

## Properties of Particleboard Made from Oil Palm Trunks Added Magnesium Oxide as Fire Retardant

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Published online: 25 April 2018

To cite this article: Selamat, M. E. et al. (2018). Properties of particleboard made from oil palm trunks added magnesium oxide as fire retardant. *J. Phys. Sci.*, 29(1), 59–75, <https://doi.org/10.21315/jps2018.29.1.5>

To link to this article: <https://doi.org/10.21315/jps2018.29.1.5>

**ABSTRACT:** *The aim of this study is to evaluate the physical, mechanical and flame retardant properties of particleboard made from oil palm trunk (OPT) with the addition of magnesium oxide as flame retardant. The physical and mechanical properties of the particleboard were evaluated based on Japanese Industrial Standard (JIS A 5908) and the flame retardant properties were determined according to International Standards Organization (ISO 4589). The particleboard was manufactured to a target density  $0.80 \text{ g cm}^{-3}$  with addition of magnesium oxide (0%, 10% and 20%). The results showed the thickness swelling and water absorption of treated particleboard decreased as the percentage of magnesium oxide increased. The untreated OPT particleboard without any flame retardant showed better mechanical strength. For thermogravimetric analysis (TGA), the treated OPT particleboard showed better thermal stability compared with the untreated OPT particleboard. The OPT particleboard treated with 20% magnesium oxide showed better flame retardant properties compared to the control and 10% magnesium oxide sample that satisfied the ISO 4589 standard requirement.*

**Keywords:** Physical properties, mechanical properties, flame retardant, oil palm trunk, magnesium oxide

### 1. INTRODUCTION

Particleboard is one of the engineered panels invented in the 19th century, but started to be commercialised in 1940s as a replacement for plywood due to shortage of lumber in plywood manufacturing.<sup>1</sup> It is usually made from a mixture of particles

bonded together with binder resin and some of the additives and then mechanically pressed into sheet form.<sup>2</sup> Due to the high demand of particleboards, it is necessary to manufacture ones that are more cost effective. Due to the material's abundance in quantity, relatively more cost effective than wood, and lower manufacturing cost, agricultural crop byproducts are a wise choice to manufacture particleboard.<sup>3</sup>

Malaysia is one of the world's largest producers and exporters of palm oil, with 5.64 million hectares of oil palm plantation recorded in 2015.<sup>4,5</sup> Besides producing a large amount of palm oil, it also produces a large amount of agricultural wastes such as oil palm fronds (OPF), empty fruit bunches (EFB), oil palm trunk (OPT), palm pressed fibres (PPF), palm oil mill effluent (POME) and palm shells.<sup>6</sup> If these wastes are not disposed well, the consequence will negatively impact the environment. To overcome this problem, the utilisation of oil palm tree to produce a variety of valuable products has been done in numerous studies. The productions of nanocrystalline cellulose (NCC), microcrystalline cellulose (MCC) and bio char proved that besides oil, oil palm tree also can be used as the main raw materials to produce other products for different applications.<sup>7-10</sup>

The production of particleboard with fire resistant properties is very important to ensure that occupants may safely evacuate, loss of property may be minimised, and firemen may extinguish the fire effectively. Yet, so far no wood material is completely fireproof; only limited fire resistance can be achieved in wood.<sup>11</sup> Flame retardants are chemical substances that are added to materials in order to inhibit or delay the spread of fire as well as to stop the polymer combustion process.<sup>4</sup> There are many types of flame retardant chemicals such as halogen-based, halogen-free and metal oxide-hydroxide minerals.<sup>12</sup> Table 1 shows the previous studies that investigated the effectiveness of flame retardant treatments on wood composites.

All these factors are reasons for the selection of raw materials and fire retardant. Previous study by Chin showed that different types of urea formaldehyde (UF) resin will give different effect especially on the physical and mechanical properties of the particleboard.<sup>1</sup> However, there is no study on the effect of OPT particleboard bonded with UF resin and magnesium oxide as additive. Although some commercial panel products such as XinLongBoard and RockMax use magnesium oxide filled with palm fibre as filler to produced fire retardant panels, the main different between these commercial products with the one produced in this study is magnesium oxide was added to reinforced and improved the flame retardant properties of OPT particleboard.<sup>11,12</sup>

Table 1: Flame retardants of various wood composites.

