Mekanika: Majalah Ilmiah Mekanika

Effect of Screw Rotation Speed on Mechanical Properties and Morphology of ABS/MCC Composites

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Abstract
Acrylonitrile Butadiene Styrene (ABS) polymer is an example of a thermoplastic polymer that requires heat in its production process. ABS polymer can also be modified to increase strength against resistance, toughness, and heat resistance by adding MCC as a reinforcement to ABS composites. Extrusion is one of the established methods of polymer processing with filler and consequently disperses filler inside the polymer. Different speed shows different behaviour of filler dispersion. Therefore, this study was conducted to know the effect of extruder screw speed variations on the mechanical, physical, and thermal stability of ABS/MCC composites. The compositions used in producing ABS/MCC composites were 96% for ABS and 4% for MCC. The production process used screw extruder speed variations of 10 rpm, 15 rpm, and 20 rpm. ABS/MCC composite in the barrel and hot press used 160 °C for the temperature process. The highest tensile strength was obtained at 10 rpm variation for 14.2 MPa. Increasing the speed of the extruder screw caused a decrease in MCC content attached to ABS which reduced the mechanical strength. ABS/MCC composite density value decreased with the increased extruder speed, as evidenced by the increasing number of voids formed based on SEM testing.

1 Introduction

Acrylonitrile Butadiene Styrene (ABS) is a polymer thermoplastic formed from 3 monomers (copolymers). The monomers composed of ABS polymer are acrylonitrile with a percentage of 15%-35%, butadiene at 5%-30%, and styrene at 40%-60% [1]. Monomers found in ABS polymer have their respective uses for ABS polymer's mechanical and physical properties. Acrylonitrile is a synthetic monomer with high mechanical strength, thermal stability, and chemical resistance. Butadiene has high impact strength and toughness, while styrene is rigid, complex, and malleable. ABS polymers can be modified to increase impact strength, toughness, and heat resistance by making ABS polymer as a matrix in the composites. Adding glass fiber to the ABS polymer can improve the mechanical properties of the composite [2]. Reinforcement particles in composites can also use natural materials—the use of natural materials used

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in polymer composites, namely cellulose fibers. There is a significant effect on the tensile, dynamic mechanical, and thermal properties of the cellulose fiber/ABS composite [3]. Microcrystalline Cellulose (MCC) is an alternative material used as reinforcement in ABS composites. MCC is pure cellulose powder that has been isolated from its alpha-cellulose. MCC raw materials come from natural sources such as fibrous plants. MCC can be used for several purposes, such as pharmaceutical, food, and composite material industries. The role of MCC in composites is as a polymer matrix filler which improves the mechanical and physical properties of matrix polymer [5]. MCC has properties such as adapting to chemical particle surfaces, blending with various polymeric matrices, and having reasonable bond control with polymer matrices. Kiziltas et al. [6] added that adding MCC affects increasing the tensile strength of nylon 6/MCC composite. Therefore, MCC has the potential to be used as a filler in ABS composites.

Developments in fabrication technology have led to new techniques for producing polymeric components with complex geometries and low costs [7-9]. The thermoplastic composite fabrication method generally uses the extrusion method. Various parameters of the extrusion process can affect the composite. The rotating speed of the extruder affects the dispersion of filler particles in the matrix. Increasing screw rotation speed can cause several possibilities, and faster screw thrust results in a higher shear rate in material, so filler dispersion in the matrix is better and affects increased mechanical properties. The second is to reduce material melting time in a barrel which causes the mixture not to melt completely [10].

Meanwhile, according to Sari et al. [11], increasing the rotational speed of the extruder can cause filler dispersion difficulty spreading and filling in polymer matrix-affected filler bonding. The matrix cannot form properly, decreasing its mechanical properties. However, if materials pass too slowly through the extruder machine, the composite burns, and its interfacial bond will be damaged.

