HDPE (g)**
rPET/HDPE	5/95	5	95

For the fabrication of 3D filament, the mixture of rPET/HDPE was blended using a single screw extruder. The aim of the extrusion process was to blend and melt both materials for the fabrication of 3D printing filament for FDM process. Figure 1 shows the summary workflow of fabricating the 3D printing filament through extrusion process. It involves three temperature zones for the nozzle, barrel, and cooling zones with a temperature setting of 220 ℃, 210 ℃, and 30 ℃, respectively. The mixture of rPET/HDPE material was fed into the barrel and extruded through the nozzle with a diameter of 1.75 mm. The speed of the single screw extruder was set at 25 rpm and the filament winder was set at 300 rpm.

2.1 Thermal Analysis of Blended rPET/HDPE 3D Filaments

In this study, thermal analysis was conducted using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) analysis to determine the thermal stability of blended rPET/HDPE 3D filaments. The DSC analysis was performed to analyze the heat capacity of materials with temperature within a controlled temperature environment. For the DSC analysis, the specimens weighed 10 mg and were encapsulated in an aluminum crucible. The sample was heated from 25 °C to 200 °C with a heating rate of 10 °C/min under nitrogen gas with a flow rate of 20 ml/min. The melting temperature is used as a result in this work.

Furthermore, the TGA analysis was also conducted to determine the degradation temperature of blended rPET/HDPE samples as it heated. A 10 mg sample of the blended rPET/HDPE 3D filaments was placed into an aluminum crucible and heated from 30 °C to 600 °C at a heating rate of 10 °C/min under nitrogen gas. The result of the degradation temperature was taken in this work for further explanation.

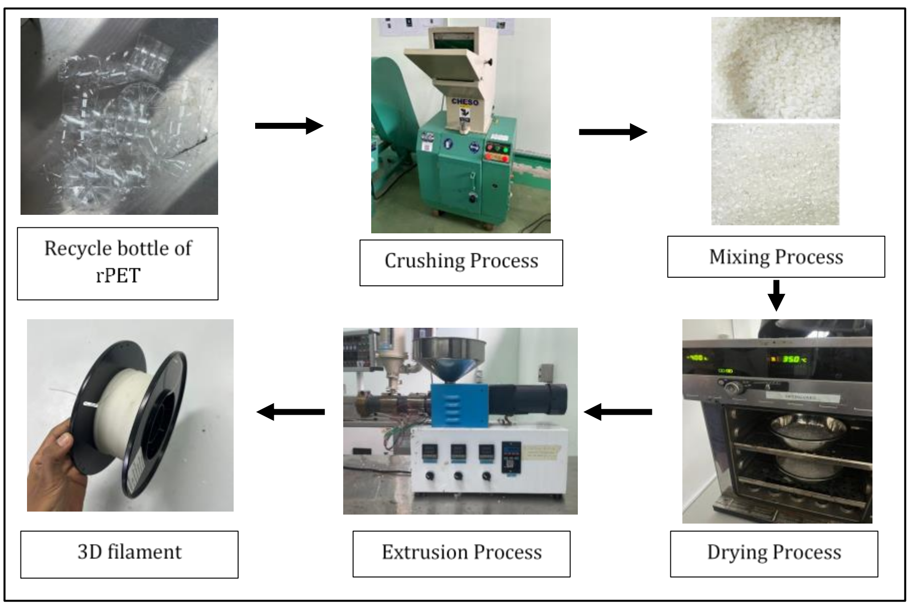

Figure 1: Summary workflow of the fabrication process of 3D printing filament through extrusion process.

2.2 Surface Morphology of Blended rPET/HDPE 3D Filaments

The surface morphology of blended material was examined using field emission scanning electron microscopy (FE-SEM). The blended rPET/HDPE 3D filaments were cut into 10 mm and coated with a thin layer of gold to enhance conductivity for better observation. The micrographs were observed with a magnification of x100 and x500 to detect any irregularities that can affect the FDM 3D printing process.

2.3 Development of 3D-printed Samples

to evaluate the mechanical properties of blended rPET/HDPE printed samples, CAD modelling was required to design the dumbbell samples from blended material (rPET + HDPE) for tensile and impact testing. The samples were designed using Fusion 360, in accordance to ASTM D638 and ASTM D6110 for tensile and impact samples, respectively, as displayed in Figure 2. Next, the designed sample was exported as Stereolithography (STL) file to a slicing software using Ultimaker Cura Software. The slicing software determined the 3D printing parameters used in this work.

