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Effect of Aluminum Hydroxide Loading on the Compression Stress and Modulus, Thermal Conductivity and Acoustic Properties of Palm-Based Polyurethane Hybrid Composite

(Kesan Penambahan Aluminium Hidroksida Terhadap Tegasan dan Modulus Mampatan, Kekonduksian Terma dan Sifat Akustik Komposit Hibrid Poliuretana Berasaskan Sawit)

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ABSTRACT

The effect of adding aluminum hydroxide (ATH) in the palm-based polyurethane hybrid composite was studied. The compression stress and modulus, thermal conductivity and acoustic property were determined. The hybrid composite was prepared by adding 10 wt% of oil palm empty fruit bunch fibre (EFB) followed by ATH at varying amount of 2, 4 and 6 wt% of the overall mass of the resin. The compression stress and modulus gave the highest values of 575 kPa and 2301 kPa, respectively at 2 wt% ATH. At 4 wt% ATH, the compression stress and modulus decreased to 431 kPa and 1659 kPa, respectively and further decreased at 6 wt% ATH to 339 kPa and 1468 kPa respectively. The k-value increased with the increment of the ATH loading exhibited a poor thermal conductivity. Sound absorption analysis indicated that the absorption coefficient was higher at higher frequency (4000 Hz) for all samples with PU-EFB/ATH with 4% ATH showed the highest absorption coefficient.

Keywords: Acoustic property; aluminum hydroxide; palm-based polyurethane; thermal conductivity

ABSTRAK

Kesan penambahan aluminum hidroksida (ATH) ke dalam komposit hibrid poliuretana (PU) berasaskan sawit telah dikaji. Tegasan dan modulus mampatan, kekonduksian terma dan sifat akustiknya ditentukan. Komposit hibrid PU disediakan dengan menambahkan 10% bt serabut tandan kosong kelapa sawit (EFB) diikuti dengan penambahan ATH pada peratus penambahan divariasikan pada 2, 4 dan 6% bt mengikut berat keseluruhan resin. Tegasan dan modulus mampatan adalah pada nilai tertinggi pada penambahan 2% bt ATH iaitu masing-masing 338 kPa dan 2209 kPa. Pada 4% bt ATH, tegasan dan modulus mampatan menurun kepada masing-masing 431 kPa dan 1659 kPa dan semakin menurun dengan penambahan 6% bt ATH kepada masing-masing 379 kPa dan 1468 kPa. Nilai k meningkat dengan penambahan ATH dan mempamerkan sifat kekonduksian terma yang lemah. Analisis serapan bunyi menunjukkan koefisien serapan yang tinggi pada frekuensi tinggi (4000 Hz) untuk semua sampel dengan PU-EFB/ATH (4% ATH) menunjukkan pekali serapan tertinggi.

Kata kunci: Aluminum hidroksida; kekonduksian terma; poliuretana berasaskan sawit; sifat akustik

INTRODUCTION

Polyurethane (PU) has been widely used in many fields such as aerospace, construction, sports and furniture. PU has many advantages for instance; high abrasion resistance, tear strength, excellent shock absorption and low density (Xu et al. 2008). PU foam has also been widely used as a thermal insulator. Addition of natural fibers as reinforcing fillers in polymeric materials has been widely used recently because of their properties which is environmental-friendly and cost effective. These lignocellulosic fibers offer low cost, low density, nonabrasive and enhanced energy recovery (Khairul Anuar Mat Amin & Khairiah Haji Badri 2007) as well as enhancing the mechanical strength of the bio-composites formed (Badri et al. 2004; Badri et al. 2005; Rozman et al. 2003).

Bio-composite is an organic material that is easily caught fire. Even though the addition of EFB in the PU system enhanced its mechanical properties, it will also weaken the thermal properties. EFB can also decrease the fire-resistivity due to its property that is easily ignited. In order to increase not only the mechanical property but also the thermal property of palm-based PU, fire retardant namely, aluminum hydroxide is added besides EFB.

Aluminum trihydroxide (ATH) which is also known as aluminum hydroxide has a molecular structure of $Al(OH)_3$. Besides low cost, other benefits from ATH also include odorless, easy to handle, non-toxic, chemically inert and non-volatile (Bonsignore 1981; Wu et al. 2004). When composites filled with ATH is being heated and subsequently burned, the ATH can absorb the heat which is being applied to it. The absorbed heat is dispersed uniformly in the ATH particles and reduced the heating rate of the composites. The decomposition of ATH will form alumina and water vapor as follow:

$$2Al(OH)_3 \xrightarrow[\Delta]{} 3H_2O + Al_2O_3 \quad (1)$$

This is an endothermic reaction with absorbed heat of 1.97 kJg^{-1}. The water vapor produced during the reaction will dilute any combustible gaseous substable evolved. Due to its ability to dilute combustible gases and slows down fire, ATH is used as flame retardant.

