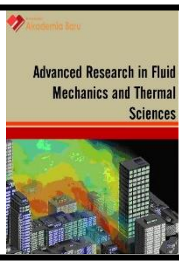
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 56, Issue 2 (2019) 276-286

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Evaluation of Kapok Fiber and Gypsum Mixture to Improve Fire Resistance

Open Access

Muhammad Arif Dandan[1,*], Mohamad Nor Musa[1], Syahrullail Samion[1], Wan Mohamad Aiman Wan Yahaya[1], Muhammad Akmal Issham[1], Fazila Mohd Zawawi[1]

[1] School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

ARTICLE INFO

Article history:
Received 13 December 2018
Received in revised form 30 January 2019
Accepted 2 February 2019
Available online 13 April 2019

ABSTRACT

Fire can be formed when these three elements, hot, oxygen, and combustible materials, are present. It produces heat and light through a chemical process of oxidation reactions that occur rapidly. It is widely known that a human's life on the earth cannot be separated from the fire. But we often hear a phrase about the fire: 'friendly when it is small, deadly when it is big'. Based on this expression, we can say that the fire is not only furnishing benefits to humans but it also can destroy property and killed many lives each year. Therefore, a fire protection should be given priority in our daily life, especially the use of fire resistant doors in commercial and office buildings. Kapok, a natural fiber, which has a low thermal conductivity has been selected and examined in this study as a fire-resistance material. The objective of this study was to find the resistance of gypsum when mixed with kapok fiber. The laboratory works involved the preparation and testing of composite samples of gypsum and kapok fiber, which were prepared with different thicknesses, namely 6.4mm, 9.5mm, and 12.7mm. Then composite samples of three different compositions, namely 1000g of gypsum: 10g of kapok, 1000g of gypsum: 20g of kapok, and 1000g of gypsum: 30g of kapok were prepared for each of those thicknesses. All the composite samples were burnt, in accordance to MS 1073 (1996), in a combustion chamber that had been designed and fabricated in Combustion Laboratory, Faculty of Mechanical Engineering. The experimental results revealed that the composite sample of 12.7 mm thickness gave the highest fire resistance for all the prescribed compositions while the composite sample of 30 g of kapok fiber produced the highest fire resistance compared to other two compositions. In short, a composite mixture of gypsum and kapok fiber has the potential to be used as a fire-resistance material in manufacturing of fire resistant doors, walls, and ceilings for the building construction sector.

Keywords:
Kapok fiber, Gypsum, Fire door

1. Introduction

Recently, Malaysia is one of a few developing countries that taking part in a global movement to study and develop natural resources [1,2]. Being one of the biggest producers and exporters of palm oils, government of Malaysia have given huge encouragement to the research and development of

* *Corresponding author.*
E-mail address: arifdandan92@gmail.com (Muhammad Arif Dandan)

palm oil based lubricant to be used in automotive [3-5] and industrial applications [6,7]. Another types of natural resource that have potential to be develop in Malaysia is Kapok which have been scientifically named as *Ceiba Pentandra*. The word kapok refers both to the tree and to the fiber it produces, which is also known as silk cotton or Java cotton. Besides, nanotechnology also becoming an area of interest for the researchers, as this technology can come out with advance products which can be very beneficial to the consumers [8-10].

Fire is one of the major disasters that can cause loss of human's life, destruction of valuable properties and resources, and environmental pollutions [11,12]. According to statistics in Malaysia, fire cases occurred in Malaysia rose from year to year. This happens due to the lack of security features in Malaysia. According to the Department of Statistics Malaysia, the number of fire breakouts by types of building has been on alarming trend; increased from 20,225 cases in 2007 to 28,741 cases in 2011 as shown in Table 1 [13].