Board	Materials	Adhesives	Additives	Authors
Particleboard	Oak ( <i>Quercus spp.</i> ), lauan ( <i>Shorea spp.</i> )	Polymeric 4,4'-methylenediphenyl isocyanate (PMDI), Phenol formaldehyde (PF)	FR1: Mixture of ammonium phosphate, diammonium phosphate, ammonium sulphate, borax, boric acid, ammonium bromide FR2: Mixture of chloride, inflammable emulsion resin, phosphide, titan white, and other volatile components	Wang et al. (2008)
Medium density fibreboard	Rubberwood fibres	UF	Sodium aluminate, zinc borate, aluminium trihydrate (ATH)	Hashim et al. (2009)
Particleboard	Kenaf	UF	Diammonium phosphate (DAP)	Kamal et al. (2009)
Particleboard	Kenaf	UF	Monoammonium phosphate (MAP)	Thinnizir et al. (2009)
Particleboard	Kenaf	UF	Mixture of boric acid (BA), guanylurea phosphate, and phosphoric acid	Izran et al. (2010)
Particleboard	Engkabang, acacia mangium	UF	Zinc borate, monoammonium phosphate	Kamal et al. (2010)
Particleboard	Rubberwood	UF	Combine phosphoric acid and BA	Izran et al. (2011)
Particleboard	Saw dust fibres	UF	BA, borax (BX)	Nagieb et al. (2011)
Particleboard	White birch	UF	BA	Pedieu et al. (2012)
Natural fibre-reinforced composite	EFB, kenaf	Polylactic acid (PLA), polystyrene (PS), epoxy resin	ATH	Tshai et al. (2014)

\*FR: Flame retardant

In this study, the OPT particles were used as the main material while the commercial panels are using the palm fibre as filler. In addition, the commercial panels as previously mentioned are using magnesium oxide as the main material to form the matrix of the panels. In this study, the physical, mechanical and thermal properties of the flame retardant oil palm trunk particleboard were investigated.

## **2. EXPERIMENTAL**

### **2.1 Particleboard Manufacturing**

OPT particles were used as raw material and were obtained from Encore Agricultural Industries Sdn. Bhd., Pahang, Malaysia. The UF resin used as binder for this study was obtained from Asta Chemicals located in Perai, Penang, Malaysia. Flame retardant additive used in this research was magnesium oxide (MgO) powder whereas ammonium chloride ( $\text{NH}_4\text{Cl}$ ) was used as hardener.

Initially, the OPT particles were dried in an oven at  $103 \pm 2^\circ\text{C}$  for 2 h to ensure that the moisture content of the particles was between 4% and 6%. The particleboard was produced to a target density of  $0.80 \text{ g cm}^{-3}$  with 6 replicates of particleboards for each set to ensure the collected data is more accurate. About 10% of UF, magnesium oxide (10% and 20%) and 1% of ammonium chloride based on oven dried weight of OPT particles were mixed manually with hand and stirred with 20 ml of distilled water. The addition of distilled water is to ensure that the UF resin is uniformly distributed within the particles since only 10% of UF resin was added into the mixture. The mixture was then placed into a mold with dimensions of  $21.0 \text{ cm} \times 21.0 \text{ cm} \times 0.5 \text{ cm}$ , followed by a pre-pressing using a cold press machine to form a mat. The mat was then hot pressed at a temperature of  $160^\circ\text{C}$  with a pressure of 40.0 MPa for 8 min. The particleboard was cooled and conditioned in a room with surrounding temperature of  $25 \pm 2^\circ\text{C}$  and a relative humidity of  $65 \pm 2\%$  for 2 days. Particleboard prepared without the addition of magnesium oxide was used as control particleboard to determine the effect of magnesium oxide on the particleboard properties.

### **2.2 Determination of pH of Oil Palm Trunk Particles**

The pH of oil palm particles was determined according to the method described by Lebow and Winandy.<sup>15</sup> Approximately 1 g of samples was mixed with 20 ml of distilled water and soaked at room temperature overnight. The pH meter (Mettler Toledo) was used to measure the pH values of untreated and treated particles.

### **2.3 Evaluation of Physical and Mechanical Properties**

The physical and mechanical tests were carried out according to Japanese Industrial Standard (JIS A 5908).<sup>16</sup> The physical tests consist of density, moisture content, water absorption and thickness swelling. For mechanical testing, the modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) were carried out using an Instron Tensile Machine Model 5582.