In this paper, the effect of ATH loading on the compression stress and modulus, thermal conductivity and acoustic properties of the palm-based polyurethane was carried out as a preliminary study in determining its capability as a fire-retardant. The PU was prepared by reacting the palm kernel oil-based (PKO) monoester (polyol) with 2, 4-diphenylmethane diisocyanate and loaded with a fixed amount of EFB at 10 wt%.

Materials and Methods

MATERIALS

The RBD PKO-based polyol was prepared using method described by Badri et al. (2001). The 2,4-diphenylmethane diisocyanate (MDI) was obtained from Cosmopolyurethane (M) Sdn Bhd, Port Klang, Malaysia. Additives for the polymerization of the polyurethane were glycerol (BHD Laboratory Supplies, England), silicon surfactant (Niax L5440) (Witco Ltd, Singapore) and also tetramethylhexanediamine (TMHDA) and pentamethyldiethylenetriamine (PMDETA) as catalysts which were obtained from Cosmopolyurethane (M) Sdn Bhd, Port Klang, Malaysia. Oil palm empty fruit bunch fibre (EFB) was obtained from Malaysian Palm Oil Board (MPOB) Dengkil, Malaysia. Aluminum hydroxide (ATH) was obtained from Fluka, Switzerland. The PU system developed used water as the blowing agent to replace chlorofluorocarbon, CFC.

METHODS

The hybrid composites were prepared using the formulation given in Table 1. The PKO-based polyol and the PU additives were blended with water using an overhead stirrer with a speed of 1000 rpm for 10 s. The EFB and ATH were added based on weight percentage of the overall weight of polyol resin. The EFB was added at fixed amount (10 wt%) while ATH was varied at 2, 4 and 6 wt%. The blend was then mixed with MDI at a ratio of 100:115 (resin to MDI). The mixture was then poured into a mould. It was then demoulded after 15 min. The composites were conditioned at room temperature for 16 h before further characterizations.

CHARACTERIZATION OF THE PU HYBRID
COMPRESSION TEST

The compression test was conducted according to the standard of BS 4370: Part 1: 1988 *(Method of Test for Rigid Cellular Material):* Method 3 *(Compression)*. Samples were cut into dimension of 50 mm × 50 mm × 50 mm. The test was carried out using Instron Universal Testing Machine model 5566 at cross-head speed of 50 mm min^{-1} until the thickness was reduced to 90% of its original thickness. The compression stress and modulus were recorded as average of five readings.

THERMAL CONDUCTIVITY TEST

Thermal conductivity was carried out using thermal conductivity analyzer model Anacon. Samples were cut into 160 mm × 160 mm × 30 mm. Thermal conductivity was calculated based on the formula:

$$\text{Thermal conductivity, } k = \frac{tQ}{A\Delta T}, \quad (2)$$

TABLE 1. Formulation for the preparation of the control PU and hybrid PU composites

Ingredients, pbw*	0 wt%	10 wt% EFB		
		2 wt% ATH	4 wt% ATH	6 wt% ATH
PKO-based polyol	90	90	90	90
Glycerol	10	10	10	10
Niax L5440	3	3	3	3
TMHDA	0.46	0.46	0.46	0.46
PMDETA	0.49	0.49	0.49	0.49
Water	4.00	4.25	4.30	4.35
Total pbw	107.95	108.20	108.25	108.30
EFB	-	10.82	10.82	10.83
ATH	-	2.16	4.33	6.50
Ratio resin: MDI	100:115	100:115	100:115	100:115

Note: *pbw: part by weight of the overall ingredients where t is thickness of the sample (m), Q is the rate of heat flow (W), A is the tested surface area of the sample (m^2) and ΔT is the temperature gradient between the hot plate and the cold plate (K).

ACOUSTIC TEST

The acoustic test was performed using impedance tube Model SCS9020B/K according to ASTM E1050-98 (Standard Test Method for Impedance and Absorption of Acoustical Materials Using Tube, Two Microphones and a Digital Frequency Analysis System) and ISO 10534-2 (Acoustics-Determination of sound absorption coefficient and impedance in the impedance tubes-Part 2: Transfer-function method). The acoustic absorption coefficient (α) is defined as the ratio of the acoustic energy absorbed by the foam ($I_{incident}$ - $I_{reflected}$) to the acoustic energy incident ($I_{incident}$) on the surface and is dependent on frequency. The tested frequency range was 125 – 4000 Hz.

