THE EFFECT OF PHYSICAL PROPERTIES ON FLAME SPREAD BEHAVIOR FOR VARIOUS PAPER / BAGASSE COMPOSITION

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For my beloved parents Mr. Ramli bin Abd Hamid and Mrs. Kamisah binti Rasid

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ABSTRACT

Fire Safety Engineering is an application of science to improve the safety from the destructive effect of the fire. Paper is well known as a material that can easily catch fire. Nowadays, many researchers have been interested to produce paper by using other natural fiber to reduce the usage of wood as raw material for paper production. However, research on flame spread towards combination paper / natural fiber is still a lack of data. Inspiration from this, the behavior of downward flame spread over paper and bagasse is experimentally investigated. This experiment was conducted by using the specimen with different thickness and different composition of bagasse. Specimen thickness was chosen at 0.7mm, 1.4mm, 2.1mm and 2.8mm; while for bagasse composition are 0%, 30%, 50%, 70% and 100%. Flame spread behavior for each specimen was videotaped by using a camera. The result showed that the flame spreads was with "U" pattern at the beginning of the combustion, but end up with different pattern according to thickness and composition of bagasse. It seen that flame spread rate decreases with increasing the thickness and composition of bagasse for the specimen. The result also shows that up to 70% bagasse, the flame spread rate is approximately constant even for different thickness. Result infers that the flame spread rate is influenced by not only bagasse composition, but also the density and the pyrolysis height; where pyrolysis height represents the area of the heat release continuity by fire source that has been removed. It shows that the flame spread rate decreases as the density increases. While for pyrolysis height, the higher the pyrolysis height the higher the flame spread rate.

ABSTRAK

Kertas merupakan salah satu contoh bagi bahan mudah terbakar. Pada masa kini, banyak penyelidikan dilakukan bagi menghasilkan kertas menggunakan serat semula jadi sebagai inisiatif bagi mengurangkan penggunaan serat pokok sebagi bahan utama dalam penghasilan kertas. Namun begitu, kajian sebaran api terhadap kertas / serat semulajadi masih belum begitu meluas. Justeru, kajian perilaku sebaran api terhadap serat kertas dan serat tebu dijalankansecara eksperimen. Kajian ini dijalankan dengan menggunakan sampel dengan ketebalan dan komposisi serat tebu yang berbeza. Ketebalan sampel bagi eksperimen adalah 0.7mm, 1.4mm, 2.1mm dan 2.8mm; manakala untuk komposisi serat tebu adalah 0%, 30%, 50%, 70% dan 100%. Perilaku sebaran api untuk setiap sampel dirakam menggunakan kamera video. Keputusan menunjukkan bahawa api tersebar dengan corak "U" pada awal pembakaran tetapi berakhir dengan corak yang berbeza mengikut ketebalan dan komposisi serat tebu. Kadar sebaran api berkurangan apabila ketebalan dan komposisi serat tebu bertambah. Hasil kajian juga mendapati bahawa, kadar sebaran api dilihat semakin konsisten walaupun dengan ketebalan yang berbeza pada komposisi serat tebu melebihi 70%. Selain itu, kadar sebaran api juga dipengaruhi oleh ketumpatan dan ketinggian pirolisis, dimana ketinggian pirolisis adalah kawasan sebaran haba setelah sumber api dipadamkan.Ia menunjukkan bahawa kadar sebaran api menurun apabila ketumpatan meningkat. Manakala bagi ketinggian pirolisis; lebih tinggi ketinggian pirolisis semakin tinggi kadar sebaran api.

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SEM	-	Scanning Electron Microscope
NaOH	-	Sodium Hydroxide
Vc/Vo	-	Flame Spread Rate Composition of Bagasse over Thickness
XPS	-	Polystyrene
PU	-	Polyurethane
PE	-	Polyethylene
FSR	-	Flame Spread
U	-	Shape of Flame Spread
V	-	Shape of Flame Spread

CHAPTER 1

INTRODUCTION

1.1 Introduction

Worldwide destruction of properties is mainly caused by fire. Statistics from the Malaysian Fire and Rescue Department is reported that about 33,640 of fire cases have been reported for the year 2013. Figure 1.1 shows fire cases occurred in Malaysia. It is seen that the most cases are from thatch and thicket. Instead of this, fire destruction from the building and its content also represents main contributor in total cases in Malaysia. There are a lot of causes contributed to the fire destruction of the building. Figure 1.2 shows there are 18 sources that can cause the burning of a building where the main cause is arson.