## 2.4 Characterisation of Particleboard

### 2.4.1 FTIR analysis

The Fourier transform infrared (FTIR) spectroscopy was used to identify any major difference in presence of functional groups between control sample and samples with magnesium oxide additive of particleboard. In this test, Nicolet Avatar 360 ESP FTIR spectrophotometer was used to analyse each material.

### 2.4.2 SEM analysis

Scanning electron microscopy (SEM) was used to observe morphological properties and bonding quality of raw material and UF resin with different concentration of magnesium oxide on panels produced. The samples were examined using SEM microscope LEO Model Supra 50 Vp, Carl Zeiss SMT, Germany with an accelerating voltage of 15 kV.

### 2.4.3 EDX analysis

The samples used for SEM analysis was then further extended to determine the elemental composition of raw materials by energy dispersive X-ray (EDX) analysis. The instrument used was Oxford INCA 400 energy dispersive X-ray microanalysis system (Oxford Instruments Analytical, Bucks, UK).

### 2.4.4 XRD analysis

The X-ray diffractometry (XRD) was used to determine the percentage of crystalline structure. The instrument used in this test was a Kristal-loflexD-5000 X-ray diffraction system (Siemens, Germany). The X-rays (Cu) were generated with an opening voltage of 40 kV and a current of 30 mA for the step scan measurement. The scanning process was then carried out at a  $2\theta$  diffraction angle in the range of 10–40 with 0.02 and 2  $\text{min}^{-1}$  scanning speed. The crystallinity index of each sample was determined using the same formula used by Segal et al.<sup>17</sup> as shown in Equation 1:

$$C_{\text{ir}}(\%) = \frac{I_{200} - I_{\text{am}}}{I_{200}} \times 100 \quad (1)$$

where

$I_{200}$  = peak intensity of crystalline fraction

$I_{\text{am}}$  = peak intensity of amorphous fraction

## **2.5 Thermal Analysis and Flame-retardant Properties of Particleboard**

### **2.5.1 TGA**

Thermogravimetric analysis (TGA) was used to determine properties of materials such as mass changes as they change with temperature and study thermal degradation reactions of materials.<sup>17</sup> In this test, a Mettler Toledo TGA/SDTA85 thermogravimeter (Mettler Toledo Corp., Switzerland) with STA software (version 9.20) was used to characterise all 3 samples.<sup>18</sup> Each sample was subjected to the increased heat with  $20^{\circ}\text{C min}^{-1}$  heating rate starts from  $30 \pm 2^{\circ}\text{C}$  up to  $800 \pm 2^{\circ}\text{C}$ .

### **2.5.2 LOI**

Limiting oxygen index (LOI) was used to determine the flammability of materials treated with flame retardant chemicals. For this test, 5 replicates with  $8\text{ cm} \times 1\text{ cm}$  dimensions from each condition was analysed according to the ISO 4589 with the Fire Testing Technology LOI instrument.<sup>19</sup>

## **3. RESULTS AND DISCUSSION**

### **3.1 pH Value of Oil Palm Trunk Particles**

The pH values of particles before and after treatments ranged between 6.33 and 10.20. OPT particles had the pH value of 6.33 which is considered as weak acid. The board treated with 10% magnesium oxide showed high alkalinity with 10.12 while 10.20 for particleboard treated with 20% magnesium oxide respectively. This is because magnesium oxide is a basic oxide that will give alkali properties to the produced board. The pH of the particles basically will affect the physical and mechanical properties of the particleboard produced.<sup>20</sup> Previous study by Yusoff et al. showed that the properties of fibre used in the production of particleboard decreased after the fibre was treated with sodium hydroxide, NaOH which is an alkaline base.<sup>21</sup>

### **3.2 Physical Properties**

The physical properties of particleboards were shown in Table 2. The average density value for all particleboards produced was not much different with a target density of  $0.80\text{ g cm}^{-3}$ . This is because same mould was used to produce each of particleboard in the laboratory. All of the OPT particleboards produced also had met the standard requirement stated in the Japanese Industrial Standard (JIS A 5908)<sup>16</sup> which was in the range of  $0.40\text{ g cm}^{-3}$  to  $0.90\text{ g cm}^{-3}$ . Moisture content

for the particleboards produced showed decreasing trend as the percentage of magnesium oxide increased and ranged at 3%–6%. For thickness swelling after 24 h, the OPT particleboard treated with 20% magnesium oxide showed the lowest thickness swell compared to untreated and particleboard treated with 10% magnesium oxide. The results for water absorption correspond well with thickness swelling. As the loading of flame retardant increased, water absorption and thickness swelling decreased. During the production of particleboard, some fire retardant additives were probably able to penetrate into the oil palm trunk particles in order to hinder water absorption of the samples. This can be seen in Figure 1 showing crystals of flame retardant additives on cell wall of particles.