SEM ANALYSIS

The SEM analysis was used to study the distribution of ATH in hybrid composites. The analysis was carried out using SEM chamber model Phillips XL-30. The dried samples were pre-coated with gold using gold sputter coater model SC500.

RESULTS AND DISCUSSION

MECHANICAL PROPERTIES

Figure 1 shows the trend in compression stress and modulus of hybrid composites with 0, 2, 4 and 6 wt% ATH. Addition of 2 wt% ATH increased the compression stress and modulus to 575.2 kPa and 2301.8 kPa, respectively but decreased with further addition of ATH to the composites. The stress put onto the PU system creates energy that is absorbed by the EFB. This energy is transferred to the PU matrix and ATH subsequently and uniformly being dispersed in the system. At higher loading of ATH (more than 2 wt%), the compression stress and modulus decreased. Further addition of the fire retardant (ATH) to the composites reduced the ability of the composites to absorb and disperse the energy. Mechanically, addition of rigid particles leads to an increase in the brittleness of the composites as observed by Dvir et al. (2003). Loading of ATH in the PU system has caused disruption in the PU system. It creates disorder to the cellular structure. The same observation was encountered by Nachtigall et al. (2006) when ATH was blended in polypropylene. There was a tendency for the ATH to weaken the mechanical strength of the composites due to the rigidity nature of the ATH particulates. Khairul Anuar Mat Amin & Khairiah Haji Badri (2007) has reported in their study using kaolinite as filler that the presence of the kaolinite disturbed the interfacial adhesion of PU matrix and EFB. These supported the findings in this study where there was reduction in the compression stress and modulus at 4 and 6 wt% ATH. Further explanation was verified by the SEM micrographs.

Figure 2 shows the SEM micrographs of the control PU and the hybrid PU composites at ATH loading of 2, 4 and 6 wt%. Figures 2 (a) shows the structure of the unfilled PU. The micrograph indicated uniform hexagonal cellular structure of PU. At 2 wt% ATH, the ATH was adhered to the cell wall together with the EFB. During compression testing, the stress transferred continuously from the matrix to the EFB and to the ATH. This resulted in a uniform dispersion of the stress. Figures 2 (c) and (d) shows ruptured cell walls of the PU composites. These created stress concentration point where it produced discontinuity in the matrix (Khairul Anuar Mat Amin & Khairiah Haji Badri 2007).

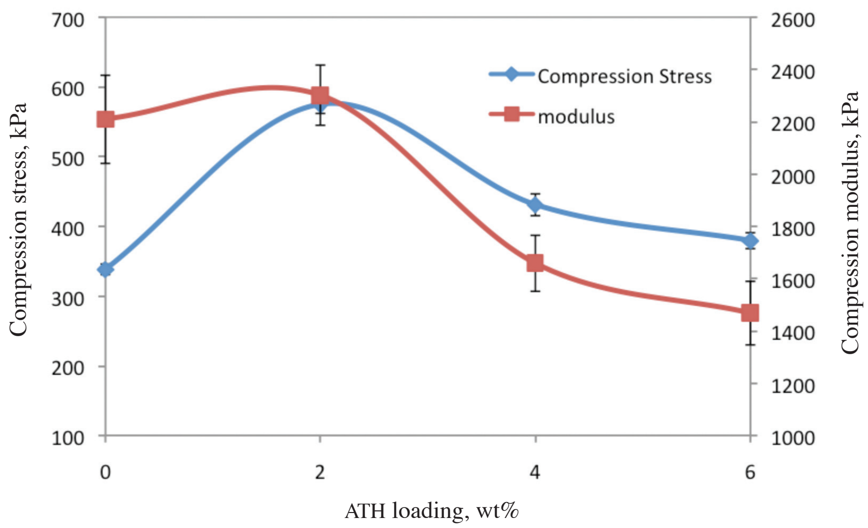

FIGURE 1. Compression stress and modulus of the control PU and the hybrid PU composites

