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A Prelude Study on Influence of Hydrophobic Ionic Liquid on Tensile and Impact Properties of HDPE/KCF Biocomposites

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AAS and SNAMJ designed and conceived the study. Author AAS performed most of the experiments. Authors AAS and KA collected and analyzed the data. All authors contributed to the writing of the manuscript. All authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

In this prelude study, the high-density polyethylene/kenaf core fiber (HDPE/KCF) biocomposites without and containing hydrophobic ionic liquid, namely 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ([Emim][NTf_2]), were prepared via melt mixing process. The process was carried out by using an internal mixer at 150°C with a rotor speed of 60 rpm. The prepared biocomposites were molded into sheets through compression molding technique at the same temperature. The molded biocomposites were cut into dumbbell and rectangular shapes for tensile and impact tests, respectively. The tensile and impact properties of the biocomposites were determined by using universal testing and impactor machines, correspondingly. The tensile test results indicated that the biocomposites containing [Emim][NTf_2] had low tensile stress and tensile modulus. Nevertheless, the biocomposites possessed high tensile extension and impact strength

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compared to the biocomposite without [Emim][NTf_2]. This study deduced that the presence of the hydrophobic ionic liquid like [Emim][NTf_2] significantly influenced the tensile and impact properties of the HDPE/KCF biocomposites.

Keywords: Ionic liquid; kenaf; biocomposite; tensile; impact.

1. INTRODUCTION

Surfactants are commonly organic compounds that are amphiphilic [1-3]. Besides that, ionic liquids are organic salts that consist of organic cations and either organic or inorganic anions. Ionic liquids have a melting temperature below 100°C, and they can be synthesized with different chemical pathways [4,5]. Ionic liquids are typically used as a solvent for the dissolution of biopolymers and bioplastics [6]. Furthermore, ionic liquids have been employed as a compatibilizer for polymer blends and polymer composites [7-9]. Ionic liquids are also used in the modification of nanofillers for the fabrication of polymer nanocomposites [10,11]. Recently, ionic liquids are applied in the preparation of kenaf-based biocomposites as well [12,13].

Biocomposites are composite materials manufactured by means of natural fibers as a filler [14-16]. The use of natural fibers can reduce the production cost of biocomposite products because they are cheap, abundant, and renewable. Many types of natural fibers, for example, bamboo [17], oil palm empty fruit bunch [18], and kenaf [19], are used for preparing biocomposites. They can be utilized in various applications such as 3D printed products [20], automotive and aircraft interior, building, and packaging. Besides that, there are numerous methods to enhance the physicochemical properties of biocomposites, for instance, alkaline treatment [21], steam explosion treatment [22], secondary mineral fillers [23,24], and fibers hybridization [25].

In this prelude study, a hydrophobic room temperature ionic liquid was used in the preparation of polyethylene/kenaf biocomposites. Additionally, the usage of this ionic liquid is advantageous due to it is easy to handle since it has a low melting temperature. It can also be processed at high temperatures as in the processing of biocomposites because of its high thermal stability. The objective of this study is to identify the influence of 1-ethyl-3-methylimidazolium bis (trifluoromethylsulfonyl) imide hydrophobic ionic liquid on the tensile and impact properties of high-density polyethylene/ kenaf core fiber biocomposites. The biocomposites with enhanced tensile and impact properties can possibly be applied in the fabrication of diverse products.

2. MATERIALS AND METHODS

2.1 Materials

High-density polyethylene (HDPE) was purchased from the Polyethylene (M) Sdn. Bhd., Malaysia. Kenaf core fiber (KCF) with a particle size of 420 µm was acquired from the National Kenaf and Tobacco Board (NKTB), Malaysia. 1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ([Emim][NTf_2]) ionic liquid with a purity of ≥98% was procured from the Sigma-Aldrich (M) Sdn. Bhd., Malaysia. All materials were used as received without further modification [19].