Fire gives a lot of benefits to mankind. However, uncontrolled fire also will adversely affect the quality of the Earth's ecosystem. The uncontrolled fire can harm the overall structure of the soil and cause the soil to become searing; thus destroying the roots of plants. The advice from qualified professionals is essential in order to improve fire management.

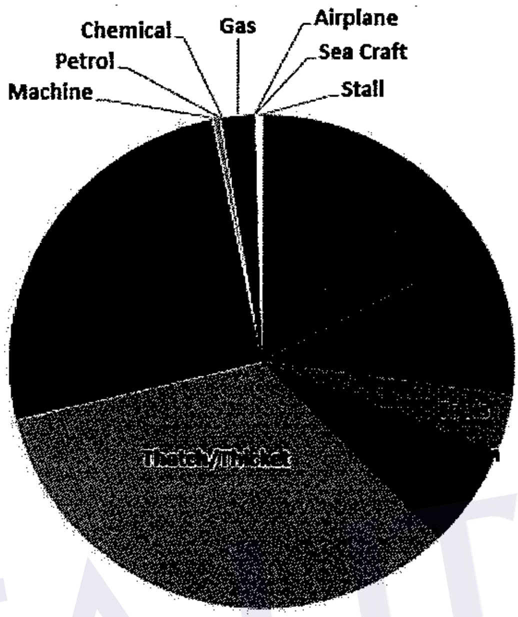


Figure 1.1: Types of fire in Malaysia (Malaysia Fire and Rescue Department, 2013)

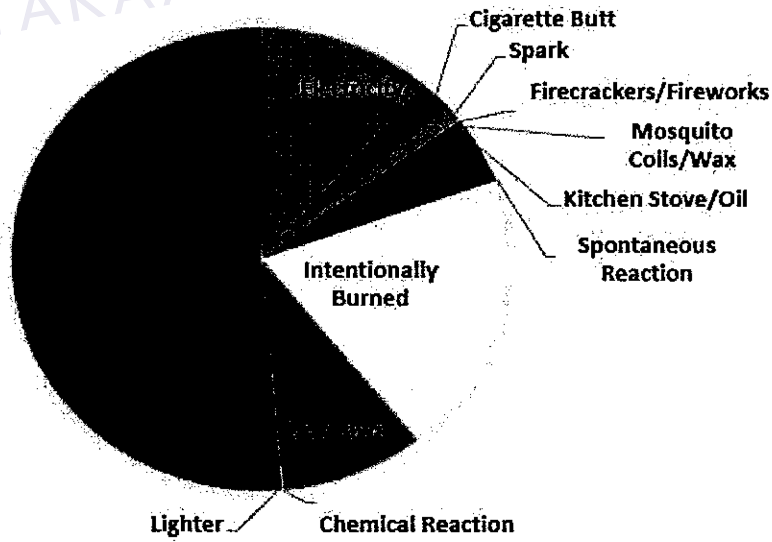


Figure 1.2: Cause of building fire in Malaysia (Malaysia Fire and Rescue Department, 2013)

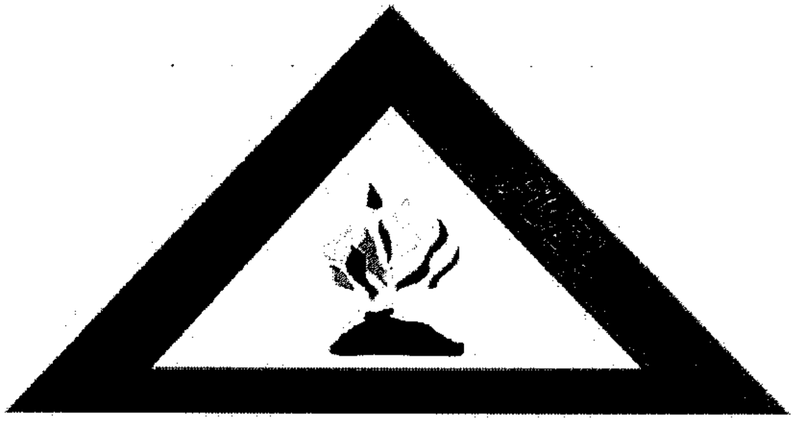
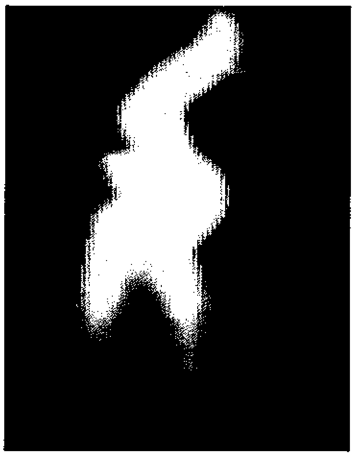