Table 1
Statistics of fire breakouts in Malaysia [3]

Item	2007	2008	2009	2010	2011
Number of fire breakouts	20,225	21,524	29,417	29,052	28,741
Number of deaths	80	88	76	89	80
Number of injuries	67	79	71	82	81
Estimate loss (RM million)	865,29	1,048,57	1,057,04	758,70	927,49
Estimated amount saved (RM million)	9,888.70	5,900.50	10,366.00	18,321.00	8,329.34

Oxygen, heat, and fuel are the three key elements which need to start and maintain for all fires. If all these elements are present, there is a great possibility to start a fire [14]. Buildings, offshore structures, ships, etc. are equipped with doors. Past experiences have taught humans a good lesson to use a fire door instead a conventional wooden or steel door. The functions of a fire door are to protect escape routes, separate area of high risks, and resist the spread of fire [15]. Fire doors can be used as a delimiter. In another way, it acts as a fire enclosure and requires a specific fire [16]. Usually a fire door is provided with a rating of 30 or 60 minutes. It is related to the duration of time the door can resist fire before becoming unstable [15]. Fire doors also are required to act as a barrier to the passage of smoke and fire to the various types of degrees. It is influenced by its location in a building and the fire hazard associated with the building. Pivot fire door is the most common type of fire door used in a building [16].

Nowadays, materials to make a fire door consist of materials that are able to withstand fire for a long time [17,18]. The materials that have been used to make a fire door are gypsum and glass fiber wool where it acts as a protective coating [19]. Normally, this fire door must be compact and able to close on its own. A composite mixture of gypsum and kapok has been considered in this study to enhance the fire resistance rating of a fire door. Kapok can be considered as the best insulation material and readily available [20]. Kapok has the ability to replace glass fiber cotton because of its features that are available in fiber glass wool [21,22]. When using fiberglass, it can cause health problem once it is swallowed and inhaled, and may remain in the lungs indefinitely. It also can contribute to lungs cancer.

2. Apparatus and Material

2.1 Basic Apparatus

The experiment was performed by setting up an experimental furnace and the specimen for the testing method. The apparatus used for the experimental testing were mostly available in

Thermodynamic Laboratory at the Faculty of Mechanical Engineering, Universiti Teknologi Malaysia. The testing was carried at ambient condition with reference to the Malaysian Standard MS 1073: PART 2: 1996 [23].

2.1.1 Gas stove (Ignition Source)

An ignition source was required in this experiment to yield the heat up to 1200˚C. A high pressure of gas stove was used to produce the required heat and to start the ignition for the experiment. Therefore, the ignition source was initiated to supply the required energy to carry out the combustion process.

2.1.2 Bricks

The furnace linings were mostly made up from bricks. According to the standard requirement of a furnace in MS 1073: PART 2: 1996, it states that the minimum lining needed is at least 50 mm which consists of low thermal inertia material so that kρc at 500˚C is smaller than 500 $\mathrm{Ws}^{\frac{1}{2}}/\,m^2$ where k is the thermal conductivity, ρ is the density, and c is the specific heat [23].

2.1.3 LPG gas cylinder (Fuel)

Liquefied petroleum gas (commonly known as LPG), a mixture of propane and butane, was used as a combustion fuel in this study. It also consisted of smaller amount of ethane. LPG was stored in the cylinder in the form of liquid-gas phase. The fluid produced 260 volumes of flammable gas per volume are of liquid.

2.1.4 Ambient temperature thermometer

The thermometer was used to measure the ambient temperature. The ambient temperature was found to be in the range from 27˚C to 33˚C.

2.1.5 Stopwatch (Timing Device)

The purpose of the stopwatch was to measure the time taken for the specimen to refuse the fire. The measurements were obtained in minutes range later and then converted into hours.

2.1.6 Type K Thermocouples

Thermo K (chromel-alumel) thermocouples were used to obtain the temperature measurement of exposed and unexposed specimen surface in this experiment. The standard specification for the thermocouples was ASTM C 177. The thermocouples function under the principle of resistance changes linearly with respect to the temperature changes. The resistance level will increase if temperature increases. Five thermocouples were placed on unexposed side of the specimen to measure its temperature changes in this experiment. This experimental procedure was carried out to obtain an accurate reading as the temperature levels were not fixed.

