Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Mechanical and Thermal Properties of 3D-Printed Acrylonitrile Butadiene Styrene Reinforced with Rubberwood Fiber

Thanate Ratanawilai[1,*], Noppanat Jaturonlux[1], Anas Awae[1], Warinthon Muangnivet[1], Zaleha Mustafa[2]

[1] Smart Industry Research Center, Department of Industrial and Manufacturing Engineering, Faculty of Engineering, Prince of Songkhla University, Hat Yai, Songkhla, Thailand
[2] Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ARTICLE INFO

Article history:
Received 25 January 2024
Received in revised form 29 May 2024
Accepted 7 June 2024
Available online 30 June 2024

Keywords:
Fused filament fabrication; wood plastic composites; mechanical properties; thermal properties; material extrusion

ABSTRACT

An additive manufacturing (AM) has become very popular due to its simplicity in producing complicated products using just one process due to the layer-by-layer addition of material, which makes it possible for more complicated products to be created. The constraint of Fused Filament Fabrication (FFF) printed components with inadequate mechanical qualities has prevented AM from being widely adopted by numerous industries. The mechanical and thermal qualities of FFF printed components which is a pure polymer could be enhanced by reinforcing the wood fiber into the polymer. In this study, the twin-screw extruder was used to produce the wood plastic composites (WPCs) filaments, which were made with ABS (Acrylonitrile Butadiene Styrene) as the matrix material and 1-3wt% rubberwood fiber (RWF) for reinforcement. The effects of the extrusion parameter, such as the volume fraction of RWF and the temperature of the extrusion process, on the 3D-printed WPCs samples were investigated. The experimental results of 3D-printed WPC sample were found that the highest compressive strength value is 24.3 MPa, obtained from the rubberwood 1wt% at the extrusion temperature 218 °C whereas the pure ABS filaments obtaining from the commercial and extrusion process gave the values of 28.9 and 14.5 MPa, respectively. The highest value of tensile strength is 8.4 MPa with the rubberwood 2wt% and temperature 198 °C whereas the pure ABS filaments obtaining from the commercial and extrusion process gave the values of 10.9 and 7.4 MPa, respectively. The morphological analysis of the 3D-printed WPC sample was observed to exhibit an effect of printing process. The result showed that an increasing temperature of extrusion process increases both tensile and compressive strengths of the samples whereas an increasing amount of fiber increases the tensile strength but decreased the compressive strength. Analysis of variance demonstrated linear factor and 2-way interaction factor of the extrusion parameter influence on compression and tensile strength significantly. The rubberwood 2wt% and the temperature 218 °C was suggested to achieve the suitable condition for extrusion process for the 3D-printed WPC sample. In addition, the discussions were supported with the thermal properties achieved from Thermogravimetric analysis and Differential Scanning Calorimetry.

---

[*] *Corresponding author.*
E-mail address: thanate.r@psu.ac.th

https://doi.org/10.37934/arfmts.118.2.7486

1. Introduction

The production technology known as additive manufacturing (AM) creates products layer by layer. This method can produce highly complicated products. The advantages of AM could be applied in various industries such as prototyping, automotive, aeronautics, aerospace, biomedical, luxury, and building [1,2]. Several techniques were generally used in the additive manufacturing process such as Vat photopolymerization, Material jetting, Binder jetting, Powder bed fusion, and Fused Filament Fabrication (FFF) technique [3,4]. FFF of 3D printing is one of the most popular AM processes since it has a low machine cost and a variety of filament materials accessible. The advantages of 3D printing are low volume production, mass customization, true rapid prototyping, and rapid design iteration [3,5]. The FFF technology, however, still has a number of significant drawbacks, including a lengthy manufacturing process, a small product size, and the low mechanical characteristics, which is its most significant drawback [4]. The FFF process results in a product with unsatisfactory mechanical qualities due to the structure of the product created by layer-by-layer material extrusion. The obtained product has weak mechanical properties since these layer connections are prone to breaking [6,7]. It has also been reported that by increasing the infill, shell thickness, and layer height of the 3D printing process, the mechanical properties of the sample can be improved [3,6]. Another noteworthy identifying is that the procedure was modified to maintain the best possible conditions for the mechanical properties of the 3D printing process, which was limited to the properties of the raw materials. The mechanical properties as well as the thermal properties of FFF printed components which is normally made from a pure polymer could be enhanced by reinforcing the wood fiber into the polymer that is known as wood plastic composites (WPCs).

WPCs are composites that contain a polymer matrix mixed with reinforcement wood fiber. The main benefit of Polymer matrix composites is that they combine the advantages of plastics and wood such as light weight, specific hardness, and high modulus of elasticity [8-10]. Wood fiber also has contributed to improved plastic properties, such as increased mechanical properties, thermal properties, and physical properties [11-13]. For this reason, WPCs are popularly used in many different industrial applications. In addition, a variety of manufacturing techniques might be used to create the WPCs' products. For example, extrusion is the core of a WPCs profile processing system to melt the polymer and mix the polymer, wood, and additives. Hot pressing or thermoforming has been used extensively in the manufacture of automobile composite parts. Injection molding has been used to produce parts containing complex geometries and requiring no finishing step [14]. It's interesting to note that both 3D printing and the production of WPCs use an extrusion process as their primary method.

The benefits of both WPCs and 3D printing, such as creating a product without using a mold, are attractive for developing a new product. Therefore, the purpose of this study was to investigate composites made from rubberwood sawdust and Acrylonitrile Butadiene Styrene (ABS) plastic by examining the impact of rubberwood fraction volume and the extrusion temperature in producing WPCs filament on the mechanical and thermal properties and microstructure of rubberwood sawdust reinforced ABS of the 3D printing samples.

2. Methodology

2.1 Materials

The Acrylonitrile butadiene styrene (ABS) filament was purchased from Fast Print (Chonburi, Thailand). This commercial ABS filament was printed to investigate as a control sample (ABS Com). A temperature printing range of 220-260 °C and a bed temperature range of 100-110 °C were recommended for the printing condition. Plastic ABS pellets were purchased from Withaya Intertrade Co., Ltd (Samutprakarn, Thailand). This commercial ABS pellet was produced to ABS filament (ABS Ext). ABS Ext was printed to investigate as another control sample. Rubberwood flour (RWF) obtained from the cutting process in local furniture industry (Songkhla, Thailand). Prior to the compounding process of WPCs, RWF was dried in an oven at 110 °C for 8 hours after being sieved through a standard sieve at 80 mesh.

