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Experimental analysis of high oxygen concentration influences on horizontal flame spread over PA6 and epoxy

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Abstract. The combustion characteristic of material in high oxygen concentration is directly related to the safety of elevated oxygen environment similar to oxygen bombs and future spacecraft. In this study, flame front and flame spread rate in high oxygen concentration are discussed. Thermoplastic material polyamide (PA6) and thermosetting material epoxy are selected as comparison material. The variation of flame front over epoxy is more stable than PA6 which has dripping phenomenon during the flame spread process. The flame spread rate of both PA6 and epoxy have a power law with the increasing oxygen concentration.

1. Introduction

The Increasing attentions have been paid to the study of flame spread characteristics of polymer materials under different conditions. Zhou et al [1, 2] studied the flame spread characteristics of rigid polyurethane. The effect of external radiation, pressure and sample size is considered. The result showed that the flame spread rate and flame height decrease with the increase of sample width and flame spread rate in Hefei is higher than Lhasa. Besides, the flame spread rates of rigid polyurethane increases under the condition of increasing external radiation. Xiao Chen [3, 4] performed experiments on PMMA under the condition of different sample orientation and give a better understanding from the heat and mass transfer theory about the effect of orientation on flame spread. In addition, many scholars have studied the effect of melting and dripping phenomenon on the flame spread of thermoplastic materials [5-11]. Also, there are a few researches on combustion behavior of materials under high oxygen concentrations [12-14].

2. Experimental setup

The experiments are conducted in HC-2 oxygen index apparatus. Oxygen concentration is changed by changing the proportion of oxygen and nitrogen. Oxygen concentration is expressed by the percent of oxygen in the air. The diameter of the glass is 8cm and the distance between sample and underside is 25cm. Bottom of glass cover is filled with small glass ball and fine sand, thereby reducing the speed of airflow and making the gas move into the glass evenly. We improve the material upholder to make apparatus enable to measure parameters of horizontal flame spread. The ambient temperature and humidity of experiment were 15±2℃ and 45%±5% respectively. The samples are 40mm in length, 4mm in diameter. A high speed Sony camera (HDR-XR160) is placed 1.5 m from the apparatus to record the flame spread process.

3. Result and discussion

Pyrolysis front is hard to measure but we can obtain the position of flame front from the video information recorded by the high definition DV at the side. So we define fire spread rate by the change of the position of flame front as

$$V_f = \frac{x_f(t+\Delta t) - x_f(t)}{\Delta t} \tag{1}$$

In the process of flame spread, the difference between thermoplastic material and thermosetting material is expressed as Figure 1.

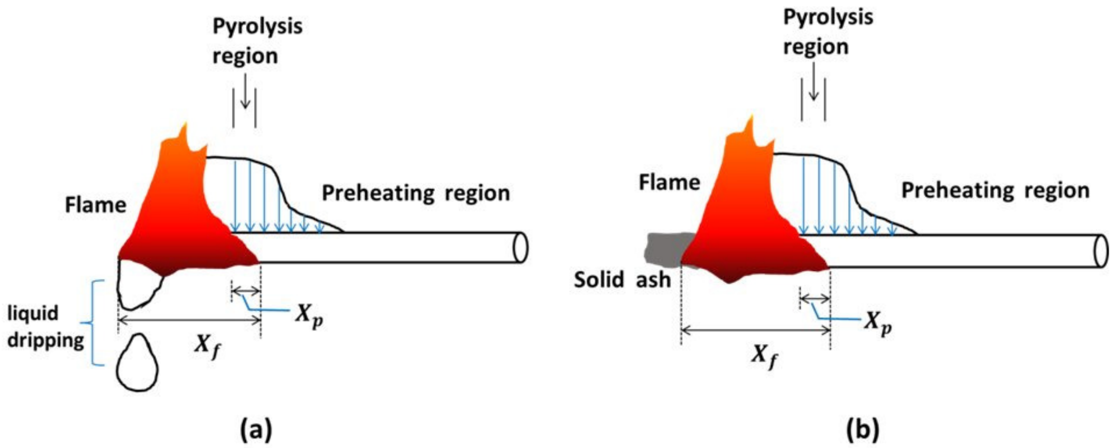

Figure 1. Illustrations of horizontal flame spreading: (a)thermoplastic sample PA6 (b)thermosetting sample Epoxy.

The local slope of the curve is defined as instantaneous flame spread rate. Different fluctuations can be observed for the samples of PA6 and epoxy. The flame front variation between PA6 and epoxy under 30% oxygen concentration is shown in Figure 2.

