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An Experimental Investigation on Melt Flow Index and Water Absorption of rHIPS/ABS/Kenaf Composite

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ABSTRACT

Despite increased awareness of environmental contamination, the recycling and modification of discarded plastics has gained popularity. In this study the composites of kenaf fibres incorporated in recycled high impact polystyrene (rHIPS)/acrylonitrile-butadiene-styrene (ABS) matrix with polypropylene-graft-maleic anhydride (MAPP) composites were mixed using twin screw extruder. This paper aims to examine the influence of water absorption and MFI of the composites. Ternary blends were prepared by varying the kenaf, MAPP loading from 0-30 (wt. %), at the varying conditions of ABS-rHIPS blends. For water absorption, the maximum percentage was 38.86% for 30 wt.% kenaf. It was noted that, rHIPS/ABS/kenaf composites which contains higher kenaf content showed greater water absorption due to higher fibre content and void percentages compared to composites having lesser amount of kenaf loading. The results also showed that the best MFI was from a mixture of 25% rHIPS, 65% ABS, 5% MAPP and 5% kenaf. From this mixture, the highest flow was produced and suitable for use in the production of products by using machines such as injection molding and extrusion. Due to the benefits associated with kenaf fibre composite as natural fibre, it can, therefore, be used as polymer reinforcement.

1. Introduction

The development of natural fibre reinforced composites become attractive research due to biodegradability, reduces cost and decreases environmental pollution and hazards. Since there are many applications that must be produced in order to reduce greenhouse gas emissions, much effort has been made to provide biodegradable and environmentally friendly materials for the upcoming generation of composite materials [1]. Many types of natural fibres, such as palm, flax, hemp, jute, straw, wood, rice husk, wheat, barley, oats, rye, bamboo, sugarcane, grass reeds, kenaf, ramie, sisal, coir, banana fibre, etc., have recently been explored for use in plastics [2]. Kenaf is one of these fibres that attracts particular interest because it is a non-wood plant fibre that can be used as reinforcement

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or filler in the polymer matrix. Kenaf fibre is also readily available on the market for the production of WPC, and it has the greatest potential for the Malaysian market [3]. The plant with a base diameter between 3 and 5 cm that can grow to a height of more than 3 m [4]. The long stem, which produces the long fibre, is one of many elements of the kenaf plant that may be separated. The kenaf stem, on the other hand, is made of two kinds of fibres, the core fibre and the bast fibre, which are used to make the outer and inner layers, respectively [5]. Non-ferrous cells are also present in a thin core pith layer known as a sponge-like tissue. According to studies, the bast fibre, which is frequently utilised to generate paper, textiles, and rope, makes up around 35% of the dry weight of the kenaf stalk. The kenaf fiber's core, which is appropriate for potting medium and animal bedding, makes up 65% of the material. Hence, this research is carried out to determine the optimum amount of recycled rHIPS/ABS/Kenaf blends together using maleic anhydride grafted polypropylene (MAPP) compatibilizer at different level loading ratio.

The process involved treatment of kenaf fibre using NaOH and further utilizing twin-screw extruder and injection moulding in the composite's fabrication process. In this study, properties determination focusses on properties such as, melt flow index, and water absorption. Water absorption, which is a component of this, is a limiting factor that may have an impact on the mechanical characteristics of composite materials and limit their applicability. Temperature, porosity, diffusivity, exposed surface area, and other variables all influence how well composite materials absorb water [6,7].

Acrylonitrile-butadiene-styrene (ABS) and recycled high impact polystyrene were the polymers combined with the kenaf (rHIPS). ABS is a widely used engineering thermoplastic owing to its desirable features which include good mechanical properties, chemical resistance, toughness, dimensional stability, good surface appearance, and easy processing characteristics [8]. Resistance and toughness are ABS's most remarkable mechanical characteristics [9,10]. The interfacial adhesion between the filler and matrix components has a significant impact on the mechanical characteristics of composite materials. However, this issue can be resolved by enhancing the contact and adhesion between the matrix and fillers [11].