*2.2 Wood Plastic Composites Process*es

WPCs were produced through the form of WPCs filament. In the first step to produce WPCs filament, ABS and RWF were dry-mixed with wood fraction volume 1-3 wt% (formulations in Table 1) and then melt-blended and dragged into wood plastic composite filament using a twin-screw extruder (Model SHJ-36 from En Mach Co., Ltd, Non-thaburi, Thailand). Ten temperature zones of an extruder were adjusted in this investigation between the ranges of 170-198, 170-208 and 170-218 °C. At the feeding zone, the minimum temperature was regulated, and at the die zone, the maximum temperature was adjusted. The screw was configured to rotate at 70 rpm. The cooling procedure employed water that was at room temperature. The regulated diameter size of the wood plastic composite filament was 1.75±0.1.5 mm. WPCs filaments were dried in an oven at 80 °C for 8 hours after cooling. The extrusion temperature for the ABS Ext control sample was set at 170-200 °C, which is within the melting range of ABS plastic. This sample was created using the same process as WPCs filament.

Table 1
The formulation of 3D printer filament samples

Formulation	Wood fraction (wt%)	Extruded temperature (°C)
RWF1T198	1	198
RWF1T208	1	208
RWF1T218	1	218
RWF2T198	2	198
RWF2T208	2	208
RWF2T218	2	218
RWF3T198	3	198
RWF3T208	3	208
RWF3T218	3	218

2.3 3D Printing Process

WPCs filaments were produced in accordance with American Society for Testing and Materials (ASTM). The specimen was created using 3D Printer (Model: Flashforge Dreamer) with a 0.4 mm diameter nozzle. The processing conditions were as follows: (1) printing speed 50 mm/s, (2) travel speed 80 mm/s, (3) printing temperature 240 °C, (4) bed temperature 100 °C, (5) 15% of fill density, (6) 0.2 mm of layer height, and (7) 1 mm of shell thickness. The specimen was printed only once for each piece. Each test was conducted 3 replications.

2.4 Mechanical Testing

The mechanical testing was conducted on an Instron Universal Testing Machine, Model 5582 to obtain the tensile and compression properties of the samples. The tensile samples with the dimensions of 9.6 mm (width) × 3 mm (thickness) × 63 mm (length) were performed according to

ASTM D 638-91 with the crosshead speed of 5 mm/min. The compression samples with the dimensions of 14.4 mm (width) × 7.2 mm (thickness) × 7.2 mm (length) were conducted according to ASTM D 6108-97 with the crosshead speed of 5 mm/min.

2.5 Thermal Testing

The thermal testing was conducted by Thermogravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC). Thermal analyzer was used to analysis and establish the thermal stability of the WPC filament. The WPCs filament, which had a length of about 3 to 4 cm, was scanned at a heating rate of 10 °C/min while being exposed to nitrogen atmosphere and temperatures between 0 and 1000 °C. The onset temperature was determined from the TGA and DTG curves.

2.6 Morphological Analysis

The WPCs filament interfacial structure and the arrangement of the filament in the samples were the main subjects of the morphological analysis. Two techniques, the digital microscope to image the samples, the filament arrangement was evaluated. Prior to and following the mechanical test, the image samples were captured with a 5x and 20x magnification to observe the behavior destructive of the sample structure. scanning electron microscopy (SEM) using for image the inner and interfacial structure in the sample were exhibited using SEM SU3900 microscope working at 10 kV.

3. Results

3.1 The Compressive and Tensile Properties

The maximum compressive strength and compressive modulus are shown in Figure 1 and Figure 2 respectively. The results of WPCs sample reached the maximum stress in the range of 8.5 – 24 MPa and compressive modulus in the range of 168 – 523 MPa. The maximum stress was affected by an increase in extrusion temperature. The possibility is that the high temperature range helps to promote coalescence. It also contributes to facilitate the coalescence between the matrix polymer and reinforcing fibers [15]. However, as the volume of the wood fraction increases, the maximum compressive strength and modulus slightly decrease. To clarify the results, an analysis of variance (ANOVA) was performed to statistically analyze all experimental results. The results of ANOVA exhibit the extrusion temperature and wood fraction volume influence on maximum compressive strength and compressive modulus significant in Figure 3. Additionally, when comparing a sample of formulation WPCs, it appears that RWF1T218 and RWF2T218 both provided the highest values of maximum compressive strength, 24.33 and 22.38 MPa, respectively, without a significant difference at $\alpha=0.05$, as shown in Table 2.

