The Enhancing Influence of Process Parameters on Acrylonitrile Butadiene Styrene Composites Reinforced with Microcrystalline Cellulose

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ABSTRACT

This study investigates the effects of different synthesis parameters of Acrylonitrile Butadiene Styrene/Microcrystalline Cellulose (ABS)/(MCC) composites on their physical, mechanical, and morphological properties. Composites were fabricated using a twin-screw extruder followed by hot pressing, with variations in the MCC volume fraction (0–8 vol%), screw speeds (10–20 rpm), and extrusion temperatures (150–170 °C). Density and flexural strength tests were conducted in accordance with ASTM standards, and the surface morphology was analyzed using Scanning Electron Microscopy (SEM). The results showed that incorporating 2–4 vol% of MCC improved both density and flexural strength by reducing voids and enhancing interfacial bonding. However, higher MCC contents led to particle agglomeration and diminished performance. A lower screw speed of 10 rpm facilitated better filler dispersion and stronger interfacial adhesion, yielding the highest flexural strength. Conversely, excessive screw speeds and elevated extrusion temperatures caused filler degradation, matrix shrinkage, and void formation, negatively impacting composite integrity. These findings demonstrate that careful optimization of filler content and processing parameters is essential to produce high-performance ABS/MCC composites with improved structural and mechanical characteristics.

Keywords-Acrylonitrile Butadiene Styrene (ABS); Microcrystalline Cellulose (MCC) filler; screw rotation speed; extrusion temperature; mechanical properties

I. INTRODUCTION

ABS is a widely used engineering thermoplastic material in various applications, including the automotive industry, structural components, consumer goods, and household electronics [1, 2]. ABS is a copolymer composed of three main monomers: styrene, acrylonitrile, and butadiene, each contributing distinct characteristics to the overall material properties [3]. Styrene provides rigidity and ease of processing, acrylonitrile enhances the chemical resistance and mechanical strength, while butadiene adds superior impact resistance, making ABS highly suitable for applications requiring durability under dynamic loading [4-6]. This synergistic combination results in ABS exhibiting excellent mechanical properties and chemical resistance, making it ideal for engineering applications that demand both performance and durability [7]. In addition, ABS offers advantages, such as low density, ease of fabrication, and high precision mouldability, which further support its widespread use as an engineering polymer [8, 9]. To enhance the base polymer properties, ABS-based composites are often developed through the incorporation of reinforcing fillers [10-12].

MCC is one such filler commonly used to reinforce polymer matrices [13]. MCC consists of partially depolymerized natural cellulose or synthetic fibers, forming rod-like crystalline structures. These crystals are aggregates of cellulose microfibrils bonded via hydrogen interactions in a highly crystalline arrangement, while retaining some amorphous cellulose characteristics [14, 15]. MCC possesses high stiffness and exhibits strong interfacial adhesion with both fibers and polymer matrices, thereby improving the overall strength and stiffness of the composite [16, 17]. Significant improvements in the physical and mechanical properties of polymer composites reinforced with MCC have been demonstrated [18-24].

However, the final properties of polymer composites are strongly influenced by both their composition and manufacturing processes [25, 26]. It has been shown that the parameters of the manufacturing process, such as screw speed, barrel temperature, and die-end temperature during extrusion processing, can significantly affect the characteristics of the resulting composites [27-30]. For instance, higher extruder temperatures can enhance the material strength due to improved polymer melt flow and mixing [31, 32]. Likewise, increased screw speed promotes greater shear rates, leading to a more uniform and homogeneous filler dispersion within the matrix [33, 34].

While several studies have investigated ABS/MCC composites and explored various manufacturing aspects affecting their mechanical performance, research specifically focusing on the influence of extrusion processing parameters remains limited. Therefore, the present study aims to identify the optimal extrusion parameters to fabricate ABS/MCC composites with enhanced mechanical properties by investigating the effects of MCC volume fraction, extruder temperature, and screw speed on the mechanical performance of the composites.

II. MATERIALS AND METHODS

A. Materials

The ABS used in this study was LG Chem HI-121H, manufactured in Korea, with a melting point of 220 °C. The MCC powder had a particle size range of 20–160 μm, a melting point of 232 °C, and a density of 1.5 g/cm³.