For example, using coupling agents such as SEBS, the first technique that can be used to enhance interfacial adhesion. Coupling agents can modify the polymer matrix and improve the product's interface strength and mechanical properties. In addition, filler treatment can also be used to enhance interfacial adhesion before mixing process. There are a few lignocellulosic filler processing issues that restrict its applications. The main problem is the compatibility of natural fillers with the high hydrophobic nature of composites [12]. The mechanical properties of composites are strongly dependent on the interfacial adhesion between the components of filler and matrix. This can be solved, however, by improving the adhesion and interaction between fillers and matrix [11].

When compared to other engineering polymers, ABS also has several limitations, such as poor heat stability, poor flame resistance, and poor mechanical qualities. These shortcomings can be fixed by adding fibres, though. Meanwhile, because of its high stiffness and simplicity in colouring and processing, High Impact Polystyrene (HIPS) is widely used in packaging, toys, bottles, household goods, electronic appliances, and light-duty industrial components. Thus, it is usual practise to add elastomer micro-particles to toughen polymer/filler hybrid composites, such as by physically combining HIPS, Mg(OH), and elastomer [13]. Future mix ratios of used plastic waste from the industrial sector combined with natural fibre are projected to rise, necessitating the resolution of recycling-related challenges.

2. Methodology

2.1 Materials Preparation

Two types of polymers were used in this research, recycle high impact polystyrene (rHIPS) (density of 1.05 g/m^3 and melt flow rate of 3.7 g/10 min) and acrylonitrile butadiene styrene (ABS) (density of 1.05 g/cm^3 and a melt flow rate of 1.8 g/10 min). rHIPS and ABS were kindly supplied by Petrochemical (Malaysia) Sdn. Bhd., Johor and Chimei Corporation, Taiwan respectively. Kenaf fibres were supplied by National Kenaf and Tobacco Board (NKTB) with an average diameter of 150 µm were employed. MAPP (Polypropylene-graft-maleic anhydride) and NaOH were supplied by Sigma-Aldrich (M) Sdn. Bhd. and were used as received. Figure 1 shows the materials being used in this research work.

Fig. 1. Materials used in the research: (a) kenaf fibre (b) rHIPS (c) ABS (d) MAPP

2.2 Sample Preparation

Kenaf fibre was treated in NaOH at 6 wt.% treatment. After treatment, the fibres were crushed into smaller size and an average diameter of 150 µm were employed. rHIPS/ABS/kenaf composites samples were prepared using a twin screw extrusion machine (Collin Teach Line 2K 25T) located at the Faculty of Engineering Technology, UC TATI, Kemaman, Terengganu. The temperatures profile was set at T1: 189˚C; T2: 206˚C; T3: 191˚C; T4: 181˚C. Table 1 shows the composition and identification of the composites produced. The composites were prepared by varying the rHIPS, ABS, kenaf and MAPP content, as shown in the Table 1. The overall fabrication process of the rHIPS/ABS/kenaf composite is illustrated in Figure 2.

Table 1
Composition of rHIPS / ABS /kenaf composites

Sample Code	Composition (wt%)			
	rHIPS	ABS	Kenaf	MAPP
KS0	50	50	0	0
K5	45	45	5	5
K10	42.5	42.5	10	5
K15	40	40	15	5
K20	37.5	37.5	20	5
K25	35	35	25	5
K30	32.5	32.5	30	5
M5	45	45	5	5
M10	42.5	42.5	5	10
M15	40	40	5	15
M20	37.5	37.5	5	20
M25	35	35	5	25
M30	32.5	32.5	5	30
R50	50	40	5	5
R45	45	45	5	5
R40	40	50	5	5
R35	35	55	5	5
R30	30	60	5	5
R25	25	65	5	5

