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Self induced buoyant blow off in upward flame spread on thin solid fuels

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ABSTRACT

Upward flame spread experiments were conducted on long thin composite fabric fuels made of 75% cotton and 25% fiberglass of various widths between 2 and 8.8 cm and lengths greater than 1.5 m. Symmetric ignition at the bottom edge of the fuel resulted in two sided upward flame growth initially. As flame grew to a critical length (15–30 cm depending on sample width) fluctuation or instability of the flame base was observed. For samples 5 cm or less in width, this instability lead to flame blow off on one side of the sample (can be either side in repeated tests). The remaining flame on the other side would quickly shrink in length and spread all the way to the end of the sample with a constant limiting length and steady spread rate. Flame blow off from the increased buoyancy induced air velocity (at the flame base) with increasing flame length is proposed as the mechanism for this interesting phenomenon. Experimental details and the proposed explanation, including sample width effect, are offered in the paper.

1. Introduction

The upward flame spread configuration is often used as a metric for quantifying the overall flammability of materials and merits further in depth study of the characteristics and boundaries of flammability. For example, NASA material flammability flight qualification test NASA-STD-6001 Test #1 [15] and Underwriters Laboratories test UL-94V [23] both utilize upward flame spread geometries similar to the ones used in this work. The result of NASA Test #1 is a simple pass/no-pass criteria based on whether the flame damaged region propagates upwards further than 15 cm on a 5 cm × 30 cm sample. The results of UL-94V are categorized based primarily on duration of burning. Neither of these tests take into account detailed mechanisms of flame propagation or extinction and are assumed to be a worst case flammability configuration based on the fact that gravity tends to accelerate flame spread in the upward direction.

It has been previously shown that sample width can have a significant effect on the characteristics of upward flame spread, including flame size, heat generation rate, and spread rate [6,7,10,14,17,19,21]. It should be clear that sample width may also affect the flame extinction limits despite the fixed width criteria in standardized flammability testing methods. In this work, upward flame spread tests were conducted in normal gravity using a special composite fabric fuel. Several sample widths were used. An unexpected but very interesting phenomenon, i.e. self-induced flame extinction when the flame reached a certain length, was observed in many of the tests. The observation and a proposed interpretation are discussed below.

2. Material and methods

The experimental setup is shown schematically in Fig. 1. This configuration mimics that of the NASA STD-6001 Test #1 and UL-94V. The thin fuel is sandwiched between four parallel stainless steel sample holders 0.035″ (0.889 mm) thick × 2.5″ (6.35 cm) wide with adjustable exposed sample width of 2-8.8 cm and height up to 1.8 m. The fuel used in this experiment is unique. It is made from a simple weave fabric consisting of thread spun with 75% cotton and 25% fiberglass strands with an area density of 0.01805 g/cm^2 and is about 0.31 mm thick. As the cotton burns away, the fiberglass component of the thread is left behind maintaining the fuels structural integrity and shape. This inert matrix simplifies the burning characteristics of the fuel by

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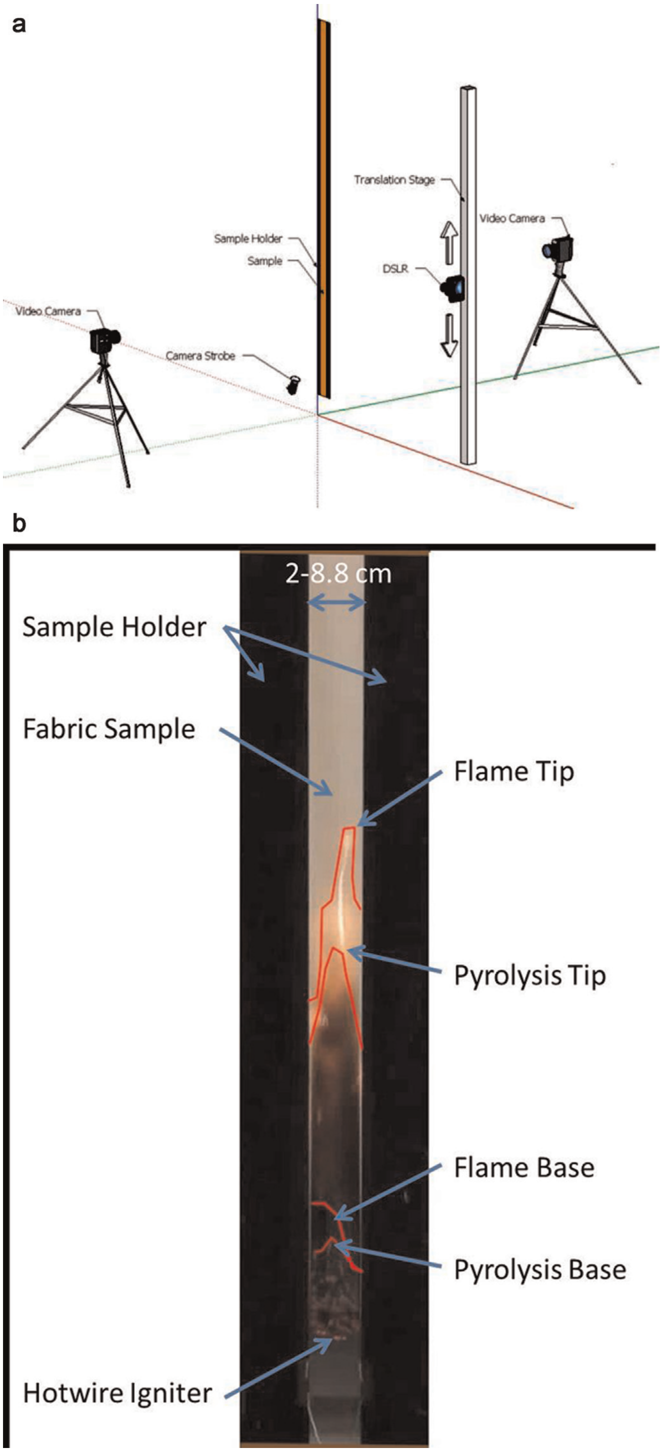