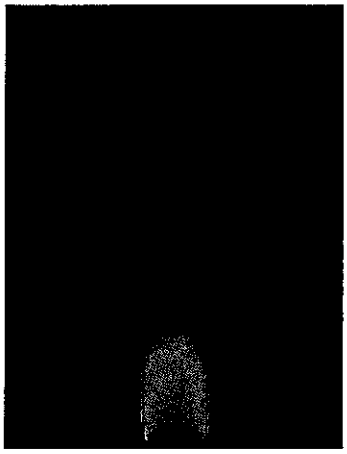
Figure 1.3: The triangle of fire (James G. Quintiere, 1998)

Fire is known as the chemical reaction that occurs between the oxygen in the air and fuel. Three main substances required in this process are oxygen, fuel, and heat. The chain between these three substances can be seen in Figure 1.3. The combustion process will end if one of this reason occur; the fuel has been burnt, the oxygen content does not suffice for combustion or the temperature of the material is below the ignition temperature. This will make the linkage between the three main elements becomes disconnected and the fire will be extinguished itself.

Combustion occurs when the fuel reacts with oxygen to release heat. The amount of oxygen will determine whether the combustion process is complete or incomplete. Figure 1.4 shows the differences between incomplete combustion and complete combustion. The gases react in a combustion process produce molecules of water (H_2O) and carbon dioxide (CO_2). This process only applies to the complete combustion of fuel, and usually, it is the blue in colour as shown.



Incomplete combustion



Complete combustion

Figure 1.4: Incomplete and complete combustion

1.2 Production of Paper

Paper is described as a thin material that produced by pressing a moist fiber pulp cellulose which derived from the wood. It is used in different ways, such as writing, printing, packaging, crafts and other. The usage of paper is introduced about 105 centuries in China by Cai Lun. During that time, the paper is fabricated by using tree and fleece fortitude.

Paper is made from wood cellulose; which needs to process as form pulp before it is continued to the next processing. The pulp is the most important elements in the papermaking process. There are many categories of principles or methods are used to produce pulp; either by mechanical pulp and chemical pulp. In order to produce pulp by using mechanical process, fibers have to be separated from the wood and the process is done by using the crushing method.

In order to get the operative results, fibers must be mixed with sodium sulfite before the crushing process. As a result, the mechanical pulp will produce the yellow/gray toned with a very smooth surface. Referring back to the method of chemical pulp, the wood first need to be cut before the wood is mixed with chemical under high pressure. This step is to ensure and measure that the wood is separate into cellulose and fiber. Next, the wood that mixed with chemical is needed to be washed and filtered to attain a uniform quality. The process for producing pulp by mechanical can be referred in Figure 1.5.

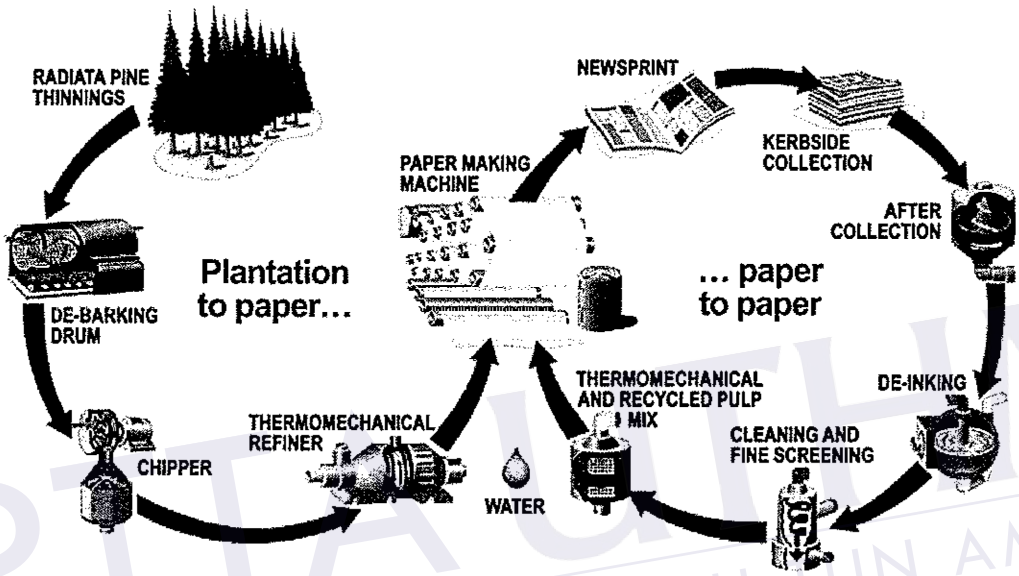


Figure 1.5: Mechanical pulp process (https://1keetingemichemistry.wordpress.com, 2018)

