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Mechanical Behavior of Polyurethane Composite Foams from Kenaf Fiber and Recycled Tire Rubber Particles

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Abstract. In the present work polyurethane foams containing various content loadings of kenaf fiber and recycled tire rubber particulates were prepared and studied, with the objective of developing alternative composite rigid foams. The influence of the filler content on the foam microstructure and its physical and mechanical behavior has been studied for three different polyurethane resin densities. Microstructural observation on fracture surface of composites was carried out using scanning electron microscopy. It has shown closed spherical cells with reduced size when the fillers are added. Nevertheless, the incorporation of kenaf fiber and recycled tire rubber particulates that refined at 80 mesh led to higher mechanical properties than that unfilled polyurethane foam. A 6% filler content loading exhibited the optimum compression stress and compression modulus, while further increase of filler content loading resulted in decline in mechanical behavior. The presence of larger filler content deteriorated the polyurethane system cellular structure and lead to poor composites strength. Overall, the use of kenaf fiber and recycled tire rubber particulates gives composite foams with comparable mechanical behavior for the studied filler reinforcement level.

Introduction

Polymeric foams are attributes useful application due to the presence of cellular structures. Among many, polyurethane (PU) foams occupy broad range of applications such as for shock damping, acoustic and thermal insulation, energy-absorbing purposes, cushioning and structural applications. As a result, PU foams are widely used in aerospace, automotive, construction, packaging, sports and furniture industries.

In recent years, the latest research and development results dealing with composite foams reinforced by the incorporation agricultural and industrial waste materials [1-3]. Lignocellulosic fillers are considered as emerging agricultural material to be used as fillers of polymeric foams, particularly, polyurethane foam. One of the agricultural waste which can be potentially used as fillers of polymeric materials is kenaf. Kenaf (*Hibiscus cannabinus*, L. family *Malvaceae*) is a warm season annual plant that able to grow under a wide range of weather conditions. There are various applications for kenaf including paper products, building materials absorbents and animal feeds. In Malaysia, National Kenaf Research and Development Program has been established in accordance of potential commercialization of product from kenaf in an effort to develop kenaf as a possible new industrial crop [1].

On the other hand, recycling and disposal of waste tire materials has become an important issue for some years. It was learned that tire accumulation is a growing environmental problem and about 800 millions of tires are rejected every years and this amount is increasing 2% each year [2].

Therefore, there are enormous efforts being carried out to reduce, reuse or recycle waste rubber products. Effectively recycling waste tires such as manufacturing natural fiber-rubber based polymeric composites could be one of the solutions.

Many works have been reported on PU composite foams. Rozman et al. [3] prepared polyurethane composites based on rice husk (RH) and polyethylene glycol and studied the mechanical and physical properties of the PU. It demonstrated that the incorporation RH approximately 45-60% in a PU system has enabled to improve the mechanical properties. On the other hand, Zhang [4] proposed use RH with waste tire particles to produce composite boards. Furthermore, Badri et al. [5,6.7] evaluated mechanical properties of the PU composites from oil palm resources consist of empty fruit bunch (EFB) and found that EFB reinforced PU foam exhibited superior mechanical properties at fiber loading 5.5%. The effects of incorporation of nanometric-sized fillers into PU system were studied by Antunes et al. [8]. They identified that the incorporation of esparto wool and montmorillonite fillers reduced the cell size of foams with higher open cell contents and lowest mechanical properties obtained.

With all this considerations in mind, rigid PU foams containing different concentration of kenaf fiber and waste tire rubber particulates were prepared and studied. This research aims to study the effects of fillers loading in enhancing the mechanical behavior of PU composite foams.

Experimental

Materials. A two-component polyurethane (PU) consisted of polyol and 2,4-diphenylmethane diisocynate (MDI). Both components are liquid at room temperature. Kenaf bast fiber and recycled tire rubber particles were obtained from industries. The size of kenaf fibers and recycled tire rubber particles obtained was 80 mesh.