Fig. 1. (a) Experimental setup: video cameras image both front and back of the thin fuel sample, a still image camera translates along the edge of the sample holder with the flame. A remote camera strobe is located behind the sample pointed at an upward angle (left). (b) Zoomed in front view shows the flame tip, pyrolysis tip, and pyrolysis base. Smoldering of left over fuel can be seen below the pyrolysis base. Thin black stainless steel sample holders can be seen to the left and right of the fuel sample (right).

preventing tearing, ripping, and curling of the solids surface as would happen with other burning materials such as paper. A detailed comparison of the burning characteristics of this fuel with other materials is given in Ref. [8].

This custom-made fabric fuel (referred to as SIBAL), named after the experiment for which it was originally designed Solid Inflammability Boundary At Low-speed [4] has been studied in a large number of careful laboratory scale experiments in a variety of environmental conditions [4,8,11]. The pre-burned SIBAL fuel can be seen in Fig. 2a, and after the flame front has passed the remaining inert matrix is shown in Fig. 2b.

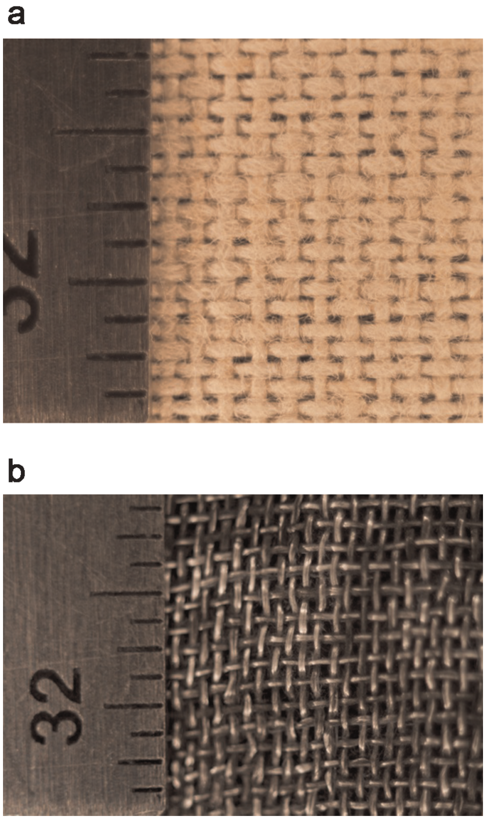

Fig. 2. (a) Unburned SIBAL fabric (left) and (b) inert fiberglass matrix after the flame has passed (right). Ruler notches are 1/32″ (0.79 mm).

The leftover fiberglass matrix has been found to act as a flame arrester since the gaps between the threads are large enough to allow gas to pass through but smaller than the quenching diameter of the flame. This allows for the somewhat unique possibility of a one-sided flame existing on a thin fabric fuel [11]. Note also that this fuel sample is sufficiently thin so that, in most experiments, it behaves as a thermally-thin specimen.

Fuel ignition was achieved using a 30 cm long 29 gage Kanthal hot wire powered with 3.7 amps (about 62 W) bent into a sawtooth pattern alternating on the front and back of the fuel surface at the free bottom edge of the fuel sample. Ignition power was removed when a robust flame was observed.

The burning material is imaged at 30 frames per second with two 1080p high-definition video cameras perpendicular to the front and back surfaces of the fuel. A third high-resolution still camera zoomed to the size of the flame views the fuel and sample holder from the edge and moves along a track parallel to the flame propagation. The still camera is capable of shooting an 8 frame burst in approximately 1 s. A strobe light located on the opposite side of the sample holder illuminates the unburned fuel vapor or smoke and captures the instantaneous smoke field. The still camera needs to integrate the light generated from the flame over approximately 1/30–1/60th of a second in order to record the image. However, the strobe illuminates the smoke field only for about 1/1000th of a second to eliminate motion blur of the smoke.

The position of the pyrolysis front and pyrolysis base are tracked with custom imaging software by searching for brightness thresholds along the centerline of the fuel sample. The threshold