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Effect of Bagasse Physical Properties & Composition on Flame Spread Behavior

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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 is conducted by using the specimen with different thickness and different composition of bagasse. Specimen thickness is chosen at 0.7mm, 1.4mm, 2.1mm and 2.8mm; while for bagasse composition is 0%, 30%, 50%, 70% and 100%. Flame spread behavior for each specimen is videotaped by using a camera. The result showed that the flame spreads with "U" pattern at the beginning of the combustion, but end up with different pattern according to thickness and composition of bagasse. It is 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.

Keywords: Fire safety, flame speed, flame propagation, baggase, natural fiber

1. Introduction

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. 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 cultivate 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 [1-5]. 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 paper making [6-8].

Flame spread behavior over combustible solid is a highly dangerous phenomenon in fire 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, several researches had been conducted to examine the flame spread behavior towards paper [9-10].

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Recently, production of paper has been composed of a natural mixture. The common fiber that use to make a paper is based from banana leaves and palm fiber. 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 [11-15]; 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.

2. Experiment Setup

Figure 1 shows the flow of the experiment. In this experiment, bagasse and recycle paper were used as main materials for fabricating specimen. During this stage, sodium hydroxide was used in the immersion process for both bagasse and paper. Then, the specimen has been fabricated by the mold and deckle. Thickness will be measured by using a digital vernier caliper. The microstructure of each specimen is examined by using Scanning Electron Microscope (SEM). Figure 2 shows the vertical flame chamber, which was used for burning testing, which is used as in previous studies [3-5].

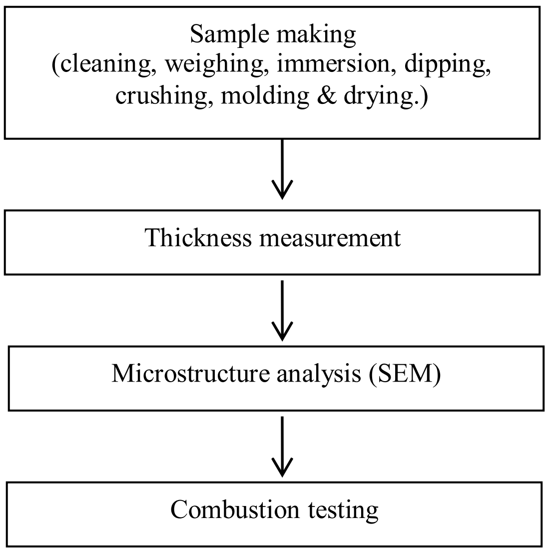


Fig. 1 - Experiment flow

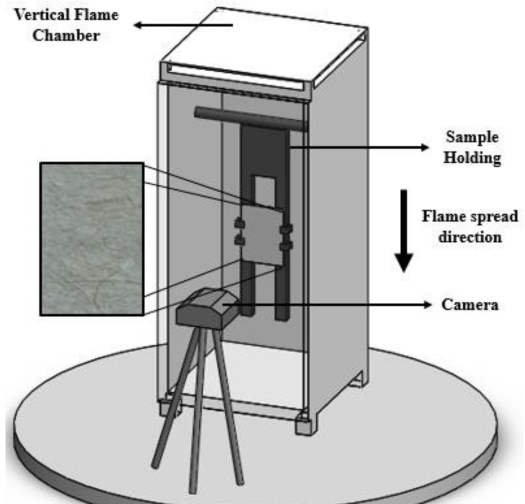


Fig. 2 - Vertical Flame Chamber

This research focused on the thickness effect on flame spread behavior over combustible solid of bagasse/paper. The thickness of the sample are 0.7 mm, 1.4 mm, 2.1 mm and 2.8 mm. This research is conducted for different bagasse composition of 0%, 30%, 50%, 70%, and 100%. Experiments have been conducted for downward flame spread since the spread rate remain quite steady. In this research, two behaviors have been examined; one is a flame spread pattern and another is flame spread rate.