B. Synthesis

The fabrication of ABS/MCC composites was carried out while varying several parameters, as presented in Table I. A pre-treatment step was performed for both ABS and MCC. ABS granules were crushed using a mechanical crusher to a particle size smaller than 297 μm. MCC was dried in an electric oven at 100 °C for 6 h to reduce its moisture content. This drying process was used to minimize the thermal degradation of MCC during the composite pellet fabrication process [35]. The pre-treated ABS and MCC were then blended using a ball mill. The ABS/MCC composite pellets were, subsequently, produced using a twin-screw extruder, as depicted in Figure 1, and cut into lengths of 1–2 cm. Finally, the pellets were molded into ABS/MCC composites using a hot press machine at a pressure of 50 bar and a temperature of 160 °C for 30 min.

TABLE I. SPECIMEN VARIATIONS OF COMPOSITE ABS/MCC

Sample code	ABS (vol%)	MCC (vol%)	Screw rotation (rpm)	Extruder temperature (°C)
CM0	100	0	15	160
CM2	98	2	15	160
CM4	96	4	15	160
CM6	94	6	15	160
CM8	92	8	15	160
CM4R10	96	4	10	160
CM4R20	96	4	20	160
CM4T15	96	4	15	150
CM4T17	96	4	15	170

Fig. 1. Twin-screw extruder.

C. Characterization

Characterization of the ABS/MCC composites was performed, including density measurements, flexural testing, and surface morphology observation. The density was measured in accordance with ASTM D3800 [36]. The flexural testing was performed based on ASTM D790 [37], using a universal testing machine equipped with a 50 kg load cell and a crosshead speed of 10 mm/min. The fracture surface morphology of the samples was examined deploying SEM.

III. RESULTS AND DISCUSSION

Figure 2 presents the density values of the various ABS/MCC composites. The samples CM2 and CM4 exhibited increased densities compared to CM0 (1.032 g/cm^3), with values of 1.065 g/cm^3 and 1.069 g/cm^3, respectively. This increase is attributed to the role of MCC as an effective filler that reduces the void content within the composite structure. MCC occupies microscopic gaps in the ABS matrix, thereby increasing the overall density [38]. However, increasing the screw rotation speed from 15 to 20 rpm (sample CM4R20) resulted in a reduced density of 1.027 g/cm^3. This phenomenon suggests that excessively high screw speeds shorten the residence time of the material inside the barrel, leading to incomplete mixing and non-uniform dispersion of MCC [39]. Consequently, MCC agglomeration and the formation of air voids occur, which decrease the composite's density. Additionally, the higher shear rate induced by increased screw speed can accelerate the degradation of the filler structure [40]. In contrast to the effect of screw speed, increasing the extrusion temperature from 160 °C to 170 °C (sample CM4T17) resulted in a slight decrease in density (1.061 g/cm^3). This outcome indicates that higher temperatures may lead to shrinkage due to a significant drop in the viscosity of ABS, which prevents the material from filling the mold completely [41].

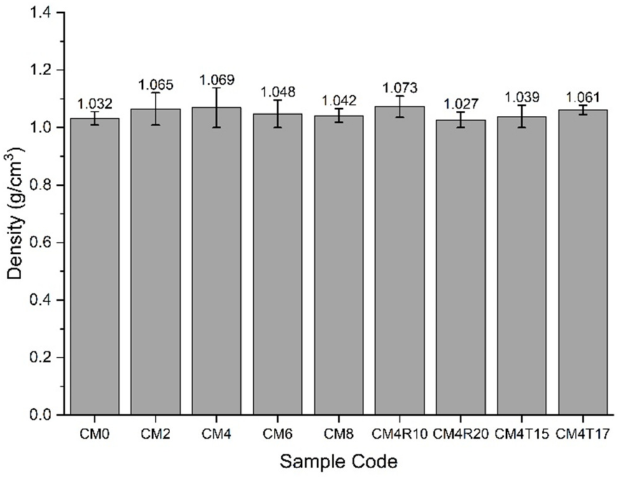


Fig. 2. Density of ABS/MCC composites.