2.2 Preparation of Biocomposites

The melt mixing process was applied to prepare the HDPE/KCF biocomposites by using an internal mixer (Brabender). The temperature and the rotor speed of the mixing process were fixed at 150°C and 60 rpm, respectively [12]. Firstly, HDPE was inserted into the mixing chamber and left to melt for 3 min, followed by KCF and left to mix for 6 min, then [Emim][NTf_2] and left for 3 min. Lastly, the mixing process was continued for another 3 min, where the plateau torque was reached [16]. The duration of the whole process was 15 min. The weight ratio between HDPE and KCF was constantly fixed to 60/40, whereas the contents of the [Emim][NTf_2] were varied from 4 to 20wt.% of the total biocomposites weight. The biocomposite containing only HDPE and KCF was also prepared for comparison purpose.

2.3 Molding of Biocomposites

The prepared biocomposites attained from the internal mixer were molded into 1mm sheets through compression molding technique by using a hydraulic hot press machine [26]. The molding procedures were preheating at 150°C for 7 min, compressing at the same temperature for 2 min, and finally cooling at 20°C for 5 min [24].

2.4 Tensile Test of Biocomposites

The biocomposite sheets were cut into a dumbbell shape by using a die cutter (type V) for the tensile test. The tensile stress, tensile modulus, and tensile extension properties were determined via ASTM D638-10 standard test method by using a universal testing machine (Instron, model 5567) equipped with a 30 kN load cell [27]. The crosshead speed and the gauge length were 5mm min^{-1} and 40mm, respectively. Ten biocomposite samples from each percentage were tested to obtain the mean values. The tensile stress and tensile extension results were analyzed by using a statistical software (Microsoft® Excel® for Microsoft 365 MSO). Single-factor analysis of variance (ANOVA) was utilized to ascertain a statistically significant difference in the tensile stress and tensile extension mean values of the samples at a 95% confidence level [28].

2.5 Impact Test of Biocomposites

The biocomposite sheets were also cut into a rectangular shape with the dimension of 60mm x 12.7mm by using a scroll saw machine (Makita, model SJ401) for the impact test. The Izod impact strength of the biocomposite samples was measured through ASTM D256-10 standard test method by using an impactor machine (Instron, model 9050) equipped with a 0.5 J pendulum. The samples were notched for 1mm depth by using a V-notch machine (Ceast, model Notchvis) [25]. The mean values of ten samples from each percentage were calculated as well. The samples were conditioned in an oven at 70°C for at least 24 hours prior to tensile and impact tests [23].

3. RESULTS AND DISCUSSION

Figs. 1 and 2 show the tensile stress and tensile modulus of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]. It can be perceived that the biocomposite without [Emim][NTf_2] has higher tensile stress than the biocomposites containing [Emim][NTf_2]. This demonstrates that the biocomposite possesses high stiffness. On top of that, the presence of [Emim][NTf_2] decreased the tensile stress of the biocomposites. Moreover, a similar trend was also noticed for the tensile modulus of the biocomposites, which significantly decreased as well. This is because of the capability of the ionic liquid to interact with the components of the biocomposites [12], which gives lower rigidity compared to the biocomposite without [Emim][NTf_2]. Thus, from these results, it displays that the presence of [Emim][NTf_2] reduced the stiffness and rigidity of the biocomposites. It was also discovered that as the content of [Emim][NTf_2] increased, the tensile stress and tensile modulus of the biocomposites also radically decreased by up to 55% and 54%, respectively.