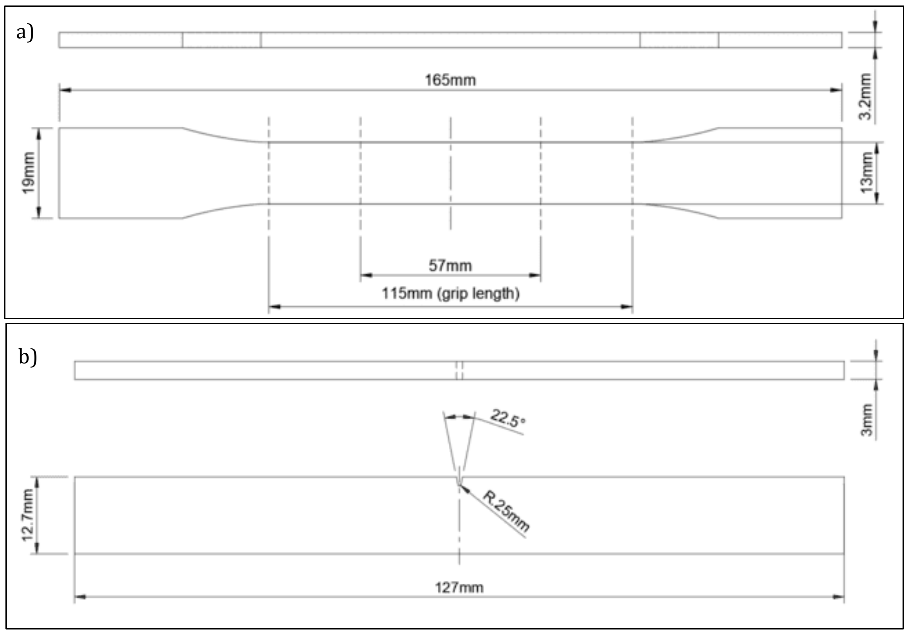

Figure 2: Dimension size of samples for (a) tensile test and (b) impact test.

In the slicing software, the printing parameters can be controlled such as layer height, nozzle temperature, and infill density. The study used varying wall line counts of 3D-printed rPET/HDPE blend to evaluate its mechanical and tribological properties. Table 2 shows the 3D printing parameters for the development of 3D-printed samples using rPET/HDPE blend with varying wall line counts. The illustrations on the arrangement of varying wall line counts for the tensile samples is shown in Figure 3. After that, the test samples were 3D-printed using the rPET/HDPE 3D filaments according to the printing parameters using Creality Ender 3 Version 2, a desktop FDM 3D printed machine (Shenzhen Creality 3D Technology Co., Ltd, China). By varying the wall line counts of 5, 10, and 15 layers, three experiments for each wall line count were conducted to determine the best wall line count for 3D-printed rPET/HDPE parts.

2.4 Mechanical Property of 3D-printed Samples Parts

The tensile properties of the 3D-printed rPET/HDPE samples were determined using a Shidmadzu universal testing machine. The 3D-printed samples were held with a 25 mm of gripping length and applied at a crosshead speed of 5 mm/min until they fracture within 0.5 to 5 minutes in testing time. In addition, impact test was conducted using Instron Ceast 9050. The experimental method was conducted by placing the samples onto an anvil with the V-notch facing away from the impact hammer. Three samples for each wall line count were used to evaluate the tensile and impact strength.

Table 2: Printing parameters for FDM process.

Parameter	Value
Nozzle size	0.4 mm
Nozzle temperature	260 ℃
Bed temperature	110 ℃
Printing Speed	60 mm/s
Filament Diameter	1.75 mm
Infill density	20%
Infill pattern	Cubic
Layer height	0.12 mm
Printing axis	X, Y, Z
Wall line count	5, 10, 15 layers

Moreover, the hardness values of the 3D-printed of blended rPET/HDPE were measured using a Shore D durometer hardness tester. The durometer is used for measuring the relative hardness of soft materials with the test method on the penetration by using a type D indenter, forced into the material with a load of 5 kgf. Five measurements were recorded at different points on the 3D-printed rPET/HDPE parts with spacing of 6 mm apart. The average hardness reading obtained from each sample were taken in this work as a final result.

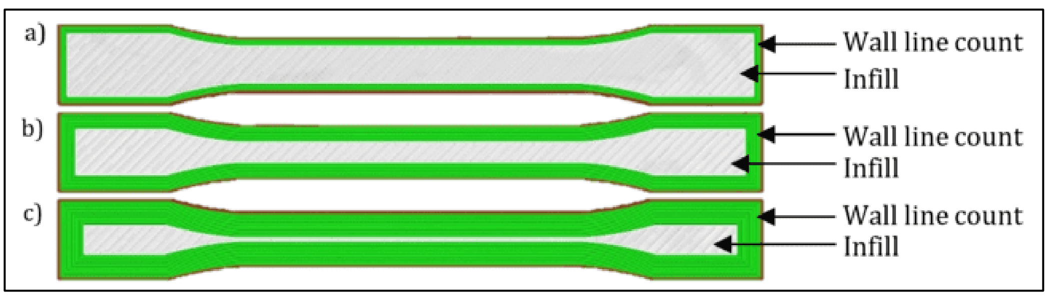

Figure 3: Illustration for the arrangement of varying wall lines with (a) 5, (b)10, and (c) 15 layers for the tensile samples.

2.5 Reciprocating Wear Test of 3D-printed Samples

In order to assess the behavior of wear characteristics of the blended rPET/HDPE with varying wall line counts, three samples for each wall line count were carried out through a linear reciprocating wear test using a ball-on-plate method, as shown in Figure 4. The flattened surface of the 3D-printed samples with varying wall line counts were used to ensure smooth contact with the counterpart material of stainless-steel ball. The test condition is shown in Table 3. The wear rate value measured in terms of weight loss (before and after test) using a weighing balance. Meanwhile, the coefficient of friction was recorded directly through the software from the wear tester machine. Each measurement is taken three times for each sample. The wear rate of the samples is calculated using the following standard formula and expressed as mm^3/Nm, as highlighted in Equation 1. After completion of the wear test, the worn surface of the 3D-printed rPET/HDPE samples were examined to determine the wear depth by using Leica digital microscope.

