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FLAME SPREAD BEHAVIOR OVER COMBINED FABRIC OF COTTON/POLYESTER

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ABSTRACT

Experiment has been conducted to study the flame spread behavior over combined fabric of cotton/polyester. Samples are ignited from the top edge and spread to the downward direction. Experiment is conducted for several weft trade angles from 0° to 90°. It is found that a significant difference is seen in the shape of burning front between $\theta = 0°$ and $\theta = 90°$. This phenomenon is influenced by the shrinking behavior of polyester thread at most preceding point of flame front for these angles. The flame spread rate is measured, which is obtained from the position of the most preceding point of the burning front at each time, at different weft thread angle. The result shows that the flame spread rate decreases as the angle increases.

Keywords: flame spread behavior, flame spread rate, combined fabric, and weft thread angle.

INTRODUCTION

Fire safety engineering is an application of science to improve the safety from the destructive effects of the fire. There are many researches on the fire safety engineering have been done in the previous and it is beginning to focus the research on the technical capability for fire preventions in complex issues. In order to improve the technical capability for fire preventions, the fundamental approach is essential which can be applied at the design stage. Such approach requires detailed understanding of combustion process from an engineering viewpoint.

Flame spread over combustible solid is a basic problem in the field of fire safety engineering. There are several studies have been done in order to explore the flame spread behavior over combustible solid [1-6]. De Ris (1669) presented the theoretical description for a laminar diffusion flame spreading against an air stream over a thin sheet. The results suggested that the flame spread rate is dependent on the density and the thickness of solid. Campbell (1971) examined the burning characteristic of filter paper. The balance diagram shows the heat is required for the paper to decompose. Di Blasi (1994) proposed the mathematical model for the degradation of porous cellulosic fuels to volatiles and chars in order to simulate the downward flame spread. Suzuki *et al*. (1994) used various thickness of filter paper to explore the flame spread mechanism over solid fuel sheets. The experimental results indicated that the flame spread rate decreases as thickness of the solid increases.

Extending from previous works related to the flame spread behavior over combustible solid, several researches have been done also in order to examine flame spread behavior over fabric. Ding *et al*. (2014) conducted simulation to study large eddy simulation of fire spread. Authors stated that flame spread behavior have major relation with factors such as material, width, thickness, placed angle and atmospheric pressure. Osorio *et al.*

(2012) conducted experiments to explore limiting conditions for flame spread in fire resistant fabrics. Results discovered that the increment in oxygen concentration will cause the external radiant flux required for flame spread to decrease. Flame spread characteristics of many thin materials will be varying with affect from thickness, external heat flux, oxygen concentration, pressure and forced flow velocity. It is also stated that limiting oxygen index (LOI) and maximum oxygen concentration (MOC) can be used to measure the flammability of material. Simultaneous flame spread is closely resemble upward flame spread, with just distinction is buoyant velocity replacing the forced flow velocity. Char layer formed when the material is heated up give effect on pyrolysis length of charring materials such as Nomex. The minimum conditions for simultaneous flame spread in fire resistant (FR) fabrics depend on externally applied radiant flux and oxygen concentration values. Bei *et al.* (2012) conducted experiment for study the burning behavior of fabric used indoor. It is found that when heat flux increase, the ignition of fabrics used are also increase. Higher heat flux will results in higher heat release rate and peak mass loss rate. The fabrics will burn violently. But when the amount of heat flux is low, smoke production rate and carbon oxide (CO) were higher. It is stated that the density of the structure and moisture content also has effects on burning behavior of fabrics. Bhalla *et al.* (1999) studied burn properties of fabrics and garments worn in India. Results indicated about the burning process of synthetics are not same with cottons or cotton–polyester blends. Heat flux, temperature and flame propagation are discussed in order to characterize the level of fire safety of the fabric. It is found that snug fitting clothes are safer than the same fabric used as loose fitting clothes.

Instead of the comprehension of the flame spread over fabric, it is also essential to understanding influence of combined fabric structure on flame spread behavior since data is still insufficient. This information is

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important in selecting material for interior furniture such as bedclothes, clothing, etc. Those products are often fabricated from the combination of natural and synthetic materials. Combined fabric made of cotton/polyester is often used in the market. Thus, in this study, the flame spread behavior over combined fabrics of cotton/polyester is explored. Cotton is used as the natural material, and polyester as the synthetic material.