In this experiment, the bare wire thermocouples were used for the exposure process. It was calibrated for five hours as per standard requirement of MS 1073: PART 2:1996. This procedure was conducted to ensure that the measuring junctions of thermocouples were not degenerated. The thermocouple readings were obtained using thermocouple scanner which was used to convert the resistant signal from the thermocouple to temperature signal [24,25].

2.2 Sample Preparation

According to the thickness in Tables 2 and Table 3, the gypsum in the form of powder was added in the coir with the given ratio. For every 1000g of gypsum, the adding method was done as per the given ratio:

Table 2
Thickness of composite mixture of gypsum and kapok fiber

Sample	Thickness (Mm)
1	6.4
2	9.5
3	12.7

Table 3
Composition ratio of composite mixture of gypsum and kapok fiber

Gypsium (Gram)	Kapok (Gram)
1000	10
1000	20
1000	30

2.3 Testing Method

The fire resistance test was performed using an experimental furnace [26]. The method used in this experiment was similar to the standard testing method recommended by the MS 1073: PART 2: 1996. Generally, the fire resistance of a material can be determined via two types of well-known methods: (1) non-combustibility method and (2) calorimetric bomb test. The non-combustibility method was used in this experiment because it was cheaper and simpler than the former method.

I. Placed the specimen in the furnace chamber with the exposed surface facing the fire in the furnace while the unexposed surface facing towards the furnace (Figure 1).

Fig. 1. Furnace set-up

II. Before performing the test, the temperature of the furnace was kept constant at 750˚C for 10 minutes (Figure 2).

Fig. 2. Furnace heat up

III. The temperature of the unexposed face was recorded. Observed five temperature readings at different locations of the sample. The ambient temperature at the beginning of the test was also recorded (Figure 3).

Fig. 3. Thermocouple scanner

IV. Took the temperature reading from the furnace using a thermocouple that was placed at the furnace (Figure 4).

Fig. 4. Thermocouples at the interior wall

V. The experimental data was collected at three minutes interval. Took the temperature reading for the unexposed surface for every three minutes interval from the five thermocouples which were placed at the unexposed surface of the sample.

VI. Took the reading until reaching the failure time for the sample. The time for the sample to fail was known as R. This value represented fire rating and was expressed in hours.

3. Results and Discussion

3.1 Experiment of Results for Fire Resistant Test

The experiment was carried out according to the MS 1073: PART 2: 1996. Prior to the test, a total of nine samples were prepared. Each sample was produced with a predetermined thickness and composition based on the predetermined ratio. Prior to testing the sample, it was dried naturally under the sun to avoid any cracks, gaps and other defects on the sample. Before conducting the test, the weight of each sample was measured using digital scales. This was done in accordance with the non-combustibility testing method. The objective for this project was to determine the fire resistant rating in hours for all the samples of gypsum composite mixture with kapok fiber.

Table 4 shows the result of fire resistant rating for all nine samples tested. Meanwhile, Figure 5 shows that the composite sample of 12.7mm thickness gave the highest fire resistant rating which 93 minutes. The second highest was the composite sample of 9.5mm thickness which recorded 87 minutes. Lastly, the composite sample of 6.4 mm thickness produced the fire resistant rating of 63 minutes only. These findings were based on the integrity failure. After a failure, cracks and smaller gaps were found on the samples. Generally, it is found that the performance of fire resistant rating achieved by these composite samples increases with thickness. Increase in thickness means increase in content of kapok fiber that has contributed for the better performance due to its structure and properties of fabrics.

Table 4
Fire resistance ratings

Composition	Thickness (mm)	Rating (min)	Max min temp (°C)	Density (kg/m^3)
G=1000g KF = 10g	6.4	63	110.4	1054.69
G=1000g KF=10 g	9.5	87	116.4	1242.11
G=1000g KF =10g	12.7	93	99.4	1108.27
G=1000g KF =20g	6.4	81	119.6	1070.31
G=1000g KF=20 g	9.5	84	106.2	863.16
G=1000g KF =20g	12.7	93	125.2	911.42
G=1000g KF =30g	6.4	102	110.6	1093.75
G=1000g KF=30 g	9.5	120	136.4	884.21
G=1000g KF =30g	12.7	141	145.8	850.39

