EFFECT OF SCREW SPEED OF WATER-ASSISTED COMPOUNDING ON THE PROPERTIES OF RECYCLED POLYPROPYLENE-REINFORCED METAKAOLIN COMPOSITE

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ABSTRACT: Recycled polypropylene (rPP) encounters challenges in mechanical properties due to chain scission that occur during processing. By incorporating metakaolin clay in the rPP composites, it can enhance its properties but achieving uniform dispersion and compatibility remains critical. Recycled polypropylene/clay (rPP/clay) composites were prepared by water-assisted extrusion that focusing on two processing factors: screw speed (50 rpm and 100rpm) and water content (0% and 10%). The efects of both compounding parameters on the physical, mechanical and morphology properties of the rPP/clay composite were investigated. The density of rPP/clay composite increase marginally with clay addition but experience average density decrement of 0.35% and 0.20% with higher screw speed and water content respectively. The tensile strength improved with increasing screw speed, and water presence further enhanced it up to 24.33 N/mm^2 which suggest that it improved the dispersion and fller-matrix interaction. Morphological analysis revealed beter dispersion and alignment at higher speed indicating potential for enhanced mechanical properties. This study underscore the potential of water-assisted compounding to optimize rPP/clay composite, contributing to sustainable solutions in polymer recycling and composite development.

KEYWORDS: *Water-assisted extrusion, screw speed, clay, plastic waste, polypropylene*

1.0 INTRODUCTION

Plastic waste composite has been extensively studied for the last decade. Reusing or recycling polymers such as polypropylene (PP) can help reduce the pollution in the environment caused by plastic waste. Polypropylene is widely used and employed in various applications due to its excellent properties such as good stiffness, high melting point, easy processability and mechanical strength [1]. However, recycled PP (rPP) generally exhibits property deterioration depending mainly on the processing condition and chemical structure. This is because the mechanical recycling of rPP can cause the breaking of the mechanical bond within its polymer main chain, called chain scission [2]. Therefore, transforming rPP into rPP composites is a promising effort. Yet, compatibility and homogeneity of every component are crucial. To achieve good properties of rPP, a good dispersion between the filler and polymer and their compatibility is essential.

Metakaolin clay is an amorphous material that is rich in alumina and silica. Previous studies show that incorporating metakaolin improves bioplastic's physicochemical and mechanical properties [3]. Research proves that using clay as a reinforcing agent in polymer-based has an efective result in enhancing the properties of the composite, such as thermal stability, mechanical strength and barrier efficiency [3-5] and it can be use to modify plastic wastes. Also, clay minerals are promising as a sorbent in many applications such as food packaging, construction and others.

Among many variations of methods to prepare rPP/clay composite, melt-blending through extrusion remains the common method because it is cost-effective and environmentally friendly, making it an appealing choice for compounding [6]. The parameters chosen for the compounding process of composites are crucial, as their processing conditions greatly affect the dispersion level of PP/clay composites which is confirmed by structural analyses (SEM and TEM) and vice versa [5]. These factors are vital when improving the composite's physical, mechanical and thermal properties [7].

Water-assisted compounding is a fascinating technique combining two distinct approaches: solution-assisted compounding and conventional melt mixing. Previously reported by Karger-Kocsis et al. [8] that water assists in the plastic composite process. The water molecules act as a carrier medium for nanofillers, improving their dispersion within the polymer matrix. Not only that, it also strikes a balance between efficient dispersion and practical manufacturing considerations. Considering the success of PP/clay nanocomposites reported by Lee et al. [5], incorporating clay using water-assisted potentially enhances the properties of rPP. Preliminary research done by our group indicates that rPP composites, when reinforced with a minimal amount of clay and subjected to water-assisted compounding, demonstrate enhanced physical and mechanical properties [7]. Yet, the study has not investigated water's effect based on the accumulative weight of the formulations at different rotor speeds.

In this study, rPP/clay composites were prepared through water-assisted extrusion. Two different processing factors were studied; screw speeds and the presence of water (with and without). The physical and mechanical properties changes during processing were investigated.