EXPERIMENTAL METHOD

Fabric samples are made by means of a weaving machine. Plain weave is chosen as the structure of the fabric. The plain weave has warp threads perpendicular to weft threads. The fabric composed of different materials is referred to as a combined fabric. In this study, cotton is used as the warp thread and polyester as the weft thread. Tables 1 and 2 show the characteristic values of these threads and combined fabrics.

Table-1. Characteristic values of threads.

	Diameter, mm	Linear density, g/m
Cotton thread	0.46	0.087
Polyester thread	0.45	0.079

Table-2. Characteristic values of combined fabrics.

	Number of threads per unit length, cm^{-1}	
	Cotton thread	Polyester thread
Cotton/ polyester	7	7

Figure-1 shows the schematic of the experimental setup. Before the burning test, the fabric sample is dried in a desiccator for more than 48 hours and the humidity in the desiccator is controlled to below 40%. The fabric sample is clamped to the holder and its area of 70 mm × 90 mm is exposed to burn. A burner is used for igniting the fabric at a point on its top edge. The sample surface is illuminated by light from light sources placed in front of the sample. The surface of the sample is videotaped to observe the flame spread behavior. The weft thread angle θ is defined based on the direction of synthetic threads, as shown in the Figure. The experiment is conducted for angles from $\theta = 0°$ to $90°$.
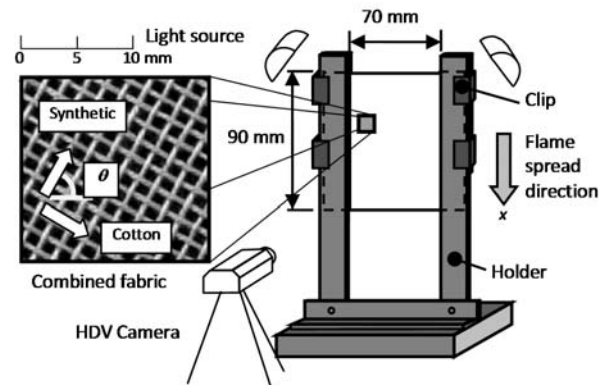

**Figure 1:** Schematic of experiment setup.

RESULT AND DISCUSSIONS

FLAME SPREAD BEHAVIOR

Figure-2 shows shapes of flame front between $\theta = 0°$ and $\theta = 90°$. As seen in Figure-2(a), the flame front is in 'V' shape when the angle is 0°. On the other hand, flat shape is observed when the angle is 90° as shown in Figure-2(b).

Figure-3 shows shapes of burning front for combined fabrics at $\theta = 0°$ and $\theta = 90°$. The cotton thread discolors when it decomposes. The burning front is determined at the edge of the discoloration. It is seen in Figure-3(a), when the flame approaches to a horizontally-lying synthetic thread from its side, the thread melts and breaks into two. The white circle (○) in the figure indicates this breaking point. After the ignition, the flame spreads outward in all directions from the ignition point. After the burning front expands over the whole width of the sample, the shape turns to 'V' shape at this angle. The flame spreads faster at the breaking point than on the other part of the burning front. The white circles are marked on a straight vertical line and the burning front becomes 'V' shape.

However, a significant different is seen in shape of the burning front at $\theta = 90°$. The flame spreads outward from the ignition point at the beginning. The shape becomes flat after the burning front expands over the whole width of the sample. There is some differences between $\theta = 0°$ and $\theta = 90°$. The shape at $\theta = 90°$ is more flat than the shape at $\theta = 0°$. Also, at $\theta = 90°$, the fabric do not show breaking points. The vertically-standing synthetic thread melts from its top end and subsequently vaporizes.