As shown in Figure 1.5, the production of paper causes the trees to be felled as the main element in the papermaking production. This activity will damage the ecosystem of the earth if there are any actions to replant the trees or rules that can control the felled of the tree. Although replanting activities are carried out, it still requires a long period for these trees to grow and mature before it can be used again to produce a paper. Due to this awareness, a lot of researches have been done by using other fibers such pineapple fiber, banana tree fiber, palm fiber and other as an alternative fiber of the paper.

1.3 Bagasse as Alternative Fiber

Sugarcane or its scientific name Saccharum Officanarum is a plant that originates from the tropical area and Asia. Sugarcane has about 37 species and is a plant that comprehends high sugar content. In most countries, sugarcane is used in the sugar industry as it can extract a huge amount of sugar from its juice. Brazil is a major producer of sugar in the world, follows by China and India. According to *Lembaga Pemasaran Pertanian Persekutuan(FAMA)*, Johor is a state that active in the cultivation and marketing of products based on sugarcane in Malaysia (LPPP, 2016). Due to this activity, about 22.6 hectares of land are covering to cultivate for sugarcane in Batu Pahat while about 173 hectares are used to cultivation sugarcane in Muar.

As known, sugarcane has beneficial not only to the production of the sugar, but also the waste product of sugarcane, called as bagasse, can be reused to produce new material or composite. One of the usages of the bagasse is that it can be used to produce paper as the alternative of the processed fiber or pulp from the trees. Based on the investigation, the chemical properties of the bagasse contain 55.75% cellulose, 20.55% lignin, 3.25% extractive and 1.85% of ash. Thus, it is suitable as the material in papermaking. Bagasse that resulting from the sugar production can be seen in Figure 1.6.

Figure 1.6: Bagasse

1.4 Problem Statement

Flame spread behavior over combustible solid is a highly dangerous phenomenon in fire (Charuchinda, Suzuki, & Dobashi, 2001). Malaysian Fire and Rescue Depart has recorded about 5817 cases that involved in a building fire and one of the factors that contributed to this fire happen is paper. Previously, (Suzuki et al., 1994; Takahashi et al., 2017) had been studies the flame spread behavior towards paper.

Recently, production of paper has been composed by a natural mixture. The common fiber that use to make a paper is based from banana leaves (Yosephine, Gala, Ayucitra, & Retnoningtyas, 2012) and palm fiber (Syamsu, Haditjaroko, Pradikta, & Roliadi, 2014). There is also the employment of unclean animals such as elephants in paper production. Unfortunately, these studies are only focused on the mechanical properties of composite paper only. Instead of mechanical properties, the study about flame spread behavior is also essential for fire safety engineering; which is still lacking and needs to be carried out. Thus, this study has been conducted to investigate the behavior of flame spread over paper/bagasse with different thickness.

1.5 Objectives

There are several objectives that involved in this study as following:-

i. To study the flame spread pattern and flame spread rate of paper, bagasse and composite of paper/ bagasse.
ii. To investigate the flame spread rate of paper, bagasse and composite of paper/ bagasse.
iii. To examine the effect of sample thickness on composition dependency of the flame spread pattern and the flame spread rate.
iv. To investigate the effect of the density and pyrolysis height on the flame spread rate of composite paper/bagasse.

1.6 Scopes

i. Experiments have been conducted for different mass fraction paper / bagasse composition of 0%, 30%, 50%, 70% and 100% paper/bagasse.
ii. Research is conducted by the downward flame spread.
iii. Samples with thickness 0.7 mm, 1.4 mm, 2.1 mm and 2.8 mm are used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed about the theory and also the scientific research that related to this study. The explanation that related to paper, bagasse and the most important is the flame spread towards combustible solid will discuss as this experiment explore the influence of flame spread behavior over combustible solid of bagasse / paper.

