Experimental study on the fire behavior of composite materials impinged by an air/kerosene premixed flame.

Raphael Ogabi[1], Brady Manescau[1], Khaled Chetehouna[1] and Samuel Senave[2]

[1]INSA Centre Val de Loire, Univ. Orléans, PRISME EA 4229, F-18022 Bourges, France

[2]DAHER, 41400 St Julien de Chédon, France

*Corresponding author's email: **raphael.ogabi@insa-cvl.fr**

Presentation outline

1. Introduction and motivation
2. Materials and Methods
3. Results and discussion
4. Conclusions and Perspectives

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Introduction cont'd..

❑ Significance of polymer composites

- ✓ Transport sector: aircrafts

❑ Desired properties of the composites (PMC)

- ✓ Light weight
- ✓ Low cost
- ✓ Ease of processability
- ✓ Relatively high mechanical properties

❑ Techniques of composite production

- ✓ Compression moulding
- ✓ VARTM
- ✓ Injection moulding

Introduction cont'd..

Aim

- The aim of this work is to highlight the effects of equivalence ratio on the fire behavior of composite materials used in the aerospace industry. Therefore to access the fire risks of such application, some standard tests were performed.

Objectives

- The characterization of the air-kerosene premixed flame by examining its temperature, heat flux density and the optimum sample position away from the burner during test.

- The pyrolysis test of three composite materials (Carbon-Phenolic, Carbon-PEKK and Carbon-BMI) in order to ascertain their fire resistance potentialities.

- Numerical validation using FDS code

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Introduction cont'd..

Problem statement ?

- European Union Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) :

✓ Responsible for the certification of aircraft materials

How to solve this problem?

❑ Quality control test

✓ Air worthiness assessment

Introduction cont'd..

❑ Research gap ?

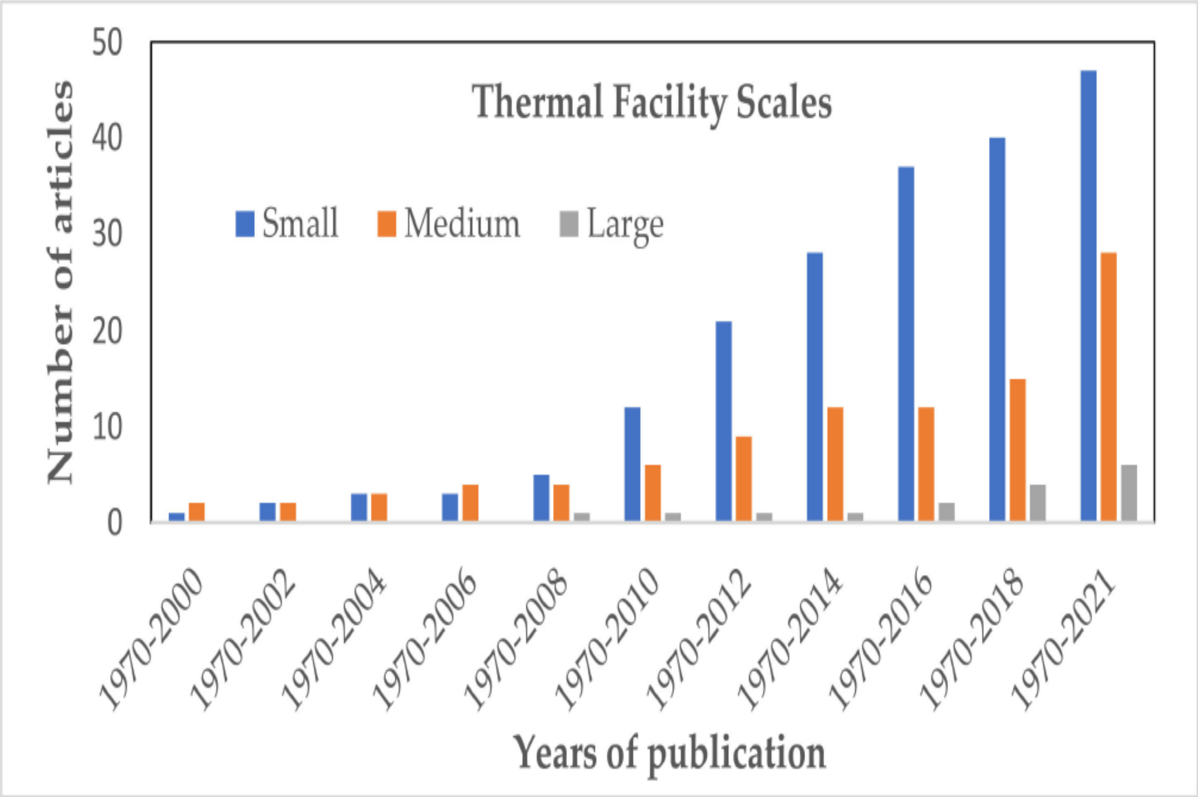


Fig 1. Number of articles published on thermal and gas emission keywords.