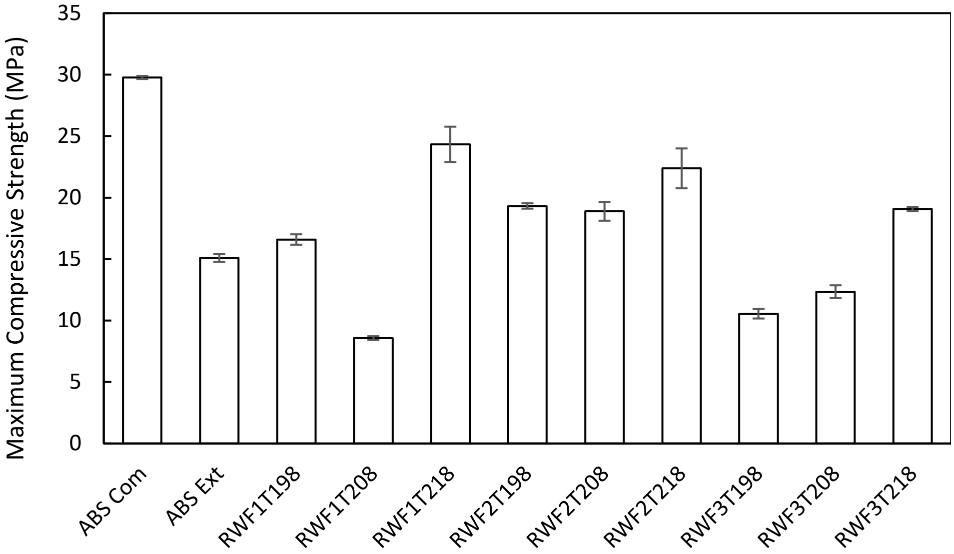


Fig. 1. Maximum compressive strength of WPCs samples

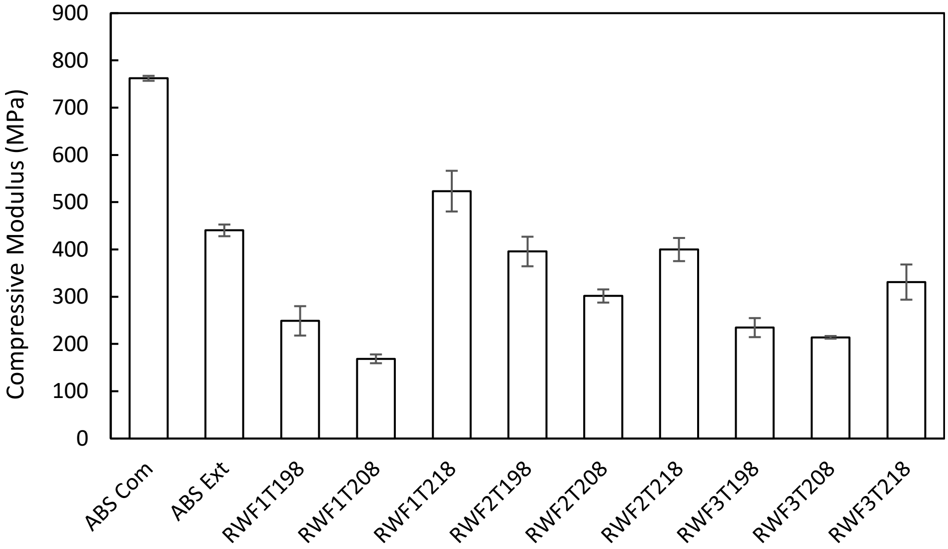
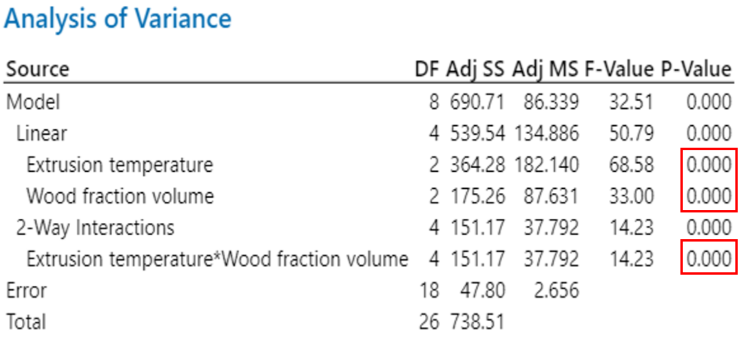


Fig. 2. Compressive modulus of WPCs samples



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	690.71	86.339	32.51	0.000
Linear	4	539.54	134.886	50.79	0.000
Extrusion temperature	2	364.28	182.140	68.58	0.000
Wood fraction volume	2	175.26	87.631	33.00	0.000
2-Way Interactions	4	151.17	37.792	14.23	0.000
Extrusion temperature*Wood fraction volume	4	151.17	37.792	14.23	0.000
Error	18	47.80	2.656		
Total	26	738.51			

Fig. 3. ANOVA test of maximum compressive strength values

The maximum tensile strength and tensile modulus are shown in Figure 4 and Figure 5 respectively. The results of WPCs sample reached the maximum tensile strength in the range of 4.80 – 8.34 MPa and tensile modulus in the range of 439 – 656 MPa. The results show similar trend with the values of the compressive strength. The trend in tensile strength has been slightly increased under the influence of increased wood fraction volume. These samples appear to have a too-low wood fraction volume. The result is a slight increase in tensile strength [10,16]. To clarify this effect, it can be seen from the SEM micrographs in Figure 6 that few natural fibers was observed in the cross-section image of WPCs sample. Additionally, the effect of extrusion temperature and wood fraction volume significantly affected as shown in Figure 7 by ANOVA testing. It reveals that both RWF2T198 and RWF3T208 gave the highest values of maximum tensile strength, 8.45 and 8.40 MPa, respectively, without a significant difference at α=0.05, as shown in Table 2.

Table 2
The result of compressive and tensile strength with ANOVA grouping test

Formulation	Maximum Compressive strength (MPa)	Compressive modulus (MPa)	Maximum tensile strength (MPa)	Tensile modulus (MPa)
RWF1T198	16.59^{B}	249.0^{CDE}	6.24^{C}	785.11^{BC}
RWF1T208	8.568^{D}	168.7^{E}	4.65^{D}	571.27^{C}
RWF1T218	24.33^{A}	523.4^{A}	7.44^{B}	527.21^{AB}
RWF2T198	19.32^{B}	395.8^{B}	8.45^{A}	471.35^{A}
RWF2T208	18.88^{B}	301.6^{CD}	8.05^{AB}	627.73^{A}
RWF2T218	22.38^{A}	399.8^{B}	7.78^{AB}	672.18^{BC}
RWF3T198	10.55^{CD}	234.7^{DE}	4.85^{D}	663.74^{C}
RWF3T208	12.34^{C}	214.1^{DE}	8.40^{A}	547.68^{A}
RWF3T218	19.07^{B}	331.0^{BC}	7.97^{AB}	486.95^{AB}