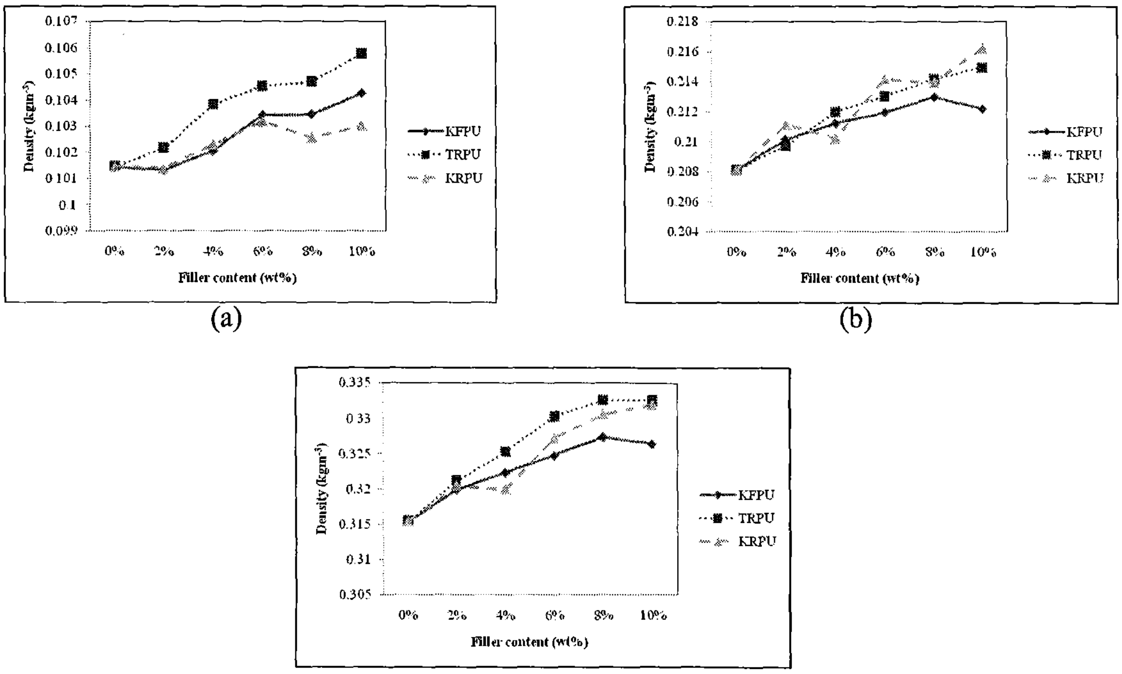
Processing method. The composite PU foams were prepared using the formulation described by Badri et al. [2] and it was produced by a one-shot process. Three different PU resin densities were used such as 0.1, 0.2 and 0.3 gcm^{-3}. The filler (kenaf fiber and tire rubber partciles) content of varied percentages (2, 4, 6, 8 and 10 %) were added according weight percentage of the overall weight of polyol component (w/w %). There are three different composite foams were produced using the methods namely kenaf fibers reinforced polyurethane foam (KFPU), tire rubber particles reinforced polyurethane foam (TRPU) and the combination of kenaf fibers (50 %)and rubber particles (50 %) reinforced polyurethane foam (KRPU).

Test methods. The density of the PU composite foams was measured according to ASTM D 1622 standard procedures with specimen dimension, 50 x 50 x 50 mm. The characterization of the cellular microstructure and of the cell size of the PU composite foams was performed using an analytical scanning electron microscope JEOL JSM–6380 with filament tension of 10 kV. First, the samples were cryogenically fractured in liquid nitrogen. Then the fracture surfaces are gold coated using gold sputter coater model JEOL JFC–1600 to make them conducting before they were scanned in the free rising direction. Mechanical behavior of the composite foams was determined using a Testometric Universal Testing Machine (100 kN). The uniaxial compression test was conducted according to ASTM D 1621 standard. Samples were cut into dimension of 50 x 50 x 50 mm. The compression test was carried out at constant cross-head speed 5 mm/min until the thickness was reduced to 90% of its original thickness. Each test was repeated five times under the same nominal condition to determine the significance of response variability. The compression stress and modulus were recorded and average value calculated.

Results and discussions

Density. Density is essential feature because it allows obtaining more low-weight material, especially when designing for weight consideration applications. Fig. 1 (a)-(c), shows that the foam density increases gradually with the addition and increasing amount of fillers for three distinct PU resin densities. The gradual increase of density in TRPU is larger than KFPU samples due to the density of raw material of recycled tire rubber particles are higher than kenaf fiber. The density of

KRPU foam composites are in between of these two types of composites. The composite foam density increment was larger by the addition of fillers into PU system when higher PU resin density is used. This is in part due to the decreased size of cells and more open cell content flow linearly by the incorporation of fillers.



(a) (b)

(c)

Fig.1. Influence of fillers on density of PU composites at different PU resin densities (a) 0.1, (b) 0.2, (c) 0.3 gcm^{-3}.

