PILOTED IGNITION OF POLYPROPYLENE/GLASS COMPOSITES IN A FORCED AIR FLOW

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INTRODUCTION

The Forced Ignition and Spread Test (FIST) is being used to study the flammability characteristics of combustible materials in forced convective flows [1]. The FIST methodology is based on the ASTM E-1321, Lateral Ignition and Flame Spread Test (LIFT) [2,3] which is used to determine the ignition and flame spread characteristics of materials, and to produce "Flammability Diagrams" of materials. The LIFT apparatus, however, relies on natural convection to bring air to the combustion zone and the fuel vapor to the pilot flame, and thus cannot describe conditions where the oxidizer flow velocity may change. The FIST on the other hand, by relying on a forced flow as the dominant transport mechanism, can be used to examine variable oxidizer flow characteristics, such as velocity, oxygen concentration, and turbulence intensity, and consequently has a wider applicability. Particularly important is its ability to determine the flammability characteristics of materials used in spacecraft since in the absence of gravity the only flow present is that forced by the HVAC of the space facility [4].

In this paper, we report work on the use of the FIST approach on the piloted ignition of a blended polypropylene fiberglass (PP/GL) composite material exposed to an external radiant flux in a forced convective flow of air. The effect of glass concentration under varying external radiant fluxes is examined and compared qualitatively with theoretical predictions of the ignition process. The results are used to infer the effect of glass content on the fire safety characteristics of composites.

EXPERIMENTAL HARDWARE AND PROTOCOL

The general configuration of the problem investigated by the FIST methodology is shown in Figure 1. It consists of a duct where a flow of oxidizer gas of prescribed oxygen concentration and velocity is forced along its longitudinal direction. A rectangular slab of fuel is embedded flush in a plate of insulating material that forms one wall of the duct. The exposed surface is impulsively subjected to an external heat flux of known intensity and approximately uniform distribution using an IR strip heater placed opposite the fuel. Ignition of fuel pyrolysates is forced with an electrically heated wire placed at the sample end. Ignition delay is defined as the time lapse from the instant that the fuel is exposed to the external radiant flux to the onset of flaming. A sudden rise in surface temperature is used to determine ignition, corroborated by visual and video observation.

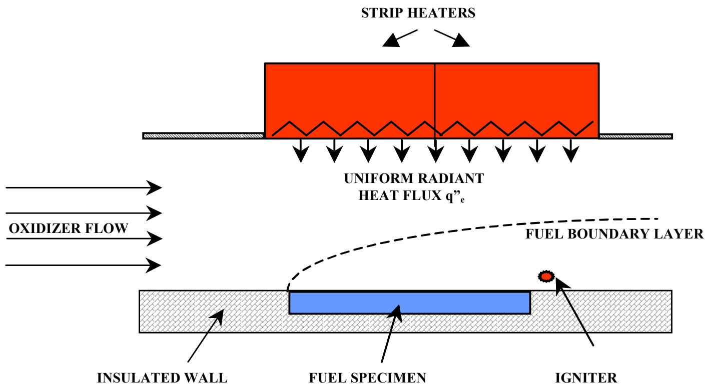

Figure 1. FIST apparatus

BACKGROUND

In the LIFT methodology, the analytical solution to the transient heating of a semi-infinite solid by a constant surface heat flux is used to determine the ignition time, by calculating the time necessary for the solid surface to attain an "ignition" temperature (T_{ig}). To obtain an analytical solution to the surface temperature (T_S), the convective heat transfer coefficient is averaged and assumed constant, and surface re-radiation is treated by means of a linear approximation at an average surface temperature. Assuming that the ignition temperature is constant, for large values of the external radiant flux, the following expression is obtained for the ignition delay time (t_{ig}) as a function of the external radiant flux

$$\frac{1}{\sqrt{t_{ig}}} = \frac{2}{\sqrt{\pi}} \frac{\alpha}{\sqrt{k\rho C}} \frac{\dot{q}''_e}{(T_{ig} - T_\infty)} \qquad (1)$$

Where the α is the material absorptivity, $\dot{q}''_e$ the external radiant flux, T_∞ the ambient temperature, k the thermal conductivity, ρ the density and C the specific heat of the solid. The product $k\rho C$ is often referred to as the "thermal inertia" of the solid. The methodology followed by the LIFT standard [2,3] can be used to qualitatively analyze the effect of glass content on the ignition characteristics of the composite. The values for $k\rho C$ from the literature [5,6] confirm that the thermal inertia of the composite increases as the percentage of glass is increased, and thus from Eq. (1) it is predicted that, for a given radiant flux and ignition temperature, the ignition delay should increase.

The glass addition has two main effects on the physics governing the material ignition delay. One is the increase in the density of the composite, which for a given external heat flux would require a longer period to reach a certain surface temperature. The other effect is the increase in thermal conductivity k, which favors the in-depth penetration of the thermal wave, and consequently also requires a longer period of time to reach a certain surface temperature for a given external heat flux. Both effects contribute to increased ignition times and critical heat fluxes for ignition.

RESULTS

In Figure 2 surface temperature histories for PP/GL with glass percentages of 0%, 20%, 30%, and 40%, at a constant heat flux of 20.0 kW/m^2 and an air velocity of 1m/s are presented. The results show that the glass percentage moderately affects the surface temperature profile, but that as the percentage of glass is increased both the surface temperature at which ignition occurs and the ignition delay increase. As explained previously, these results are due primarily to the increase of the thermal inertia of the composite as the glass content is increased.