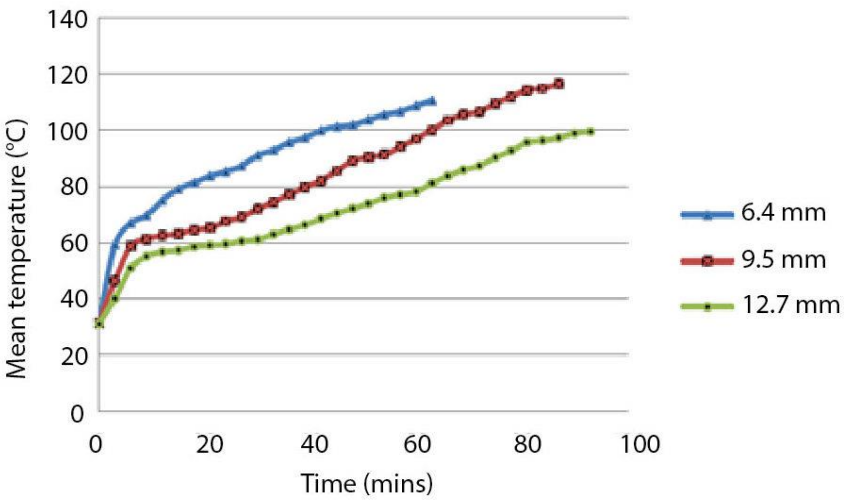


Fig. 5. Fire resistant test results of gypsum 1000 g: kapok fiber 10 g for different thicknesses

Figure 6 shows the plots for gypsum 1000g: kapok fiber 20g for different thicknesses. The best fire resistant performance was shown by composite sample of 12.7mm thicknesses which could last for 93 minutes before it failed. This was followed by the composite samples of 9.5mm (i.e., 84 minutes) and 6.4mm (i.e., 81minutes). From the observation, propagating gaps and crack were found to have occurred on the samples. The fire resistant rating achieved in formed to be similar to those produce by composite samples of gypsum 1000g: kapok fiber 10g.

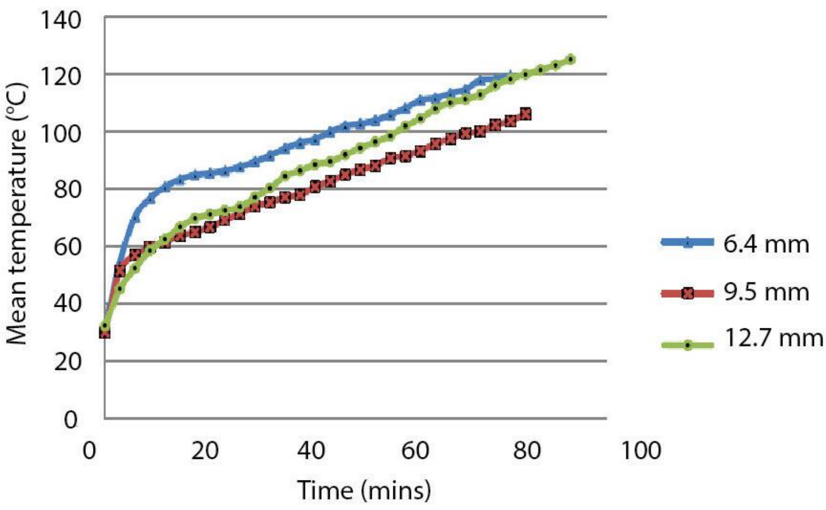


Fig. 6. Fire resistant test results of gypsum 1000 g: kapok fiber 20g for different thicknesses

Figure 7 shows that the highest fire resistant rating recorded was 141 minutes, which was achieved by the composite sample of 12.7mm thickness. This was followed by the composite samples of 9.5mm thickness (i.e., 120 minutes) and 6.4mm thickness (i.e., 102 minutes). Again, cracks and propagation of gaps were found on the failed samples at the end of the end. When comparing to the previous results revealed by the composite samples of gypsum 1000g: kapok fiber 10g and gypsum 1000g: kapok fiber 20g, this sample (i.e., gypsum 1000g: kapok fiber 30g) of thickness 12.7mm experienced the longest time prior to failure.