The flexural strength of the ABS/MCC composites is presented in Figure 3. The results show that the addition of MCC at 2 vol% (sample CM2) and 4 vol% (sample CM4) led to an increase in flexural strength, reaching 54.91 MPa and 55.92 MPa, respectively, compared to the control sample CM0 (51.04 MPa). This improvement indicates that the incorporation of MCC in optimal amounts (2–4 vol%) enhances the flexural strength by reducing the voids and promoting a stronger interfacial bonding within the composite [42]. However, increasing the MCC content beyond 4 vol% resulted in a decline in flexural strength, as observed in samples CM6 and CM8. A decrease in flexural strength was also noted with increased screw rotation speed. The sample CM4R20, processed at a screw speed of 20 rpm, exhibited lower flexural strength of 50.02 MPa. This reduction is attributed to insufficient residence time at higher screw speeds, leading to poor filler dispersion and inadequate bonding between MCC and the ABS matrix [43]. These weak interfacial regions act as stress concentrators and are prone to failure under bending loads [44, 45]. The effect of screw rotation speed was further confirmed by the CM4R10 sample, processed at 10 rpm, which exhibited the highest flexural strength of 57.08 MPa. The extrusion temperature also influenced the flexural strength of the ABS/MCC composites. The highest strength (55.92 MPa) was achieved at 160 °C (sample CM4), which provides sufficient thermal energy to combine ABS with MCC without causing thermal degradation. In contrast, at 170 °C (sample CM4T17), the flexural strength decreased to 53.24 MPa, indicating that the excessively low viscosity of ABS at higher temperatures may lead to shrinkage and the formation of internal voids within the extrudate [46]. The surface morphology of the ABS/MCC composites is shown in Figure 3.

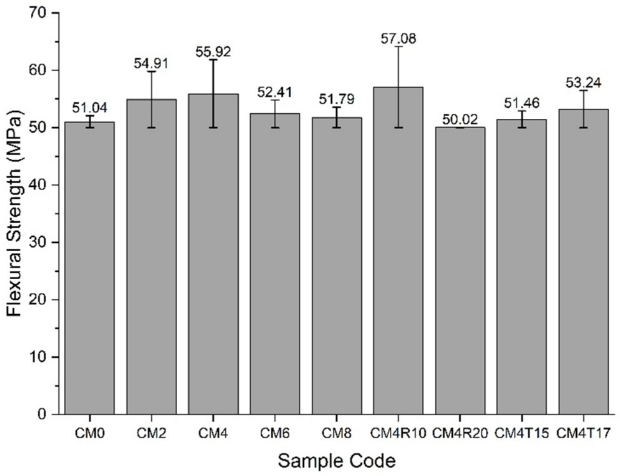
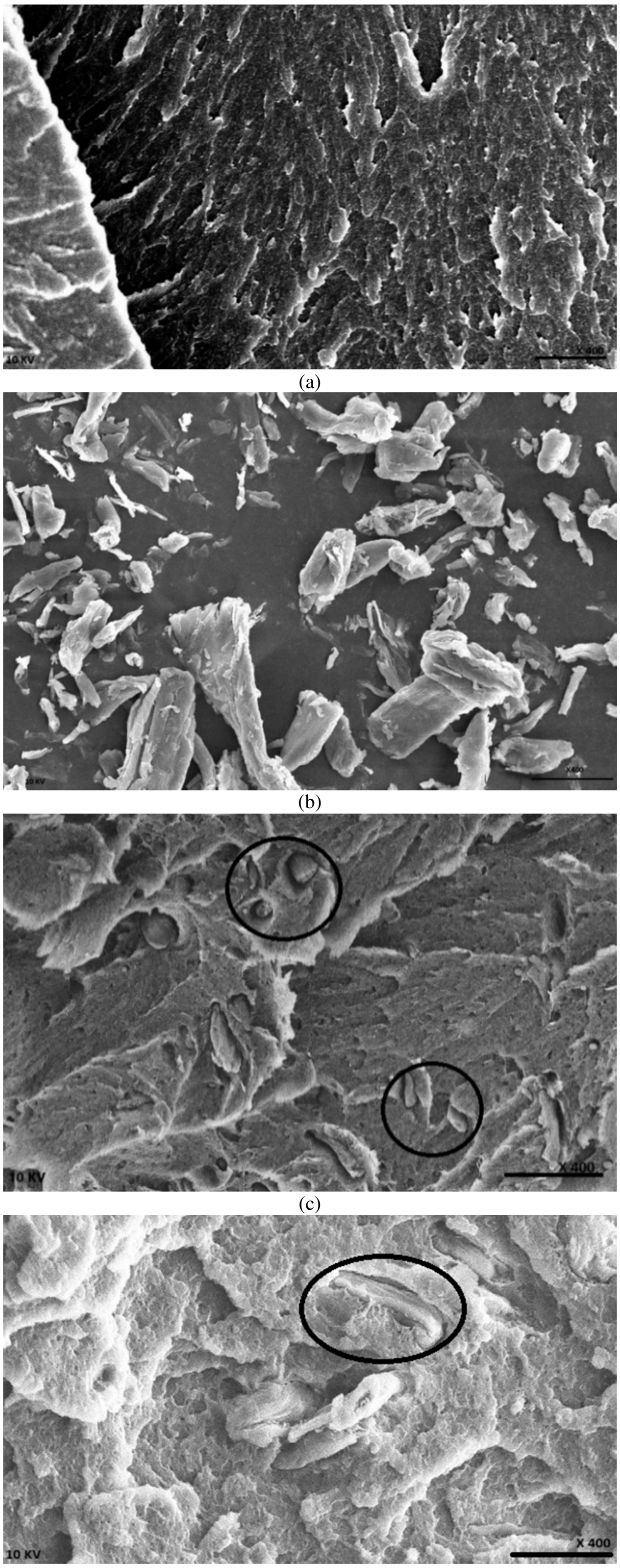