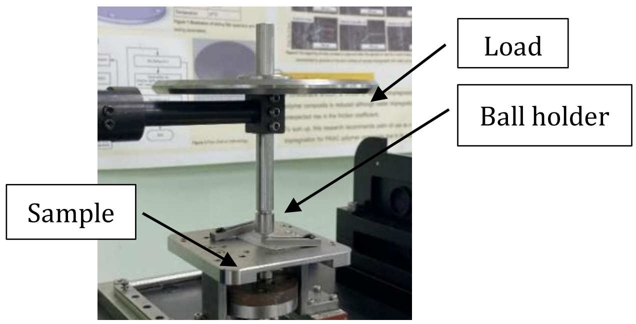

Figure 4: Machine setup for linear reciprocating wear test.

Table 3: Wear Test Condition.

Specimen	**Liner motion reciprocating wear test condit**
Applied load	10 N
Frequency	10 Hz
Wear test duration	30 minutes
Stroke length	15 mm
Speed	60 rpm
Counter-part body	Stainless steel ball (diameter: 6mm)

$$\text{Wear rate} = \frac{\text{Weight loss } (g)}{\text{Density } (g/mm^3) \times \text{Normal load } (N) \times \text{Sliding distance } (m)} \quad (1)$$

3.0 RESULTS AND DISCUSSION

3.1 Thermal Analysis of Blended rPET/HDPE Filaments

Table 4 presents the summarized DSC and TGA analysis results for pure HDPE and blended rPET/HDPE. In this work, the melting temperature and degradation temperature were examined using DSC and TGA analysis, respectively as illustrated in Figures 5 and 6. Based on the DSC analysis results, the melting temperature of pure HDPE was revealed at 133.3 °C. Meanwhile, with the addition of 5 % rPET, it can be seen that the melting temperature reduced to 132.1 °C, indicating a reduction of 0.9 %. It can be seen that the addition of 5 % rPET with HDPE affects the thermal stability, resulting in lower melting temperature compared to pure HDPE. This is believed to occur due to rPET creating additional structural disturbance, which affects material compatibility, and therefore lowering the melting temperature. A similar study by Vaucher et al. (2022) shows that incorporating recycled material affects the thermal stability of blended material. The research conducted with pure rPET and rPET with varying rHDPE of 2 %, 5 %, and 10 %. Based on the results, the pure rPET exhibits a higher melting temperature compared to the addition of rHDPE of 10 %, with a value from 253.1 °C to 252.2 °C, respectively. This indicated that increasing the content of recycled materials reduced the melting temperature of blended materials.

Table 4: Summary of the DSC and TGA analysis of pure HDPE and blended rPET/HDPE.

Samples	**DSC**	**TGA**
	T_m (℃)	**T_{max} (℃)**
HDPE	133.3	481.9
Blended rPET/HDPE	132.1	487.5

Meanwhile, the TGA analysis for pure HDPE exhibits a maximum degradation temperature of 481.9 ℃, as shown in Figure 6. However, the maximum degradation temperature increases with the addition of 5 % rPET, which showed a value of 487.5 ℃. The addition of rPET resulted in an increment of 1.2 %. According to the results, the degradation temperature affected by the addition of rPET, led the rPET/HDPE blend having a higher degradation temperature compared to pure HDPE. This might be attributed to the incorporation of rPET, which improves the crystallinity of the HDPE blend, making it more resistant to early thermal degradation. Conversely, the addition of the recycled material can affect the degradation temperature within blend, which aligns with Techawinyutham et al. (2021), which stated that blending higher content of recycled materials of rPETG with pure materials of HDPE affect the thermal stability of blended materials. The increasing rPETG of 10 % with HDPE exhibits a maximum degradation temperature of 486 ℃. However, with the increment of rPETG to 90 %, the maximum degradation temperature reduces to 424 ℃, resulting a lower degradation temperature with a difference of 12.76 %.

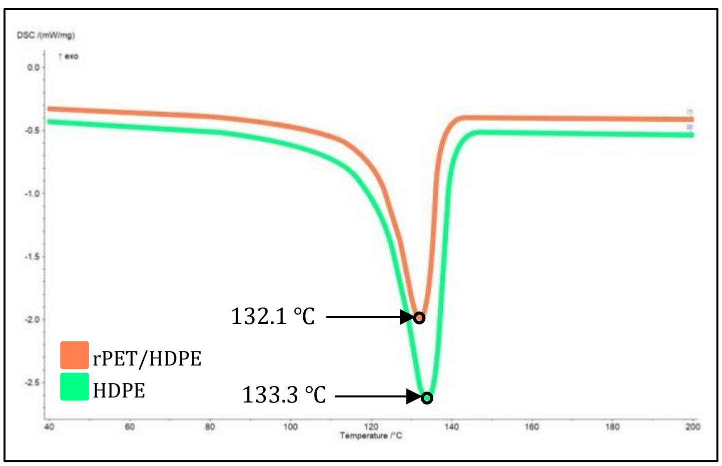

Figure 5: DSC curve for pure HDPE and rPET/HDPE samples.

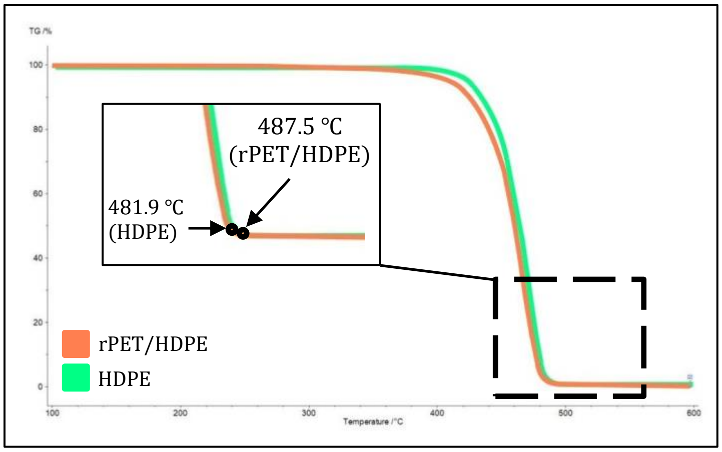

Figure 6: TGA graph for pure HDPE and rPET/HDPE samples.