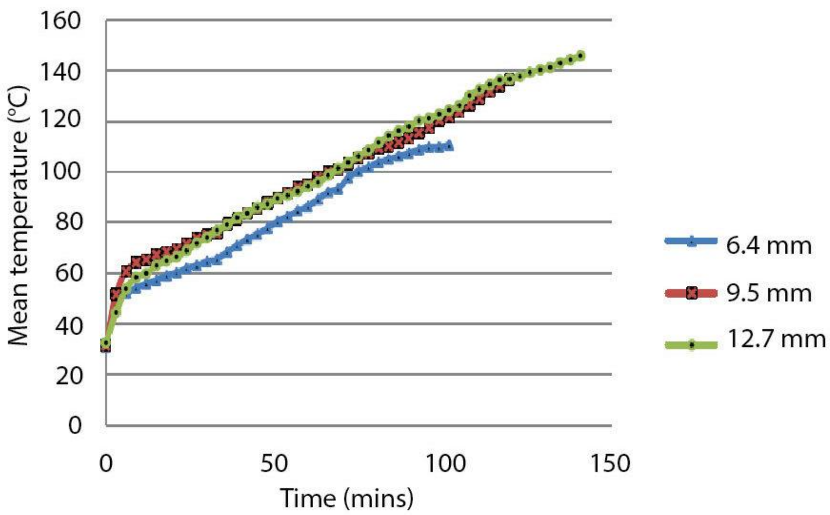


Fig. 7. Fire resistant test results of gypsum 1000g: kapok fiber 30g for different thicknesses

3.2 Notching Effects

During samples preparation, notching effect is one of the problems that were clearly seen after the sample had been totally dried from healing process. Notching effects on the sample that was prepared are presented in Figure 8. This problem did affect the temperature readings taken during the experiment. Based on the readings taken from that had been fixed at the five thermocouples selected points of the unexposed surface, all the thermocouples were found to have given different values. An average value was used in the analysis to mitigate the notching effect.

Fig. 8. Notching on the sample

3.3 Effect of Density

The weight of each sample should be measured using a digital scale and the volume of the said sample should be obtained to compute the density of each sample. Generally, the computed density affects the testing and preparation of the samples. Water content in the sample increases with density. A total of nine samples were prepared. Each sample was made with a predetermined thickness and composition based on a predetermined ratio. So, each of the samples had different density values.

Table 4 shows that density effects fire resistance rating. It can be summarized that the fire resistance rating of those samples decreased as the samples thickness increased. From the observation, it seems that the high density will be effected when the samples did not cured properly. Besides that this problem also happened during the preparation of samples. When high water content was uncontrolled added during the mixture process and do not stir it completely, it will lead to the high density. This problem might cause the samples experienced premature crack where the fiber which is kapok did not manage to bond the gypsum particles in order to create a stronger composite bond.

3.4 Effect of Compactness

Figure 9 shows the uneven thickness of those composite samples that contributed to fluctuate temperature readings taken during the experiment works. Kapok fiber is a delicate matter and light in weight. During sample preparation, kapok fiber was mixed together with water and gypsum. In fact, it was very challenging to mix kapok and gypsum homogeneously in the form of slurry, and this phenomenon might have led to inconsistent compressibility of the kapok fiber.

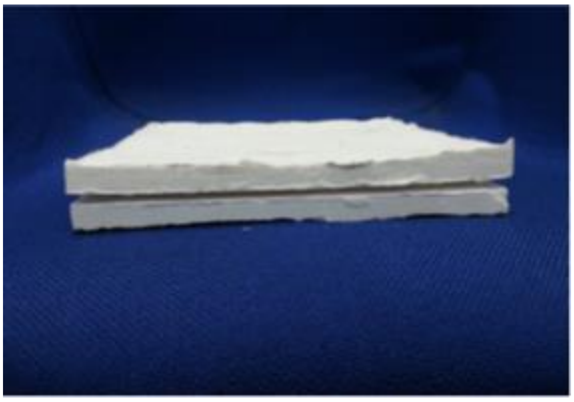


Fig. 9. Effect of compactness on those samples

This problem contributed to the formation of gaps and holes on the samples after the curing process. Therefore, compactness affects fire resistant rating of the samples. The fire resistant would increase accordingly with kapok fiber's composition in the composite sample. Due to this problem, future studies should also focus on the formation of composite samples with even thicknesses and smooth surfaces.