*Grouping Information Using the Fisher LSD Method and 95% Confidence

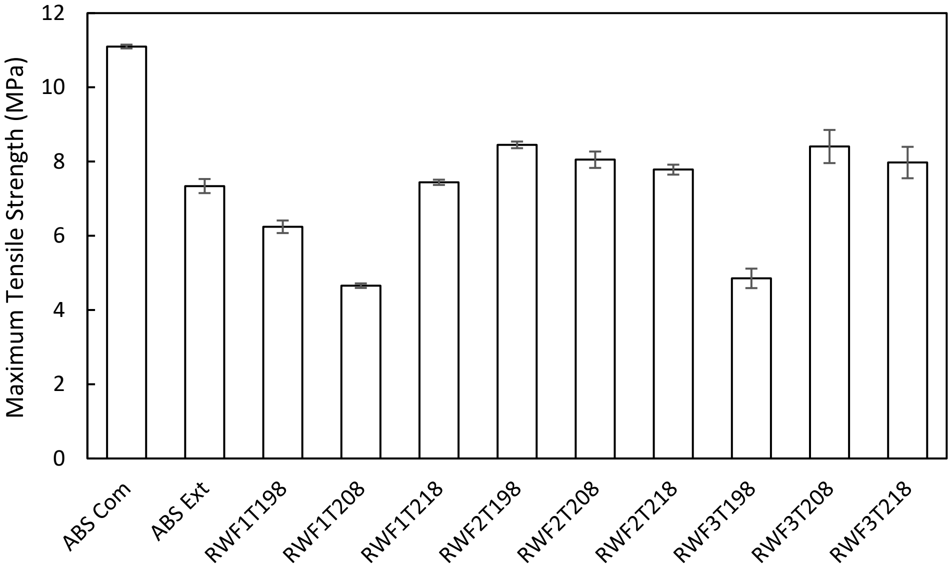


Fig. 4. Maximum tensile strength of WPCs samples

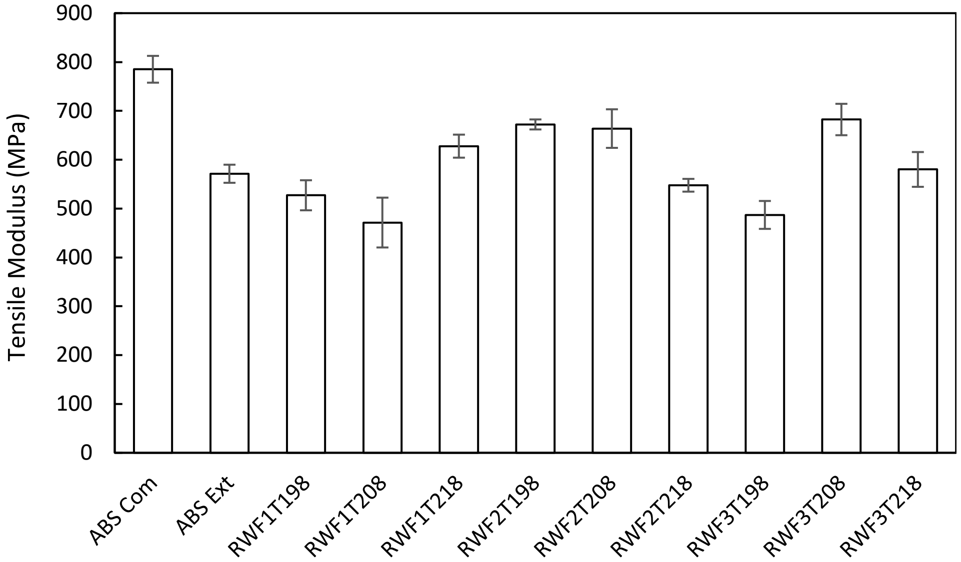
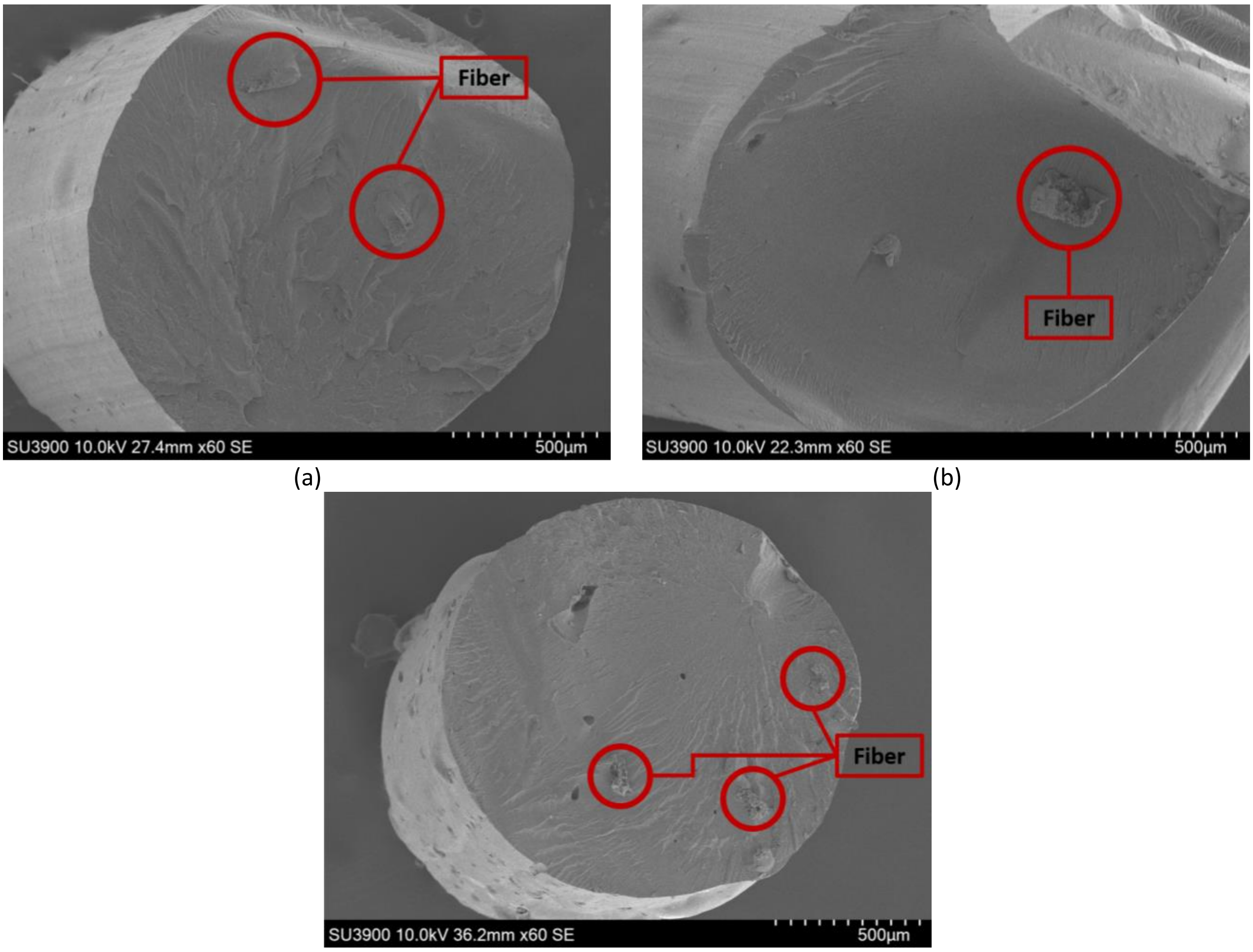