3. Methodology

This research involves 4 important stages, as described in Figure 1. As mentioned in section 2, bagasse and recycle paper was used as main materials, while, sodium hydroxide was used in the immersion process. The mold and deckle specimen was used to fabricate the sample. Then, thickness and microstructure of each specimen is examined by using a digital vernier caliper and Scanning Electron Microscope (SEM), respectively. For the burning test, the vertical flame chamber has been used as shown in Figure 2.

Figure 3cshows the flame spread during the experiment. The flame spread is captured from the front view for each of the specimen in order to observe the combustion process. It has been analyzed based on the recorded video during the experiment. The detail of flame spread pattern that occurs during the experiment is drawn for every 15 second. Pattern of the flame spread is determined based on the leading edge of the flame spread, as represented by the yellow line in Figure 3. The leading edge is chosen at that area since the oxygen easily diffuses into char particles as burning starts.

The detailed observation of the flame spread pattern of burning front has been fixed from the time 0s to 105s for all specimens, in order to allow the comparison between each specimen. The comparison has been chosen until 105s because it is the shortest time taken to complete the combustion process. The result shows that the flame spread pattern for each specimen is started with "U" shape in the early combustion process, but the overall pattern of flame structure for each specimen is slightly different due to the different thickness and composition of bagasse. The flame spread structure may also be affected by the phenomenon during the combustion process.

Figure 4 shows the position of the flame spread measured. The flame spread rate is obtained by measuring the position of the most preceding points of the burning front of the flame during the combustion process. The measurement is taken at every 15s as mention before. The position is measured 10 mm from the upper side of the sample. This procedure is essential in order to remove the effect of the ignition process.

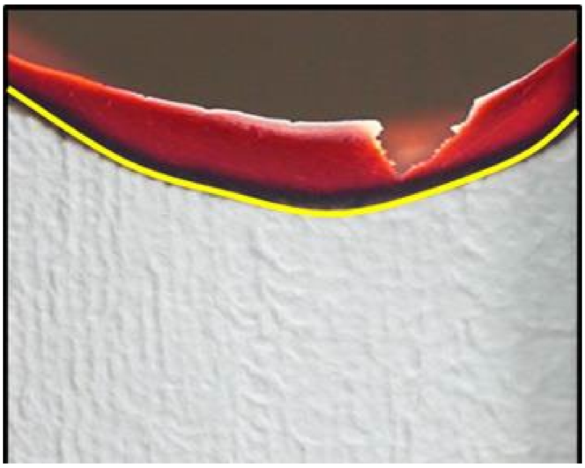


Fig. 3 - Leading edge of flame spread pattern

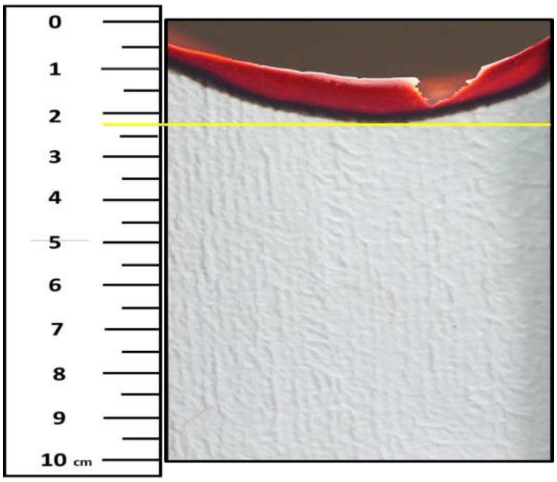


Fig. 4 - Measurement of the flame spread rate

4. Results & Discussions

4.1 Flame speed pattern

Figure 5 shows the flame spread pattern for 0% bagasse, 50% bagasse, and 100% bagasse with 2.1 mm thickness. It is seen that the flame spread pattern is deferred for each composition. For pure paper, the flame spreads with the U-shape at the beginning of the combustion. The shape remains during the combustion process. For 50% bagasse, the similar pattern of the flame spread with the pure paper is seen at the beginning of the combustion. However, the flame spread pattern becomes flat during the combustion. While the flame for 100% bagasse seems to be unstable and the flame spreads only at the center of the specimen. Similar behavior is also seen for 0.7mm, 1.4mm, and 2.8mm. It is indicated that the composition of bagasse has significant influence on the flame spread pattern compared to the thickness of the specimen.