Table 2: The physical (a) and mechanical (b) properties of control sample and particleboard added with magnesium oxide.

Sample	Density (g cm <sup>-3</sup> )	Moisture content (%)	Water absorption (%)		Thickness swelling (%)		MOR (MPa)	MOE (MPa)	IBS (MPa)
			2 h	24 h	2 h	24 h			
Control sample	0.81 (0.03)	5.57 (0.22)	91.61 (6.32)	118.01 (6.86)	34.22 (6.11)	41.45 (8.64)	5.80 (1.33)	1149.60 (185.73)	1.16 (0.75)
10% MgO	0.81 (0.06)	4.75 (0.16)	88.67 (8.12)	99.92 (7.26)	31.44 (6.14)	38.51 (7.36)	4.30 (1.31)	848.40 (161.03)	0.62 (0.44)
20% MgO	0.80 (0.04)	3.92 (0.14)	77.71 (7.42)	85.70 (7.56)	20.91 (5.77)	28.83 (6.95)	2.90 (1.06)	786.60 (145.50)	0.54 (0.23)

Notes:

MOR = Bending strength, MOE = Bending modulus, IBS = Internal bond strength

\*10% MgO: Particleboard mixed with 10% magnesium oxide

\*20% MgO: Particleboard mixed with 20% magnesium oxide

\*Values in parentheses represent the standard deviation

### 3.3 Mechanical Properties

The results of mechanical properties for all the particleboards produced were shown in Table 2. Based on Table 2, the collected data for mechanical properties showed similar trend as the physical properties. It shows the decreasing trend for MOR, MOE and IBS of OPT particleboards as the percentage of flame retardant additive increased. The control samples which are free from any flame retardant showed the highest average reading for all three mechanical tests. The OPT particleboard added with 20% magnesium oxide gives the lowest average reading MOR, MOE as well as IBS. This might be due to the presence of flame retardant additives deposited on the particles of OPT particleboards as indicated by the SEM analysis (Figure 2). The deposited of flame retardant in particleboard probably will interfere the inter-particle bonding between the particles that will weaken the mechanical strength of the particleboard.

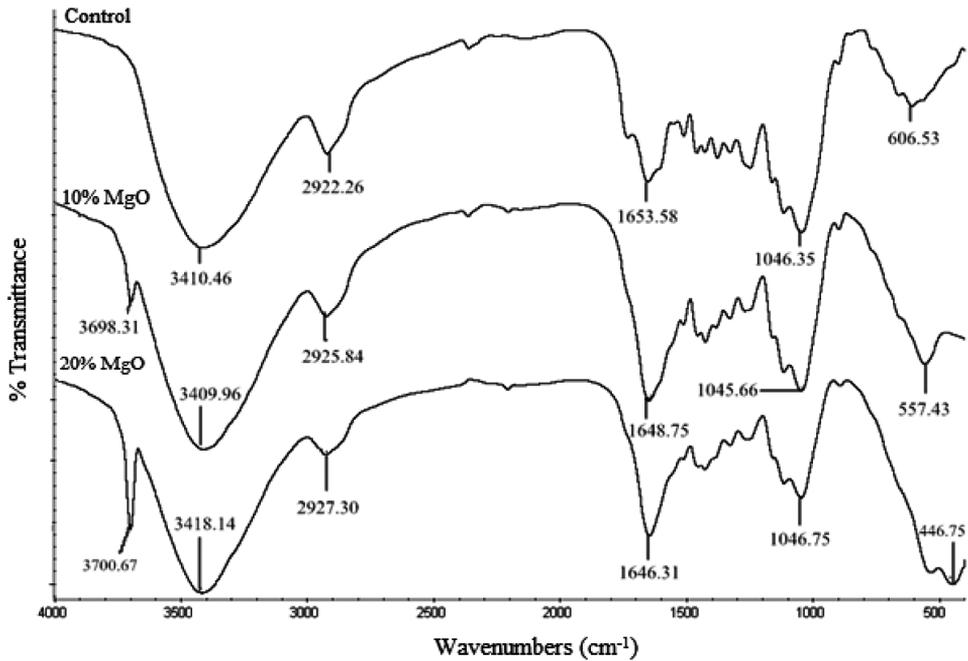


Figure 1: FTIR spectrum for control sample and particleboards treated with different loading of magnesium oxide.