Morphological Characterization. Fig. 2 presents an example of SEM micrographs obtained for foams reinforced by tire rubber particles at different filler loadings, respectively. Similar microstructural characterization was observed for KFPU and KRPU foam composite samples. There was observed that whatever the filler type and the foam densities, particles are correctly dispersed. The apparent cell size distribution as a function of the foam density was evaluated from the SEM image analysis. It was found that the foam cell sizes decreased as a function of fillers content for studied PU resin densities. Similarly, the cell size becomes small as the density of the PU foam was increased. The range of the cell sizes obtained were 508 – 333 μm, 484 – 295 μm and 467 – 284 μm for 0.1, 0.2 and 0.3 g/cm^3, PU resin density, correspondingly. Thus, the filler addition does not induce any modification of the cell morphology but a decrease of its size.

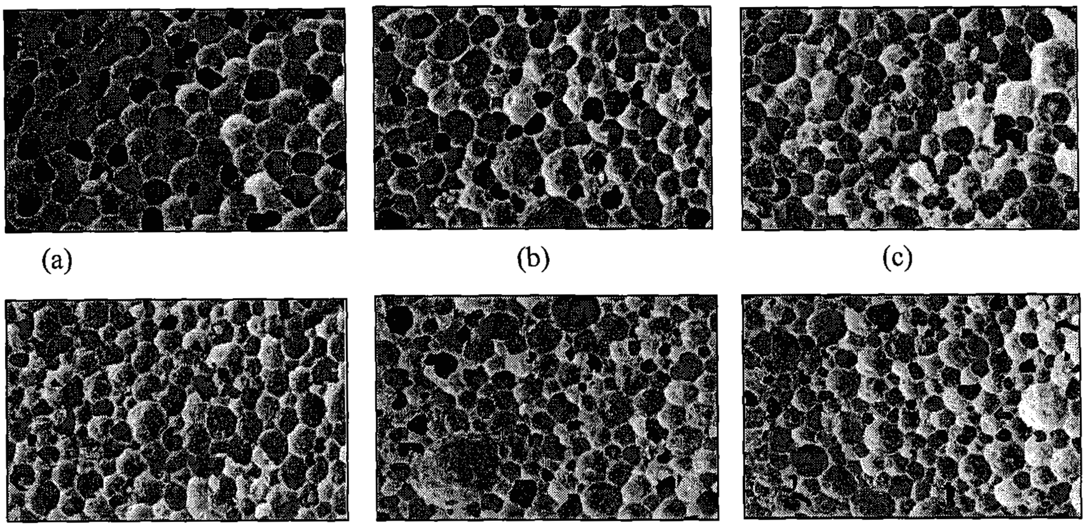
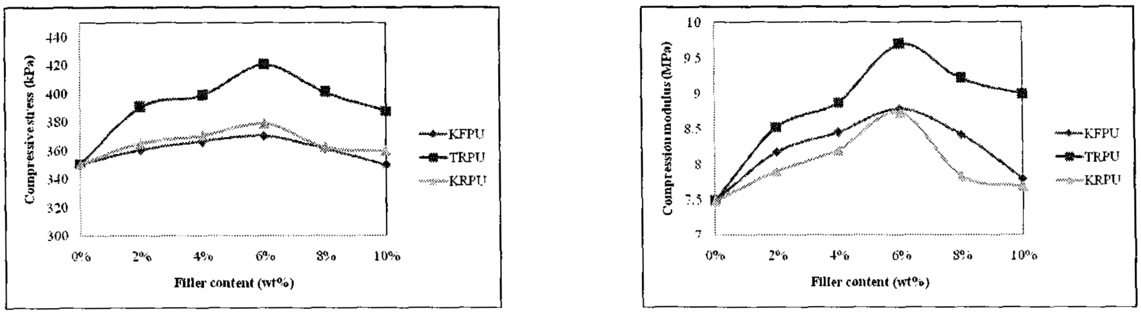


Fig. 2. SEM Micrograph of rubber filled PU foams (a) Unfilled PU, (b) 2%, (c) 4%, (d) 6%, (e) 8%, (f) 10%.

