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Firing Properties of Palm Fiber and Jute Fiber Hybrid MDF Crosslinked With Polyurethane and Magnesium Hydroxide ($Mg(OH)_2$) by Prepolymerization Process

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Abstract The goal of this analysis is to test some of the fire properties of a new hybrid medium density fiberboard (MDF) developed using a fiber mixture composed of 60:40 empty fruit bunch (EFB) and JUTE fiber coupled with palm-based pPU acting as a 70:30 binding binder. Magnesium hydroxide ($Mg(OH)_2$) was used as the fire retardant at loading percentage of 0, 5, 10, and 15 wt% of the total mass of the matrix. JUTE as well as EFB fiber had a size range of 350 to 750 μm. Fire resistivity was evaluated by bomb calorimetry and Fire test. The results indicated substantial improvements. The enthalpy measured by bomb calorimetry showed that hybrid-MDF's combustion enthalpy rose with increased ATH charge. The fire experiment was showing a lower burning rate (from 5.9 mm / s to 3.4 mm / s) when the $Mg(OH)_2$ percentage load was raised.

Keywords EFB fiber, JUTE fiber (JUTE), Magnesium hydroxide ($Mg(OH)_2$), pre-polyurethane (pPU)

Introduction

The growing demand for environmentally friendly fabrics coupled with the need to reduce the cost of conventional fibers led to the development of new bio-based and reinforced composites based on petroleum. Bio-composites or natural fiber-composites were also given more attention. Natural fiber composites are made of natural or synthetic resins combined with natural fibers [3]. Natural fibers such as hemp, flax and JUTE exhibit mechanical properties that are similar, and even comparable, to synthetic fibers such as glass. However, they are cheaper, lighter, biodegradable and easily available as agricultural resources in many developing countries [16]. Composites engineered from these natural fibers have the potential to be an excellent alternative to composites from synthetic fiber. Sectors like automotive. Medium-density fiberboard (MDF) is a dry panel that is and created from lignocellulosic fibers that are combined with a synthetic resin like phenol formaldehyde resin (PF), urea formaldehyde resin (UF), or isocyanate binder. Processing takes place in the presence of moisture and requires both heat and pressure [15, 7]. Commercial MDF is available in thicknesses ranging from about 3 to 100 mm and densities ranging from 450 to 900 kg/m³.

A hybrid composite's composition consists of more than one kind of fiber reinforcement or matrices, or a combination of both. The lack of certain elements of one type of fiber is complemented with other fibers with the help of hybridization. Therefore a balance between performance and cost can be accomplished in order to achieve a good material quality [11]. Joseph et al [10] experimented with onon banana and glass fibers reinforced phenol formaldehyde. They concurred with Amuthakkannan et al [2] that composite mechanical properties are determined by the fiber length and optimal fiber length. Among the types of wooden-based materials commonly employed in building and household furnishing construction are various medium-density fiberboards, or MDF. The most critical limitation of MDF is its susceptibility to flame hazards, and thus ensuring that the materials are capable of resisting flames is important [12].

The fire resistance of the board composite is very important nowadays, especially when the composite is used as structural components. The primary objective of a fire-resistant structural design is to maintain the structural intergrity during a fire for a sufficient period so that all the occupants may safely evacuate, firemen may extinguish the fire, and the loss of property may be minimized [9]. Particulate board is a combustible substance according to Shalbafan et al [17]. In this paper the flame retardance of hybrid MDF made from a mixture of EFB fiber and JUTE fibers (70:30) coupled with palm-based pPU as a binder was examined at a ratio of 60:40. The synthetic MDF was used as a fire retardant chemical in the form of Magnesium hydroxide ($Mg(OH)_2$). A new hybrid of hybrid medium density fiberboard (MDF) has the thermal and fire properties were evaluated.

Experimental

Materials and Preparation

The palm-based polyol (PKO-p) was supplied by UKM Technology Sdn Bhd through its pilot plant at MPOB/UKM Station, Pekan Bangi Lama, Malaysia. The crude 4, 4-methylene diphenyldiisocyanate (MDI), (Cosmonate M-200) was purchased from Cosmo-polyurethane, Port Klang, Malaysia. Acetone was supplied by Merck Sdn Bhd, Shah Alam, Malaysia. Polyethylene glycol (PEG200 with molecular weight of 200 Da) was purchased from Fluka Chemie Sdn. Bhd. Oil palm empty fruit bunch fiber (EFB) was obtained from Syarikat Seri Ulu Langat, Banting, Malaysia. Magnesium hydroxide ($Mg(OH)_2$) was manufactured by Fluka, Switzerland.