### 3.4 Characterisation of Particleboard

#### 3.4.1 FTIR analysis

This analysis was conducted to obtain a clear view of OPT particleboard before and after treated with magnesium oxide and to determine the existence of any new functional groups. The results of FTIR are shown in Figure 1. There was not much difference in spectra for all the particleboards produced. The significant different was at the peak around 4000–3500  $\text{cm}^{-1}$  for all the OPT particleboards produced. It was obvious that only OPT particleboard treated with 10% and 20% magnesium oxide had the peak which was 3698.31  $\text{cm}^{-1}$  and 3700.67  $\text{cm}^{-1}$  respectively. This may be caused by the presence of stretching O-H groups that form after the reaction between magnesium oxide and water during particleboard making.<sup>21</sup>

#### 3.4.2 SEM analysis

This analysis was carried out to observe the distribution of adhesive and additive in the OPT particleboard produced. Figure 2 (a) and (b) with 500X and 1000X magnification showed that UF resin are well mixed with particles on both samples.

With larger 1000X magnification for Figure 2(a), the clear view of silica was observed in untreated OPT particleboard sample which is similar to the previous finding by Darmawan et al.<sup>22</sup> The natural presence of silica in OPT particles could help to improve the flame retardant properties but at the same time may decrease the physical and mechanical properties of the prepared particleboard.<sup>23</sup> In Figure 2(b) with 1000X magnification, the presence of round shape magnesium oxide was observed scattered on the particles surface. The magnesium oxide observed in this study is supported by Tamilselvi et al. finding where it showed similar shape of magnesium oxide.<sup>24</sup>

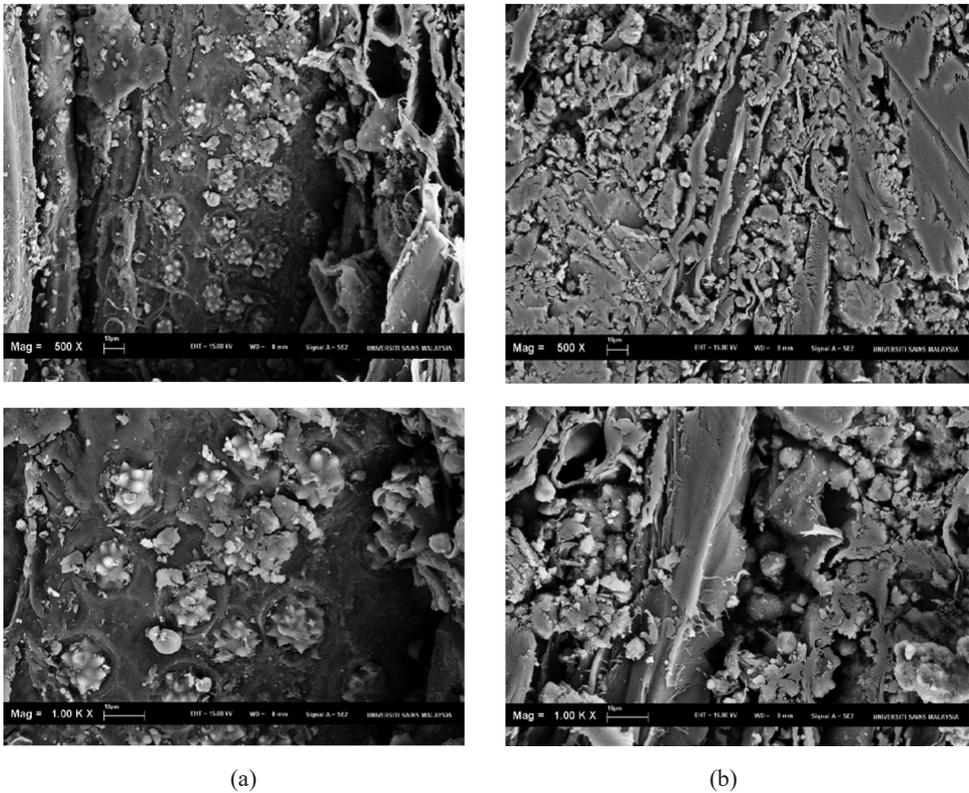


Figure 2: SEM micrograph of cross sectional view of (a) untreated OPT particleboard, and (b) OPT particleboard treated with 20% magnesium oxide (magnification = 500X and 1000X).

