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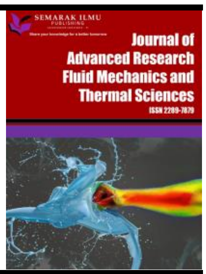

Fire Resistance Rating for Gypsum and Kapok Fiber Composite Materials

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ABSTRACT

Fire rated door is one of the passive fire protection systems that can prevent fire and smoke from spreading when a fire occurs. The purpose of this study was to analyze fire rated doors made of Gypsum and Kapok fiber composites. This fire rated door has been manufactured in accordance with Malaysian Standard MS1073: Part 2: 1996. This fire rated door has been modified with various composite compositions and thicknesses. The results showed that the fire rated door made of Gypsum and Kapok fiber can last from 30 to 60 minutes. This study clearly shows that door thickness is very important in the manufacture of fire rated door.

1. Introduction

Fire accidents are usually unexpected and sudden, because they can happen anywhere and at any time. Fire can be a human hazard that can risk human life, property loss and environmental pollution [1]. Figure 1 shows fire incidents by type of premises in 2016, showing residential statistics dominated by 54.89%, followed by other cases (21.58%) and commercial or industrial buildings (20%). In the case of fire accidents, fire protection systems in buildings are needed to comply with the rules on fire safety in buildings. Fire door is one of the passive fire protection systems that act as fire protection to prevent the spread of fire and smoke within a certain period of time [2,3]. Although the fire door is fire resistant, it is not fully fire proof and will only slow down the spread of fire for a prolonged period of time. Normally, the ideal door is able to withstand the spread of fire for at least 30 minutes. The door must be able to withstand fire until it becomes damaged. This is because the fire door also uses combustible material in its mixture, such as gypsum with metal or a fire resistant base. The location of the fire door in the building and the fire risk in the building are vital since they will help citizens evacuate from the building before the fires enclose the roof, giving fire fighters enough opportunity to clear flames and save buildings and property from destruction.

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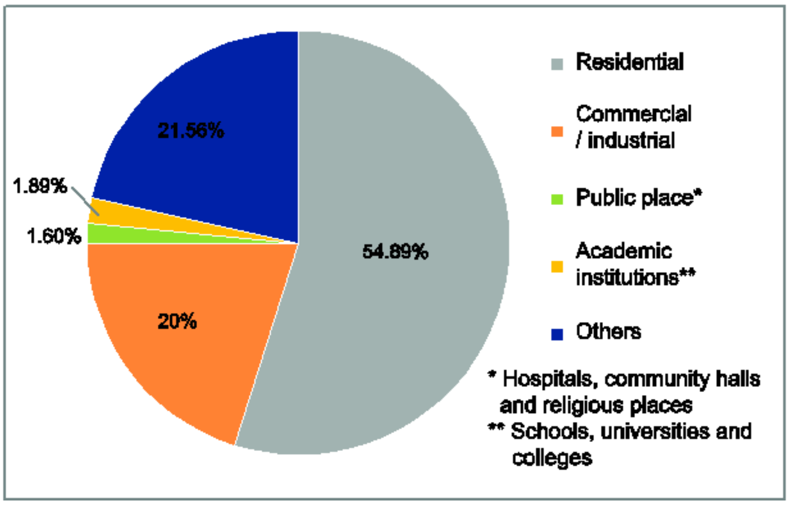

Fig. 1. Fire incidents by type of premises in 2016 [4]

Each country has its own standard regulations regarding the design, testing and installation of fire doors. For example, the United States has separate regulatory bodies that carry out guidelines. In order to render fire doors efficient, fireproof walls must be installed. The fire strength of the doors should be three quarters of the wall resistance. For example, if the walls can resist fire in a period of 120 hours, the fire door must stand for at least 90 minutes. This device would mean that the door works more quickly and would provide time for citizens to escape from the building. The requirement for a fire door for the entire Malaysian construction industry was clearly stated in the Uniform Building By-laws of 1984 (Amendment 2012). The second rule of Regulation By-Law 186 of the Uniform Building By-Law 1984 states that fire doors used in buildings in Malaysia requiring mandatory fire resistance tests in accordance with the Malaysian standard – MS 1073:Part 3:1996. One hour fire-rated and two hours fire-rated are the two most common fire resistance ratings in Malaysia. Commercial fire doors generally made of thick wood or heavy metals may cause human injury [5]. This drawback brings considerable research into the development of a light fire door [1,5-7]. The material parameter is known to affect fire resistance performance [8]. Composite materials are of great interest to researchers in developing light fire doors.