3.2 Surface Morphology of rPET/HDPE 3D Filaments

Based on Figure 7, the surface morphology of the 3D filaments of rPET/HDPE blend was examined to assess the quality of 3D filaments for FDM process. At x100 magnification, shown in Figure 7 (a), it can be seen that the surface of rPET/HDPE filaments produce a smooth and flat surface with small rPET particles. This minor defect is likely to be due to a good fusion between the recycled and pure polymers, suggesting that the rPET has successfully blended with pure HDPE blend during extrusion process. Other than that, Figure 7 (b) shows scratch surfaces at x500 magnification. The resulting scratches may form during the extrusion process, leading to minor surface defects on the 3D filament. However, the presence of this minor defects was still suitable and acceptable to be used for FDM process due to the 3D filament re-melted during 3D printing process, which eliminated the scratch surface. Previous study with Arrigo et al. (2022), which demonstrated that incorporating lower recycled Polypropylene (PP) content with pure PP in 3D filament exhibits better surface morphology compared with higher rPP. The study shows that only 30-40 % of rPP exhibits a smooth surface quality compared to the higher rPP blends. Moreover, increasing the rPP to 50 % and above resulted in surface defects such as uneven surface and roughness on the surface of the 3D filament. From this finding, it can be observed that the blended of rPET/HDPE 3D filaments is a feasible blended material for FDM process.

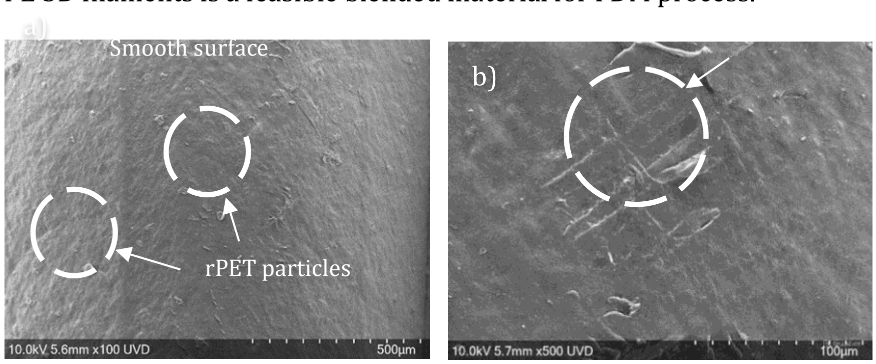

Figure 7: FE-SEM images of blended rPET/HDPE 3D filament with a magnification of (a) x100 and (b) x500.

3.3 Mechanical Properties of 3D-printed rPET/HDPE Samples

Table 5 shows the summary of the mechanical properties of 3D-printed rPET/HDPE samples with varying wall line counts for better overview. It demonstrates the results obtained for tensile, impact strength and hardness value were increasing with the increment from 5 to 10 wall counts. However, the mechanical properties were reduced when using 15 wall line counts. For detailed discussion for each result, Figure 8 displayed the tensile strength results obtained from the 3D-printed rPET/HDPE samples with varying wall line counts of 5, 10, and 15 layers. Based on the figure, it can be seen that the highest tensile strength was exhibited by the 10 wall line counts at 28.34 MPa, while the lowest tensile strength shown by the 5 wall line counts at 14.25 MPa. Then, by increasing to 15 wall line counts, the tensile strength slightly increases with a value of 20.48 MPa. According to the findings, the 10 wall line counts show the highest tensile strength, which is two times higher than the 5 wall line counts. This might be attributed to a balanced structure between flexibility and rigidity, allowing better load transfer and uniform stress distribution without premature failure. Meanwhile, the 5 wall line count shows the lowest tensile strength due to weak interlayer bonding and higher stress concentrations, resulting more prone to failure and low tensile strength. These findings aligned with prior research conducted by Nguyen et al. (2024) which investigated the tensile strength of rPET with varying wall line counts of 1, 2, and 3 layers. It was revealed that the 2 wall line count shows a higher tensile strength with a value of 44.8 MPa compared to 1 and 3 wall line counts with a tensile strength of 31 MPa and 42.7 MPa, respectively.

Table 5: Summary of mechanical properties of blended rPET/HDPE with varying wall line counts.

Parameters	**Tensile strength (MPa)**	**Impact strength (kJ/m²)**	**Shore D hardness (shore D)**
5 wall line counts	14.25	103.67	40.8
10 wall line counts	28.34	131.36	46.4
15 wall line counts	20.48	121.93	43.8

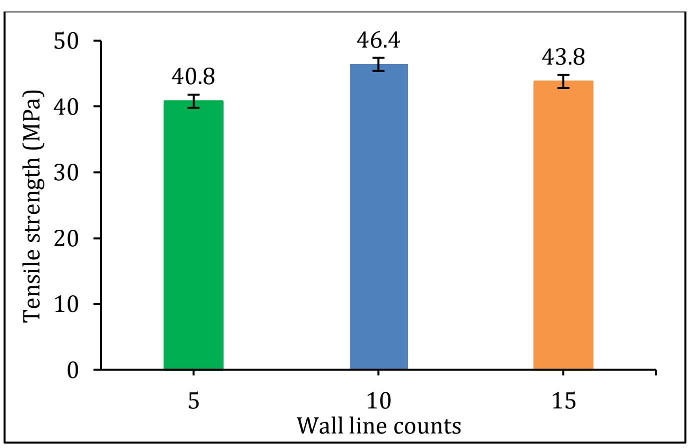

Figure 8: Tensile strength of blended rPET/HDPE with different wall line counts.