### 3.4.3 EDX analysis

EDX was used to analyse the elemental composition of flame retardant OPT particleboard compared to control sample. The results obtained in EDX (Figure 3) can be used to prove the results obtained in SEM analysis. From Figure 3, it can

be seen that control sample contained carbon (C), silica (Si) and oxygen (O). The highest percentage of element detected in control sample is oxygen with 72.29% followed by carbon with 26.71%. About 1% of silica was recorded in this sample and it is supported by previous SEM analysis that the presence of crystal-like structure in control sample. This 1% of silica is natural silica from the OPT particle that could help to improve the flame retardant properties of the particleboard.<sup>25</sup> In the OPT particleboard treated with 20% magnesium oxide, about 60.14% of oxygen, 22.96% of magnesium and 16.90% of carbon was recorded. High percentages of magnesium in this sample is due to high amount of flame retardant.

The percentage of carbon and oxygen decreased as the percentage of magnesium oxide increased as indicated in Figure 3. High loading of magnesium oxide added is the main reason that lead to the increase of magnesium (22.96%). Furthermore, high percentage of magnesium oxide detected in this analysis also indicates that the OPT particles are well mixed with the flame retardant.

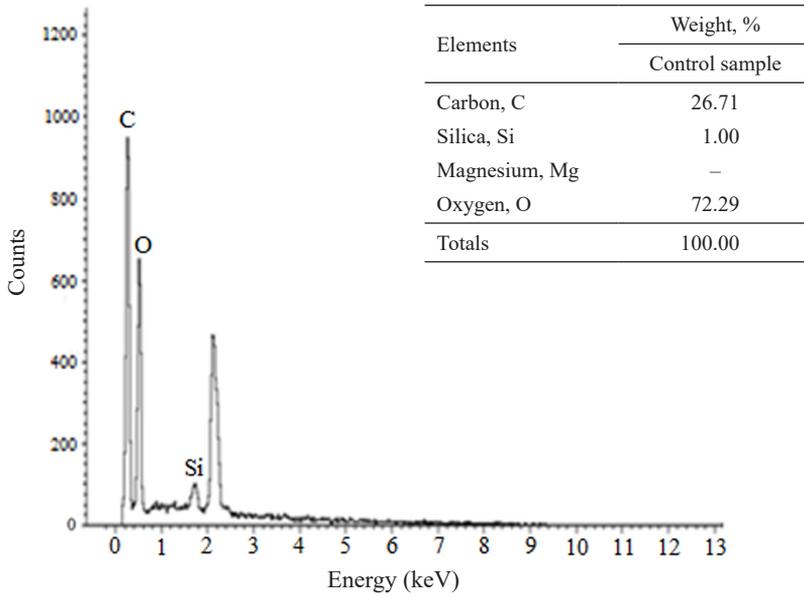
#### **3.4.4 XRD analysis**

This analysis was conducted to determine the crystallinity of crystal structure and lattice constant of OPT particles before and after the particleboard making. As presented in Figure 4, there are no major differences in crystallinity index before and after the production of particleboard. However, there is a slight change detected in the OPT particleboard treated with 10% magnesium oxide with 58.7% compared to the OPT particles with 58.0%. The control sample which is free from addition of flame retardant gives 54.9%. Moreover, the crystallinity index of control OPT particleboard showed lower reading than the treated particleboard with 54.9%. This is due to the addition of magnesium oxide that deposited on the particles. In addition, the effect of treated OPT particleboard is supported by the SEM and EDX analysis as previously discussed.