Dried EFB and JUTE fibers were refined using Ika Werke MF10 heavy-duty grinder and then sieved to obtain sizes of 350-750 µm. The resin was prepared by mixing PKO-p and PEG200 in acetone (20 wt %). The crude MDI was also mixed with acetone (25 wt %). Both mixtures were agitated separately in small beakers at 200 rpm for 60 s at room temperature. The amount of PKO-p and MDI used were at a ratio of 1:2. This formed the prepolymerised polyurethane resin (Pre-PU).The hybrid medium-density fiberboard (MDF) was produced by mixing $Mg(OH)_2$ and hybrid EFB/JUTE with pre-PU. The amount of PKO-p and MDI used was at a ratio of 100:200. The ratio of EFB to JUTE was predetermined from earlier stage at 60:40 and pre-PU to hybrid EFB/JUTE was fixed at 30:70. The $Mg(OH)_2$ was premixed with hybrid EFB/JUTE at varying amount of 5, 10, and 15 %w/w individually as shown in Table 3.3 Then, the mixture was added to the prepolymers and blended for 60 s prior to compression at 56 °C for 9 min at 760 MPa. The MDF was conditioned at room temperature for 24 h and then cut to desired size using Seppach circular saw model TS400IS for further characterizations.

Characterization

Bomb Calorimetry

Bomb calorimeter model IKA C 4000 was used to determine the initial enthalpy. 1.00 g of PU composites was put in the sample cup. The bomb was prepared by putting a wire (5 cm length) between two electrodes. A thread was also tied on the divider of the two wires touching the sample. The bomb was placed inside the chamber and was close tightly with purging oxygen at a pressure of 30 bar oxygen into the chamber. The chamber was transferred to a container where 1.8 L distilled water was poured and monitoring was carried out using the calorimeter IKA system [5].

Burning test

This test method was carried out to determine the flame resistance and burning characteristics of MDF and effect of flame retardant on MDF according to the ASTM D 5048-90 Procedure B method. The MDF produced were cut to test samples with dimensions of 125 mm × 30 mm × 10 mm (length × width × thickness). The test samples were then clamped at one end so that its position is at 30°. The blue flame from the Bunsen burner was positioned within the range of 25 – 30 mm from the specimens for 5 s. The overall burning time and the final length of the specimens were recorded.

Results and Discussion

Bomb calorimetric analysis

A series of thermodynamic evaluations were carried out by using bomb calorimetry in the form of enthalpy measurement. The bomb calorimetric measurement exhibited a constant increase in enthalpy value as depicted in Figure 1. In the hybrid composites, both fibers are encapsulated by PU resin, the increasing concentration of lignin offers protection to EFB during charring process, hence there by an increase in enthalpy is observed. The increase charring density is further support by the presence of $Mg(OH)_2$ in the hybrid-MDF [6]. In addition, the amorphous nature of $Mg(OH)_2$ promotes the formation of thermal charring on the surface of the condensed phase which blocks the release of gaseous fragments and prevents the transfer of heat back to the burning composite system [19]. Moreover, due to higher hydrophilic nature of JUTE, more internal energy is required, hence affecting enthalpy of the system. The unfilled hybrid-MDF shows an enthalpy value of 15.2 × 103 (kJ/kg), which is higher than JUTE-MDF. However, at 5 % $Mg(OH)_2$, a shift in the enthalpy value was observed at 16.3 × 103 (kJ/kg), which is higher than the unfilled hybrid-MDF as well as JUTE-MDF as shown in Figure 3. This increase in enthalpy is in accordance to the thermal degradation behavior, where hybrid-MDF showed better thermal stability and higher charring density then the individual system and this is mainly due to the hybrid effect of fibers within the system. $Mg(OH)_2$ suppresses oxygen and flammable gases by creating a non-flammable molecular layer on the surface of the fibers, thus enhancing the enthalpy values [20].