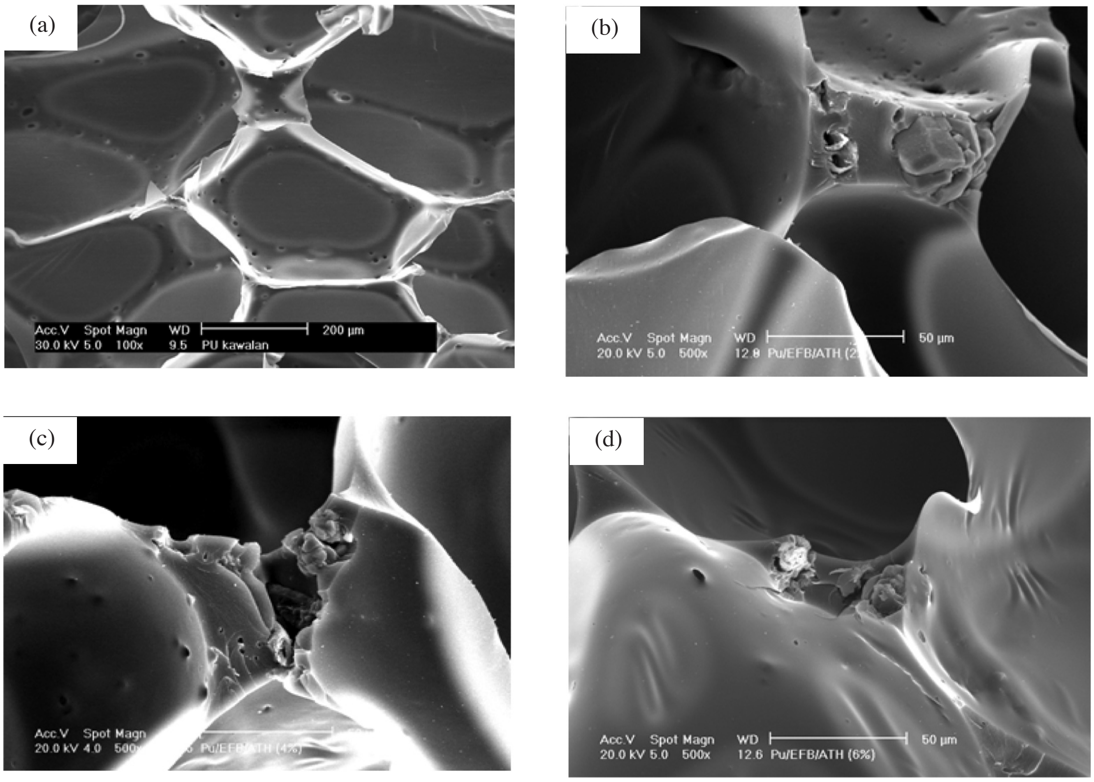

FIGURE 2. SEM micrographs of the (a) control PU, hybrid PU composites filled with (b) 2 wt% ATH (c) 4 wt% ATH and (d) 6 wt% ATH

THERMAL CONDUCTIVITY

Figure 3 shows the thermal conductivity ($Wm^{-1}K^{-1}$) of the hybrid PU composites at various ATH loading (wt%). The thermal conductivity increased with increasing ATH loading in the system but decreased at 6 wt% ATH. This indicated that the addition of ATH in the PU system contributes to poor thermal conductivity. The disability of ATH to dissipate the energy in term of heat flow resulted in higher k-value at higher ATH loading. Benli et al. (1998) reported that fine incorporation of filler particles in the matrix enhanced the thermal conductivity. When heat was introduced to the hybrid composites, ATH as rigid particles absorb an amount of heat and transfer it to the nearest ATH in the system. Modesti et al. (2002) also reported that addition of solid particles in the composites leads to higher thermal conductivity. The thermal conductivity of the hybrid PU system at 6 wt% ATH decreased maybe due to random dispersion of the ATH particles in the PU-EFB matrix as reported by Kumlutas et al. (2003). It might also be due to the ruptured cell wall that increased the diffusion rate of carbon dioxide out and air inside the system. Since air has lower k-value compared to the carbon dioxide, the whole hybrid PU composites exhibited an improved thermal conductivity.

ACOUSTIC PROPERTY

The acoustic property (Figure 4) showed that at lower frequencies (125 – 500 Hz), poor sound absorption was observed. The absorption coefficient (α) was the highest at 4 wt% ATH compared to 2 and 6 wt% ATH. All hybrid PU composites indicated higher absorption coefficient at frequency ranges at 2000-4000 Hz. When the incident sound wave hit the ATH, the sound energy is dispersed in the composites due to the attenuation of air viscosity in the cell pore. Interaction between the vibrated ATH increased the low frequency attenuation thus increase the absorption coefficient (Zhou et al. 2006).