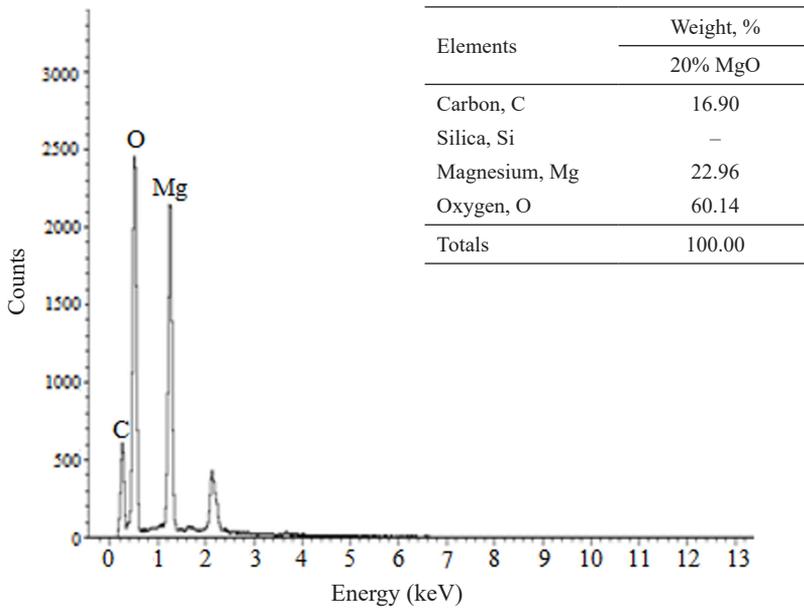
### **3.5 Thermal Analysis and Flame Retardant Properties**

#### **3.5.1 TGA analysis**

This analysis is to study thermal degradation and to determine properties of materials as the temperature changes.<sup>26,27</sup> In this study, the decomposition of OPT particleboard with three different conditions was evaluated. The control sample was used as relative to the effectiveness of the OPT particleboard treated with magnesium oxide.<sup>28</sup> Based on Figure 5(a), three stages of weight loss were observed on each sample.



(a)



(b)

Figure 3: SEM micrograph and EDX spectrum of OPT particleboard of (a) untreated OPT particleboard, (b) OPT particleboard treated with 20% magnesium oxide.

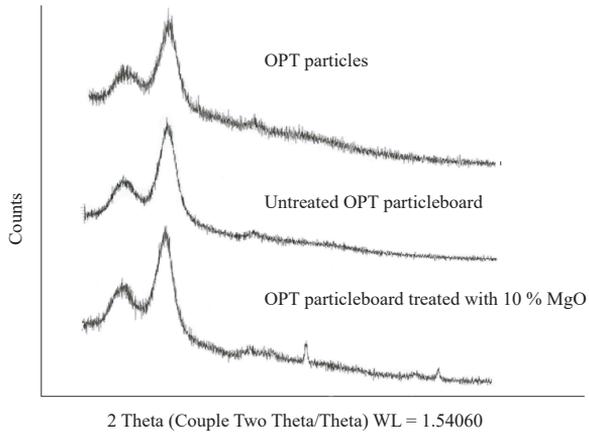
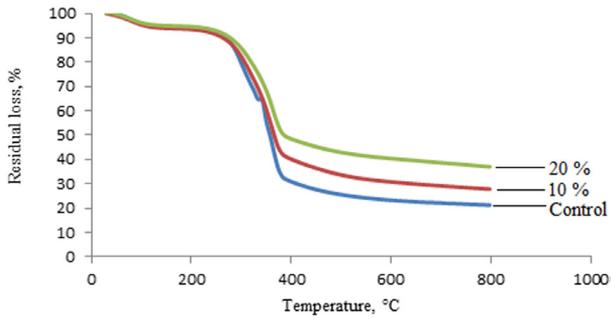
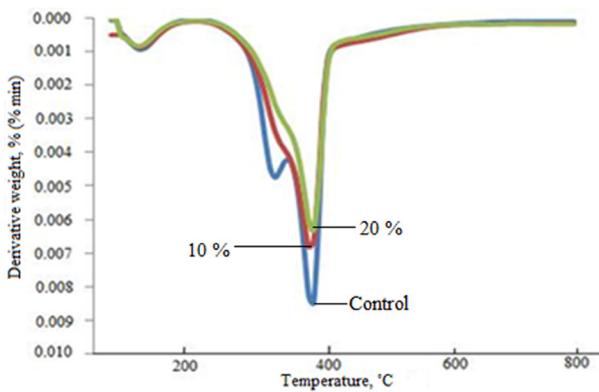


Figure 4: XRD of OPT particle and particleboard prepared.