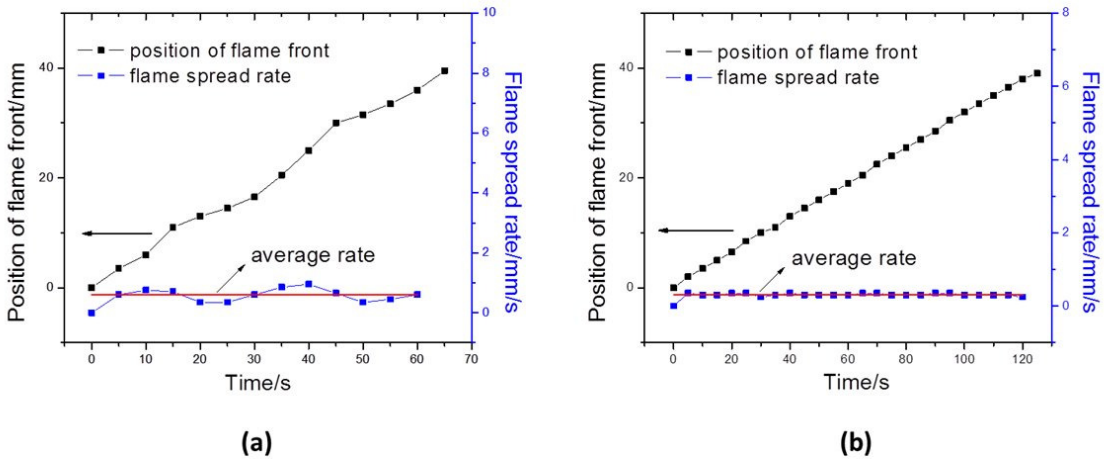

Figure 2. Flame front trajectories and time evolutions of the flame spread rate under 30% oxygen concentration: (a) PA6 and (b) epoxy.

With the increase of environmental oxygen concentration, gas phase chemical reaction was accelerated and the react between pyrolysis gas and oxygen become intense, increasing the heat release rate and flame temperature. High flame temperature increases the convictive flux and radiate flux, thus speeding up the horizontal flame spread. The variation of flame front about PA6 and epoxy from 25% to 50% of oxygen concentration is shown in Figure 3.

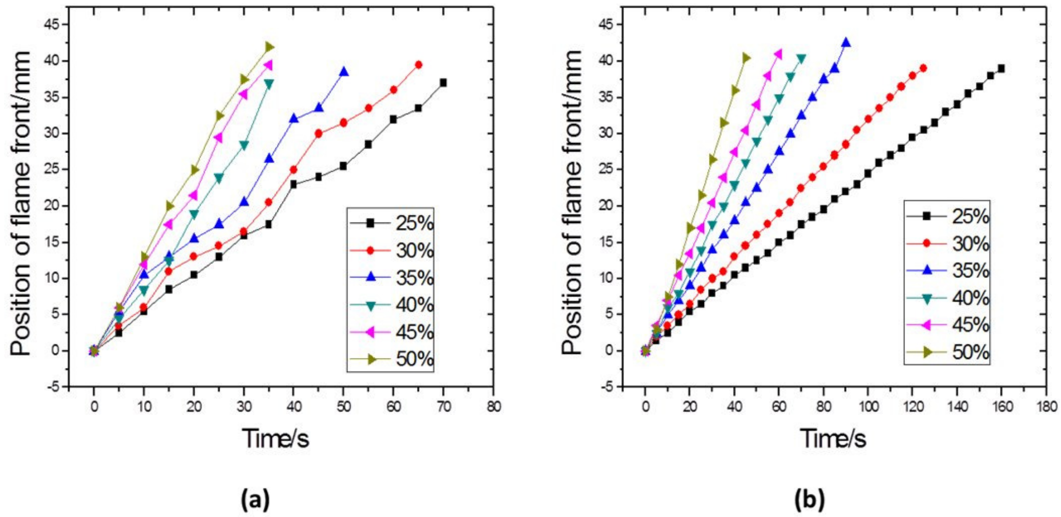

Figure 3. The variation of flame front under oxygen concentration from 25% to 50%: (a) PA6 and (b) epoxy.

Horizontal flame spread rate and heat flux from the flame for thermally thick material developed by Quintiere [15] proposed a formulation for flame spread rate of thermal thick material as

$$v_f \approx \frac{4(\dot{Q}_F^{"})^2 \delta_P}{\pi k \rho c (T_{ig} - T_\infty)^2} \tag{2}$$

$\dot{Q}_F$ is a part of combustion heat, so it can be written as

$$\dot{Q}_F = \zeta \dot{q}_f \tag{3}$$

According to oxygen consumption method [12], the relationship between flame combustion heat flux and oxygen concentration can be expressed as

$$\dot{q}_f = E\dot{V}_{298}\chi_{O_2}\left(\frac{\phi}{\phi(\alpha-1)+1}\right) \tag{4}$$