Wang et al. [12] studied the effect of different screw speeds on short fiber-rubber composite material's physical and mechanical properties (SFRC). The screw speeds were 10 rpm, 15 rpm, 20 rpm, 25 rpm, and 30 rpm. Physical and mechanical properties are better when the screw speed is 15 rpm. This indicated that short fibers are well-orientated. When the screw speed is 15 rpm, die pressure, and extruding speed is propitious for short fibers to get orientated. If the screw speed is lower, the extruding speed is low, while if the screw speed is higher, the die pressure will be too high, leading to higher extruding speeds. Too-low and high extruding speeds have harmful effects on the orientation of short fibers. Based on the description above, this study aims to investigate the effect of screw rotation speed on the extruder machine of ABS/MCC composites. In addition, the mechanical properties of the composites were analyzed using tensile tests, and the fracture morphology was observed using scanning electron microscopy.

2 Experimental Methods

2.1 Materials

This research used ABS LG ABS HI121H obtained from LG Chemical Korea. This matrix had mechanical properties, as shown in Table 1. Microcrystalline Cellulose used from Merck with code 1.02330.0500 has properties as shown in Table 2.

Table 1. Mechanical Properties of ABS

Description	Value	Unit
Density	1.04	gr/cm^3
Tensile Strength	45	MPa
Melting Point	220	°C

Table 2. Mechanical Properties of MCC.

Description	Value	Unit
Density	1.5	gr/cm^3
Size	5-40	µm

2.2 Methods

To solve the hydrogen bonding problem in MCC, there was a treatment for drying MCC using the oven at 105 ^{0}C for 16 hours to decrease the humidity of MCC. ABS pellets were crushed using a crusher machine into powder and then meshed until size 50 mesh. ABS was mixed with MCC using a Kirin KBB-515 SG blender with a 4% MCC volume fraction. ABS/MCC powder blends were produced in a two-stage process. In the first stage, the ABS/MCC blend was extruded at various screw speeds at 10 rpm, 15 rpm, and 20 rpm with barrel and nozzle temperature at 160 °C. The extrudates were cooled at room temperature and granulated into pellets using a pelletizer. The hot press process produced the specimen panels for testing in the second stage. ABS/MCC pellets were compression molded at 160 °C. The holding time was set for 30 minutes in the hot press process. The fabrication process of ABS/MCC composite is shown in Figure 1.

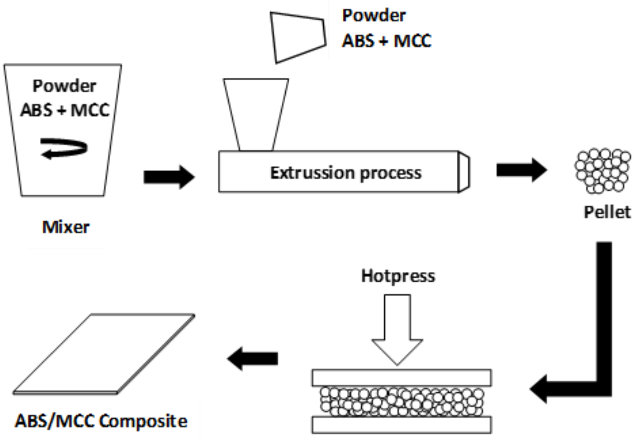


Figure 1. The fabrication process of ABS/MCC composite

The LS-6090 100-watt CO_2 CNC laser cutting machine cut composite panels into tensile test specimens. Cutting parameters were set at 45 watts for cutting power and 7 m/min for cutting speed. Tensile testing was conducted according to ASTM standard D638 (type IV) [13] using a universal testing machine with a 10 mm/min crosshead speed. Observations with a microscope were carried out using fracture of tensile test results.