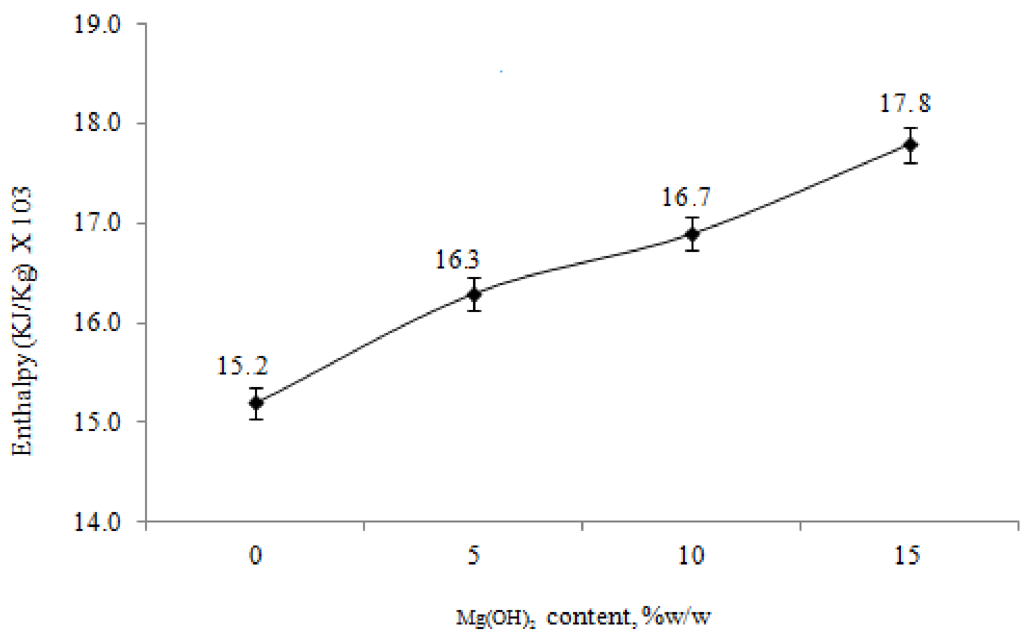

Figure 1: Enthalpy of the control hybrid-MDF and $Mg(OH)_2$-filled hybrid-MDF

It is proposed that when the concentration of $Mg(OH)_2$ increases, density of $Mg(OH)_2$ along the hybrid fibers also increases, hence more internal energy is required to break the energy barrier [13]. Thus, the higher the concentration of $Mg(OH)_2$, the higher enthalpy of the system. This was clearly evident at 15 % $Mg(OH)_2$, where the enthalpy was increased to 17.8 × 103 (kJ/kg). Within the hybrid system, the physical adhesion between two fibers along with the $Mg(OH)_2$ presence suppresses this effect, hence improving the internal resistance towards burning, thus offering higher enthalpy values. Higher lignin content within EFB comparatively to JUTE fibers supports the formation of charring density within hybrid system as a synergistic effect, hence improving the overall heat release and enthalpy properties [1].

This effect shows its prominence with increasing concentration of $Mg(OH)_2$ within hybrid-MDF. When $Mg(OH)_2$ was used in various loading levels, it helps to further increase the charring density, and this was observed in the thermal behavior studies also, so affecting the enthalpy values [4].

Burning test

The fire test for hybrid-MDF systems revealed a significant change in flame retardant property. Direct correlation for this behavior is that the flammability of natural fibers is contributed by its cellulose content [1]. One of the well-known flame retardants, $Mg(OH)_2$ used for natural fiber composites is used with the combination of char developing cellulose material, hence the hybrid-MDF offers improved charring content due to increased concentration of lignin from JUTE fibers along with $Mg(OH)_2$. The burning test indicated synergistic or combined effect of hybrid fibers. As shown in Figure 2 the burning rate of $Mg(OH)_2$/hybrid-MDF was slightly lower than the control hybrid-MDF at 5.9 mm/s.