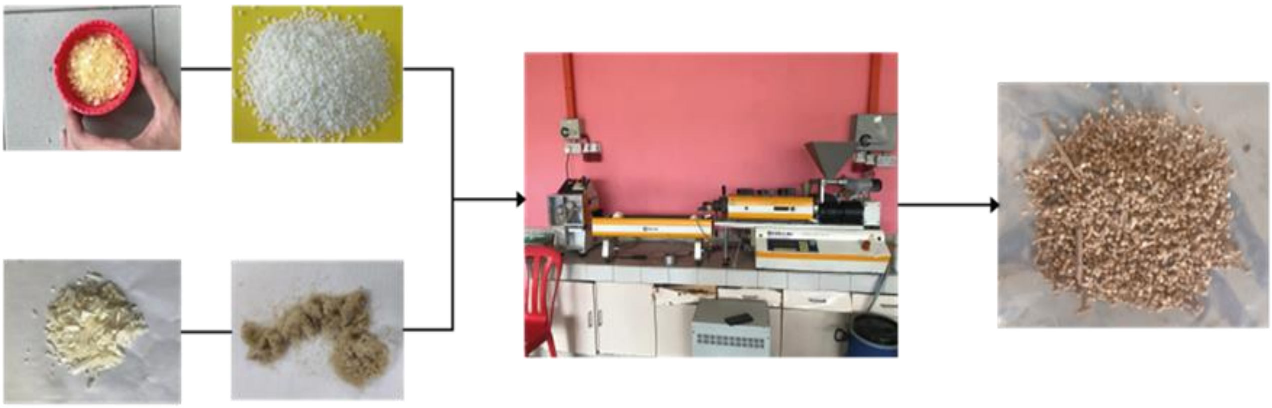

Fig. 2. Fabrication process of the rHIPS/ABS/kenaf composite

2.3 Melt Flow Index

Melt Flow Index (MFI) is a measure of the ease of flow of the melt of a thermoplastic polymer. The method is described in the standards ASTM D1238. The MFI of rHIPS/ABS/kenaf composites was determined using MFI Model D4002HV from ALPHA Technologies. MFI was expressed in grams of polymer per 10 minutes of duration of the test at 190°C.

2.4 Water Absorption

The samples undergo a water absorption test, for 5 days following ASTM D570. Before the immersion, all samples were conditioned in an oven at 50°C for 24 hours. The rHIPS/ABS/kenaf composite samples were cut into 2cm x 2cm sample sizes and weight before immersion in water. The test was conducted at room temperature. The increase in weight was reported as a percentage of water absorbed. The calculation is shown in Eq. (1):

$$Water\ Absorption\ percentage = \frac{W1-Wo}{Wo} * 100\% \tag{1}$$

where W_0 represents the weight before immersion and W_1 represents the weight of the immersed sample. rHIPS/ABS/kenaf composite samples soaked for water absorption test were shown in Figure 3.

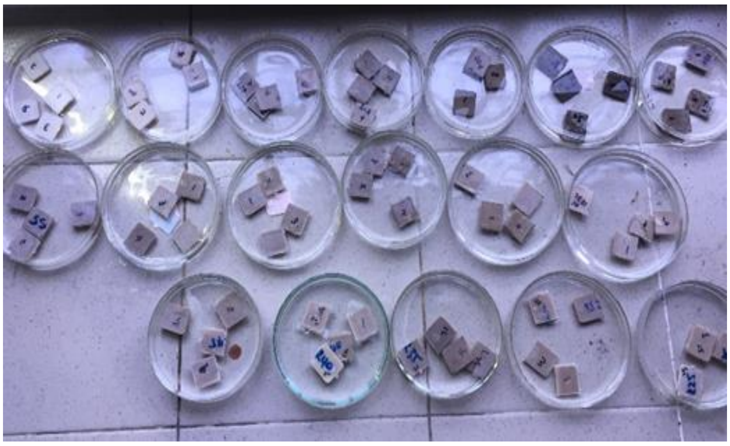

Fig. 3. Water absorption test of rHIPS/ABS/kenaf composite

3. Results

3.1 Melt Flow Index

MFI is a method to determine the flow rate of the melt of a thermoplastic polymer. It describes the mass of polymer (in gram) flow through a capillary with designated diameter and length by a constant applied pressure. MFI and viscosity of the polymer melt are inversely proportional to each other under the test conditions.