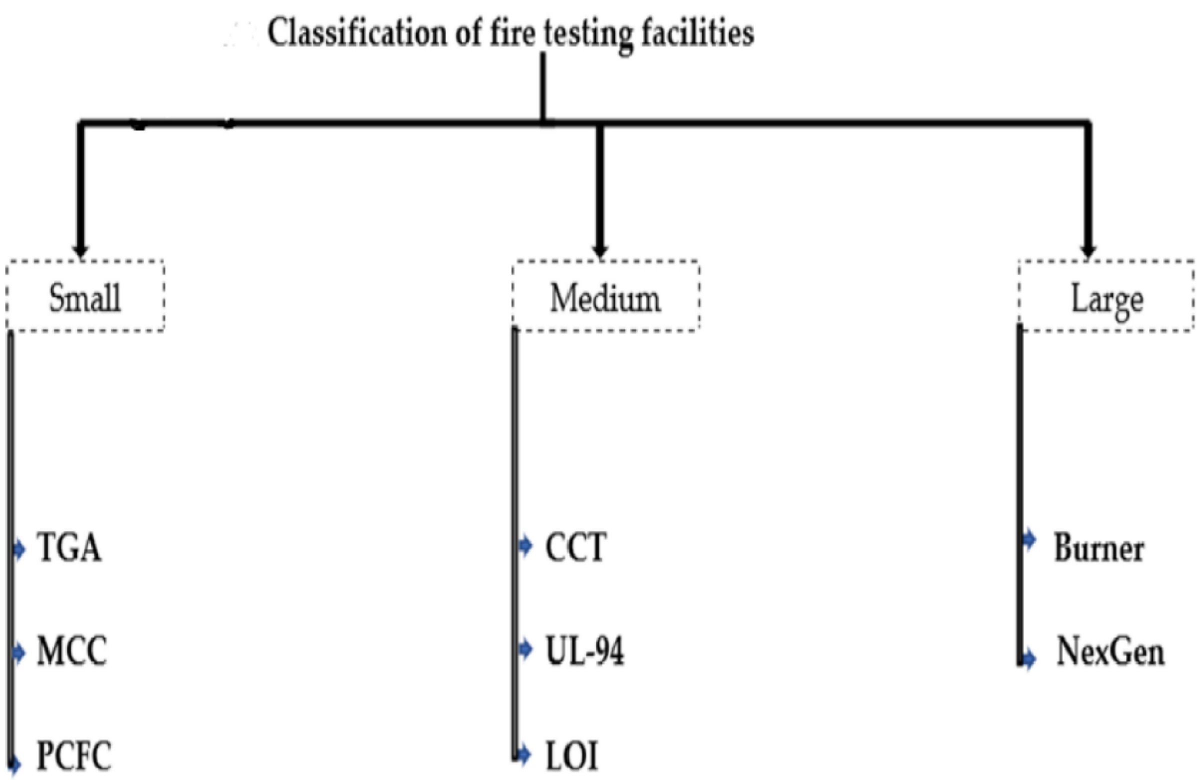


Fig 2. The classification of facilities based on different scales

(Yi-Huan Kao et al.,)

Materials and Methods

- Types of composites materials used
- NexGen Burner Setup
- Thermocouple tree installation

Materials

- **The materials are fabricated and supplied by DAHER manufacturer.**

- ✓ The carbon-phenolic matrix consists of 6 layers of phenolic carbon with a thickness of 1.5 mm for a fibre mass fraction of 40%.

- ✓ The thermoplastic-PEKK matrix consists of 12 layers of carbon with a thickness of 1.5 mm for a mass fraction of 41% fibre.