3 Result and Discussion

3.1 Density Test

The density of ABS/MCC is shown in Figure 2. As shown in Figure 2, the density of ABS/MCC decreased as the rotation speed increased. ABS/MCC density for 10 rpm, 15 rpm, and 20 rpm was collected as 1.05, 0.97, and 0.94 gr/cm^3, respectively. The phenomenon of decreasing composite density value with increasing screw rotation can be seen from polymer rheology. ABS polymer is a non-Newtonian fluid where the viscosity of the melt decreases gradually with the increase of shear rate caused by increasing screw rotation speed. This is called pseudo-plastic flow (shear-thinning) [14]. The decrease of melt viscosity due to increasing shear rate caused matrix and filler to flow freely in the barrel could result in swell in extrudate form. Swelling in extrudate was characterized by the number of cavities in the extrudate. The cavities in the extrudate resulted in a density value of composite decrease. They obtained porosity values at 10 rpm, 15 rpm, and 20 rpm speeds of 1.87%, 2.5%, and 9.2%, respectively.

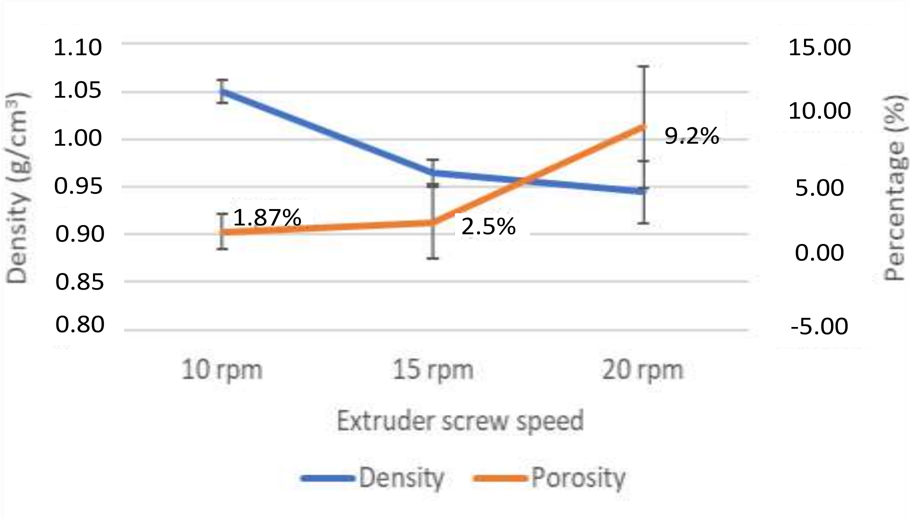


Figure 2. The density of ABS/MCC composite at different screw speed extrusion

3.2 Tensile Strength

Figure 3 shows the stress-strain curve of tensile test ABS/MCC composites. The highest tensile stress value was in the 10 rpm extruder rotational speed variation of 14.2 MPa. This showed that the filler adhered well to the matrix at a screw speed variation of 10 rpm. The increase in extruder screw speed reduces the residence time of the composite melt in a barrel which caused a reduction in MCC attached to the ABS. The lowest tensile stress value was found in the 20 rpm extruder rotational speed variation of 9.2 MPa and the tensile stress at 15 rpm variation of 10.4 MPa.

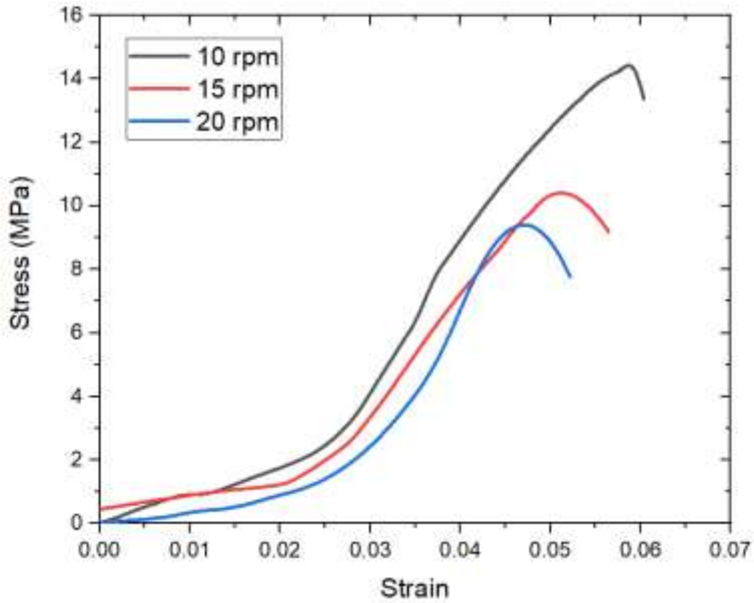


Figure 3. Stress-strain curve of ABS/MCC composite at different screw speed extrusion