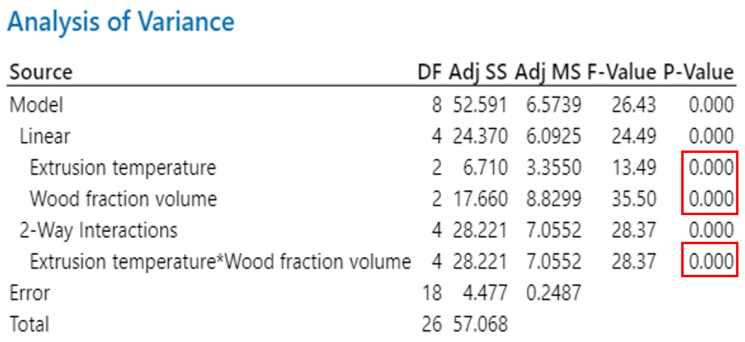
Fig. 5. Tensile Modulus of WPCs samples



(a) (b)

(c)

Fig. 6 SEM micrographs of increasing wood fraction volume in WPCs (a) Wood 1 wt% (RWF1T218) (b) Wood 2 wt% (RWF2T218) (c) Wood 3 wt% (RWF3T218)



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	52.591	6.5739	26.43	0.000
Linear	4	24.370	6.0925	24.49	0.000
Extrusion temperature	2	6.710	3.3550	13.49	0.000
Wood fraction volume	2	17.660	8.8299	35.50	0.000
2-Way Interactions	4	28.221	7.0552	28.37	0.000
Extrusion temperature*Wood fraction volume	4	28.221	7.0552	28.37	0.000
Error	18	4.477	0.2487		
Total	26	57.068			

Fig. 7. ANOVA test of maximum tensile strength values

The extrusion temperature and wood fraction volume significantly influenced the compressive and tensile strength of the samples for all formulations. However, on compressive and tensile strength, the wood fraction volume at low volume of 0 – 3 wt% had a minor impact. The wood fraction volume is the main effect on mechanical properties of composites material. This increase is the result of the WPC sample's inclusion of reinforcement fibers, which led to the development of good mechanical properties [10].

3.2 Thermal Properties

Thermogravimetric analysis involves measurement of the weight loss or gain of a material as a function of time and temperature [17]. The TGA and derivative thermogravimetric (DTG) curves containing ABS filament commercial, ABS filament pure extrusion, and WPCs filament at a formulation of RWF2T218 are shown in Figure 8 and Figure 9, respectively. Figure 8 exhibited the decomposition of the samples by two steps. The first step decomposition onset at 309.47°C, 306.82°C, and 347.58 °C with the weight loss at 8.65%, 10.45%, and 21.10% for the samples with commercial, extrusion, and WPCs of RWF2T218, respectively. This result explains the WPCs sample decomposition onset at temperature higher than ABS pure. This implies that wood fiber as reinforcement also improves thermal stability. The cellulose and hemicelluloses components of the reinforcement-fiber in the composites degraded in the temperature range 274–459 °C [18,19]. In the second step decomposition onset at 382.28°C, 378.51°C, and 383.48°C with the weight loss at 68.71%, 70.42%, and 52.37%. This might be the result of ABS decomposition and this phenomenon has also been reported for other polymers [20,21].