Gypsum is a porous, lightweight and environmentally friendly building material commonly used because of its heat insulation and fire resistance [9]. Owing to its benefit, gypsum is mostly used for construction and agricultural purposes. Nowadays, natural fibers such as hemp, jute, bagasse, sisal and kapok are gaining attention in the construction sector due to their many advantages, including light weight and biodegradability. The authors also published an in-depth study on the development of palm oil-based bio-lubricant, one of Malaysia's natural resources with a promising future for commercialization [10-17]. Kapok also environmentally friendly and has a lot of economically advantageous [18]. Kapok fiber was selected in the present research due to its durability, light weight and outstanding thermal insulation characteristics. Kapok fiber is well insulated due to its air-filled lumen structure [7]. In view of the above, this study aims to evaluate the fire resistance rating of gypsum and kapok fiber composites. The fire resistance rating of composite materials was evaluated using a non-combustibility test in accordance with Malaysian Standard MS1073: Part 2:1996 with varying composition and thickness.

2. Methodology
2.1 Materials and Sample Preparation

Gypsum and kapok fiber were selected to be used as fire-resistant material due to their environmentally friendly, low cost and local availability. Gypsum was commonly used fire resistance material due to its ability to retain and release moisture to cool down the surrounding temperature after burning [8]. The properties of gypsum are soft, perfect cleavage, specific gravity and low harness. It's extremely soft, and can be easily scraped with a fingernail and has a Mohs hardness number of 2. Gypsum has a specific gravity and thermal conductivity of 2.3 and 0.17 w/ (m.K) [19]. Kapok fiber is a natural fiber with good heat insulation due to its air-filled lumen structure [20].

Gypsum and kapok are mixed at different ratios and thicknesses. The specimens were prepared by manually mixing the gypsum and kapok fiber with water until the slurry was created. The slurry was then poured into a mould made of wood with dimensions (L×W×T) of 200×200×20 (mm) and compressed until the appropriate thickness was obtained. The specimens were dried under sunlight for 6 hours until the specimens become solid (see Figure 2). The density of the specimens was obtained by calculation. The descriptions of the specimens included in the present study are given in Table 1, where ρ is density of specimen (kg/m^3); m is mass of specimen (kg) and v is the volume of specimen (m^3). The volume of the specimen is calculated by multiplying the length (m), width (m) and thickness (m) of the specimen.

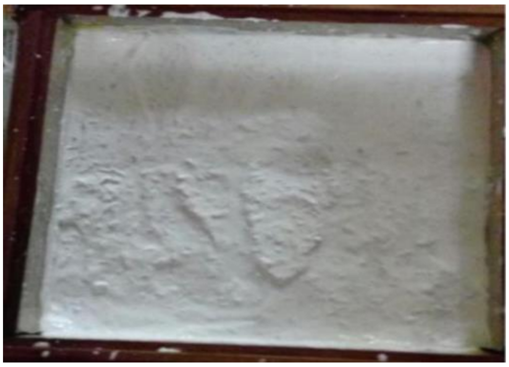

Fig. 2. Representative of the Gypsum and Kapok composite fiber specimens produced

Table 1
The composition of the gypsum and kapok fiber, thickness and the density of the specimen

Specimen name	Gypsum (g)	Kapok fiber (g)	Thickness (mm)	Density, ρ (kg/m^3)
S1	490	10	6.4	898.44
S2	490	10	9.5	860.53
S3	490	10	12.7	862.20
S4	480	20	6.4	878.91
S5	480	20	9.5	834.21
S6	480	20	12.7	799.21
S7	470	30	6.4	753.90
S8	470	30	9.5	713.16
S9	470	30	12.7	700.79

2.2 Test Setup and Procedure

In the present analysis, the fire resistance rating of composite specimens was measured using a non-combustibility test in compliance with Malaysian Standard MS1073: Part 2:1996 (Method for the determination of fire resistance (General Principle). This approach was used to assess the duration of composite fire resistance material that can tolerate standard fire exposure to have a standard temperature-time curve for the testing of composite fire resistance materials. The temperature was determined on the unexposed surface of the specimen. This approach was preferred because the application of this method is more convenient and cost-effective than the other method. In the present analysis, the fire resistance rating was examined by fire integrity using a small-scale experimental setup.