Furthermore, the impact test result of the 3D-printed rPET/HDPE samples with varying wall line count were observed in Figure 9, which revealed that the 10 wall line counts produce the highest impact strength at 131.36 kJ/m^2, which is 21 % higher than the 5 wall line counts with a value of 103.67 kJ/m^2. It is then followed by the 15 wall line counts with a value of 121.93 kJ/m^2, with a slight increase of 17 %. Generally, it can be seen that the 5 wall line counts produce the lowest impact strength compared to the 10 wall line counts. This could be because of the fewer wall line counts, creating more internal voids within structure, making it more prone to sudden impact forces. However, the 10 wall line counts provide an optimal balance within internal structure and wall line counts, which resulted in better flexibility to absorb impact energy and resist sudden impact fracture. Similar observations can be seen with Hamzah et al. (2024), that use pure PLA with varying wall line counts of 6, 18, and 30 layers. The result indicates that the 18 wall line exhibits the highest impact strength, in comparison to the 6 and 30 wall line counts. This is due to the 18 wall line count having a well-balanced of flexibility and rigidity, resulting in better energy absorption.

Other than that, the shore D hardness value of 3D-printed rPET/HDPE samples with varying wall line counts of 5, 10, and 15 layers are shown in Figure 10. The results show that the 10 wall line counts produce the highest hardness value at 46.4 shore D. However, it can be seen that the lowest hardness value was exhibited by the 5 wall line counts and followed by the 15 wall line counts, with a value of 40.8 and 43.8 shore D, respectively. These results show that varying wall line counts can affect the hardness value, with the 10 wall line counts produced the highest hardness value, in comparison to the 5 wall line counts. This could be due to balance internal structure of infill and wall line counts, which improve the ability of material to resist surface penetration during indentation, resulting in high hardness value. However, reducing to 5 wall line counts affect material distribution, leading to a less rigid structure that resulted in the structure to be less resistant to surface indentation. Earlier investigation by Zeng et al. (2022) showed comparable results, revealed by varying printing parameters of the build orientation can influence the hardness value. The investigation revealed that the flat build orientation shows the highest hardness value, while increasing the build orientation angle to 90°, reduces the hardness value.

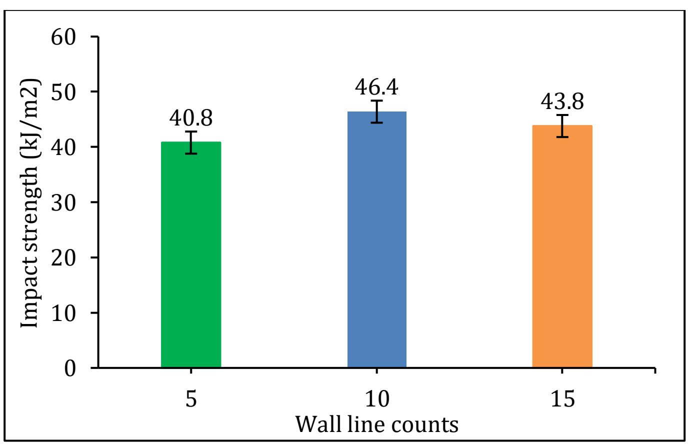

Figure 9: Impact strength of blended rPET/HDPE with varying wall line counts.

3.4 Wear Rate and Coefficient of Friction For 3D-printed rPET/HDPE Samples

The tribological properties of 3D-printed rPET/HDPE samples with varying wall line counts were assessed through a linear reciprocating test carried out under a stainless-steel ball. Figure 11 and 12 demonstrates the wear rate and coefficient of friction of different wall lines of 5, 10, and 15 layers, respectively. Based on Figure 11, it was found that the 10 wall line counts exhibit the lowest wear rate with a value of 38.18 x 10^{-5} mm^3/ Nm. Meanwhile, the 5 wall line counts show the highest wear rate, followed by the 15 wall line counts with a value of 76.37 x 10^{-5} mm^3/ Nm and 57.37 x 10^{-5} mm^3/ Nm, respectively. Based on the results, it revealed that the 10 wall line counts exhibit the best wear rate compared to the 5 and 15 wall line counts. The wear rate for the 10 wall line counts could be attributed to the higher resistance to surface deformation and abrasion, leading to lower material removal, which is suggested by the hardness results. However, the 5 wall line counts have the highest wear rate due to fewer wall line count and low hardness value, resulting in a flexible structure, which is prone to surface deformation. Hence, it can be concluded that there is a direct correlation between wear rate and hardness value of varying wall lines counts on the 3D-printed rPET/HDPE samples.

Furthermore, the coefficient of frictions of the samples were assessed in this work, which the value is depicted in Figure 12. Generally, it can be seen that the 10 wall line counts produced the lowest coefficient of friction with a value of 0.47. Moreover, increasing to 15 wall line count produces a coefficient of friction value of 0.54, while the highest value for the coefficient of friction was revealed by the 5 wall line counts at 0.58. According to the findings, the 10 wall line counts have the lowest coefficient of friction value, in comparison to the 5 and 15 wall line counts. This is thought to be due to the 10 wall line counts providing an optimal balance, by evenly distributing loads across the surface, producing lower coefficient of friction value. Recent investigation shown by Singh & Bharti. (2021) provide comparable results, indicated by varying printing speed of 50, 100, 150, and 200 mm/sec. The result shows that the printing speed of 100 and 150 mm/sec was the optimal setup for achieving the wear rate and coefficient of friction value for 3D-printed parts.