2.2 Paper Demand

As discussed in Chapter 1 (Sub-title 1.2) , paper is a thin material produced by pressing together moist fibers of cellulose pulp derived from wood, rags or grasses and it is dried into flexible sheets. It is a versatile material with many uses, including writing, printing, packaging, cleaning and a number of industrial or construction. The use of non-timber resources as ingredients for the production of paper covers 10% of its use throughout the world (Wahab et al., 2012) but it depending on the country. Currently, demand for paper increases as technological progress increases. The usage of wood as a raw material in the paper production causes deforestation and subsequent possibility of a limited timber resources crisis. In recent years, demand for pulp has been increased rapidly, especially at the developing countries. Due to the shortage of wood resources as the primary basis for the production of paper, other alternatives such as the introduction of non-wood lignocellulose-based material has been used as a substitute for wood. There are some material that have been commercialized as an alternative, such as the empty fruit bunches of oil palm, banana fiber and carpet grass (Gutiérrez, Río, & Martínez, 2009).

2.2.1 Alternative fiber for paper production

As mentioned above, due to the shortage of wood resources and to reduce the deforestation, other alternative sources have been introduced to replace the cellulose pulp from wood for papermaking. The experiments by using pineapple leaf fiber as raw material in paper production have been conducted to assess the advantages in term of mechanical properties, especially tensile strength, tearing strength and thickness of the paper (Wahab et al., 2012). Sample of pineapple leaf fiber is mixed with a recycle newspapers in different composition of which is 25%, 35%, 45%, 55%, 65% and 75% pineapple leaf fiber mixed with 75%, 65%, 55%, 45%, 35%, and 25% of the recycle newspapers. The mixture has been tested for mechanical properties and thickness by using the Universal Testing Machine (UTM) and micrometers.

It indicates that the mixture has the similar basic properties of the paper such as it can be written, torn and it can absorb moisture. However, when evaluating the terms of thickness and other features found on the paper produce, it can only be used as the medium of packaging such as boxes. The tearing test is found that the used force decreases when the beatings increases. Based on the observation made, such things happen due of the size of pineapple leaf fibers progressively decreases when the beatings increases. Thus, based on the pictures taken using a microscope, the fibers have been found to be dispersed and located position of the fiber pattern is not fixed. In addition the mechanicals properties, electrical properties and chemical properties of the natural fibers are very good as a place of choice in the manufacturing.

Then the investigation of the mixture of the empty oil palm fruit bunch and microbial cellulose from Nata de Cassava for paper manufacture had been carried out by Syamsu et al., 2014. This experiment also has been conducted on the mechanical properties which are focused on the tensile testing and the capability of water absorption. Figures 2.1 and 2.2 show bunches of fibers that have been processed and the microbial cellulose of Nata de Cassava, respectively.

Figure 2.1: Empty oil palm fruit bunch (Syamsu et al., 2014)

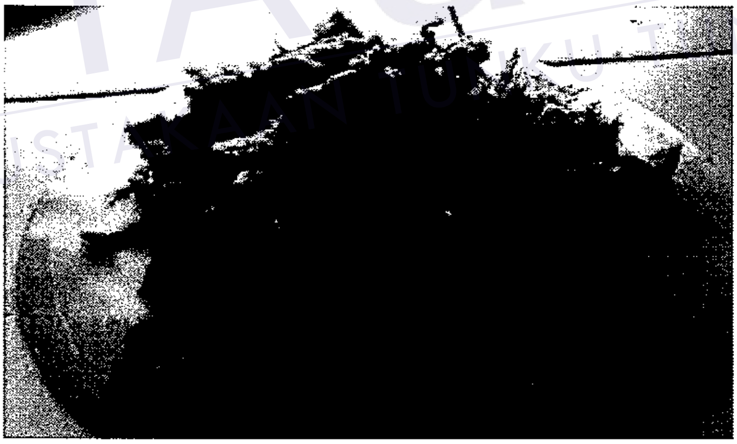


Figure 2.2: Microbial cellulose from Nata de Cassava (Syamsu et al., 2014)

This sample of paper was also mixed with different composition between these two materials, which is empty oil palm fruit bunch pulp of 0%, 25%, 50%, 75% and 100% composition mixed with 100%, 75%, 50%, 25% and 0% composition of microbial cellulose from Nata de Cassava. In this experiment, it is added with the tapioca starch as additive substance in order to increase the bonding between both materials. The result from the experiment indicates that pure empty oil palm fruit brunch has the lower value of tensile test compared to other composition and the higher for tensile test goes to pure microbial cellulose from nata de cassava. It indicated that by increasing the composition of microbial cellulose from Nata de Cassava, the values of the tensile strength also increased.