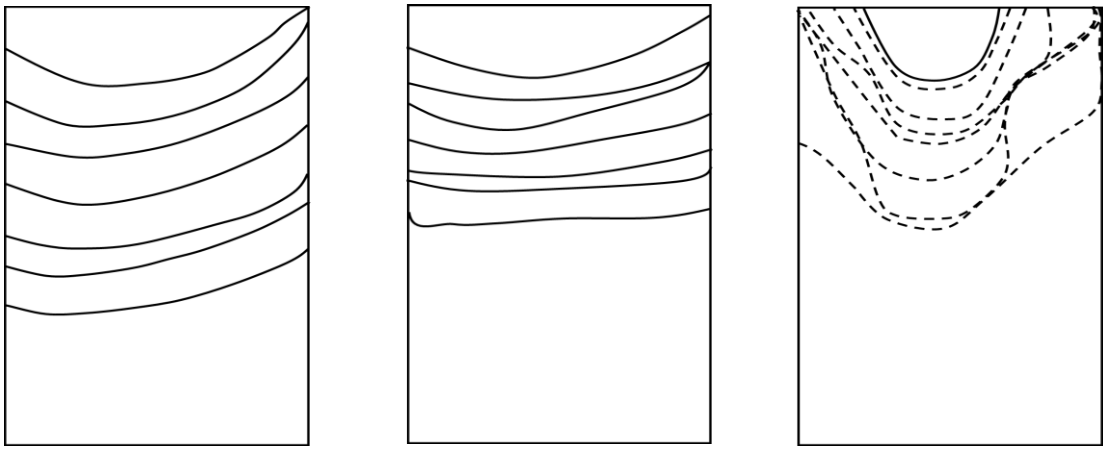
The bagasse composition may have some influenced on the flame spread phenomenon. In order to examine this influence, each sample is analyzed by Scanning Electron Microscope (SEM) before the combustion testing. Figure 6 shows the microstructure image for each composition. In this experiment, SEM is used in order to roughly verify the presence of the paper fiber and bagasse fiber. This is essential since the size of the fiber is strongly influenced on the flame retardant.

Figure 6 (a) shows the SEM image for pure paper, it is seen that the fiber size is smaller compared to the fiber of bagasse, which is shown in Figure 6 (c). Figure 6 (b) shows that the bagasse fiber, as represented by the red arrow, is well blended with paper for the sample of 50% bagasse. Regarding to the Figure 5, the difference in size significantly influences on the flame spread pattern for all compositions of bagasse. Apart from of the flame pattern, the bagasse fiber also has a strong influence on the flammability of the sample. It is seen from the results, the flame is continuously spread for 0% and 50% bagasse. However, the flame is self-extinguished for the sample with 100% bagasse.

4.2 Flame speed rate

Instead of flame pattern, another important factor in flammability is the flame spread rate. The flame spread rate is determined from the most preceding points of the burning front of the flame during the combustion process. In order to determine the flame spread rate, the position of the preceding point is measured for every 15s and it is plotted in term of position (mm) against time (s).

Figures 7 and 8 show position of the most preceding points of the flame against time. From the plot data, the equation of the straight line is determined from the gradient of the plotted graph. Figures 7 and 8 show the plotted date for thickness 2.1mm with 30% of bagasse and 1.4mm with 100% of bagasse, respectively. The results show that the flame spread rate for this specimen are 0.437mm/s and 0.157mm/s.