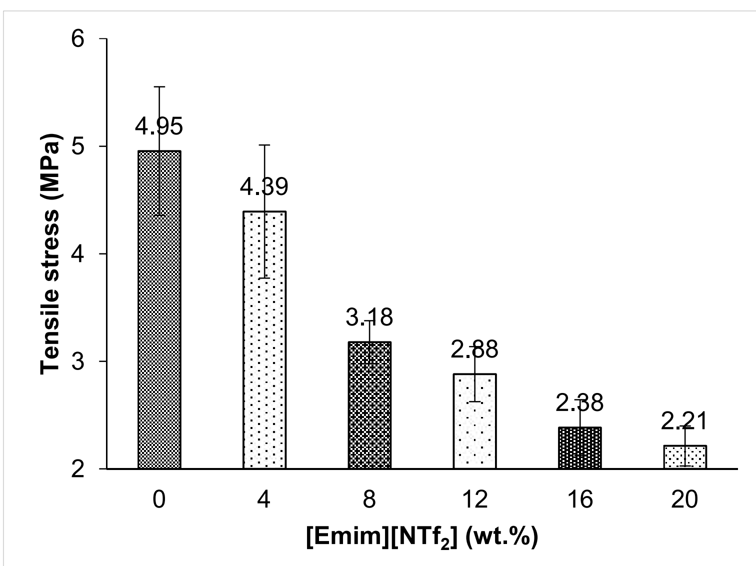

Fig. 1. Tensile stress of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

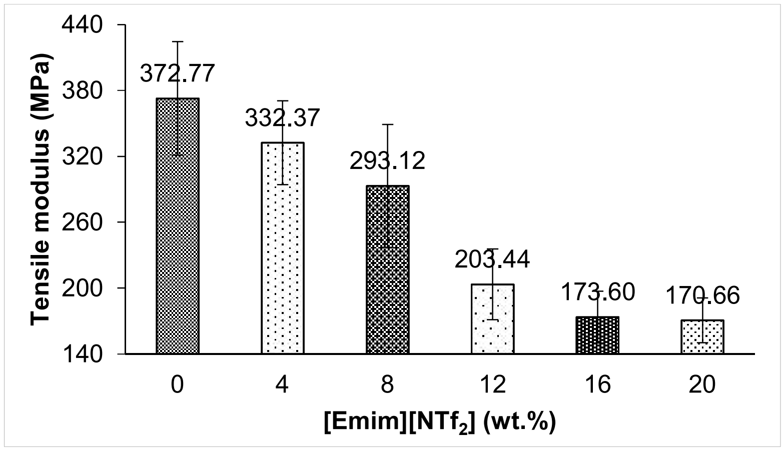

Fig. 2. Tensile modulus of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

Figs. 3 and 4 indicate the tensile extension and impact strength of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]. It can be observed that the tensile extension and impact strength of the biocomposite without [Emim][NTf_2] are lower compared to the biocomposites containing [Emim][NTf_2]. This shows that the biocomposite has low extensibility and toughness. On the other hand, the presence of [Emim][NTf_2] increased the tensile extension and impact strength of the biocomposites. This is due to the formation of free volume by the [Emim][NTf_2] in the biocomposites, which allows for the mobility of the HDPE molecular chains [12]. Therefore, from these findings, it exhibits that the presence of [Emim][NTf_2] considerably enhanced the extensibility and toughness of the biocomposites. It was also found that the tensile extension and impact strength of the biocomposites increased in direct proportion to the content of [Emim][NTf_2]. However, the optimum content of [Emim][NTf_2] was 12wt.%, whereby the tensile extension and impact strength increased by up to 58% and 28%, respectively.

Tables 1 and 2 exhibit the single-factor ANOVA results of the tensile stress and tensile extension of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]. The total numbers of the biocomposite samples are six, and ten replicates were tested for each sample. The source of variation of the tensile stress and tensile extension had been divided into two categories, namely, between groups (BG) and within groups (WG). F-value is the ratio of the mean square of BG to the mean square of WG. The P-values were less than 0.05 in the Tables 1 and 2, which rejected the zero hypothesis [28]. Hence, it can be inferred that there are statistically significant differences in the tensile stress and tensile extension among the different HDPE/KCF biocomposite samples at a 95% confidence level.