4. Conclusion

Kapok, a natural fiber, is a good insulating material which has the potential to be used in a fire door manufacturing. Many studies have shown that kapok has many functions that can make it as an insulating material. Kapok is also able to replace glass fiber cotton because of its features that are available in fiberglass wool.

An experimental work has been carried out to determine the impact of kapok fiber on fire resistant rating of a fire door. A fire furnace was designed and fabricated according to the standard recommended by the MS 1073: PART 2: 1996. A total of nine samples were prepared and had been tested successfully. Each sample was fabricated of three different thicknesses (i.e., 6.4mm, 9.5mm, and 12.7mm) and three different ratios namely 1000g gypsum : 10g kapok fiber, 1000g gypsum: 20g kapok fiber, and 1000g gypsum : 30g kapok fiber.

The experimental results revealed that all the nine samples gave different fire resistant values which were directly related their compositions and ratios. The highest fire resistant rating achieved was 141 minutes for the composition of 1000g gypsum : 30g kapok fiber with a thickness of 12.7 mm. the lowest fire resistant rating was 63 minutes for the composition of 1000g gypsum : 10g kapok fiber with a thickness of 6.4mm.

From the observation, it clearly showed that the thickness of the samples has a significant impact on the fire resistant rating. In addition, the different compositions of kapok fiber in the composite samples also were found to have an effect on the fire resistant rating. Generally, the fire resistance rating increases with thickness. Also, it is found that the fire resistant rating increases with composition of kapok fiber in the composite samples. Therefore, kapok fiber should be considered as an insulated construction material in the manufacturing of fire resistant doors, ceilings, and wall panels in order to provide a better safety protection from fire. In summary, it can be said that this project had successfully achieved its objective to determine the fire resistant rating of the gypsum composite mixture with kapok fiber.

Acknowledgement
The authors would like to express their thanks to the Research Management Centre (RMC) of Universiti Teknologi Malaysia (UTM) for the Research University Grant (17H96, 15J28, 20H29), Faculty of Mechanical Engineering, UTM and Ministry of Education of Malaysia for their support.