(a) 0% Bagasse - 2.1mm (b) 50% Bagasse - 2.1mm (c) 100% Bagasse - 2.1mm

Fig. 5 - Flame spread pattern for every 15s

Fig. 6 - Microstructure image for different bagasse composition

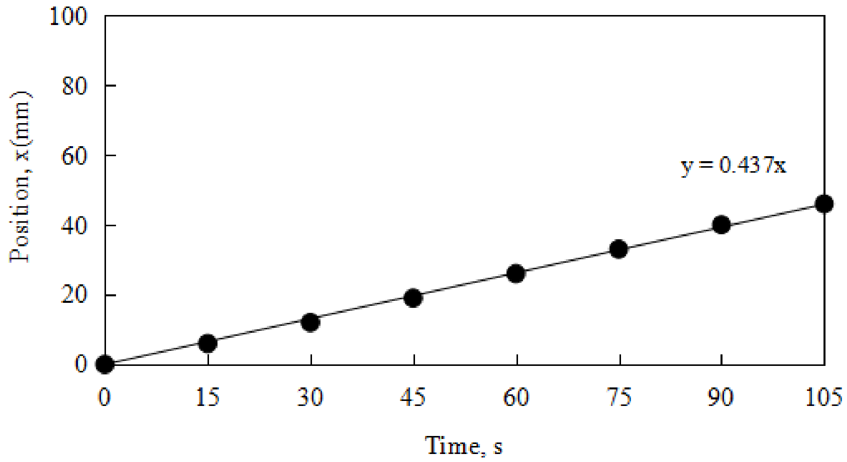


Fig. 7 - Position of the flame against time for 2.1mm (30% Bagasse)

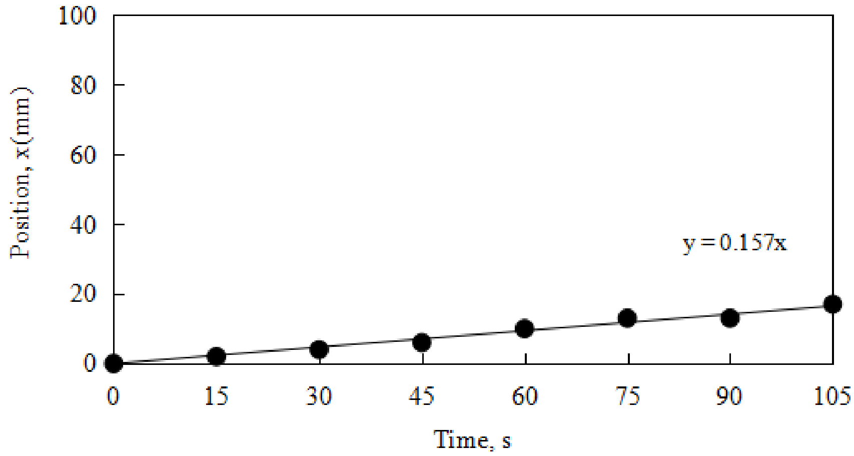


Fig. 8 - Position of preceding point of the flame against time for 1.4mm (100% Bagasse)

Figure 9 shows the flame spread rate for different composition of bagasse with the thickness of 0.7mm, 1.4mm, 2.1mm and 2.8mm. For 0%, 30% and 50% of bagasse, it is indicated that the flame spread rate decreases significantly as the thickness increases.The flame spread rate for pure paper with 0.7mm, 1.4mm, 2.1mm and 2.8mm thickness decrease from 0.951 ± 0.010 mm/s, 0.808 ± 0.010 mm/s, 0.582 ± 0.019 mm/s, and 0.311 ± 0.013 mm/s, respectively. For this region of bagasse composition, it is inferred the flame spread rate decreases as the thickness increases. This is consistent with the previous study conducted over PMMA sheets [9].

However, different behavior is seen in 70% and 100% bagasse. It is found that only the slight difference of the flame spread rate is seen for all thickness. For these compositions, the flame extinguishes during the experiment thus there is no significant difference in the flame spread rate between each thickness. The flame becomes unstable and does not spread through the whole specimen, but only at the center of the specimen.

Figure 9 also shows that for all thickness, the flame spread rate decreases as the bagasse composition increases. In order to study this influence, the relation between the ratio of V_c/V_0 with the bagasse composition is plotted in Figure 10. V_c represents the flame spread rate at different bagasse composition and V_0 is the flame spread rate of pure paper. It indicates that all thickness exhibit the similar trend. The flame spread rate decreases significantly for 0%, 30%, and 50% of bagasse. However, the flame spread rate is nearly constant between 70% and 100% bagasse.