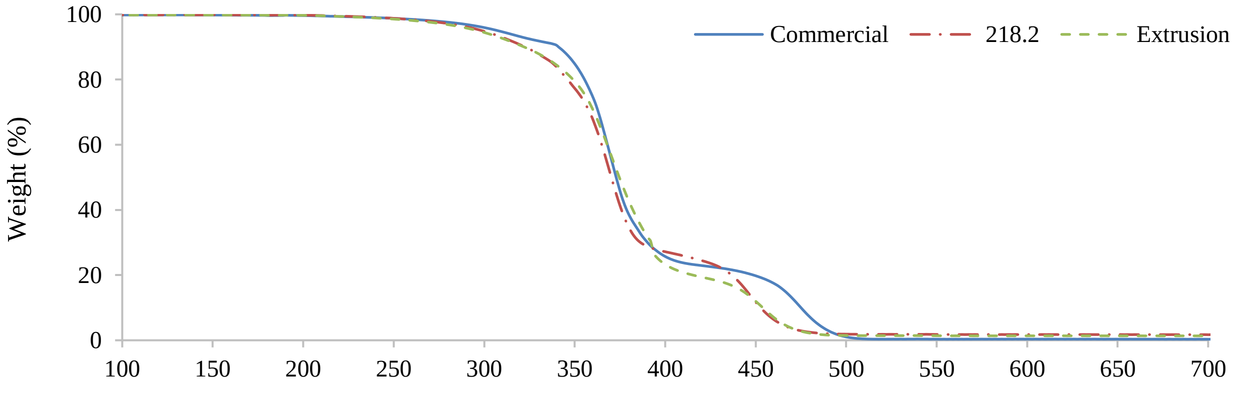


Fig. 8. Thermogravimetric analysis curves of samples

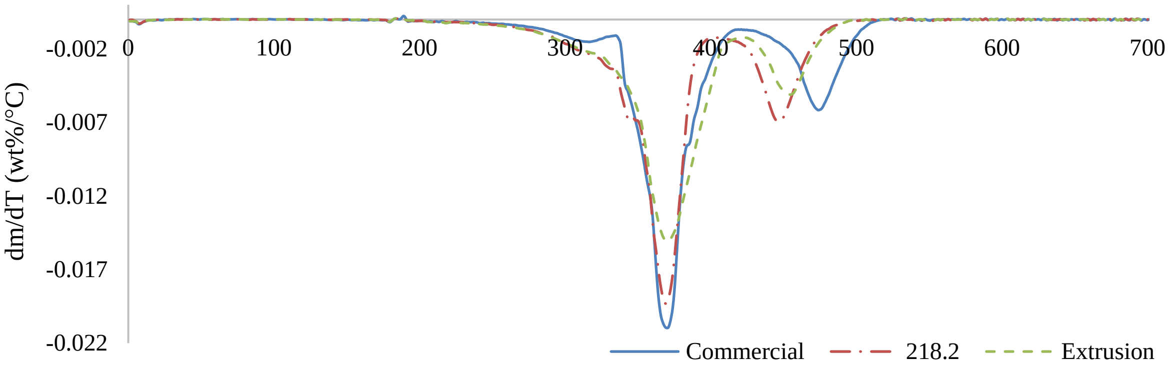


Fig. 9. Derivative thermogravimetric curves of samples

3.3 Morphological Analysis

The interfacial structure and arrangement of the filament of WPCs samples was investigated using SEM and Digital microscope. Figure 6 is a SEM image to show an increasing wood fraction volume from 1-3 wt% at extrusion temperature 218 °C (RWF1T218, RWF2T218, and RWF3T218) of WPCs samples. It noticed that in WPCs with rubberwood content of 1-3 wt%, natural fiber distribution in the extruded filament was hardly noticeable. It seems that wood fraction volume of 3 wt% is still too low comparing with the total weight of filament. Due to the volume of wood being too low, mechanical properties are slightly impacted. This is supported by the results of a digital microscope performed on the external structure, which clearly show that the wood fraction volume is too low (see Figure 10) The arrangement of the filament in the sample WPCs is not impacted either by the extrusion temperature. The fact that the FFF process involves extruding material from filament to create samples is another noteworthy finding. This indicates that the extrusion process is performed twice during the stage of producing filament and creating a sample. The various temperature extrusion stages of producing filament did not have an influence on sample structure as seen in Figure 11. The arrangement of the filament of WPCs samples in this research exhibit the low stability of the printing. The compare ABS Commercial with WPCs samples, ABS Commercial has high stability of printing the material each layer more than WPCs samples (see in Figure 11(a) and Figure 11(d)). Resulting, the mechanical properties of ABS Commercial higher than WPCs samples. Additionally, the sample structure's destructive behavior demonstrated the importance of printing and material quality. This behavior begins at the load affected layer connections in the sample and progresses to the load affected material. It is evident from Figure 11(c) and Figure 11(d).

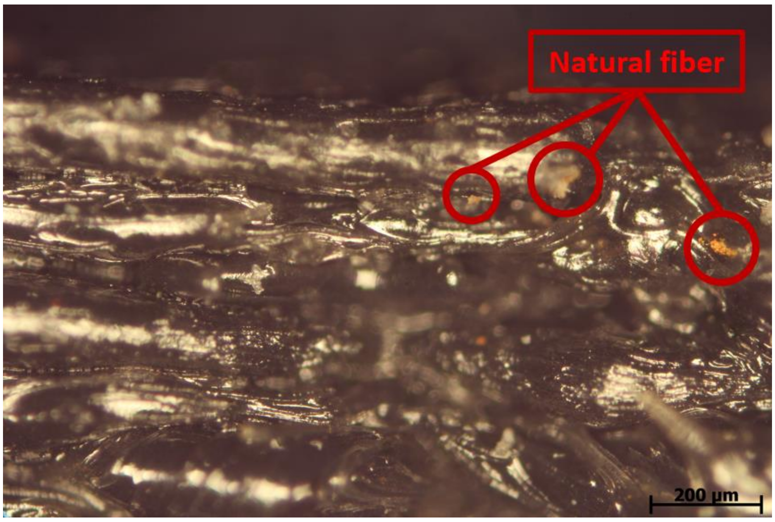
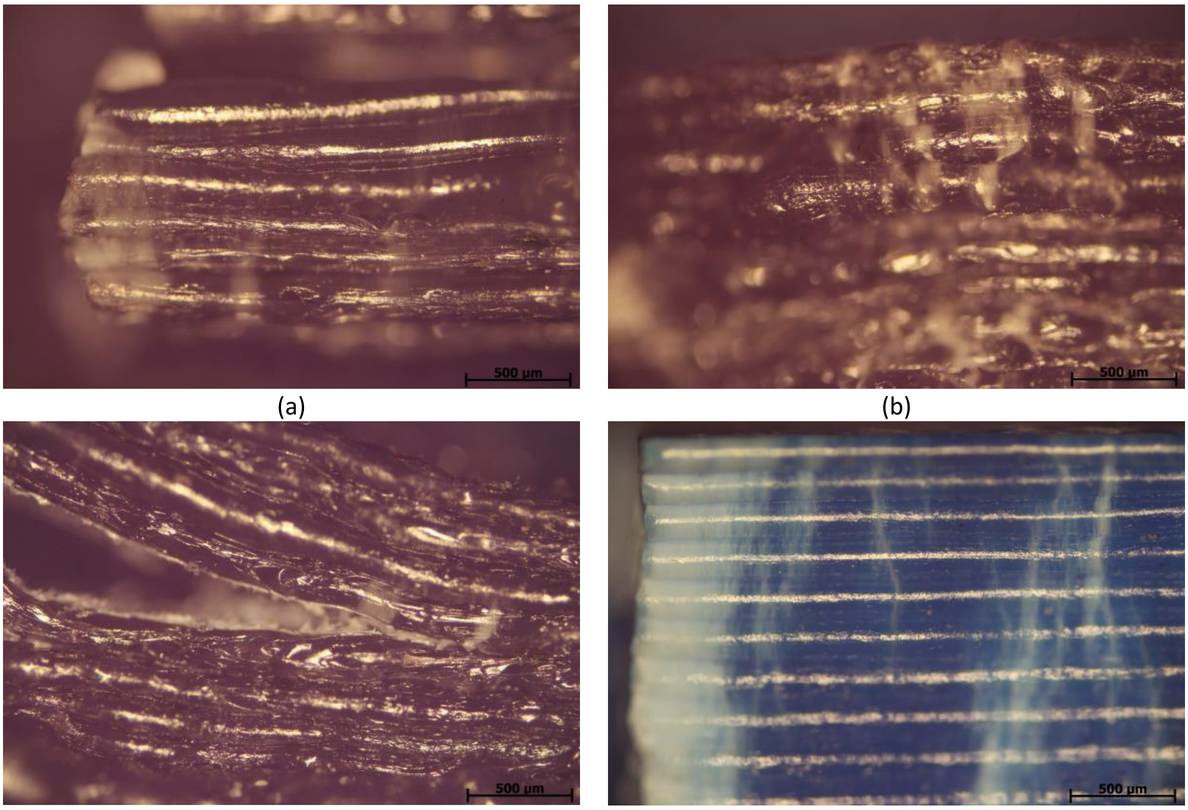