References
[1] Golshokouh, I., S. Syahrullail, F. N. Ani, and H. H. Masjuki. "Investigation of palm fatty acid distillate as an alternative lubricant of petrochemical based lubricants, tested at various speeds." *Int. Rev. Mech. Eng* 7, no. 1 (2013): 72-80.
[2] Noorawzi, Nuraliza, and Syahrullail Samion. "Tribological effects of vegetable oil as alternative lubricant: a pin-on-disk tribometer and wear study." *Tribology Transactions* 59, no. 5 (2016): 831-837.
[3] Jabal, Mohammed Hassan, Farid Nasir Ani, and S. Syahrullail. "The tribological characteristic of the blends of Rbd palm olein with mineral oil using four-ball tribotester." *Jurnal Teknologi* 69, no. 6 (2014).
[4] Sapawe, N., Syahrullail Samion, P. Zulhanafi, C. S. Nor Azwadi, and M. F. Hanafi. "Effect of addition of tertiary-butyl hydroquinone into palm oil to reduce wear and friction using four-ball tribotester." *Tribology Transactions* 59, no. 5 (2016): 883-888.
[5] Hassan, Mohammed, Farid Nasir Ani, and S. Syahrullail. "Tribological performance of refined, bleached and deodorised palm olein blends bio-lubricants." *Journal of Oil Palm Research* 28, no. 4 (2016): 510-519.
[6] Syahrullail Samion, Kenji Nakanishi, and Shunpei Kamitani. "Investigation of the effects of frictional constraint with application of palm olein oil lubricant and paraffin mineral oil lubricant on plastic deformation by plane strain extrusion." *Japanese journal of tribology* 50, no. 6 (2005): 727-738.
[7] Razak, D. M., S. Syahrullail, N. Sapawe, Y. Azli, and N. Nuraliza. "A new approach using palm olein, palm kernel oil, and palm fatty acid distillate as alternative biolubricants: improving tribology in metal-on-metal contact." *Tribology Transactions* 58, no. 3 (2015): 511-517.
[8] Afifah, A. N., S. Syahrullail, and N. A. C. Sidik. "Magnetoviscous effect and thermomagnetic convection of magnetic fluid: A review." *Renewable and Sustainable Energy Reviews* 55 (2016): 1030-1040.
[9] Sidik, Nor Azwadi Che, Maysam Khakbaz, Leila Jahanshaloo, Syahrullail Samion, and Amer Nordin Darus. "Simulation of forced convection in a channel with nanofluid by the lattice Boltzmann method." *Nanoscale research letters* 8, no. 1 (2013): 178.
[10] Hasan, Husam Abdulrasool, Zainab Alquziweeni, and Kamaruzzaman Sopian. "Heat Transfer Enhancement Using Nanofluids For Cooling A Central Processing Unit (CPU) System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 51, no. 2 (2018): 145-157.
[11] Bernhart, Daniela. "The effect of support conditions on the fire resistance of a reinforced concrete beam." (2004).
[12] Menon, G. B., and J. N. Vakil. "Handbook on Building Fire Codes." *Fire Adviser, Govt. of India, CED-22 Fire Fighting Sectional Committee, Bureau of Indian Standards* (1988).
[13] *Statistics of fire breakouts in Malaysia*. 2011, Department of Statistics Malaysia.
[14] Prashant, T. "The essential aspect of fire safety management in high rise buildings." *Faculty of Civil* (2007).
[15] Jackson, S., *Development of Wireless Reproducts*. 2006, Durham University.
[16] Capote, J. A., D. Alvear, Orlando Abreu, M. Lazaro, Y. Boffill, A. Manzanares, and M. Maamar. "Assessment of physical phenomena associated to fire doors during standard tests." *Fire technology* 49, no. 2 (2013): 357-378.
[17] Bengtsson, L.-G., *Enclosure fires*. 2001: Swedish Rescue Services Agency.
[18] Biarnes, M., B. Freed, and J. Esteves. "Combustion, sl: E Instruments International LLC." (2013).
[19] Doktan, M. "The long term stability of room and pillar workings in a gypsum mine." (1983).
[20] Kartina, AK Siti, and MH Nor Suhaila. "Oil sorption capacity of kapok fiber." *In 2012 IEEE Colloquium on Humanities, Science and Engineering (CHUSER)*, pp. 876-878. IEEE, 2012.
[21] Hori, Keko, Maxima E. Flavier, Shigenori Kuga, Thi Bach Tuyet Lam, and Kenji Iiyama. "Excellent oil absorbent kapok [Ceiba pentandra (L.) Gaertn.] fiber: fiber structure, chemical characteristics, and application." *Journal of wood science 4*6, no. 5 (2000): 401.
[22] Peng, C. and W. Fumei. "An investigation of heat flow through kapok insulating material." *Journal of Textile & Apparel/Tekstil ve Konfeksiyon*, no. 19(2) (2009).
[23] SIRIM, *Methods for Determination of the Fire Resistance-General Principle, in A Malaysian Standard*. 1996, SIRIM: Shah Alam, Malaysia.
[24] Blagojevic, Milan Dj, and Dusica J. Pesic. "A new curve for temperature-time relationship in compartment fire." *Thermal science 15*, no. 2 (2011): 339-352.

[25] Cooper, Leonard Y., and Kenneth D. Steckler. *Methodology for developing and implementing alternative temperature-time curves for testing the fire resistance of barriers for nuclear power plant applications*. No. NUREG--1547. Nuclear Regulatory Commission, 1996.

[26] Baroudi, Djebar. *Thermal models for fire safety: calculation of flame spread on surfaces and heating of structures*. Helsinki University of Technology, 2007.