Fig. 3. Flexural strength of ABS/MCC composites.

For the CM0 sample, illustrated in Figure 3(a), the fracture surface appears relatively smooth and homogeneous. This observation is consistent with the composition of CM0, which contains no MCC filler, and therefore exhibits a morphology dominated by the pure ABS polymer matrix. The absence of filler particles results in a clean, non-porous surface structure. Such a morphology indicates that no filler distribution has occurred within the matrix, which corresponds to the lack of mechanical enhancement via void filling or particle reinforcement [47]. The distribution of MCC on sample CM8 is portrayed in Figure 3(b). In contrast to sample CM8, the fracture surface of sample CM4, evidenced in Figure 3(c), displays several regions, highlighted by circles that indicate the distribution of MCC particles within the ABS matrix. These observations suggest that the addition of 4 vol% MCC contributes to partial void filling within the matrix. This incomplete dispersion may result from an insufficient mixing time to achieve a homogeneous MCC distribution in the molten ABS. Additionally, the relatively high viscosity of ABS at the 15 rpm screw speed may not have provided adequate matrix wetting of the MCC particles.



(a)

(b)

(c)

(d)

Fig. 4. Surface morphology of: (a) CM0, (b) CM8, (c) CM4, and (d) CM4R10.

The presence of voids and micro-gaps further indicates imperfect interfacial bonding, which could serve as initiation sites for microcracks when external loads are applied. This supports previous findings according to which, suboptimal mixing impedes interfacial interactions and reduces mechanical strength [48]. Sample CM4R10, which is shown in Figure 3(d), exhibits a denser and smoother fracture surface, with MCC particles well embedded in the ABS matrix, as indicated by the circled areas. In this case, the reduced screw speed of 10 rpm allows for longer residence time, facilitating a more thorough mixing. This results in a more uniform MCC distribution and stronger interfacial bonding between MCC and the ABS matrix. The observed phenomena of fiber pullout and fiber breakage suggest that some MCC particles bonded strongly enough with the matrix to fracture under mechanical loading. The fiber breakage indicates a robust interfacial adhesion, while the fiber pullout reflects areas where MCC was not fully integrated with the matrix [48]. These findings highlight that processing parameters, particularly screw speed, play a critical role in optimizing interfacial bonding and improving the flexural strength of ABS/MCC composites.

IV. CONCLUSION

This study investigated the effects of MCC volume fraction, screw rotation speed, and extrusion temperature on the mechanical and morphological properties of Acrylonitrile Butadiene Styrene/Microcrystalline Cellulose (ABS)/(MCC) composites. Adding 2–4 vol% MCC enhanced the density and flexural strength by improving filler dispersion and interfacial bonding. In contrast, contents above 4 vol% caused agglomeration of the MCC and voids, reducing performance. A screw speed of 10 rpm improved mixing and residence time, yielding better mechanical strength and uniform morphology, while the 20 rpm speed decreased dispersion quality and damaged the filler. The optimal extrusion temperature was 160 °C. A higher temperature (170 °C) reduced strength due to lower viscosity and shrinkage. Unlike prior studies focusing only on MCC content, this work evaluates the combined effects of filler content and processing parameters. The integrated approach clarifies processing–structure–property relationships in ABS/MCC systems. These findings highlight the value of process optimization for high-performance, bio-based thermoplastic composites.