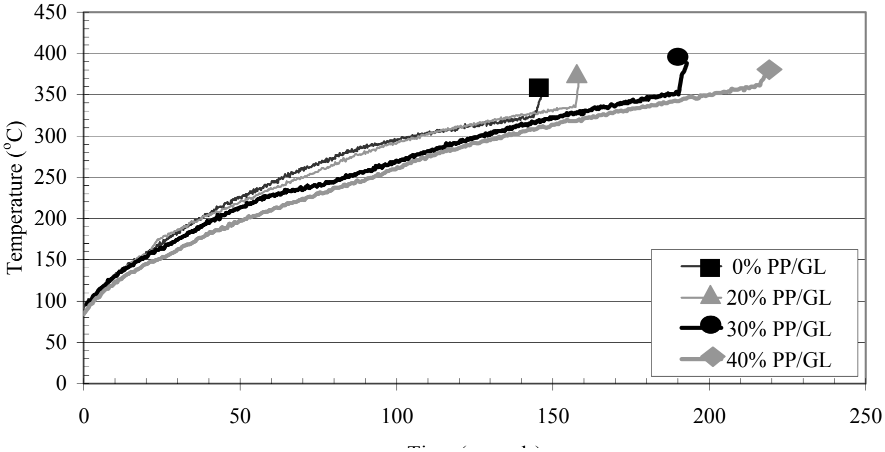

Figure 2. Surface temperature histories for different glass concentrations at a radiant flux of 20 kW/m^2 and air velocity of 1 m/s.

Figure 2 shows that ignition delay and critical heat flux for ignition (asymptotic value of the heat flux for large ignition times) are functions of the glass concentration in the composite, increasing as the glass concentration is increased. Three to four tests are conducted for each data point but error bars have been removed for clarity of presentation.

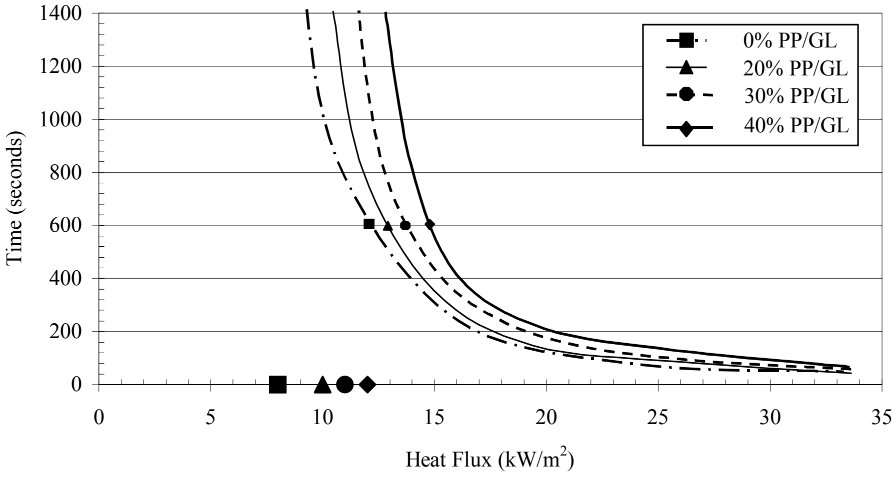

Figure 3. Ignition delay graph for PP/GL of different fiberglass percentages and air velocity of 1 m/s.

Correlation of the ignition delay data of Fig. 3 with Eq. (1) can be used to experimentally determine the kρC of the composite. It is found that calculated value of kρC qualitatively agrees with the values obtained from the literature, although there is quantitative disagreement due to fuel pyrolysis effects that are not included in Eq. (1).

The critical heat flux for ignition obtained from Figure 3 can be used to produce ignition/ no ignition diagrams (Figure 4), where a "no ignition" region can be defined based on the fiberglass content of the composite under a given external heat flux. This has important fire safety implications.

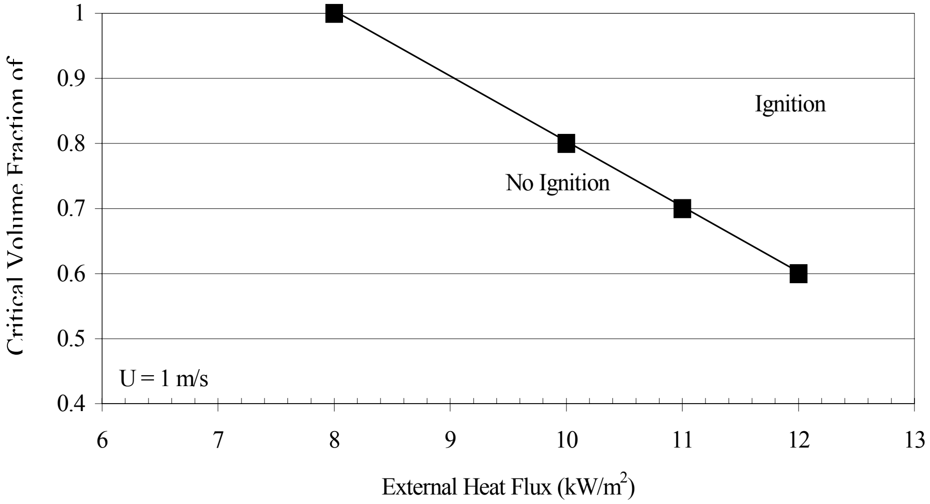

Figure 4. Critical PP volume fraction for ignition.

CONCLUDING REMARKS

It has been shown that the glass volume fraction of a composite material affects its ignition characteristics, particularly near the critical heat flux range. Whereas the use of fire-retardant matrix materials is usually the primary means for improving fire safety in composites, the present research suggests that fire safety may also be enhanced by using composites with high glass concentrations.

ACKNOWLEDGMENTS

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