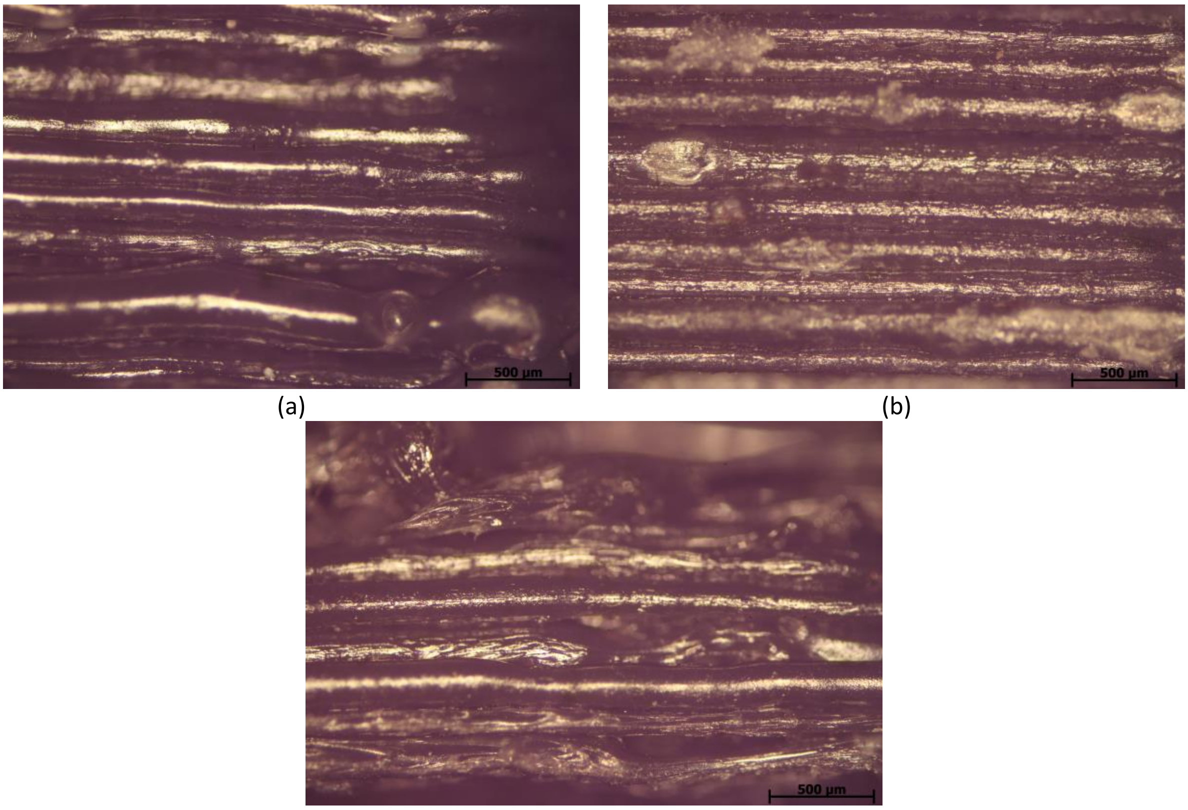
Fig. 10. The arrangement of the filament in the RWF3T218 at magnification 20x



(a) (b)

(c) (d)

Fig. 11. The arrangement of the filament in the samples at magnification 5x (a) RWF1T218 (b) RWF2T218 (c) RWF3T218 (d) Pure ABS commercial



(a) (b)

(c)

Fig. 11. The arrangement of the filament in the samples at magnification 5x (a) RWF1T198 (b) RWF1T208 (c) RWF1T218

4. Conclusions

In this study, the impact of the wood fraction volume and extrusion temperature on the mechanical, thermal, and microstructural characteristics of rubber wood sawdust reinforced ABS is investigated. The slight increase in compressive and tensile strength was significantly influenced by the increasing amount of the wood fraction (0–3 wt%). Moreover, the addition of wood fiber in ABS filament enhances thermal stability. Another notable finding is that mechanical testing produced statistically validated results, even though morphological analysis indicated that the sample structure is not significantly affected by varying temperature extrusion stages of producing filament. It appears that the sample's compressive and tensile strength has significantly increased due to the high extrusion temperature (218°C). Nevertheless, the primary factor affecting FFF products is still print quality by 3D printing. The product is also significantly impacted by factors related to the filament material.

Acknowledgement

The authors would like to express their thanks to the Rubberwood Technology and Management Research Group (ENG-54-27-11-0137-S) of the Faculty of Engineering, Prince of Songkla University, Thailand for the support in carrying out this work.

References

[1] Liu, Jun, Lushan Sun, Wenyang Xu, Qianqian Wang, Sujie Yu, and Jianzhong Sun. "Current advances and future perspectives of 3D printing natural-derived biopolymers." *Carbohydrate Polymers* 207 (2019): 297-316. https://doi.org/10.1016/j.carbpol.2018.11.077

[2] de Castro Sales, Diego, Antônio Eduardo Cabral, and Marcelo S. Medeiros Jr. "Development of fiberboard panels

manufactured from reclaimed cement bags." *Journal of Building Engineering* 34 (2021): 101525. https://doi.org/10.1016/j.jobe.2020.101525

[3] Mandala, Radhika, Anjaneya Prasad Bannoth, Suresh Akella, Vijaya K. Rangari, and Deepa Kodali. "A short review on fused deposition modeling 3D printing of bio-based polymer nanocomposites." *Journal of Applied Polymer Science* 139, no. 14 (2022): 51904. https://doi.org/10.1002/app.51904