REFERENCES

[1] A. Zulfi, D. A. Hapidin, M. M. Munir, F. Iskandar, and K. Khairurrijal, "The synthesis of nanofiber membranes from acrylonitrile butadiene styrene (ABS) waste using electrospinning for use as air filtration media," *RSC Advances*, vol. 9, no. 53, pp. 30741–30751, 2019, https://doi.org/10.1039/C9RA04877D.

[2] D. G. Zisopol, I. Nae, A. I. Portoaca, and I. Ramadan, "A Statistical Approach of the Flexural Strength of PLA and ABS 3D Printed Parts," *Engineering, Technology & Applied Science Research*," vol. 12, no. 2, pp. 8248–8252, Apr. 2022, https://doi.org/10.48084/etasr.4739.

[3] S. Kapoor, M. Goyal, and P. Jindal, "Effect of functionalized multi-walled carbon nanotubes on thermal and mechanical properties of acrylonitrile butadiene styrene nanocomposite," *Journal of Polymer Research*, vol. 27, no. 2, Feb. 2020, Art. no. 40, https://doi.org/10.1007/s10965-020-2014-z.

[4] M. Harris, J. Potgieter, S. Ray, R. Archer, and K. M. Arif, "Acrylonitrile Butadiene Styrene and Polypropylene Blend with Enhanced Thermal and Mechanical Properties for Fused Filament Fabrication," *Materials*,

vol. 12, no. 24, Dec. 2019, Art. no. 4167, https://doi.org/10.3390/ma12244167.

[5] B. E. Tiganis, L. S. Burn, P. Davis, and A. J. Hill, "Thermal degradation of acrylonitrile–butadiene–styrene (ABS) blends," *Polymer Degradation and Stability*, vol. 76, no. 3, pp. 425–434, Jun. 2002, https://doi.org/10.1016/S0141-3910(02)00045-9.

[6] N. Rasana, K. Jayanarayanan, H. T. Mohan, and T. Keller, "Static and dynamic mechanical properties of nanosilica and multiwalled carbon nanotube reinforced acrylonitrile butadiene styrene composites: theoretical mechanism of nanofiller reinforcement," *Iranian Polymer Journal*, vol. 30, no. 11, pp. 1211–1225, Nov. 2021, https://doi.org/10.1007/s13726-021-00962-5.

[7] S. G. Nukala, I. Kong, A. B. Kakarla, W. Kong, and W. Kong, "Development of Wood Polymer Composites from Recycled Wood and Plastic Waste: Thermal and Mechanical Properties," *Journal of Composites Science*, vol. 6, no. 7, Jul. 2022, Art. no. 194, https://doi.org/10.3390/jcs6070194.

[8] N. C. Das and S. Maiti, "Electromagnetic interference shielding of carbon nanotube/ethylene vinyl acetate composites," *Journal of Materials Science*, vol. 43, no. 6, pp. 1920–1925, Mar. 2008, https://doi.org/10.1007/s10853-008-2458-8.

[9] V. K. Sachdev, S. K. Sharma, M. Tomar, V. Gupta, and R. P. Tandon, "EMI shielding of MWCNT/ABS nanocomposites in contrast to graphite/ABS composites and MWCNT/PS nanocomposites," *RSC Advances*, vol. 6, no. 51, pp. 45049–45058, 2016, https://doi.org/10.1039/C6RA04200G.

[10] A. T. Phung, H. T. Dzung, N. P. D. Linh, V. M. Duc, and N. T. Liem, "Acrylonitrile butadiene styrene/wood sawdust particles composites: mechanical and morphological properties," *Iranian Polymer Journal*, vol. 33, no. 1, pp. 67–78, Jan. 2024, https://doi.org/10.1007/s13726-023-01236-y.

[11] P. Peter, N. Rasana, K. Jayanarayanan, and M. Remanan, "Acrylonitrile Butadiene Styrene Hybrid Composite with Aluminium Nitride and MWCNT Nanofillers: Evaluation of Thermomechanical and Wear Behaviour," *Journal of Inorganic and Organometallic Polymers and Materials*, vol. 35, no. 3, pp. 1941–1954, Mar. 2025, https://doi.org/10.1007/s10904-024-03396-7.