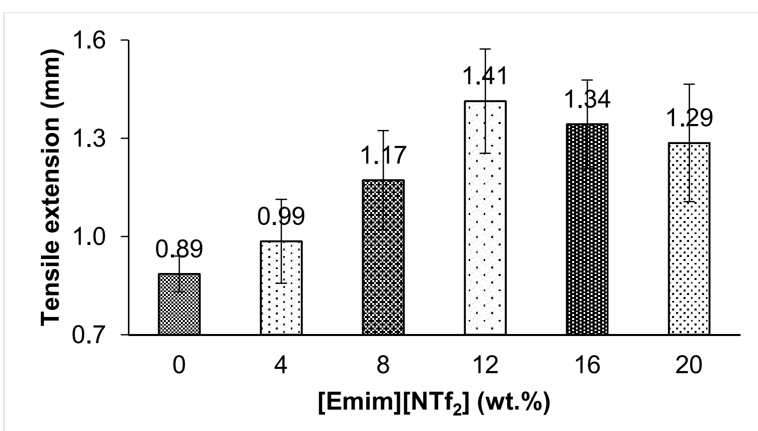

Fig. 3. Tensile extension of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

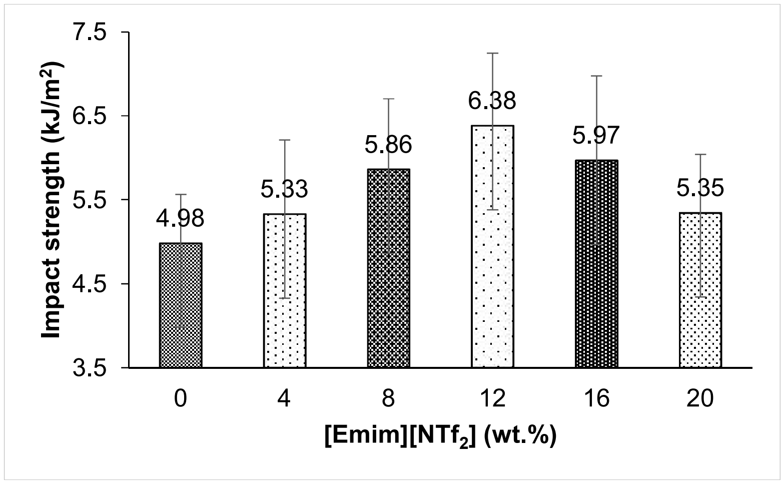

Fig. 4. Impact strength of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

Table 1. Single-factor ANOVA result of the tensile stress of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

Source of Variation	SS	df	MS	F	P-Value
BG	61.31328	5	12.26266	77.79357	1.97×10^{-23}
WG	8.512058	54	0.157631	-	-

SS = sum of square, df = degree of freedom, MS = mean square, F = F-value, Number of samples = 6, Number of observations = 60

Table 2. Single-factor ANOVA result of the tensile extension of the HDPE/KCF biocomposites without and containing [Emim][NTf_2]

Source of Variation	SS	df	MS	F	P-Value
BG	2.169636	5	0.433927	22.02869	5.86×10^{-12}
WG	1.063707	54	0.019698	-	-

SS = sum of square, df = degree of freedom, MS = mean square, F = F-value, Number of samples = 6, Number of observations = 60

4. CONCLUSIONS

The low tensile stress and tensile modulus were found in the biocomposites containing [Emim][NTf_2] as indicated by the tensile test results. However, the tensile extension and impact strength of the biocomposites increased by up to 58% and 28%, respectively, compared to the biocomposite without [Emim][NTf_2]. In addition, there are statistically significant differences in the tensile stress and tensile extension among the different biocomposite samples. It can be concluded that the tensile and impact properties of the HDPE/KCF biocomposites can significantly be influenced by the presence of the hydrophobic ionic liquid like [Emim][NTf_2]. This is due to the existence of the interaction between the ionic liquid and the biocomposite components, which decreased the stiffness and rigidity but increased the extensibility and toughness of the biocomposites.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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