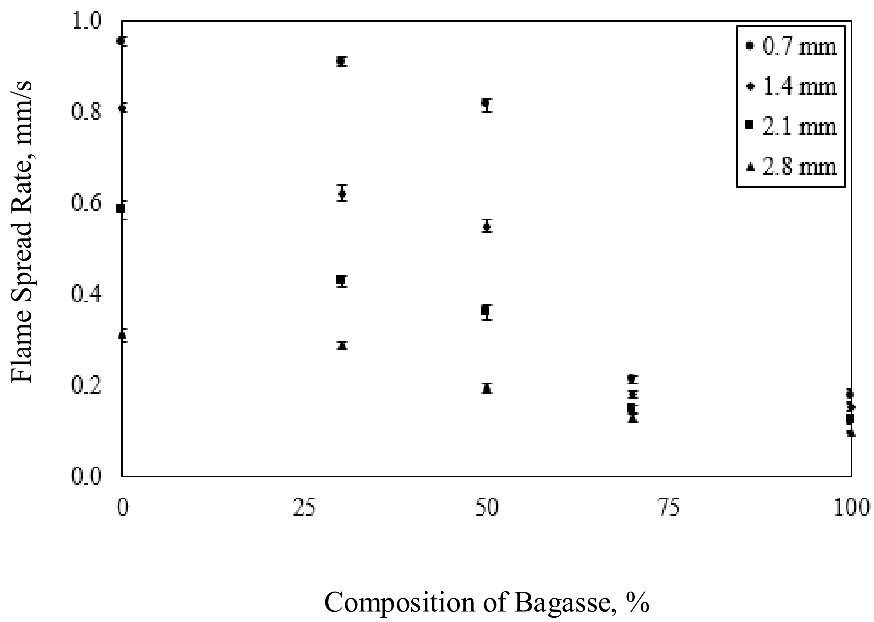


Fig. 9 - Flame spread rate against composition of bagasse

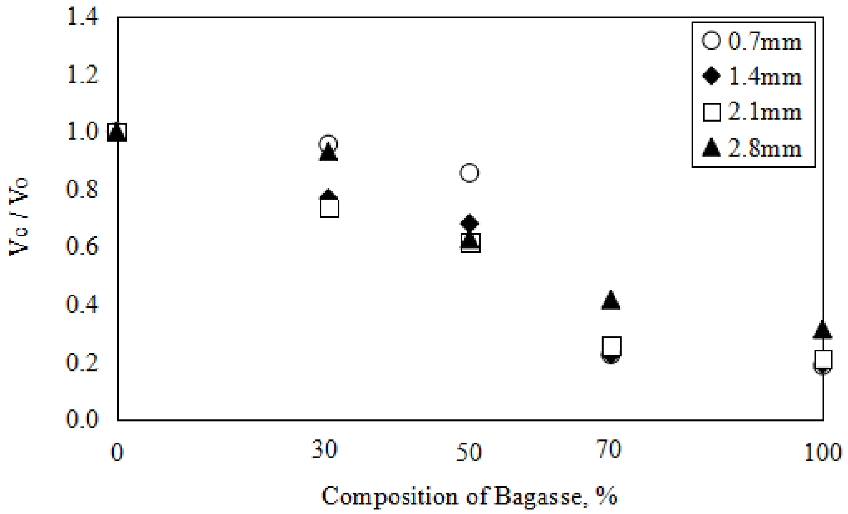


Fig. 10 - V_c / V_0 against composition of bagasse

5. Conclusions

In this experiment, the effect of bagasse physical properties & composition on flame spread behavior has been studied and several results are obtained:

1. The flame spread pattern differs between the bagasse composition. The flame spreads continuously for 0%, 30%, and 50% of bagasse. However, for 70% and 100% of bagasse, the flame spread becomes unstable and extinguishes during the experiment.
2. For 0%, 30% and 50% of bagasse, it is indicated that the flame spread rate decreases significantly as the thickness increases. However, for 70% and 100% bagasse, only the slight difference of the flame spread rate is seen for all thickness.
3. It indicates that all thickness exhibit the similar trend. The flame spread rate decreases significantly for 0%, 30%, and 50% of bagasse. However, the flame spread rate is nearly constant between 70% and 100% bagasse.

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