[12] N. Sriputtha, F. Wiwatwongwana, and N. Promma, "Investigation of Polycaprolactone/Carboxymethyl Cellulose Scaffolds by Mechanical and Thermal Analysis," *Engineering, Technology & Applied Science Research*, vol. 12, no. 1, pp. 8175–8179, Feb. 2022, https://doi.org/10.48084/etasr.4711.

[13] E. C. Ramires, J. D. Megiatto, A. Dufresne, and E. Frollini, "Cellulose Nanocrystals versus Microcrystalline Cellulose as Reinforcement of Lignopolyurethane Matrix," *Fibers*, vol. 8, no. 4, Mar. 2020, Art. no. 21, https://doi.org/10.3390/fib8040021.

[14] S. P. Bangar, O. J. Esua, C. Nickhil, and W. S. Whiteside, "Microcrystalline cellulose for active food packaging applications: A review," *Food Packaging and Shelf Life*, vol. 36, Apr. 2023, Art. no. 101048, https://doi.org/10.1016/j.fpsl.2023.101048.

[15] W. Pan *et al.*, "Construction of microcrystalline cellulose-based composite cathode materials with three-dimensional tertiary spatial conduction structures and their enhanced electrochemical properties," *Journal of Electroanalytical Chemistry*, vol. 980, Mar. 2025, Art. no. 118942, https://doi.org/10.1016/j.jelechem.2025.118942.

[16] C. H. Wibowo, D. Ariawan, E. Surojo, and S. Sunardi, "Microcrystalline Cellulose as Composite Reinforcement: Assessment and Future Prospects," *Materials Science Forum*, vol. 1122, pp. 65–80, May 2024, https://doi.org/10.4028/p-viYb6d.

[17] E. Gorgun, A. Ali, and Md. S. Islam, "Biocomposites of Poly(Lactic Acid) and Microcrystalline Cellulose: Influence of the Coupling Agent on Thermomechanical and Absorption Characteristics," *ACS Omega*, vol. 9, no. 10, pp. 11523–11533, Mar. 2024, https://doi.org/10.1021/acsomega.3c08448.

[18] T. Sango, A. Koubaa, M. Ragoubi, M. C. N. Yemele, and N. Leblanc, "Insights into the functionalities of cellulose acetate and microcrystalline cellulose on water absorption, crystallization, and thermal degradation kinetics of a ternary polybutylene succinate-based hybrid composite," *Industrial Crops and Products*, vol. 222, Dec. 2024, Art. no. 119572, https://doi.org/10.1016/j.indcrop.2024.119572.

[19] W. S. Yong, Y. L. Yeu, P. P. Chung, and K. H. Soon, "Extraction and Characterization of Microcrystalline Cellulose (MCC) from Durian Rind for Biocomposite Application," *Journal of Polymers and the Environment*, vol. 32, no. 12, pp. 6544–6575, Dec. 2024, https://doi.org/10.1007/s10924-024-03401-7.

[20] F. Zhang *et al.*, "Effect of micro-cellulose fiber on the mechanical, shrinkage properties and ballistic impact resistance of high-performance cement composites," *Construction and Building Materials*, vol. 463, Feb. 2025, Art. no. 139963, https://doi.org/10.1016/j.conbuildmat.2025.139963.

[21] P. Balan *et al.*, "Microcrystalline cellulose extraction from comprehensive characterization of Mangifera indica leaf biowaste for high-performance bio-based polymer composites," *Journal of Polymer Research*, vol. 32, no. 1, Jan. 2025, Art. no. 23, https://doi.org/10.1007/s10965-024-04251-6.

[22] H. Fouad *et al.*, "Preparation and characterization of carboxymethyl microcrystalline cellulose from pineapple leaf fibre," *Scientific Reports*, vol. 14, no. 1, Oct. 2024, Art. no. 23286, https://doi.org/10.1038/s41598-024-73860-4.

[23] I. García-Castellanos, D. Nath, R. Krishnan, M. Misra, and A. K. Mohanty, "Green Composites from Plasticized Cellulose Acetate and Microcrystalline Cellulose: Effect of Maleated Cellulose Acetate on the Biocomposite Performance," *ACS Sustainable Resource Management*, vol. 2, no. 4, pp. 594–604, Apr. 2025, https://doi.org/10.1021/acssusresmgt.4c00484.