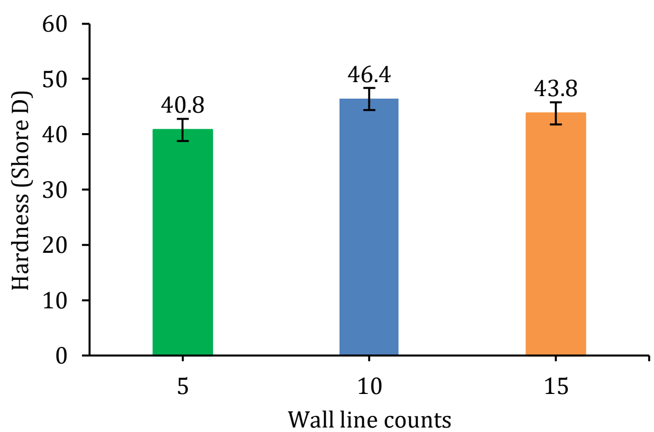

Figure 10: Shore D hardness value of blended rPET/HDPE samples with varying wall line counts.

3.5 3D Surface Topography of 3D-printed rPET/HDPE Samples

Following the wear rate and CoF analysis, the 3D surface topography images of the reciprocating wear tracks on the 3D-printed rPET/HDPE samples after rubbing were carried out and the results are shown in Figure 13. Additionally, the wear depth on the wear surface of the 3D-printed rPET/HDPE samples with varying wall lines of 5, 10, and 15 layers is shown in Table 6. Based on the 3D topography images, the 10 wall line counts exhibit the lowest wear depth at 53.38 µm, while the 5 wall line counts resulted in highest wear depth with a value of 113.75 µm. However, increasing the wall line count to 15 layers, the wear depth slightly decreases the wear depth at 110.76 µm, with a difference of 2.6 %, compared to the 5 wall line counts. The wear depth profile of the samples is displayed in Figure 14. It can be observed clearly that the different trends of the wear penetration profile with different wall line counts. From this graph, it demonstrates the 10 wall line that counts experience the lower wear depth compared to other samples.

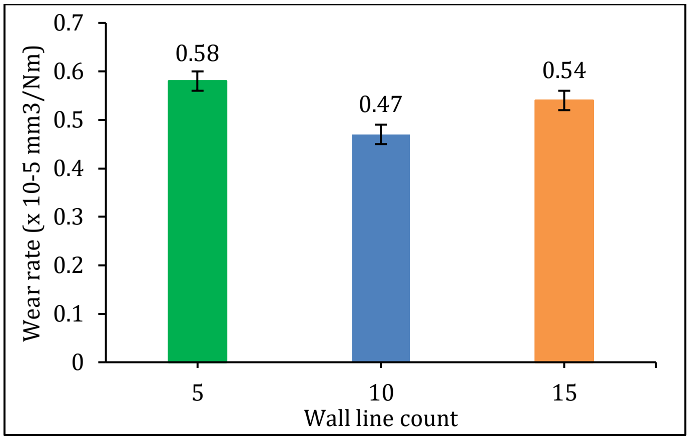

Figure 11: Wear rate of rPET/HDPE samples with varying wall line counts.

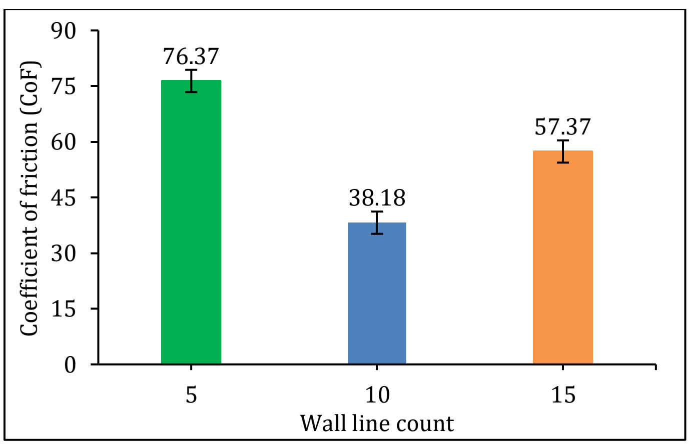

Figure 12: Coefficient of Friction (CoF) of rPET/HDPE samples with varying wall line counts.

Overall, the 10 wall line counts show the lowest wear depth, in comparison to the 5 and 15 wall line counts. This might be attributed due to the wall line count and infill density, creating a balanced structure of contact area that allows an even load dissipation and better heat dissipation, leading to better wear resistance. Furthermore, the 5 wall line counts produce the highest wear depth which is caused by the thinner outer wall line counts, creating weaker interlayer adhesion that led to delamination and higher material removal under frictional forces. Past studies by Hanon & Zsidai. (2021) also shows similarities with different build orientation that affect the wear depth of 3D-printed samples. The study revealed that horizontal build orientation has the lowest wear depth due to having a larger contact area, resulting a smoother surface and distributes load evenly, which reduce the wear depth. Other than that, the 45° angle build orientation has the highest wear depth. This is because the 45° angle build orientation produced smaller contact area and non-uniform contact surface, leading to high material removal and deeper wear tracks.