In this work, there are 3 variations of filler loading i.e., kenaf, compatibilizer MAPP and thermoplastic rHIPS, are investigated. It should be noted that ABS and HIPS have significant differences in MFI. The MFI of virgin thermoplastic ABS is 8.76 g(10 min)$^{-1}$, whereas virgin HIPS is 7.50 g(10 min)$^{-1}$ [14]. The purpose of adding kenaf fibres in the matrix is to enhance the composite' mechanical properties [15]. On the other hand, adding kenaf will restrict the flow of the polymer thus the MFI values is expected higher. The effect of varying kenaf composition on MFI composite is given in Figure 4. KS0 sample contains 0 wt.% kenaf gives MFI average values of 1.417 g(10 min)$^{-1}$. K5 is 5 wt.% kenaf give 6.201 g(10 min)$^{-1}$, K10 is 4.724 g(10 min)$^{-1}$,K15 is 3.576 g(10 min)$^{-1}$, K20 is 2.375 g(10 min)$^{-1}$, K25 is 2.503 g(10 min)$^{-1}$ and K30 gives 2.550 g(10 min)$^{-1}$.

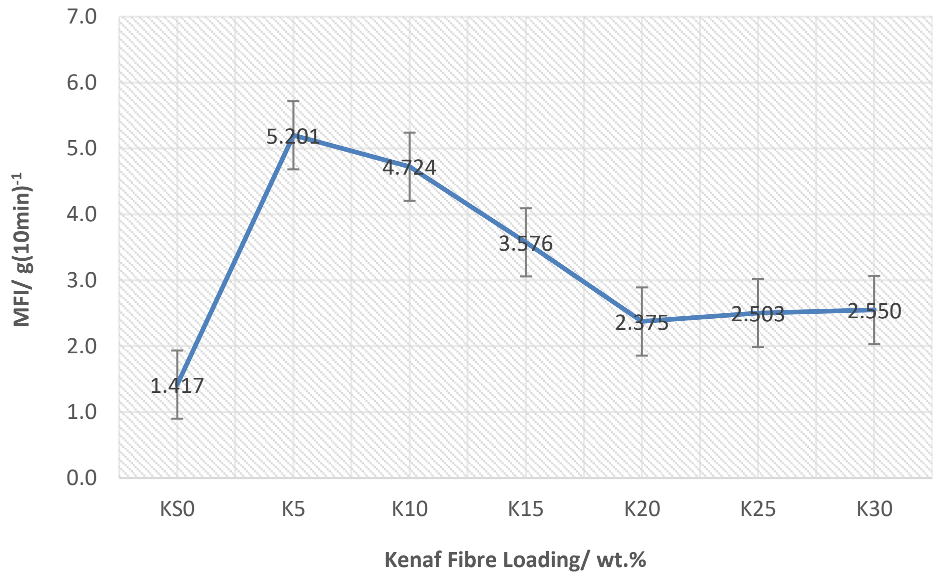

Fig. 4. MFI against varying kenaf fibre loading

MFI value for sample KS0 of 50-50 wt.% rHIPS/ABS is very low as in Figure 4, but as the kenaf fibre composition is added by 5 wt.%, the MFI of the composite is increased tremendously. The MFI then reduces as the kenaf composition gradually increases by 5wt.% to 30 wt.%. At 20 wt.% and higher, the MFI seems to be constant. This observation is similar to a study by Mashelmie *et al.,* [8] where kenaf addition in kenaf/ABS composite up to 10 wt.% increase the MFI to 0.8208 g(10 min)$^{-1}$ then gradually decrease. The MFI values obtained of in this study is lower than Mashelmie *et al.,* [8] might be due to the addition of rHIPS (recycled).