[24] P. Wetchakama, S. Boopasiri, P. Sae-Oui, P. Poosimma, and C. Siriwong, "Preparation and Application of a Zinc Oxide/Microcrystalline Cellulose Composite as a Cure Activator in Comparison with a Commercial Zinc Oxide Composite," *ACS Omega*, vol. 10, no. 6, pp. 5953–5962, Feb. 2025, https://doi.org/10.1021/acsomega.4c09909.

[25] A. Kiziltas, D. J. Gardner, Y. Han, and H.-S. Yang, "Mechanical Properties of Microcrystalline Cellulose (MCC) Filled Engineering Thermoplastic Composites," *Journal of Polymers and the Environment*, vol. 22, no. 3, pp. 365–372, Sep. 2014, https://doi.org/10.1007/s10924-014-0676-5.

[26] K. Crews, C. Huntley, D. Cooley, B. Phillips, and M. Curry, "Influence of Cellulose on the Mechanical and Thermal Stability of ABS Plastic Composites," *International Journal of Polymer Science*, vol. 2016, pp. 1–10, 2016, https://doi.org/10.1155/2016/9043086.

[27] J. Chen, X. Wang, Z. Long, S. Wang, J. Zhang, and L. Wang, "Preparation and performance of thermoplastic starch and microcrystalline cellulose for packaging composites: Extrusion and hot pressing," *International Journal of Biological Macromolecules*, vol. 165, pp. 2295–2302, Dec. 2020, https://doi.org/10.1016/j.ijbiomac.2020.10.117.

[28] A. Selvam, S. Mayilswamy, R. Whenish, R. Velu, and B. Subramanian, "Preparation and Evaluation of the Tensile Characteristics of Carbon Fiber Rod Reinforced 3D Printed Thermoplastic Composites," *Journal of Composites Science*, vol. 5, no. 1, Dec. 2020, Art. no. 8, https://doi.org/10.3390/jcs5010008.

[29] Z. Weng, J. Wang, T. Senthil, and L. Wu, "Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing," *Materials & Design*, vol. 102, pp. 276–283, Jul. 2016, https://doi.org/10.1016/j.matdes.2016.04.045.

[30] T. S. S and M. M, "An experimental analysis of mechanical properties for a dissimilar pattern structure in the 3-D printing of a PLA5F filament using the Taguchi method," *Materials Research Express*, vol. 11, no. 10, Oct. 2024, Art. no. 105304, https://doi.org/10.1088/2053-1591/ad82af.

[31] R. Subramani, A. K. Kalidass, M. D. Muneeswaran, and B. Gantala Lakshmipathi, "Effect of fused deposition modeling process parameter in influence of mechanical property of acrylonitrile butadiene styrene polymer," *Applied Chemical Engineering*, vol. 7, no. 1, Jan. 2024, https://doi.org/10.24294/ace.v7i1.3576.

[32] C. S. Davis, K. E. Hillgartner, S. H. Han, and J. E. Seppala, "Mechanical strength of welding zones produced by polymer extrusion additive manufacturing," *Additive Manufacturing*, vol. 16, pp. 162–166, Aug. 2017, https://doi.org/10.1016/j.addma.2017.06.006.

[33] R. Maertens, L. Schöttl, W. V. Liebig, P. Elsner, and K. A. Weidenmann, "Study of material homogeneity in the long fiber thermoset injection molding process by image texture analysis," *Advanced Manufacturing: Polymer & Composites Science*, vol. 8, no. 1, pp. 22–32, Jan. 2022, https://doi.org/10.1080/20550340.2022.2033905.

[34] A. A. Yussuf, I. Massoumi, and A. Hassan, "Comparison of Polylactic Acid/Kenaf and Polylactic Acid/Rise Husk Composites: The Influence of the Natural Fibers on the Mechanical, Thermal and Biodegradability Properties," *Journal of Polymers and the Environment*, vol. 18, no. 3, pp. 422–429, Sep. 2010, https://doi.org/10.1007/s10924-010-0185-0.

[35] D. Trache *et al.*, "Microcrystalline cellulose: Isolation, characterization and bio-composites application—A review," *International Journal of Biological Macromolecules*, vol. 93, pp. 789–804, Dec. 2016, https://doi.org/10.1016/j.ijbiomac.2016.09.056.