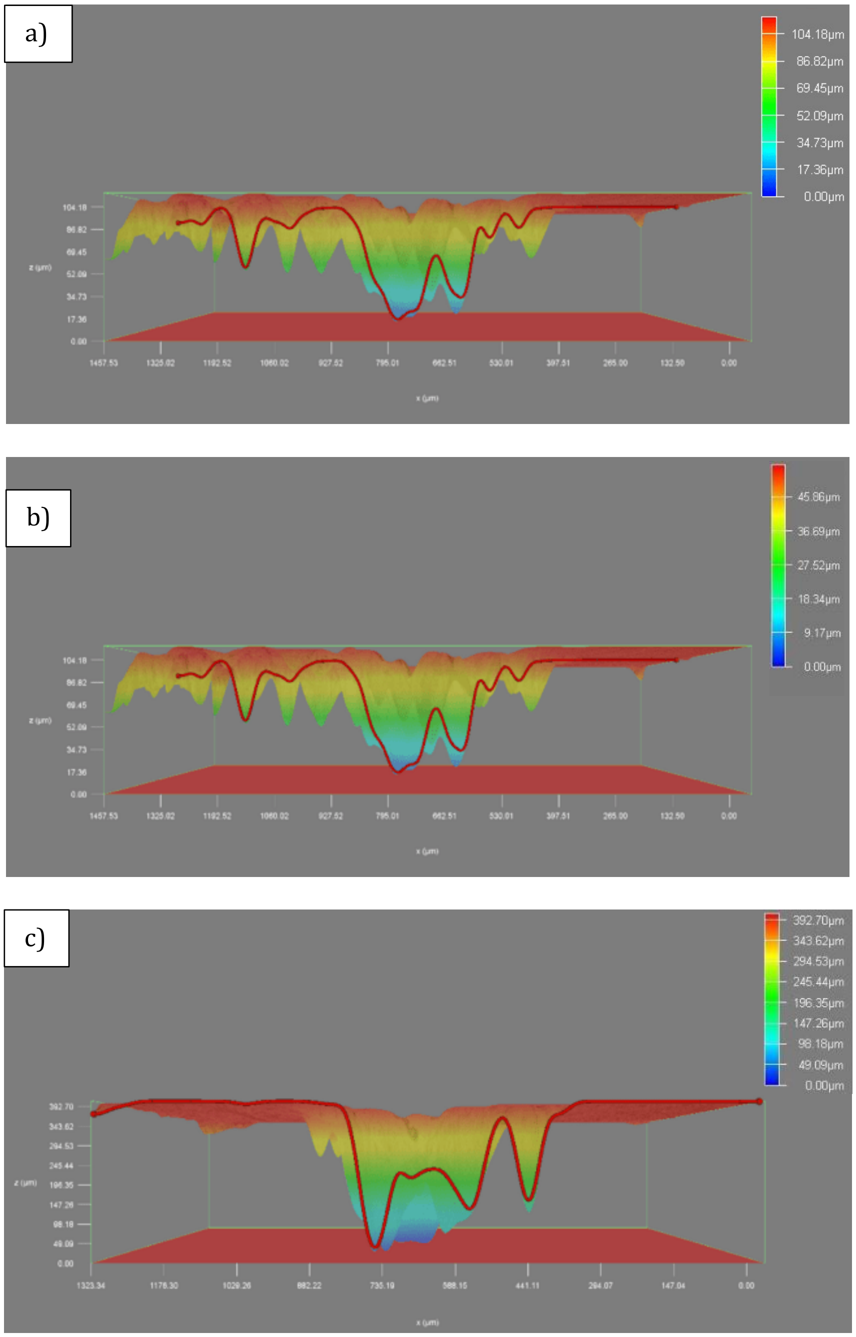

Figure 13: 3D surface topography of rPET/HDPE samples with varying wall line counts of (a) 5, (b), and (c) 15 layers.

Table 6: Wear depth on the blended rPET/HDPE with varying wall line counts.

Samples	Maximum height (µm)	Minimum height (µm)	Total wear depth (µm)
5 wall line counts	113.98	0.23	113.75
10 wall line counts	53.89	0.51	53.38
15 wall line counts	114.33	3.57	110.76

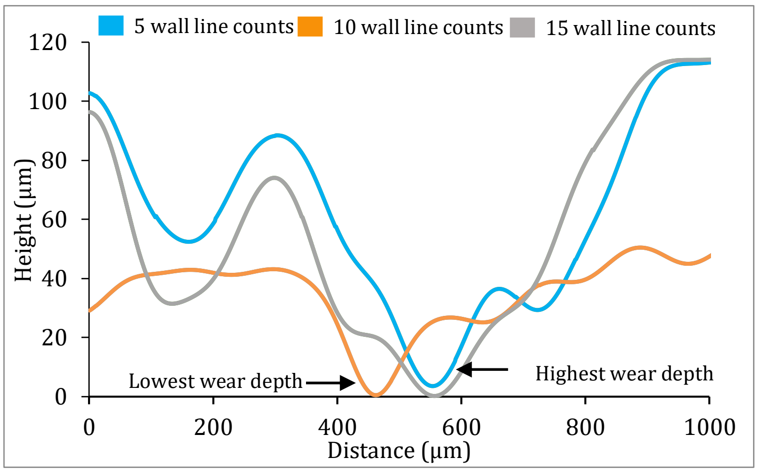

Figure 14: Profile measurements of wear depth on the blended rPET/HDPE samples with different wall line counts.