This observed behaviour is because the kenaf mixture mixed into composites varies in value. The decrement of MFI value in g(10 min)$^{-1}$ when kenaf fibre is start to introduce in the blends. It shows that higher loading of kenaf fibre increased the viscosity of rHIPS/ABS/MAPP composites because melt flow rate is inversely proportional to viscosity of the melt at the condition of the test. Among the other possible reasons that cause different values is due to the size of the kenaf, i.e., the kenaf size used is 150 microns. Besides, the addition of alkaline kenaf in the composition of the composite material will reduce the results of the MFI. Alkaline treated kenaf has largely decreased the number of impurities and hence given a smoother surface to the fibres in the composites [16].

The function of MAPP is a common compatibilizer of HIPS/ABS polymer [17]. It is worth to understand the effect of MAPP composition to the flow or viscosity of the composite. Figure 5 shows the MFI as the MAPP composition varied. Varying the compatibiliser MAPP composition from 5 to 30 wt.%, the resulting fluctuating MFI between 3.624 g(10 min)$^{-1}$ to 5.599 g(10 min)$^{-1}$. The lowest flow is at 25 wt.% (M25) and the highest at 30wt.% MAPP (M30). Thus, it cannot be concluded that increasing composition of MAPP compatibiliser is directly proportional to improve the composite flow or viscosity. A study conducted by Sabri *et al.,* [18] varying MAPP between 1-7 wt.% in kenaf/graphene/PP composite showed fluctuation of percent in elongation at break indicating that the addition of MAPP has no direct effect on the flow or softening of the composite. Junaedi *et al.,* [19] found that addition MAPP in short carbon fibre/PP composite up to 15 wt.% loading increases the ductility, however at 35 wt.% loading has no change in ductility but slightly drop in strength and modulus.

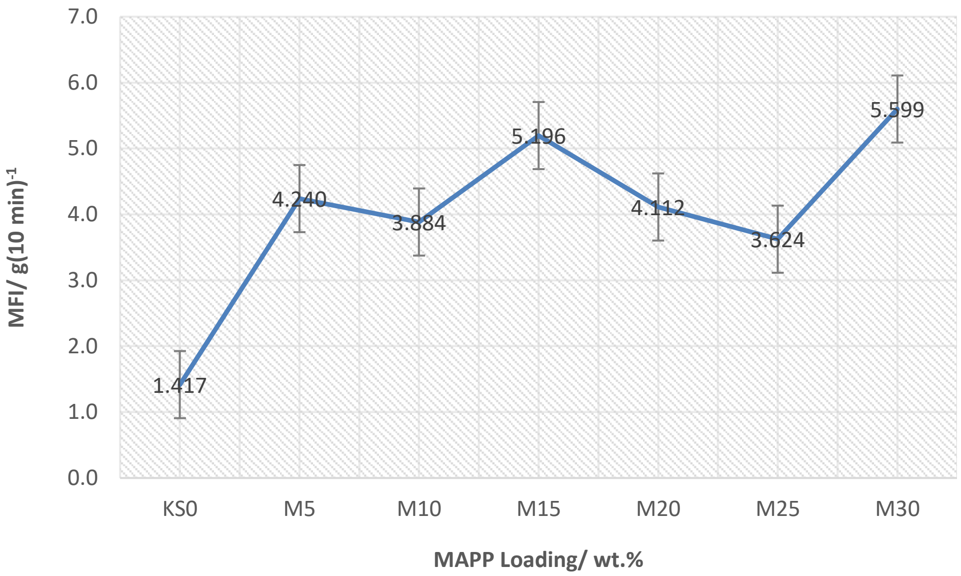

Fig. 5. MFI against varying MAPP loading

MFI result for composite composition varying rHIPS is shown in Figure 6. Sample KS0 is rHIPS/ABS without kenaf and compatibilizer. Varying rHIPS composition from 25-50 wt.% does not much affecting the flow and viscosity of the composite. The lowest average value is for 45 wt.% rHIPS sample at 5.16 g(10 min)$^{-1}$ and the highest average value is for 30 wt.% rHIPS samples at 6.078 g(10 min)$^{-1}$. It can be concluded that, the best a mixture is R45 with 45-45-5-5 wt.% of rHIPS-ABS-kenaf-MAPP. This is because, R45 give the highest flow and suitable for injection moulding and extrusion production.