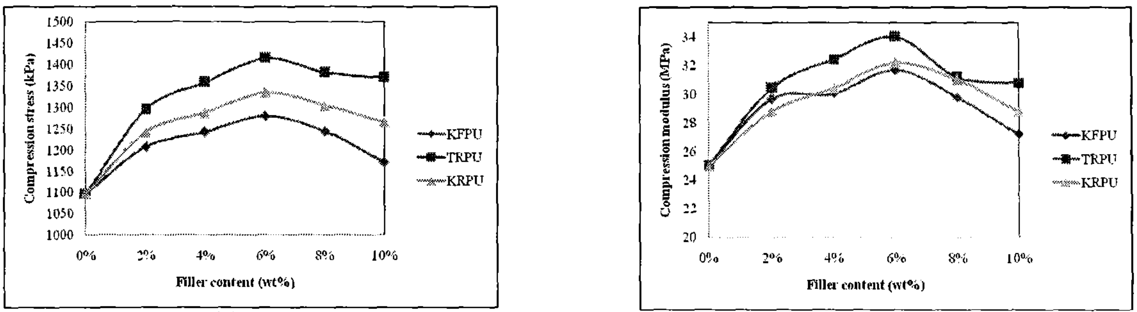
Mechanical properties. The response of the foams to compressive loading demonstrated in three stages namely linear-elastic region, yielding with plateau stress and densification when the stress increases rapidly with the strain. Specifically, the mechanical properties of the composite foams were presented in terms of the compressive stress and compression modulus at liner elastic region. Fig. 3 shows the maximum compression stress and modulus at 5% strain for studied composite foam samples. The trend shows an increasing pattern up to 6% fillers and decreases thereafter for all type of composite foams. It was found that the performance of the TRPU was higher than that of KFPU foam and followed by KRPU samples. This was attributed due to the tire rubber particulates provide better interaction with PU matrix than kenaf fiber particulates. This is mainly due to nature of tire rubber particulate that exhibit hydrophobic characteristic. Whilst, kenaf fiber particulates exhibit hydrophilic in nature and causes poor interface with PU matrix followed with lower compression values than TRPU.



(a) (b)

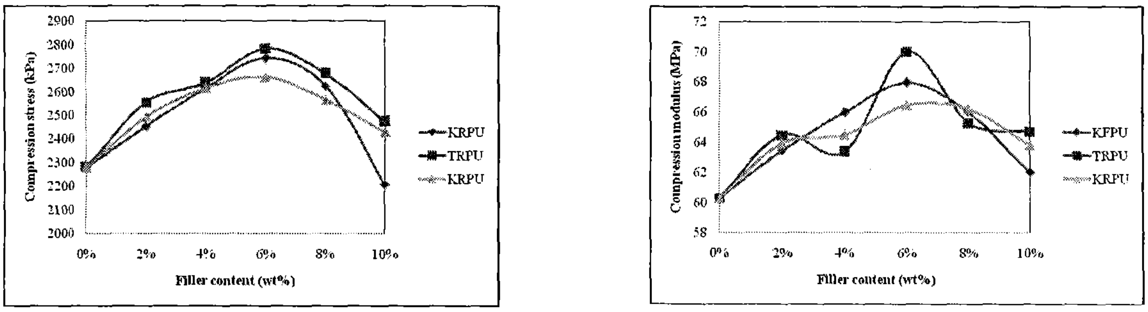
Fig. 3. Compressive properties at 5% strain as a function of fillers contents for various filler types at $100kgm^{-3}$ PU resin density (a) compression stress, (b) compression modulus.

The influence of the fillers in reinforcing the PU foam as the density of PU matrix increases was also studied and their results were interpreted in the Fig. 4 and Fig. 5.



(a) (b)

Fig. 4. Compressive properties at 5% strain as a function of fillers contents for various filler types at 200kgm^{-3} PU resin density (a) compression stress, (b) compression modulus.



(a) (b)

Fig. 5. Compressive properties at 5% strain as a function of fillers contents for various filler types at 300kgm^{-3} PU resin density (a) compression stress, (b) compression modulus.

The results indicated that compression strength and modulus were increased up to optimum fillers content about 6% and followed by decreased value. Whatever the density of PU resin, when fillers were incorporated into the PU matrix, it shows certain improvement up to optimum fillers content and thereafter the performance is decreases. At higher fillers levels, all polyurethane systems seem to exhibit decreasing strength. This may due to decreased bonding of the filler as the ratio of filler surface area to matrix volume has reached the highest values possible and thus, decreases the degree of encapsulation of the matrix around the particulate filler. Moreover, at higher filler loading, the filler has the tendency to tear the wall of the cellular structure. Consequently, PU system would lose its strength. Table 1 illustrates the improvement in mechanical properties of composite foams recorded at 6% filler content than that of unfilled PU.

Table 1: The percentages of increase in compression stress and modulus of PU composite foams.

Samples	100		200		300	
	Mechanical strength [%]	Compression Modulus [%]	Mechanical strength [%]	Compression Modulus [%]	Mechanical strength [%]	Compression Modulus [%]
KFPU	5.6	17.4	16.5	26.8	20.4	12.8
TRPU	19.9	29.5	28.9	36.1	22.1	16.1
KRPU	8.1	16.6	21.6	29.0	16.8	10.3

Conclusions

The incorporation of kenaf fiber and recycled tire rubber particulates has improved the mechanical behavior of PU composite foams than that of unfilled PU foam. The mechanical properties of composite foam samples displayed a maximum compression stress and modulus up to 6% fillers content and decreased thereafter. Furthermore, this new alternative composite foams can be employed for structural applications.

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