2.0 METHODOLOGY

2.1 Raw Materials and Preparation

Recycled polypropylene (melting point: 130°C; density: 0.92g/cm^3) was supplied from San Miguel Yamamura Plastic Film Sdn. Bhd. Meanwhile, kaolin clay was supplied by Edutech Supply & Service. The recycled polypropylene (rPP) pellets were mixed manually with 1% clay, and water ranged from 0 to 10% of water. After that, the mixture of rPP/clay and water was mixed together in a single screw extruder model Cincinnati Extrusion GCE 30T according to the formulation and screw speed in Table 1 and was cut using the palletizer. Next, the pallet was dried in an oven at 80°C for 24 hours.

The dried mixing pallets were compressed using a hot press (Laboratory Press Model GT7014-A), and the molding temperature and pressure were set at 200°C and 140 kg/cm^{2,} respectively. The total duration for the hot press was 45 minutes, with 15 minutes of preheating and cooling each and 30 minutes of compressing time.

Table 1: The formulation and processing parameter of rPP/clay composite

Sample	rPP (wt%)	Clay (wt%)	Water by accumulative weight (wt%)	Temperature (°C)	Speed (rpm)
rPP/clay/0/50	99	1	0	230	50
rPP/clay/10/50	99	1	10	230	50
rPP/clay/0/100	99	1	0	230	100
rPP/clay/10/100	99	1	10	230	100

2.2 Density Measurement Test

The density of the rPP/clay composite samples was determined using an Electronic Densimeter (MD-MD3002, AlfaMirage, Japan). The measurements adhered to ASTM D792 guidelines and were conducted based on the Archimedes principle. At least three measurements were taken for each sample to calculate the average value.

2.3 Tensile Testing
Tensile tests were conducted using the Shimadzu AGS-X Series Universal Testing Machine per ASTM D638-03 Type 1. The crosshead speed was set at 50 mm/min and performed at room temperature. The average values were counted based on five samples.

2.4 Scanning Electron Microscopy (SEM)
Scanning electron microscopy (SEM) with a Zeiss EVA 50 instrument was used to analyze the fracture morphological structure of the tensile test samples. The SEM examination was carried out at an accelerating voltage of 5 kV using secondary electron mode at 1000x magnifications. Prior to SEM observation, the sample surfaces were cut and gold-coated to enhance electron reflection during imaging.

3.0 RESULTS AND DISCUSSION
3.1 Density
Table 2 tabulates the control sample rPP and rPP/clay composite density. The highest density of 0.9123 g/cm^3 was obtained by rPP/clay/0/50, and the control sample exhibited the lowest. The result shows that adding 1% of kaolin clay will increase the composite density compared to virgin rPP. In contrast, water and higher speed tend to reduce it. It is obvious that increments in screw speed from 50 to 100 rpm and water content from 0 to 10 wt% reduced average density to 0.35% and 0.20%, respectively. Hence, the rotor speed played a bigger role than water in decreasing density. The narrow standard deviation of the rPP/clay composites indicated their homogenous properties. These findings strongly correlate to the composites' morphological characteristics, where higher void density was observed in samples with higher screw speed.

Table 2: The density of rPP/clay composite with standard deviation

Sample	Clay loading (wt%)	Density (g/cm^3)	Relative density	Standard Deviation
rPP	0	0.9043	0	0.0232
rPP/clay/0/50	1	0.9123	0.00885	0.0061
rPP/clay/10/50	1	0.9110	0.00741	0.0026
rPP/clay/0/100	1	0.9097	0.005971	0.0021
rPP/clay/10/100	1	0.9073	0.00332	0.0012

3.2 Tensile Strength of Composite
The tensile strength of rPP/clay composites is shown in Figure 1 for the effect of rotor speed and water content. At the screw speed of 50rpm, the composite exhibit tensile strength of 20.70 N/mm^2 and with the presence of water by 10%, it was slightly increase to 22.18 N/mm^2. It may suggest that, water plays a role in strengthening the polymer matrix. While, when the sample was compounded with higher screw speed at 100rpm, the tensile strength further rise to 24.06 N/mm^2. The increasing in speed will enhance the material properties due to improve in mixing and alignment. Interestingly, when water was aided at 10% into the compound and process at 100rpm, the strength was at the highest peak, which was 24.33 N/mm^2. This showed that, when water was presence, the material will experience less stress and could maintain its quality even under challenging processing.