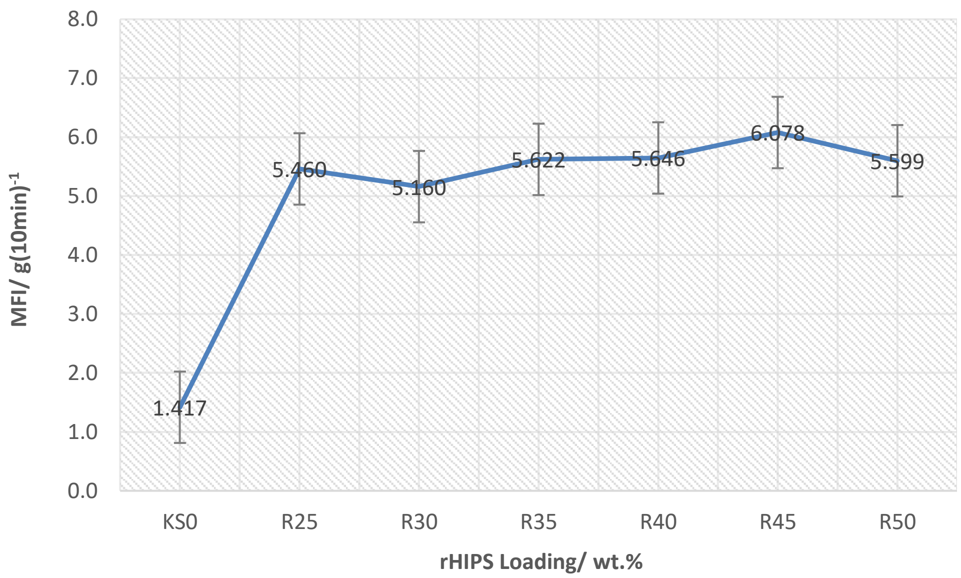

Fig. 6. MFI against varying rHIPS loading

3.2 Water Absorption

The water uptake in a material is determine by the water absorption test. Most materials have a tendency to absorb some water from the environment, and it effect the polymers in many ways, especially its mechanical properties. The water absorption test was conducted for 5 days at room temperature and the results are in percentages of water absorbed into the samples.

In general, all samples of kenaf/ABS/rHIPS composites showed an increment in water absorption for the 5 days duration. The water absorption of varying kenaf loading from 5 wt.% to 30 wt.% is shown in Figure 7. The sample with kenaf loading of 30 wt.% shows the highest percent of water absorbed. This observation is because of the incorporation of kenaf fibres attract more water uptake in the samples. A review study done by Akil *et al.,* [4] concluded that most kenaf fibre reinforced composites had water absorption up to 25% in distilled water after immersion for 80 hours. Another study done by Yusuff *et al.,* [20] found that as the kenaf fibre loading in kenaf/epoxy composite increases from 30, 40 and 50 vol.%, the water absorption in 5 days is 25%, 28% and 43% respectively. The value of water absorption in kenaf/acrylic based polyester with 45% volume fraction fibre showed 40% for alkali treated and 55% for untreated kenaf fibre [21]. All in all, as the kenaf fibre content increases regardless of the matrix used, the water absorption is increased proportionally. This is due to the behaviour of natural fibres and kenaf has higher cellulose and hemicellulose which contain hydroxyl (OH) and acetyl (C_2H_3O) groups that attracted to water or high hydrophilicity [22].