2.3 Bagasse Usage in Paper Production

Figure 2.3 shows one of the prevalent cellulosic agro-industrial that resulting from the cane stalks left over once crushing and extraction of the juice from the sugar cane (Soccol et al., 2000). In the latest years, there has been growing trend towards further capable utilization of agro-industrial residues, as well as bagasse. Numerous processes and products have been utilized bagasse as a raw material, including electricity generation, pulp and paper production, also products based on fermentation. Other than that, it is also used as fuel for boiler in sugar industries by sugar factories themselves. The usage of waste product such as bagasse for several process is due to the understanding of the significance developing renewable resources.

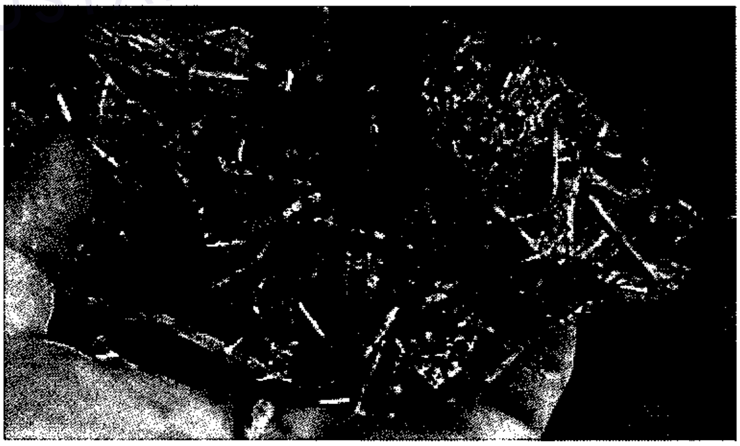


Figure 2.3: Bagasse (Loh et al., 2013)

Bagasse is made up of approximately 50% cellulose and 25% of hemicellulose and lignin. Based on chemically, bagasse contains about 50% cellulose, 30% pentosans, and 2.4% ash (Soccol et al., 2000). Han et al. (1983) indicated that bagasse contain about 50% cellulose, 28% hemicellulose and 15% lignin. Although the percentage of lignin and hemicellulose are different by both research, it is agreed that the percentage of cellulose contained in bagasse is about 50%. Other that, from the analysis by Loh et al. (2013), it also identified that bagasse constituents are cellulose, hemicellulose, lignin, ash and wax. This composition of bagasse makes it as an ideal ingredient to be applied and utilized as reinforcement fiber in composite materials for the purpose of creating new materials which possess distinct physical and chemical properties. The bagasse has been chosen as an ideal raw material in manufacturing new products since it has low fabricating costs and high quality green end material.

2.3.1 Application of Bagasse

It is estimated that about 700 million ton of bagasse are produced annually throughout the world (Monteiro, Candido & Braga, 2016). Several studies have been carried out aiming to identify the benefits of bagasse as a new material in manufacturing product. The potential of bagasse or polyester composite for tribological applications has been explored by El-Tayeb, 2008. In this reconnoiter it used bagasse/polyester (SCRP) and glass fiber (abrasive)/polyester (GRP) for tribological properties purpose. This investigated have been found that both material make the unidirectional fiber reinforcement more effective. SCRP has better wear and friction resistance than GRP. The chopped and unidirectional SCRP (C-SCRP) and unidirectional SCRP (U-SCRP), chopped GRP (C-GRP) and chopped strand mat (CSM) from GRP (CSM-GRP), evidenced that when load increases, friction coefficient decreases. An increase in load would cause the wear resistance of C-SCRP, U-SCRP, and CSM-GRP to increase while for C-GRP, it is decreased. Accordingly, the critical fiber length is around 5 mm (minimum wear rate) and wear rates decrease when fiber length is 1-5 mm and increase at 10 mm. Thus, bagasse is a good material to be utilized for increasing wear resistance of C-SCRP composite.

REFERENCES

Aigbodion, V. S., Hassan, S. B., Ause, T., & Nyior, G. B. (2010). Potential Utilization of Solid Waste (Bagasse Ash), *9*(1), 67–77.

Avinash, G., Kumar, A., & Raghavan, V. (2016). Experimental analysis of diffusion flame spread along thin parallel solid fuel surfaces in a natural convective environment, *165*, 321–333.

Ayani, M. B., Esfahani, J. A., & Mehrabian, R. (2006). Downward flame spread over PMMA sheets in quiescent air: Experimental and theoretical studies. *Fire Safety Journal*, *41*(2), 164–169.

Azahari, M., Mohd, S., Sapit, A., Mohammed, A. N., Husaini, A., Hushim, M. F., Khalid. (2017). Flame spread behavior over combustible thick solid of paper , bagasse and mixed paper / bagasse Flame spread behavior over combustible thick solid of paper , bagasse and mixed paper / bagasse.