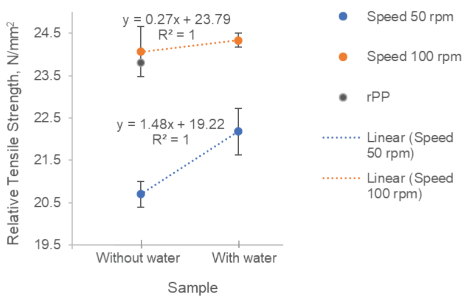

Figure 1: Relative tensile strength of rPP/clay composite

While, the trend line in Figure 1 show the effect of water played a greater role in improving the tensile strength of the composite when compounded at 50rpm compared to 100rpm. It may suggest that the water and the screw speed during compounding plays a significant role in the mechanical properties of the composite material. It could be advantages for mixing when using higher screw speed and water could ensure that the material did not suffer detrimental effect due to excessive heat and shear. Hence, it would get better dispersion of filler in the composite. Research shown that the better dispersion and filler-matrix interaction could be the main reason and factor resulting in increasing trend in the graph [9].

3.3 Morphological Characteristics

The micrographs of rPP/clay composite tensile fracture surfaces at 1000x magnifications are depicted in Figure 2. Figure 2 (a) exhibit a layered and flaky surface and a void possibly showing the effect of water on the material dispersion. Evidence suggested that irreversible microstructure damage in the form of microvoid along the binder interface occur when the material is strained [8]. As the applied strain increases, the damage will occur as a successive nucleation of the microvoids tearing [10]. While Figure (b) shows a fibrous, elongated strand structure which suggests a better alignment and stretching of the material. Studies have shown that the clay was not intercalated at a low shear rate, resulting in insufficient dispersion. Under high speed, it could supply sufficient shear force and the clay was intercalated and dispersed well [5].

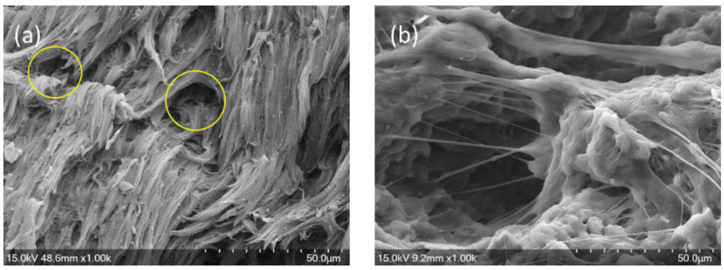

Figure 2: (a) rPP/10/50 and (b) rPP/clay/0/100 at 1000x magnifications.
The circle shows the size of the voids.

3.0 CONCLUSIONS

In this study, rPP/clay composite have been successfully prepared through water-assisted compounding method that focusing on two processing parameter which are screw speed and water content. To characterize the rPP/clay composite, its physical, mechanical and morphological properties were investigated. The result indicates that adding metakaolin clay will slightly increase the density of rPP/clay composite up to 0.9123 g/cm^3. Conversely, higher screw speeds and water content resulted in a decrease in average density of 0.35% and 0.20% respectively, highlighting the influence of processing parameters on the composites. While, the tensile strength showed significant improvemnets as the screw speed increase and this effect was further amplified by the presence of water up to 24.33 N/mm^2. This suggest that, the dispersion and alignment within the composite matrix were improved. The findings were supported by morphological analysis, revealing improved microstructural characteristic at higher screw speeds, crucial for optimizing mechanical properties.

In conclusion, this study highlights the potential of water-assisted compounding as a viable method to modify the properties of rPP/clay composite. It provides sustainable options for polymer recycling and composite development. Further research could focus on optimizing these parameters to maximize composite performance in different applications within the plastic industry.

ACKNOWLEDGMENTS

This research is funded by Ministry of Higher Education (MOHE) of Malaysia through the Fundamental Research Grant Scheme (FRGS). No: FRGS/1/2023/T01/UTEM/03/1. The authors also would like to thanked Universiti Teknikal Malaysia Melaka for the support.

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