The specimen masses were initially determined and both the ambient temperature and the initial furnace temperature were reported. The ambient temperature of the laboratory should be between 24°C to 35°C in order to conform with the standard MS1073: Part 2:1996. The furnace, composed of bricks with a scale of 5000×2300×3000 mm, was heated at a steady range of 650°C to 700°C and kept constant for 10 minutes. Liquid petroleum gas has been used to ignite the gas stove to provide standard fire exposure conditions. The specimen was horizontally put inside the furnace and exposed to the flame. Five thermocouples (type K) were connected to the surface (unexposed face to fire) of the specimen to track the temperature change. The temperature evolution on the surface of the specimen was measured every three minutes until the failure occurred. Failure time is known as R, which is the fire resistance rate. In the present study, failure integrity is defined when burns, cracks, holes, and gaps have been found. Figure 3 displays the schematic diagram of the experimental setup and location of the thermocouples on the surface of the specimen.

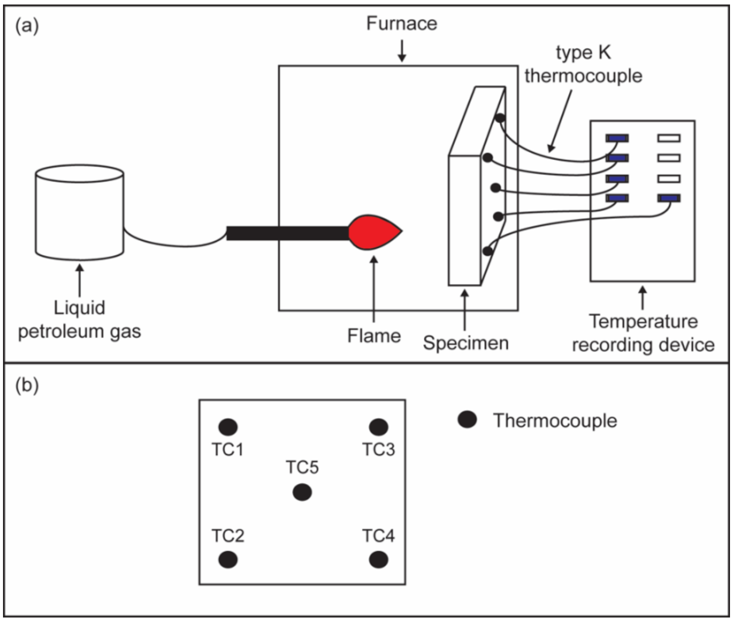

Fig. 3. (a) Schematic diagram of the experimental setup used and (b) the position of the thermocouples on the surface of the specimen

3. Results and Discussion

3.1 Fire Resistance Rating

The present study examines the fire integrity of composite gypsum and kapok fiber materials in a small-scale experimental setup. Figure 4 illustrates the temperature fluctuations of the unexposed surface of the composite gypsum and kapok fiber materials as a function of time at varying mass and thickness of the specimens. Table 2 displays the time of failure and the highest mean temperatures reached during the test. From Figure 4 and Table 2, it is generally observed that temperature rises as time increases. From the results obtained, it can be found that the temperature of the specimen displays a dramatic improvement from the ambient temperature to 86°C in the first 10 minutes. This is because the furnace was preheated from 650°C to 750°C until the specimen was put in the furnace. In comparison, the most significant rise in temperature over time was found in thinner specimens (S1, S4 and S7). It can also be shown that thicker specimens (S1, S4 and S7) have a lower temperature rise with time. These results suggest that as the thickness of the specimen increases, the temperature rise over time decreases.

In gypsum (490g) to kapok fiber (10g) formulations (Figure 4(a)), the specimens S1, S2 and S3 began to fail at 42, 51 and 60 minutes, respectively, and the maximum temperature on the unexposed surface was 117.62°C, 121.51°C and 125.42°C respectively. In gypsum (480g) to kapok fiber (20g) formulations (Figure 4(b)), the specimens S4, S5 and S6 began to fail at 39, 45 and 60 minutes respectively, and the maximum temperatures on the unexposed surface at 125,29°C, 113,07°C and 131,20°C respectively. In gypsum (470g) to kapok fiber (30g) formulations (Figure 4(c)), specimens S7, S8 and S9 began to fail at 30, 39 and 45 minutes, respectively, and the maximum temperature on the unexposed surface at 119,69°C, 126,76°C and 130,51°C respectively. The failure integrity was determined by the observation on the specimen. The specimens were examined, and after the failure time cracks and propagate gaps were observed in the samples.