[4] Velu, Rajkumar, Felix Raspall, and Sarat Singamneni. "3D printing technologies and composite materials for structural applications." In *Green Composites for Automotive Applications*, pp. 171-196. Woodhead Publishing, 2019. https://doi.org/10.1016/B978-0-08-102177-4.00008-2

[5] Claudic, Yannis, David A. Zopf, Melis Ozkan, Remi di Francia, and H. U. Weiguo. "Current use of 3D printing in plastic surgery." *Annals of 3D Printed Medicine* 11 (2023): 100119. https://doi.org/10.1016/j.stlm.2023.100119

[6] Saenz, F., C. Otarola, K. Valladares, and J. Rojas. "Influence of 3D printing settings on mechanical properties of ABS at room temperature and 77 K." *Additive Manufacturing* 39 (2021): 101841. https://doi.org/10.1016/j.addma.2021.101841

[7] Patel, Kautilya S., Dhaval B. Shah, Shashikant J. Joshi, and Kaushik M. Patel. "Developments in 3D printing of carbon fiber reinforced polymer containing recycled plastic waste: A review." *Cleaner Materials* (2023): 100207. https://doi.org/10.1016/j.clema.2023.100207

[8] Mustafa, Zaleha, Tuan Muhammad Idzzuddin Nawi, Vaseetha Ravichandran, Toibah Abd Rahim, and Thanate Ratanawilai. "Rubberwood-Recycled Polypropylene Composites: Effect of Water Immersion on Tensile Properties." In *International Conference and Exhibition on Sustainable Energy and Advanced Materials*, pp. 167-170. Singapore: Springer Nature Singapore, 2021. https://doi.org/10.1007/978-981-19-3179-6_30

[9] Ratanawilai, Thanate, and Chainarong Srivabut. "Physico-mechanical properties and long-term creep behavior of wood-plastic composites for construction materials: effect of water immersion times." *Case Studies in Construction Materials* 16 (2022): e00791. https://doi.org/10.1016/j.cscm.2021.e00791

[10] Khamtree, Sriwan, Thanate Ratanawilai, and Sukritthira Ratanawilai. "Determining the optimum conditions for silane treated rubberwood flour-recycled polypropylene composites using response surface methodology." *Materials Today Communications* 24 (2020): 100971. https://doi.org/10.1016/j.mtcomm.2020.100971

[11] Ratanawilai, Thanate, Vira Leelasilapasart, Chainarong Srivabut, and Sukritthira Ratanawilai. "Thermo-mechanical Properties and Dead-load Creep Model Analysis of Recycled Polypropylene and Rubberwood Waste Composites for Construction Materials." *Fibers and Polymers* 23, no. 7 (2022): 1956-1964. https://doi.org/10.1007/s12221-022-4709-8

[12] Ratanawilai, Thanate, and Kampanart Taneerat. "Alternative polymeric matrices for wood-plastic composites: Effects on mechanical properties and resistance to natural weathering." *Construction and Building Materials* 172 (2018): 349-357. https://doi.org/10.1016/j.conbuildmat.2018.03.266

[13] Mustafa, Zaleha, Anira Shahidah Razali, Thavinnesh Kumar Rajendran, Siti Hajar Sheikh Md Fadzullah, Sivakumar Dhar Malingam, Toibah Abd Rahim, and Thanate Ratanawilai. "Moisture absorption and thermal properties of unidirectional pineapple leaf fibre/polylactic acid composites under hygrothermal ageing conditions." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 96, no. 2 (2022): 65-73. https://doi.org/10.37934/arfmts.96.2.6573

[14] Gardner, Douglas J., Yousoo Han, and Lu Wang. "Wood-plastic composite technology." *Current Forestry Reports* 1 (2015): 139-150. https://doi.org/10.1007/s40725-015-0016-6

[15] Zhang, Yingying, Miaojie Xu, Xinrui Zhang, Juyang Li, Chang Wu, Shan Cao, Yayun Hu, and Guangzhong Luan. "Impacts of extrusion temperature and α-subunit content on structure of zein extrudate and viscoelasticity of the plasticized network." *Food Research International* 162 (2022): 112129. https://doi.org/10.1016/j.foodres.2022.112129

[16] Homkhiew, Chatree, Surasit Rawangwong, Worapong Boonchouytan, Wiriya Thongruang, and Thanate Ratanawilai. "Composites from thermoplastic natural rubber reinforced rubberwood sawdust: Effects of sawdust size and content on thermal, physical, and mechanical properties." *International Journal of Polymer Science* 2018 (2018). https://doi.org/10.1155/2018/7179527

[17] Zainudin, Amira Syuhada, and Abdul Rahim Othman. "Thermal Stability of PALF-PP and PALF-PLA for Natural Fiber Honeycomb Core Materials." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 87, no. 1 (2021): 20-29. https://doi.org/10.37934/arfmts.87.1.2029

[18] Kumar, Roopesh, Abhijeet Ganguly, and Rajesh Purohit. "Thermogravimetric analysis of natural fiber reinforced hybrid composites-A review." *Materials Today: Proceedings* (2023). https://doi.org/10.1016/j.matpr.2023.08.025

[19] Natali, Maurizio, Luigi Torre, Ivan Puri, and Marco Rallini. "Thermal degradation of phenolics and their carbon fiber derived composites: A feasible protocol to assess the heat capacity as a function of temperature through the use of common DSC and TGA analysis." *Polymer Degradation and Stability* 195 (2022): 109793. https://doi.org/10.1016/j.polymdegradstab.2021.109793

[20] Feng, Jie, Cristina Carpanese, and Alberto Fina. "Thermal decomposition investigation of ABS containing Lewis-acid type metal salts." *Polymer Degradation and Stability* 129 (2016): 319-327. https://doi.org/10.1016/j.polymdegradstab.2016.05.013

[21] Czégény, Zs, E. Jakab, M. Blazsó, T. Bhaskar, and Y. Sakata. "Thermal decomposition of polymer mixtures of PVC, PET and ABS containing brominated flame retardant: Formation of chlorinated and brominated organic compounds." *Journal of Analytical and Applied Pyrolysis* 96 (2012): 69-77. https://doi.org/10.1016/j.jaap.2012.03.006