Bhaskaran, K. K., King, M. D., Takahashi, S., Nagumo, T., & Wakai, K. (2000). Downward Flame Spread Over Poly (Methyl) Methacrylate, *28*, 2891–2897.

Bhattacharjee, S., Bundy, M., Paolini, C., Patel, G., & Tran, W. (2013). A novel apparatus for flame spread study. *Proceedings of the Combustion Institute*, *34*(2), 2513–2521.

Bhattacharjee, S., Paolini, C., Tran, W., Ray, J., & Takahashi, S. (2015). ScienceDirect Temperature and CO 2 fields of a downward spreading flame over thin cellulose : A comparison of experimental and computational results. *Proceedings of the Combustion Institute*, *35*(3), 2665–2672.

Charuchinda, S., Suzuki, M., & Dobashi, R. (2001). Behavior of flames spreading downward over napped fabrics, *36*, 313–325.

Chow, W. K. (2008). Flame spread over plastic materials in flashover room fires, *22*, 629–634.

Comas, B., Carmona, A., & Pujol, T. (2015). Experimental study of the channel effect on the fl ame spread over thin solid fuels. *Fire Safety Journal*, *71*, 162–173.

Consalvi, J. L., Pizzo, Y., Porterie, B., & Torero, J. L. (2007). On the flame height definition for upward flame spread, *42*, 384–392.

Dorez, G., Ferry, L., Sonnier, R., & Taguet, A. (2014). Journal of Analytical and Applied Pyrolysis Effect of cellulose , hemicellulose and lignin contents on pyrolysis and combustion of natural fibers, *107*, 323–331.

El, M. (2008). A study on the potential of sugarcane fibers / polyester composite for tribological applications, *265*, 223–235.

Feier, I. I., Shih, H.-Y., Sacksteder, K. R., & Tien, J. S. (2002). Upward flame spread over thin solids in partial gravity. *Proceedings of the Combustion Institute*, *29*(2), 2569–2577.

Gani, A., & Ã, I. N. (2007). Effect of cellulose and lignin content on pyrolysis and combustion characteristics for several types of biomass, *32*, 649–661.

Gollner, M. J., Williams, F. A., & Rangwala, A. S. (2011). Upward flame spread over corrugated cardboard. *Combustion and Flame*, *158*(7), 1404–1412.

Gong, J., Zhou, X., Li, J., & Yang, L. (2015). International Journal of Heat and Mass Transfer Effect of finite dimension on downward flame spread over PMMA slabs : Experimental and theoretical study. *International Journal of Heat and Mass Transfer*, *91*, 225–234.

Govindarajan, D., & Jayalakshmi, G. (2011). XRD , FTIR and SEM studies on calcined sugarcane bagasse ash blended cement, *2*(4), 38–44.

Guedes, R. E., Luna, A. S., & Torres, A. R. (2018). Journal of Analytical and Applied Pyrolysis Operating parameters for bio-oil production in biomass pyrolysis : A review, *129*(November 2017), 134–149.

Gutiérrez, A., Río, J. C., & Martínez, A. T. (2009). Microbial and enzymatic control of pitch in the pulp and paper industry, 1005–1018. http://doi.org/10.1007/s00253-009-1905-z

Han, Y. W., Catalano, E. A., & Ciegler, A. (1983). Chemical and Physical Properties of Sugarcane Bagasse Irradiated with, 34–38.

Hou, Y., Cheng, X., Liu, S., Liu, C., & Zhang, H. (2015). Experimental study on upward flame spread of exterior wall thermal insulation materials. *Energy Procedia*, *66*, 161–164.

Huang, H., Tian, M., Liu, L., Liang, W., & Zhang, L. (2006). Effect of Particle Size on Flame Retardancy of Mg (OH) 2 -Filled Ethylene Vinyl Acetate Copolymer Composites.

Jae, S., Kim, M., Park, J., Fujita, O., & Chung, S. (2015). Flame spread over electrical wire with AC electric fields : Internal circulation , fuel vapor-jet , spread rate acceleration , and molten insulator dripping. *Combustion and Flame*, *162*(4), 1167–1175.

Jeefferie, A. R., Fariha, O. N., Warikh, A. R. M., Yuhazri, M. Y., Sihombing, H., & Ramli, J. (2011). Preliminary Study On The Physical And Mechanical Properties Of Tapioca Starch / Sugarcane Fiber Cellulose Composite, *6*(4), 7–15.