(a) $\theta = 0°$ (b) $\theta = 90°$

Fig. 2 Shape of flame front

(a) $\theta = 0°$ (b) $\theta = 90°$
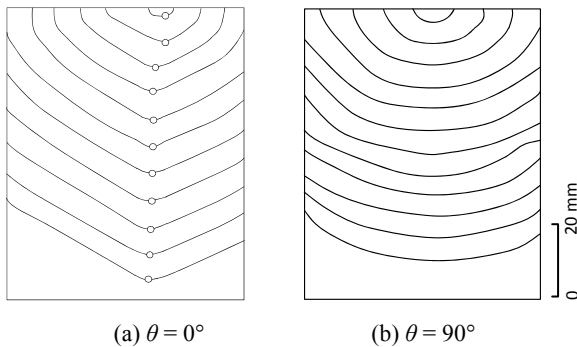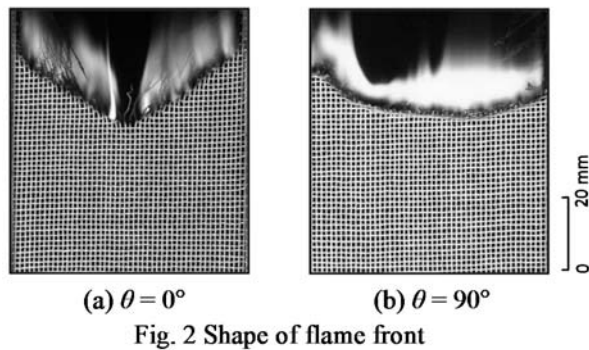
∘ Breaking point

Figure-3. Shape of burning front.

The shape of burning front is influenced by the shrinking behavior of polyester thread. Figure 4 shows the shrinking behavior of polyester thread at $\theta = 0°$. It is seen the polyester thread melts when the edge of discoloration on the cotton thread approaches. The polyester thread breaks into two and it pulls the cotton thread when it shrinks.

Figure-5 shows the different shrinking behavior of polyester thread at $\theta = 90°$. The polyester thread melts and the molten polyester attaches to the cotton thread. As shows in (b) (2), the polyester thread melts gradually in the direction of the thread. The molten polyester attaches to the cotton thread and it pulls the cotton thread in the direction of polyester melting. The movement changes the distance between cotton threads. The distance becomes narrower as time increases.

Figure-6 shows the progress of decomposition on the cotton/polyester fabric at $\theta = 0°$. The dotted line indicates the position of discoloration, and the arrow represents the movement of it. The figure shows that the cotton thread continues to discolor during the polyester thread melts and disappears.

Figure-7 shows the different between the weft thread angles on the progress of decomposition. It is seen the distance between cotton threads becomes narrower as the polyester thread continues to melt. The cotton thread discolors gradually as time increases.
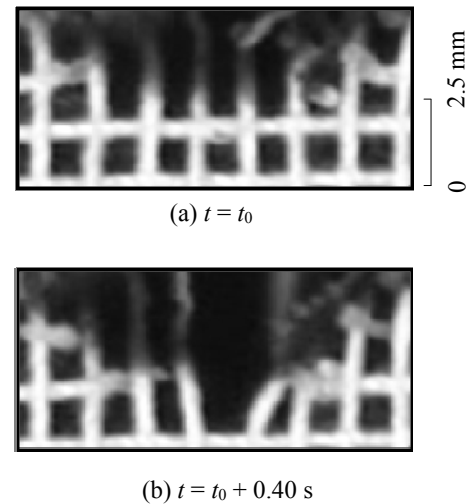

(a) $t = t_0$

(b) $t = t_0 + 0.40$ s

Figure-4. Shrinking behavior of polyester ($\theta = 0°$).

(a) $t = t_0$

(b) $t = t_0 + 0.40$ s
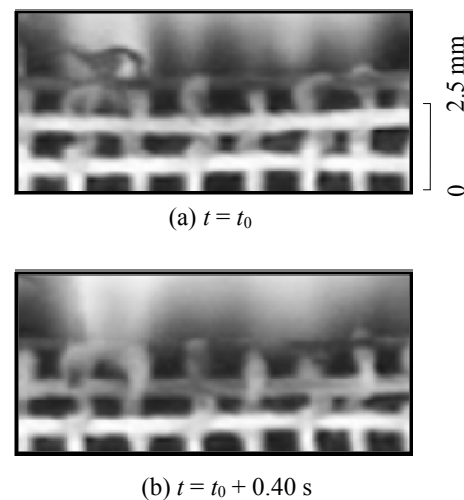
Figure-5. Shrinking behavior of polyester ($\theta = 90°$)