CONCLUSIONS

The effect of aluminum hydroxide in the mechanical, thermal conductivity and acoustic property of the palm-based polyurethane composites has been studied. The hybrid PU composites with 2 wt% ATH showed higher properties for compression stress and modulus, thermal conductivity and acoustical characteristics. However, the acoustic study indicated that loading at 4 wt% ATH showed higher absorption coefficient at the range of 2000-4000 Hz. The loading of ATH is able to improve the mechanical, thermal and acoustic properties of the composites. However, it is suggested that treatment of ATH shall be carried out to improve the properties. Treatment of ATH with titanate as a coupling agent might be able to improve the mechanical properties of the composites.

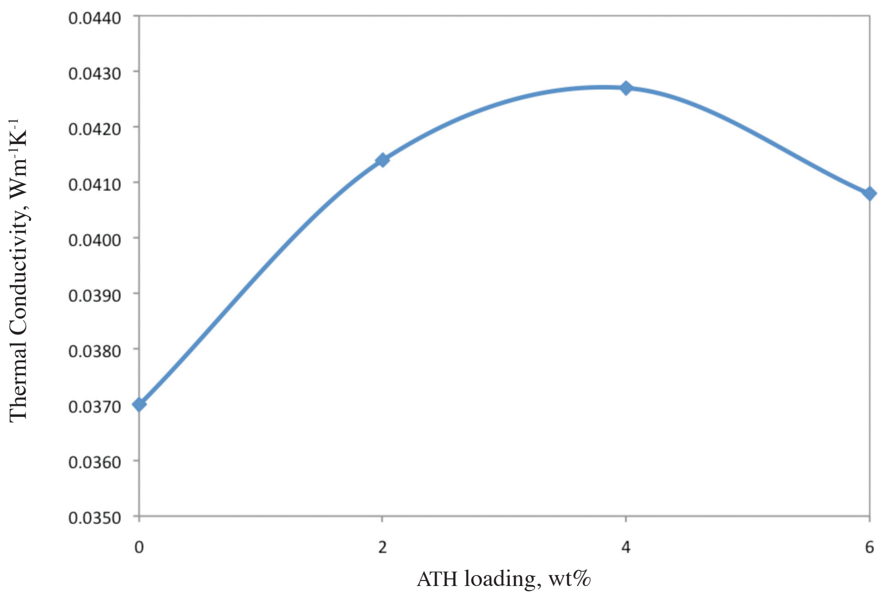

FIGURE 3. Thermal conductivity of the hybrid PU composites (with fixed amount of EFB at 10 wt%)

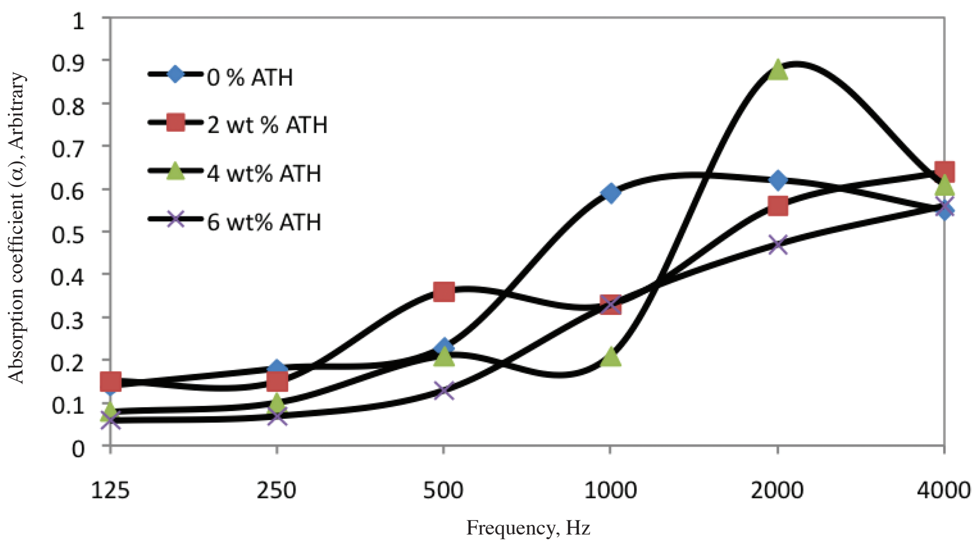

FIGURE 4. Acoustic property of the hybrid PU composites

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