Increasing extruder rotational speed can enhance the stiffness of ABS/MCC composite. The composite had the highest stiffness obtained at a screw speed variation of 20 rpm because it had the highest elasticity modulus. The lowest elasticity modulus value in the 10 rpm screw speed variation is shown in

Figure 4. This happened because a higher elasticity modulus was obtained, and less composite can change the shape due to stress [15]. In general, increasing elasticity modulus is caused by poor interfacial bonding between filler and matrix [16].

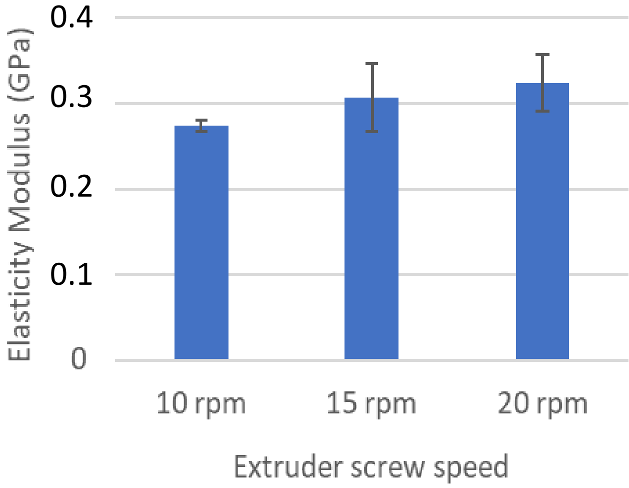


Figure 4. The elasticity modulus of ABS/MCC composite at different screw speed extrusion

Based on Figure 3, increasing extruder rotational speed decreased the ABS/MCC hybrid strain. The increased extruder rotational speed reduced the matrix's ability to keep the load due to tensile loading. This caused the filler to separate from the matrix, reducing the composite ability to have strain due to tensile loading. The decrease in tensile strain indicated that the composite was getting stiffer.

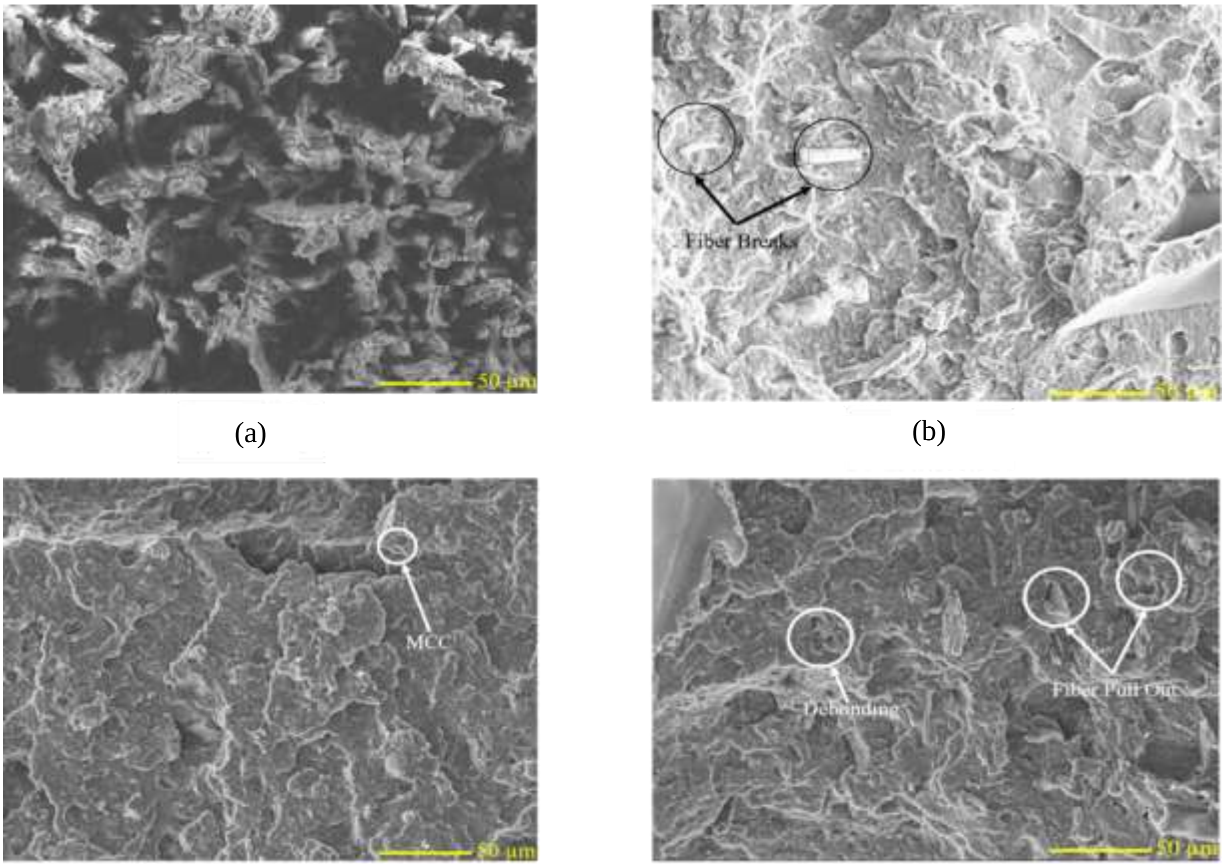
Table 3. Tensile stress and elasticity modulus of ABS/MCC composites at different screw speed extrusion