CONCLUSIONS

This study highlights the investigation of the blended rPET and HPDE as 3D filament for FDM process. From the works, the recycling material of rPET is feasible for 3D printing applications. Furthermore, the finding demonstrates the effect of varying wall lines counts on the mechanical and tribological properties of 3D-printed rPET/HDPE blend using FDM process. It can be concluded that varying wall lines of 5, 10, and 15 layers can have significant effect on mechanical and tribological properties. The key findings include:

(a) The addition of rPET into HDPE affects the melting temperature and degradation temperature of blended material showing the reduction of melting temperature and increment of degradation temperature compared to pure HDPE.
(b) The surface morphology of 3D filament of rPET/HDPE blend shows a smooth and even surface with minor defects. These findings were considered acceptable for the FDM process.
(c) The best mechanical properties for 3D-printed rPET/HDPE blend were exhibited by the 10-wall line counts with the formation of dense and compact structure, which effectively balanced the internal structure and improving load dissipation, resulting in higher hardness value, tensile and impact strength.
(d) The lowest wear rate and coefficient of friction were obtained by the 10 wall line counts, which have better wear resistance and less friction with lesser wear depth on the worn surface.

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REFERENCES

Arrigo, R., Battegazzore, D., Bernagozzi, G., Cravero, F., Ribero Pedraza, D. N., & Frache, A. (2022). Recycled PP for 3D Printing: Material and Processing Optimization through Design of Experiment. Applied Sciences, 12(21), 1-12.

Daminabo, S. C., Goel, S., Grammtikos, S, A., Nezhad, H, Y., & Thakur, V, K. (2020). Fused deposition modeling-based additive manufacturing (3D printing): techniques for polymer material systems. Materials Today Chemistry, 16, 1-23.

Hamzah, A,H., Paijan, L,H., Bakar, M,H., Mamat, M,F., Maidin, N,A., Musa, S, I. (2024). effect of wall line count on the mechanical properties of FDM 3D-printed PLA parts. Malaysian Journal of Microscopy, 20(2), 34–44.

Hanon, M, M., & Zsidai, L. (2021). Comprehending the role of process parameters and filament color on the structure and tribological performance of 3D printed PLA. Journal of Materials Research and Technology, 15, 647-660.

Hanon, M, M., Kovács, M., & Zsidai, L. (2019). Tribology behaviour investigation of 3D printed polymers. International Review of Applied Science and Engineering, 10 (2), 173-181.

Hasan, M, R., Davies, I, J., Pramanik, A., John, M., & Biswas, W, K. (2024). Technical assessment of 3D-printed spur gears produced from recycled PLA. Research Square, 1-42.

Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A., & Haq, M. I. U. (2022). 3D printing –A review of processes, materials and applications in industry 4.0. Sustainable Operation and Computers, 3, 33-42.

Mazurchevici, A. D., Nedelcu, D., & Popa, R. (2020). Additive manufacturing of composite materials by FDM technology: A review. Indian Journal of Engineering & Materials Sciences, 27, 179-192.

Nguyen, P. Q. K., Panta, J., Famakinwa, T., Yang, R. (Chunhui), Ahmed, A., Stapleton, M., Sassaman, D., Snabes, S., & Craff, C. (2024). Influences of printing parameters on mechanical properties of recycled PET and PETG using fused granular fabrication technique. Polymer Testing, 132, 1-10.

Norani, M, N, M., Abdollah, M, F, B., Abdullah, M, I, H, C., Amiruddin, H., Ramli., F, R., & Tamaldin, N. (2020). Correlation of tribo-mechanical properties of internal geometry structures of fused filament fabrication 3D-printed acrylonitrile butadine styrene. Industrial Lubrication and Tribology, Emerald Publishing, 72 (10), 1259-1265.

Singh, M., & Bharti, P, S. (2021). Parametric Influence of Process Parameters on the Wear Rate of 3D Printed Polylactic Acid Specimens. Indian Journal of Pure & Applied Physics, 59, 244-251.

Singh, R., Bedi, P., Kumar, R., Singh, S., & Ahuja, I. (2020). Wear properties of rapid tooling prepared by reinforcement of SiC-Al2O3 in HDPE domestic waste. Materials Today: Proceedings, 33, 1468-1471.

Techawinyutham, L., Tengsuthiwat, J., Srisuk, R., Techawinyutham, W., Mavinkere Rangappa, S., & Siengchin, S. (2021). Recycled LDPE/PETG blends and HDPE/PETG blends: mechanical, thermal, and rheological properties. Journal of Materials Research and Technology, 15, 2445–2458.

Tümer, E, H., & Erbil, H., Y. (2021). Extrusion-Based 3D Printing Applications of PLA Composites: A Review. MDPI Coatings, 11 (4), 1-42.
Vaucher, J., Demongeot, A., Michaud, V., & Leterrier, Y. (2022). Recycling of Bottle Grade PET: Influence of HDPE Contamination on the Microstructure and Mechanical Performance of 3D Printed Parts. Polymers, 14(24), 1-15.
Zaidi, A, A, M, A., & Gawhari, F, J, A. (2024). Types of Polymers Using in 3D Printing and Their Applications: A Brief Review. European Journal of Theoretical and Applied Sciences, 1 (6), 978-985.
Zeng, Y, S., Hsueh, M, H., Lai, C, J., Hsiao, T, C., Pan, C, Y., Huang, W, C., Chang, C, H., & Wang, S, H. (2022). An Investigation on the Hardness of Polylactic Acid Parts Fabricated via Fused Deposition Modeling. MDPI Polymers, 14, 1-10.