(a) $t = t_0$ (b) $t = t_0 + 0.20$ s   (c) $t = t_0 + 0.40$ s
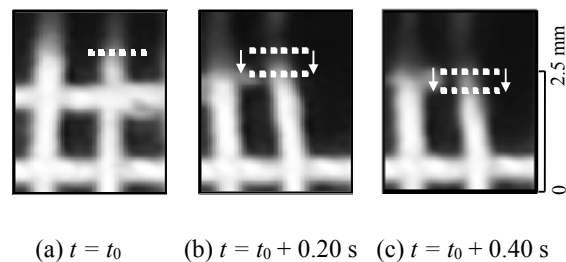
Figure-6. Progress of decomposition ($\theta = 0°$).

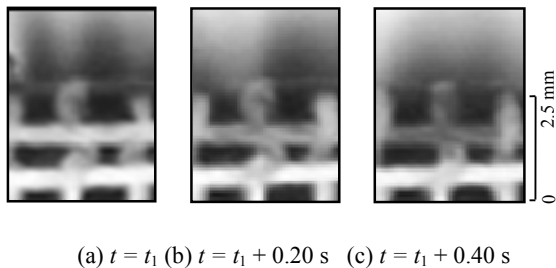(a) $t = t_1$ (b) $t = t_1 + 0.20$ s (c) $t = t_1 + 0.40$ s

Figure-7. Progress of decomposition ($\theta = 90°$).

FLAME SPREAD RATE

Flame spread rates are obtained from Figure-3 by measuring the position of the most preceding point of the burning front at each time. In order to avoid the influence of the initial transition process after the ignition, the position is measured from $x = 20$ mm (to 60 mm), where x is the vertical distance from the top edge of the fabric in downward direction.

Figure-8 shows the flame spread rate of cotton/polyester fabric with respect to weft thread angle. Figure shows the flame spread rate at $\theta = 0°$ is fastest among all the angles. It is found the flame spread rate decreases as the weft thread angle decreases. This angle dependency of the flame spread rate may be influenced by the shrinking behavior of polyester thread at most preceding point of flame front.
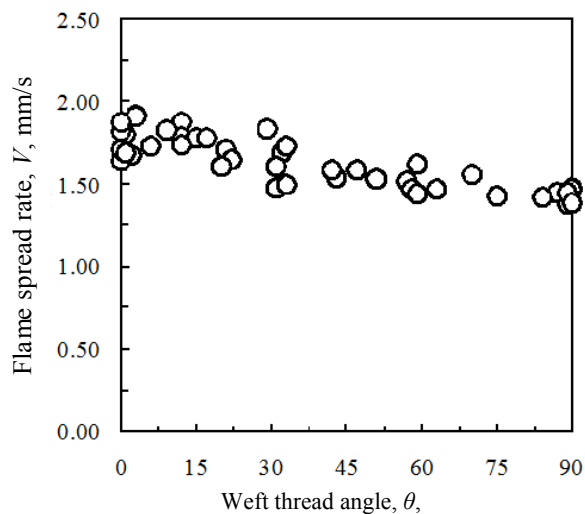

Figure-8. Dependence of flame spread rate V on weft thread angle θ.

As it is seen in Figure-6, the distance between cotton threads becomes wider during the polyester thread melts and breaks at $\theta = 0°$. On the other hand, it is different at $\theta = 90°$ as the distance between cotton threads tends to be narrower as the polyester thread continues to melt. The movement of the cotton threads may affected on the density of the fabric during the burning process, which

can be the reason of this angle dependency of flame spread rate.

CONCLUSIONS

In this study, flame spread over combined fabrics of cotton/polyester is examined and following results are obtained:
1. Shapes of burning front differ between weft thread angles. This difference is presumed to be caused by different shrinking behaviors of polyester thread.
2. Angle dependency of flame spread rate is obtained, flame spread rate decreases as the angle increases.

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