Variations (rpm)	Tensile Stress (MPa)	Elasticity Modulus (GPa)
10	14.2	0.274
15	10.4	0.307
20	9.3	0.324

3.3 Dispersion of microcrystalline cellulose particle

MCC particles and the fracture morphology of the composite tensile test were observed microscopically using scanning electron microscopy. The result of scanning electron microscopy (SEM) can be seen in Figure 5. Based on SEM, the micron size of MCC ranges from 6 to 11 µm, as shown in Figure 5a. Increasing the extruder rotational speed reduces the MCC dispersion in the ABS matrix. Based on the SEM observations, it can be seen that increasing the rotational speed of the extruder can reduce the number of fiber breaks. The fiber breaks can be seen in Figure 5b. Fiber breaks were formed because matrix and fiber bonding blend properly, so when it receives a load, the fiber cannot separate from the matrix [17].

Meanwhile, increasing the rotational speed of the extruder enhanced the number of fiber pulls out, as shown in Figure 5d. Fiber pulls out formed because it cannot blend with the matrix, so the fiber is loose and forms debonding when it receives a load [17]. Many fiber breaks indicated that the MCC can spread well in the ABS matrix.



(a) (b) (c) (d)

Figure 5. SEM micrographs revealing the size of MCC and MCC dispersion to the composites: (a) MCC, (b) 10 rpm, (c) 15 rpm, and (d) 20 rpm.

4 Conclusions

The ABS/MCC composite tensile test results showed that increasing extruder rotational speed decreased tensile strength and tensile strain but increased elasticity modulus. The highest tensile strength at 10 rpm variation was 14.2 MPa, and the lowest at 20 was 9.3 MPa. Tensile strain decreased with the highest value at 10 rpm variation of 0.049 and the lowest at 20 rpm variation of 0.037. The modulus of elasticity increased with the lowest value at 10 rpm variation of 0.274 GPa and the highest at 20 rpm variation of 0.324 GPa. The density value of the ABS/MCC composite decreased with increased extruder rotational speed. This occurred because increasing screw rotational speed caused swelling of extrudate form, resulting in more cavities forming in the extrudate. The SEM observations showed that increasing extruder rotation reduced the number of fiber breaks formed. Many fiber breaks indicate that the MCC can spread well in the ABS matrix.

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