Combining Eqs. (2), (3) and (4), the relationship between flame spread rate and oxygen concentration can be expressed as

$$v_f \propto \chi_{O_2}{}^{m} \tag{5}$$

Figure 4. shows the fitting results of those two kinds of materials. The best-fit relationship between thermoplastic material PA6 and thermosetting are

$$v_{PA6} = 4.86\chi_{O_2}{}^{1.34}, with 25\% \le \chi_{O_2} \le 50\% \tag{6}$$

$$v_{Epoxy} = 3.12\chi_{O_2}{}^{1.87}, with 25\% \le \chi_{O_2} \le 80\% \tag{7}$$

The fitting results of those two kinds of materials shows that the horizontal flame spread rate over both thermoplastic materials and thermosetting materials increase according to a power low with the increasing oxygen concentration.

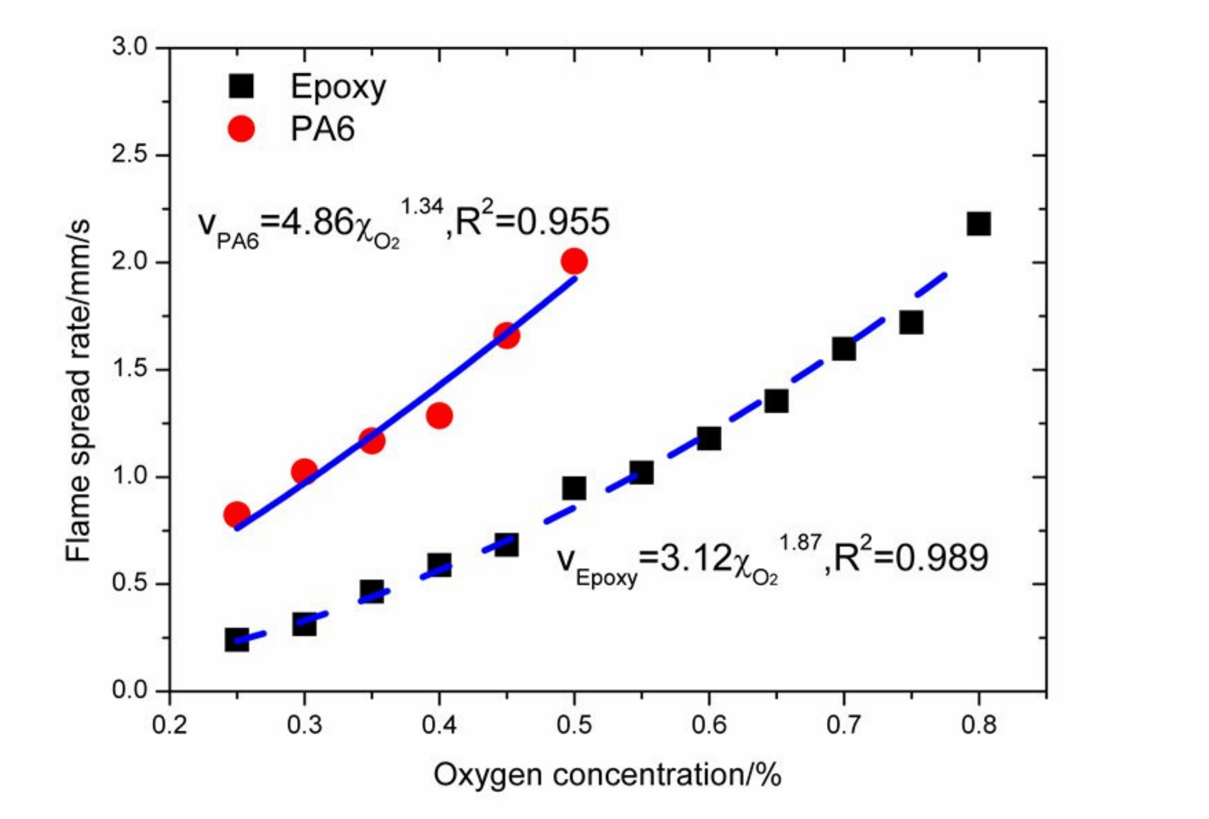

Figure 4. Flame spread rate over PA6 and Epoxy as a function of oxygen concentration. Points indicate the experimental date, and the dotted lines are the best fits.

4. Conclusions

In this work, a series of small size experiments of horizontal flame spread over PA6 and epoxy under different high oxygen concentration have been conducted to study the effect of ambient oxygen concentration flame front and flame spread rate. The difference of flame front between thermoplastic material and thermosetting material are also discussed in this paper. The main result of this work is shown as follows:

The movement flame front of PA6 is not stable changing with time under high oxygen concentration; Compared to thermoplastic material PA6, thermosetting material epoxy has stronger stability.

The horizontal flame spread rate increases according to a power law with the increase of oxygen concentration.

5. Acknowledgement

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