Based on the results, composite gypsum and kapok fiber materials were found to be able to withstand fire rated for 30 minutes to 60 minutes. These findings comply with the standard MS1073: Part 2:1996 for 1-hour fire rate, which is the most common fire rating of the fire door at the entrance and stairway. Longer duration of fire resistance material indicates better fire resistance rating. Figure 4 also shows that an increase in the composition of kapok fiber may lead to a corresponding decrease in the fire resistance rating. This finding shows that the composition of composite materials has an impact on the fire resistance rating. In addition, for each composition of composite gypsum and kapok fiber, it can be seen that the increase in the thickness of the specimen increases the duration of the fire resistance material. This finding is consistent with previous studies conducted by Lai and Lin [21] and Muhammad *et al.,* [22]. Reasons could be threefold: (a) the difference in the density of the specimens, i.e., the lower density of the specimens will provide a higher fire resistance rating, as evidenced by the density measurement in Table 1, which shows that the density of the specimens decreases as the thickness increases [4]; (b) the deterioration of the material; and (c) thermal deformation due to heat deformation [8]. The latter two reasons will cause thinner specimens to be unable to withstand longer fire ratings.

Among all specimens, S3 (490:10g with 12.7mm thickness) and S6 (480:20g with 12.7mm thickness) were able to withstand 60 minutes of fire rated, indicating that these two specimens (S3 and S6) had the highest fire resistance rating. The maximum temperature on the unexposed surfaces of S3 and S6 is 125.42°C and 131.20°C respectively. The surface temperature distribution of the specimens was further analysed in order to identify which one is the best.

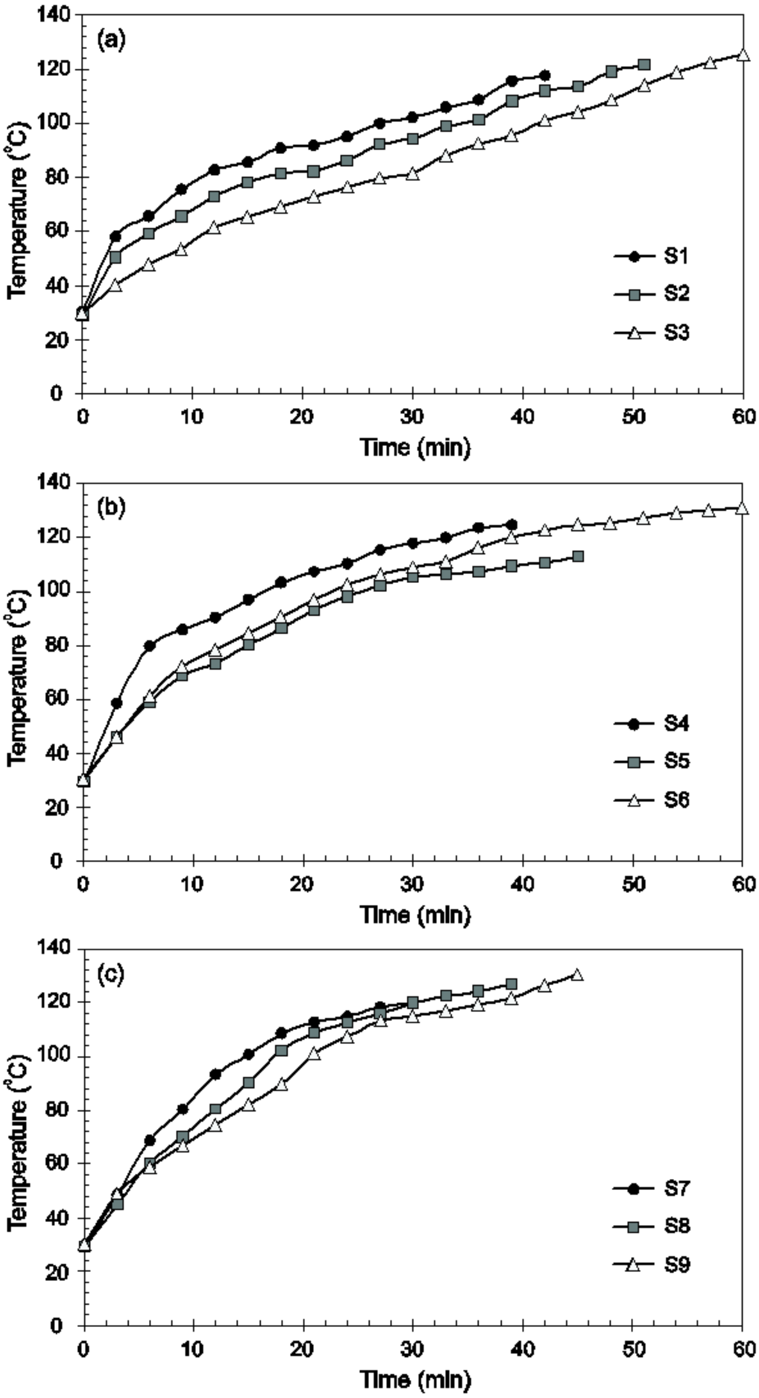

Fig. 4. Comparison of temperature-time curves of different mass ratios of gypsum to kapok fiber (a) 490:10 g; (b) 480:20 g and 470:30 g at different thicknesses