Jiang, L., Miller, C. H., Gollner, M. J., & Sun, J. (2017). Sample width and thickness effects on horizontal flame spread over a thin PMMA surface. *Proceedings of the Combustion Institute*, *36*(2), 2987–2994.

Journal, B., Leite, J. L., & Pires, A. T. N. (2004). Characterisation Of A Phenolic Resin And Sugar Cane Pulp Composite, *21*(02), 253–260.

Kleinhenz, J., Feier, I. I., Hsu, S., James, S. T., Ferkul, P. V, & Sacksteder, K. R. (2008). Pressure modeling of upward flame spread and burning rates over solids in partial gravity, *154*, 637–643.

Kumar, A., Shih, H. Y., & T'ien, J. S. (2003). A comparison of extinction limits and spreading rates in opposed and concurrent spreading flames over thin solids. *Combustion and Flame*, *132*(4), 667–677.

Kumar, C., & Kumar, A. (2013). Gravity modulation study on opposed flame spread over thin solid fuels. *Proceedings of the Combustion Institute*, *34*(2), 2675–2682.

Leventon, I. T., & Stoliarov, S. I. (2013). Evolution of flame to surface heat flux during upward flame spread on poly(methyl methacrylate). *Proceedings of the Combustion*

Institute, *34*(2), 2523–2530.

Loh, Y. R., Sujan, D., Rahman, M. E., & Das, C. A. (2013). Review Sugarcane bagasse - The future composite material: A literature review. *Resources, Conservation and Recycling*, *75*, 14–22.

Monteiro, S. N., Candido, V. S., Braga, F. O., Bolzan, L. T., Weber, R. P., & Drelich, J. W. (2016). Sugarcane bagasse waste in composites for multilayered armor. *European Polymer Journal*, *78*, 173–185.

Ruo-wen Zong, Jie Ren, Xi-ping Liu, Y. Z. (2017). ScienceDirect Study of Downward Flame Spread Risk Evaluation of the Study of Downward Flame Spread and Fire Risk Evaluation of the Study of Downward Flame Spread and Fire Risk Evaluation of the Thermoplastic Materials Study of Downward Flame Spread and Fi. *Procedia Engineering*, *211*, 590–598.

Soccol, C., Pandey, A., Soccol, C. R., Nigam, P., & Soccol, V. T. (2000). Biotechnological potential of agro-industrial residues . I : Sugarcane bagasse Biotechnological potential of agro-industrial residues . I : sugarcane, *8524*(March 2014).

Suzuki, M., Dobashi, R., & Hirano, T. (1994). Behavior of Fires Spreading Downward Over Thick Paper, 1439–1446.

Syamsu, K., Haditjaroko, L., Pradikta, G. I., & Roliadi, H. (2014). Campuran Pulp Tandan Kosong Kelapa Sawit dan Selulosa Mikrobial Nata de Cassava dalam Pembuatan Kertas. *Jurnal Ilmu Pertanian Indonesia (JIPI)*, *19*(April), 14–21.

Takahashi, T., Daitoku, T., & Tsuruda, T. (2017). Behavior of the flame spread along a thin paper-disk in a narrow space. *Proceedings of the Combustion Institute*, *36*(2), 3011–3017.

Viruthagiri, G., Sathiya, S., & Shanmugam, N. (2014). Reuse of Sugarcane Bagasse Ash (SCBA) for Clay Brick Production, (August), 1–5.

Wahab, S., Yusuf, Y., Ahmad, R., Mustapa, S., & Tahar. (2012). Producing Paper using Pineapple Leaf Fiber, *390*, 3382–3386.

Watanabe, Y., Torikai, H., & Ito, A. (2011). Flame spread along a thin solid randomly distributed combustible and noncombustible areas. *Proceedings of the Combustion Institute*, *33*(2), 2449–2455.

Yosephine, A., Gala, V., Ayucitra, A., & Retnoningtyas, E. S. (2012). Dalam Pembuatan Kertas Serat Campuran, *11*(2), 94–100.

Zhang, X., & Yu, Y. (2011). Experimental studies on the three-dimensional effects of opposed-flow flame spread over thin solid materials. *Combustion and Flame*, *158*(6), 1193–1200.

Zhao, X., Liao, Y. T., Johnston, M. C., James, S. T., Ferkul, P. V, & Olson, S. L. (2017). Concurrent flame growth , spread , and quenching over composite fabric samples in low speed purely forced flow in microgravity. *Proceedings of the Combustion Institute*, *36*(2), 2971–2978.