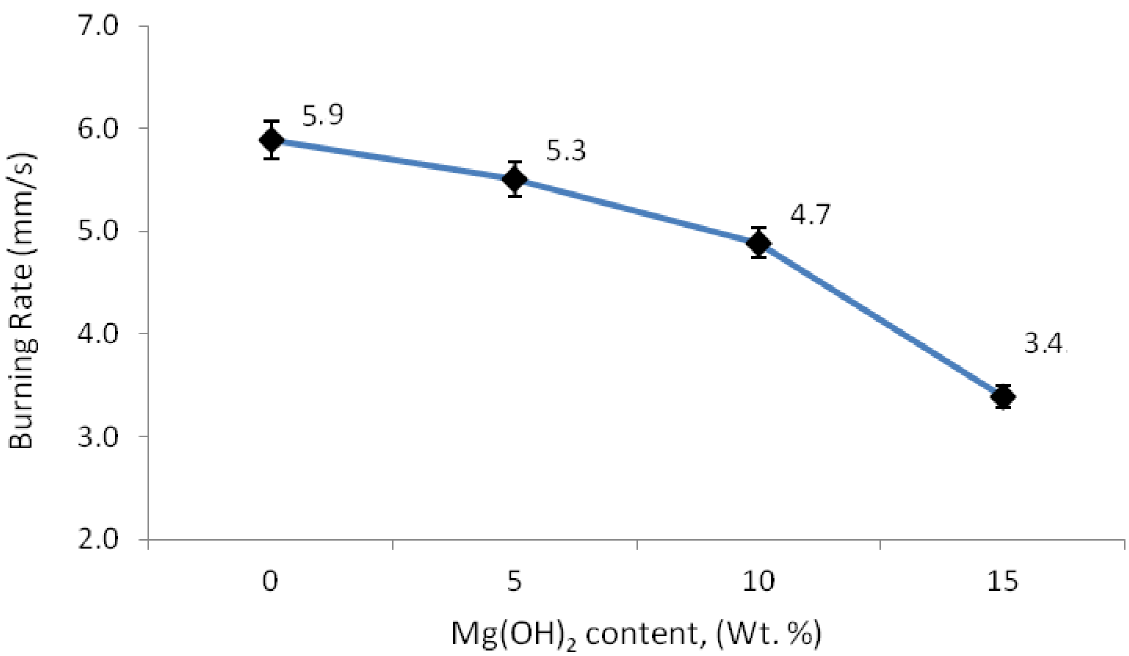

Figure 2: Burning rate of hybrid-MDF filled with 0, 5, 10 and 15 % $Mg(OH)_2$

Control hybrid-MDF burnt area covering a bigger surface area of 5.9 mm/s as opposed to when $Mg(OH)_2$ was added to the hybrid-MDF. This finding has been supported by Pandey et al [14] who mentioned that fireboard is highly flammable without flame retardant. However, a remarkable reduction was noticed when $Mg(OH)_2$ concentration was increased to a maximum of 15 % $Mg(OH)_2$. This phenomenon has been supported by the fact that $Mg(OH)_2$ possess heat absorbing capacity thereby inhibiting the combustion rate [15]. Therefore, the burning effect of the $Mg(OH)_2$/hybrid-MDF at 15 % $Mg(OH)_2$ was at 3.4 mm/s while 5.9 mm/s were observed at 5% $Mg(OH)_2$. This indicates that the burning effect of the hybrid was indirectly proportional to the $Mg(OH)_2$ loading. Thus, $Mg(OH)_2$ decomposes into two stable compounds resulting in the production of water vapor and alumina or aluminum oxide. The cellulosic content along with increase lignin concentration from JUTE fiber offers better increase heat absorption and lower burning rate while with addition of $Mg(OH)_2$, the values get better and this is the combined effect of $Mg(OH)_2$ and hybrid fiber interaction at microcellular level.

Conclusion

In this study, a new hybrid medium density fiberboard (MDF) was used in combination with a palm-centric pPU as a binder using a 60:40 empty fruit (EFB) fiber and JUTE (JUTE) fiber blend. ATH supplements were created for 5, 10, and 15 percent w / w tests. Both JUTE and EFB ranged in size from 350 to 750 μm. The enthalpy measured by the bomb calorie measurement showed that the Hybrid MDF combustion enthalpy increased with increasing $Mg(OH)_2$ load. In fire tests, increasing the percent load of Mg $(OH)_2$ slowed the burning rate (5.9 mm / s to 3.4 mm / s).

A new hybrid medium density fiberboard (MDF) was developed in this study using a fiber mixture composed of 60:40 empty fruit bunch (EFB) and JUTE (JUTE) fiber coupled with a pPU centered on the palm that acts as a binder. At 5, 10 and 15 per cent w / w testing, an ATH addendum was made. Both JUTE and EFB had sizes ranging from 350 to 750 μm. The enthalpy measured using bomb calorimetry showed that hybrid-MDF combustion enthalpy rose with increased loading of $Mg(OH)_2$. The fire check was showing a lower burning rate (from 5.9 mm / s to 3.4 mm / s) when the $Mg(OH)_2$ percentage load was raised.

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