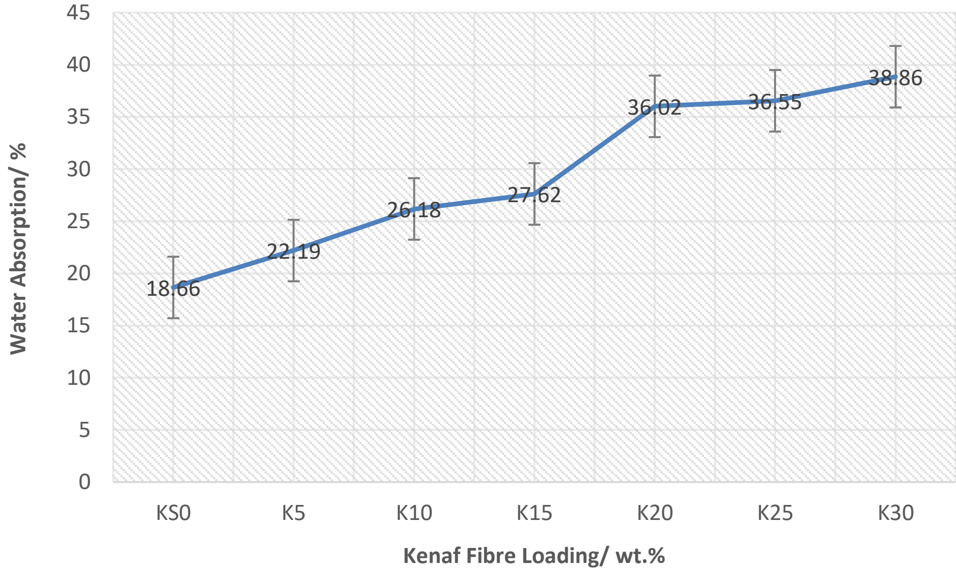

Fig. 7. Water absorption against varying kenaf fibre loading

The water uptake variation was found to differ slightly for as MAPP loading in the composites increases as shown in Figure 8. The water absorbance for KS0 sample which contain 50-50-0-0 wt.% rHIPS-ABS-kenaf-MAPP respectively is as high as 18.66% then drop to 8.02% for sample S5 as the composition of the composite is 45-45-5-5 wt.% rHIPS-ABS-kenaf-MAPP respectively. As the composition of MAPP increases from 5-15 wt.%, the water uptake gradually increases by 30%. However, as the MAPP composition increases from 15-30 wt.%, the water uptake is drastically increase by 160%.