(a)



(b)

Figure 5: Illustrations of (a) TG and (b) DTG curves of OPT particleboards treated with different percentage of magnesium oxide compared to control sample.

The initial weight loss took place due to the drying and evaporation of moisture and other volatile materials from 50°C to 150°C. The second stage of weight loss is caused by the degradation of non-celluloses materials such as hemicelluloses ranging from 150°C to 300°C. In addition, it also represents the breakage of glycosidic bond in the sample. In second stage, the percentage of weight residue for the particleboard treated with magnesium oxide showed almost similar results with 73.21% for 10% magnesium oxide treated particleboard and 73.40% for particleboard treated with 20% magnesium oxide whereas, the control particleboard sample gives the lowest residue with 68.95%. The third stage or final stage of weight loss for all sample occurred in the range 300°C to 380°C. The degradation and depolymerisation of  $\alpha$ -celluloses in the samples took place in this stage.<sup>29</sup> At the end of this analysis, the highest percentage of residue was observed in particleboard treated with 20% magnesium oxide with 43.08% followed with the 10% treated particleboard with 27.90% and control sample with 21.34%.

From this analysis, it is proven that the addition of magnesium oxide successfully improved the thermal stability of the sample. An increase in the percentage of flame retardant showed higher percentage of residue. This is because magnesium oxide acts as a good insulating barrier capable of resisting the heat.<sup>30</sup> Although the control OPT particleboard samples contain silica, it is not good enough to overcome the high temperature exposed on it producing low residue than other samples. The magnesium oxide provides a protective region in the particleboard that enables it to prevent thermal degradation of the sample. Previous study by Tay et al. stated that as the amount of flame retardant increase, the degradation temperature increase, and the mass residue will also increase.<sup>31</sup>

From the results obtained, it has been confirmed that magnesium oxide has the potential to be used for flame retardant applications. According to DTG graph as shown in Figure 5(b), the control particleboard sample had the fastest rate of degradation followed by 10% and 20% magnesium oxide. This is because as the loading of magnesium oxide increases, the higher temperature is required to degrade the sample. The control sample needed more time and temperature to degrade the components in sample, resulting in the most weight loss.

### 3.5.2 LOI

This analysis was conducted to calculate the minimum percentage oxygen index needed to maintain flaming combustion of flame retardant OPT particleboard under specified laboratory conditions.<sup>32</sup> Table 3 shows the results of LOI obtained for all the particleboards produced. Based on the findings of a previous study, it had been understood that the greater the amount of oxygen required to burn the

samples, the greater the flame resistance of the substance.<sup>1</sup> It also proved that any materials with LOI value greater than 26% were considered to be flame retarded and the LOI value of at least 28% would indicate that the materials had good fire resistance capability.<sup>1,15</sup>

Table 3: LOI for all the particleboards produced.

Particleboard	LOI (%)
Control sample	25.65
10% magnesium oxide	29.27
20% magnesium oxide	30.81

From Table 3, the OPT particleboard treated with 20% magnesium oxide had the highest LOI value with 30.81% followed by particleboard treated with 10% magnesium oxide with 29.27% and control sample with 25.65%. It shows that a small amount of magnesium oxide could significantly improve the flame retardant properties of particleboard. All of these might be due to the distribution of flame retardant added and the matrix of particleboard that may affect the mechanism of flame retardant. As the loading of flame retardant increased, the higher oxygen concentrations required to ignite the particleboard.

#### 4. CONCLUSION

The physical properties of the oil palm trunk particleboard were not affected by the increased of flame retardant except for thickness swelling, and water absorption which slightly decreased as the percentage of magnesium oxide increased. The mechanical properties of the particleboard decreased as the percentage of flame retardant increased since the deposited magnesium oxide will hinder the inter-particle bonding among the particles and the dispersion of urea formaldehyde resin. The addition of magnesium oxide successfully improves the thermal stability and the flame retardant properties of the oil palm trunk particleboard. Based on the findings in this study, the potential of magnesium oxide as flame retarder in OPT particleboard were evaluated.

#### 5. ACKNOWLEDGEMENTS

We acknowledge Universiti Sains Malaysia (USM) for the Research University Grant (RU 1001/PTEKIND/814256). We also thank Encore Agricultural Industries Sdn. Bhd., Pahang for providing raw materials and Asta Chemicals, Perai, Penang for providing urea formaldehyde resin to be used in this study.

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