[36] *Test Method for Density of High-Modulus Fibers*, ASTM D3800-22, ASTM International, May 2022, https://doi.org/10.1520/D3800-22.

[37] *Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, ASTM D790-17, ASTM International, Jul. 2017, https://doi.org/10.1520/D0790-17.

[38] A. Ashori and A. Nourbakhsh, "Performance properties of microcrystalline cellulose as a reinforcing agent in wood plastic composites," *Composites Part B: Engineering*, vol. 41, no. 7, pp. 578–581, Oct. 2010, https://doi.org/10.1016/j.compositesb.2010.05.004.

[39] I. Adhana, D. F. Smaradhana, D. Ariawan, W. W. Raharjo, and B. Yusuf, "Effect of Screw Rotation Speed on Mechanical Properties and Morphology of Abs/Mcc Composites," *Mekanika: Majalah Ilmiah Mekanika*, vol. 22, no. 1, Mar. 2023, Art. no. 23, https://doi.org/10.20961/mekanika.v22i1.70884.

[40] G. Graninger, S. Kumar, G. Garrett, and B. G. Falzon, "Effect of shear forces on dispersion-related properties of microcrystalline cellulose-reinforced EVOH composites for advanced applications," *Composites Part A: Applied Science and Manufacturing*, vol. 139, Dec. 2020, Art. no. 106103, https://doi.org/10.1016/j.compositesa.2020.106103.

[41] O. Ulkir, I. Ertugrul, S. Ersoy, and B. Yağımlı, "The Effects of Printing Temperature on the Mechanical Properties of 3D-Printed Acrylonitrile Butadiene Styrene," *Applied Sciences*, vol. 14, no. 8, Apr. 2024, Art. no. 3376, https://doi.org/10.3390/app14083376.

[42] A. Kiziltas, D. J. Gardner, Y. Han, and H.-S. Yang, "Determining the mechanical properties of microcrystalline cellulose (MCC)-filled PET-PTT blend composites," *Wood and Fiber Science*, vol. 42, no. 2, pp. 165–176, Apr. 2010.

[43] H.-S. Yang, H.-J. Kim, J. Son, H.-J. Park, B.-J. Lee, and T.-S. Hwang, "Rice-husk flour filled polypropylene composites; mechanical and morphological study," *Composite Structures*, vol. 63, no. 3–4, pp. 305–312, Feb. 2004, https://doi.org/10.1016/S0263-8223(03)00179-X.

[44] R. S. Chen, S. Ahmad, M. H. Ab Ghani, M. N. Salleh, and Gan, "Influence of Screw Speed on the Mechanical Properties of Twin-Screw Extruded Rice Husk Flour Recycled Thermoplastic Composites," in *International Conference on Agricultural, Ecological and Medical Sciences (AEMS-2015) Feb. 10-11, 2015 Penang (Malaysia)*, Feb. 2015, https://doi.org/10.15242/IICBE.C0215137.

[45] N. S. ÇetiN, N. Özmen ÇetiN, and D. P. Harper, "Vinyl acetate-modified microcrystalline cellulose-reinforced HDPE compositesprepared by twin-screw extrusion," *Turkish Journal of Agriculture and Forestry*, vol. 39, pp. 39–47, 2015, https://doi.org/10.3906/tar-1402-115.

[46] S. Hassanifard and K. Behdinan, "Impact of Rheology-Based Optimum Parameters on Enhancing the Mechanical Properties and Fatigue of Additively Manufactured Acrylonitrile–Butadiene–Styrene/Graphene Nanoplatelet Composites," *Polymers*, vol. 16, no. 9, May 2024, Art. no. 1273, https://doi.org/10.3390/polym16091273.

[47] L. P. Fonseca, W. R. Waldman, and M. A. De Paoli, "ABS composites with cellulose fibers: Towards fiber-matrix adhesion without surface modification," *Composites Part C: Open Access*, vol. 5, Jul. 2021, Art. no. 100142, https://doi.org/10.1016/j.jcomc.2021.100142.

[48] W. N. R. W. Jaafar, S. N. Surip, and N. N. Azmi, "Effect of Screw Rotation Speed on Mechanical Properties of Extruded PLA/Kenaf Nanocomposites," *Advanced Materials Research*, vol. 748, pp. 61–64, Aug. 2013, https://doi.org/10.4028/www.scientific.net/AMR.748.61.