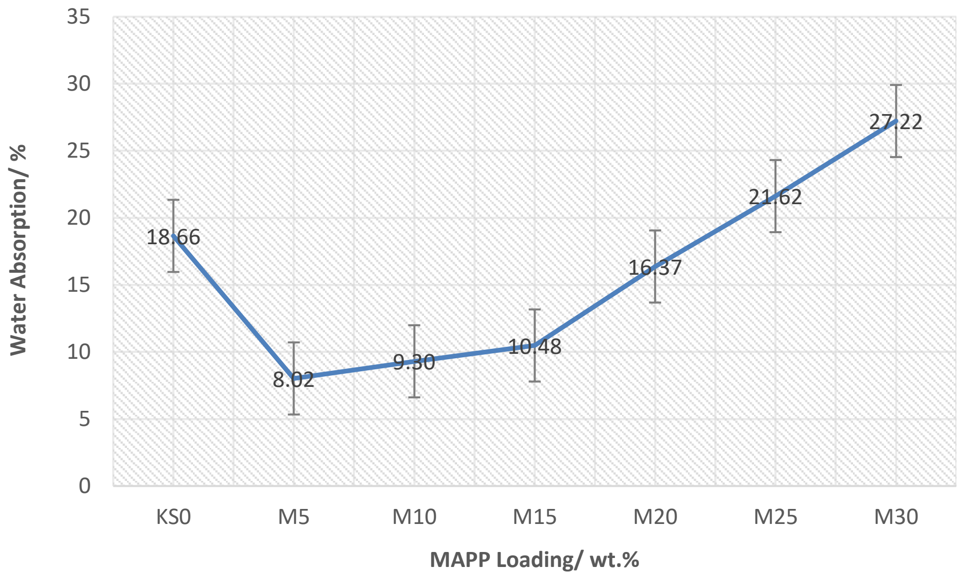

Fig. 8. Water absorption against varying MAPP loading

HIPS polymer is commonly used in packaging, toys, bottles, household, electronic appliances due to its good strength, high impact strength at low temperature and relatively low cost. Thus, it is expected that rHIPS has lower mechanical strength compared to the virgin. The water absorbed vary with rHIPS loading as shown in Figure 9. As the amount of rHIPS increases from 25 to 50 wt.%, the water uptake is gradually increasing. The water absorption percentage drop a bit for sample without kenaf and compatibilizer MAPP. This observation is similar to the study conducted by Ayrilmis *et al.,* [23] where the amount of water absorption in PP/HIPS hybrid composites is so much affected by HIPS loading. Water absorption of 100 wt.% HIPS is tripled compared to 100 wt.% PP that are 0.03 and 0.01% respectively [23].

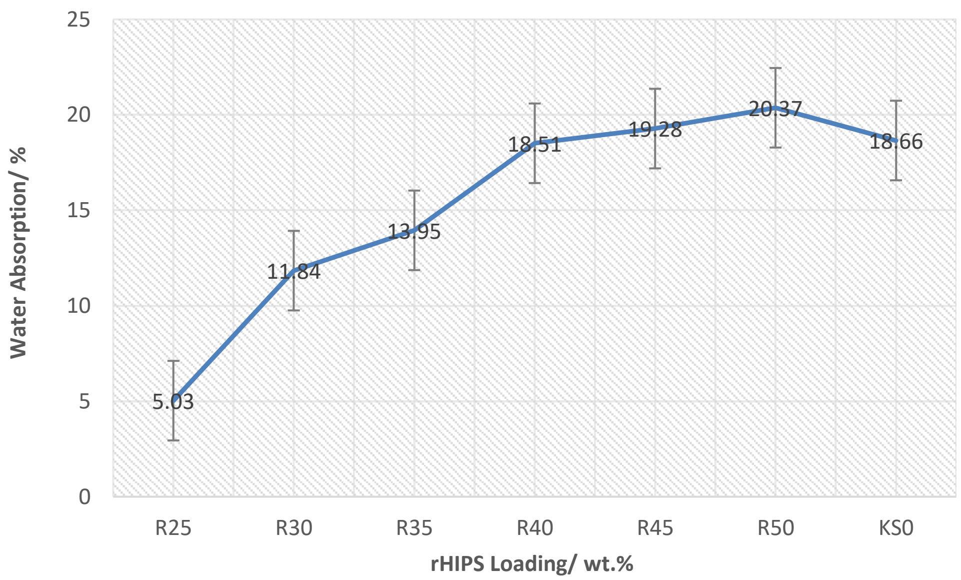

Fig. 9. Water absorption against varying rHIPS loading

4. Conclusions

The twin-screw extrusion machine was used to produce the treated kenaf fibre to the rHIPS/ABS matrix at various fibre loadings. According to ASTM D570, the water absorption test was run for 5 days. The samples underwent a 24-hour conditioning period in an oven set to 50°C prior to the immersion. The results show that ABS mixed with 20% kenaf is the best among these 19 blends. Finally, for water absorption, this composite 47 mix showed (37.5% rHIPS, 37.5% ABS, 5% SEBS and 20% kenaf) the highest flow rate compared to others. Based on the research done and the findings from kenaf/rHIPS/ABS composites, it can be said that the treated kenaf fibre, rHIPS, and ABS matrix have strong interfacial adhesion, which causes the water absorption % in kenaf/rHIPS/ABS composites to grow with the increment of filler loading. With the addition of a coupling agent, NaOH treatment improved the adherence of the fibre to the matrix.

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