Table 2
Fire resistance rating

Specimen name	Rating, t (minutes)	Maximum mean temperature, T (°C)
S1	42	117.62
S2	51	121.51
S3	60	125.42
S4	39	125.29
S5	45	113.07
S6	60	131.20
S7	30	119.69
S8	39	126.76
S9	45	130.51

3.2 Surface Temperature Distribution

Figure 5 shows the surface temperature distribution for specimens (a) S3 and (b) S6. Specimen S6 shows that the temperature difference between the five positions of the thermocouples was smaller than that of specimen S3, which showed that the temperature distribution of specimen S6 was also more uniform compared to that of specimen S3. The uneven temperature distribution can be attributed to the notching effect and compactness of the specimens [1].

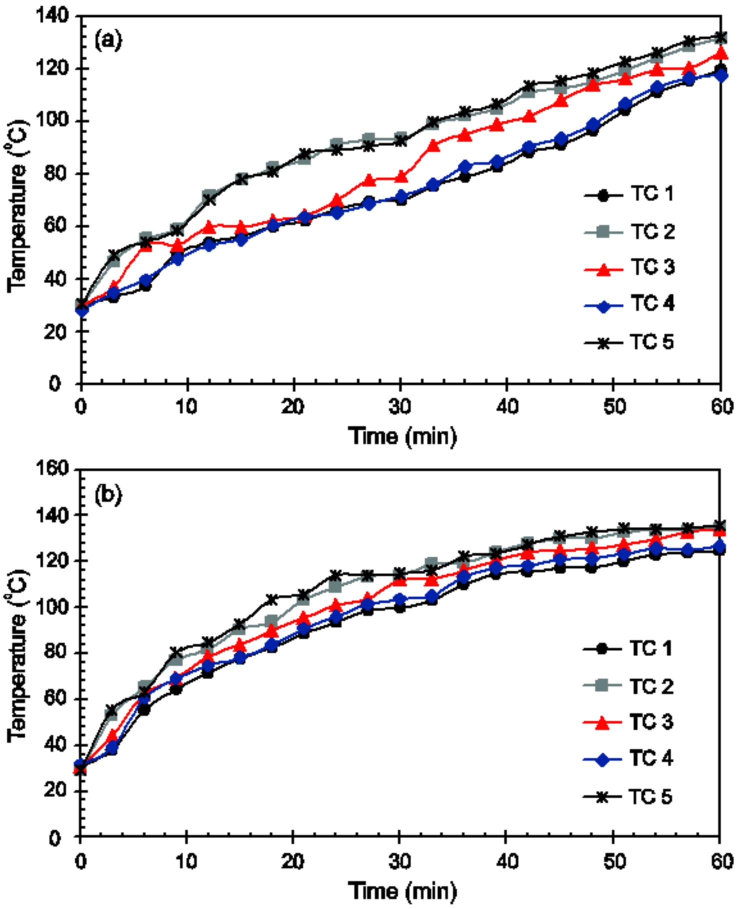

Fig. 5. Surface temperature distribution of specimens comprising gypsum to kapok fiber mass ratio of a) 490:10 g to 12.7 mm thickness (S3) and (b) 480:20 g to 12.7 mm thickness (S6)

It is possible that the shortcomings of current research in the preparation of a homogeneous mixture of gypsum and kapok fiber might have affected the findings obtained. Since the kapok fiber is very light in weight, it is difficult to prepare a homogeneous mixture with gypsum. This constraint may have contributed to inconsistent compressibility of the kapok fiber, thus leading to the formation of uneven specimen thickness. As these phenomena exist, i.e. (i) the notching of the specimen and (ii) the uneven thickness of the specimen, the tip of the thermocouple cannot be in contact with the surface resulting in uneven and fluctuating temperature distribution.

4. Conclusions

The present research was aimed at determining the fire resistance rating of gypsum and kapok fiber composites using a non-combustibility test in compliance with MS1073: Part 2:1996. On the basis of the findings obtained, the following conclusions can be drawn. Gypsum and kapok fiber composite is a good material to be used as a fire resistant door, such as at the entrance and stairs, since it can survive a fire for at least 30 minutes to 60 minutes. The analysis also illustrated the impact of thickness on the fire resistance rating. As a result, it may be concluded that the fire resistance rating improves when the specimen thickness increases. S6 is concluded, of all specimens, to have the best fire resistance rating based on longer fire resistance duration (60 minutes) and more uniform surface temperature distribution.

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