- ✓ The carbon-BMI matrix consists of 6 folds of carbon fibres, thickness of 1.5 mm and for mass fraction of 42% fibre

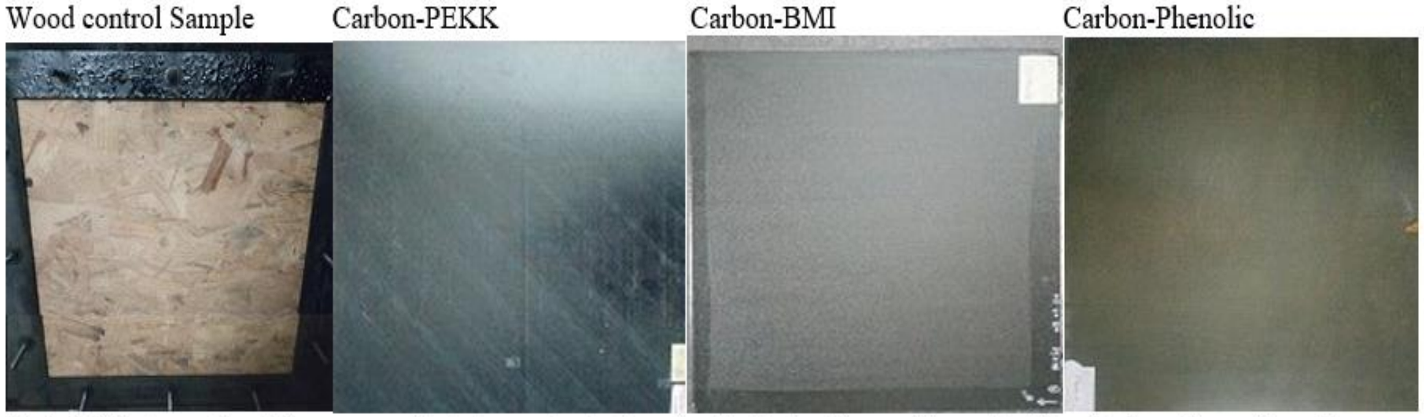


Plate 1. Photographs of the composite test samples before the 5 minutes fire resistance test (vertical configuration –face before exposure to heat flux)

Materials

Phenolic

- ✓ Good for high-temperature applications where parts must meet fire safety standards.
- ✓ Forms aromatic cross linkage with phenol attached group (toxic volatile emission).
- ✓ It has a lower thermal conductivity and a T_m = 220°C

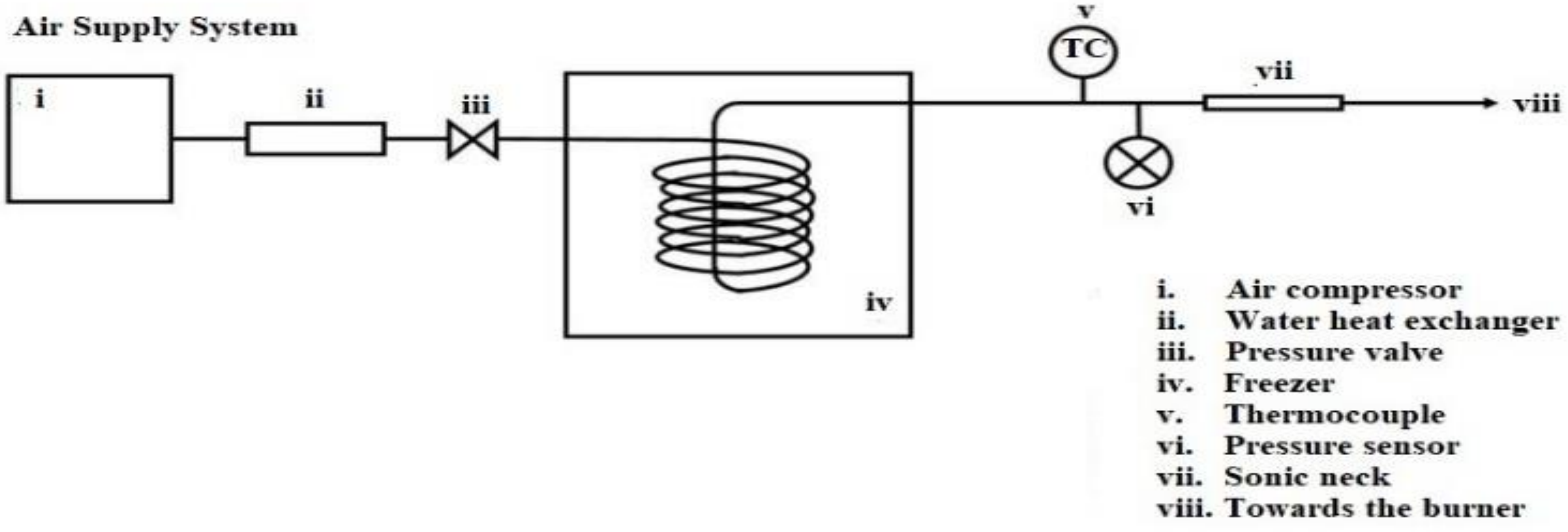
BMI

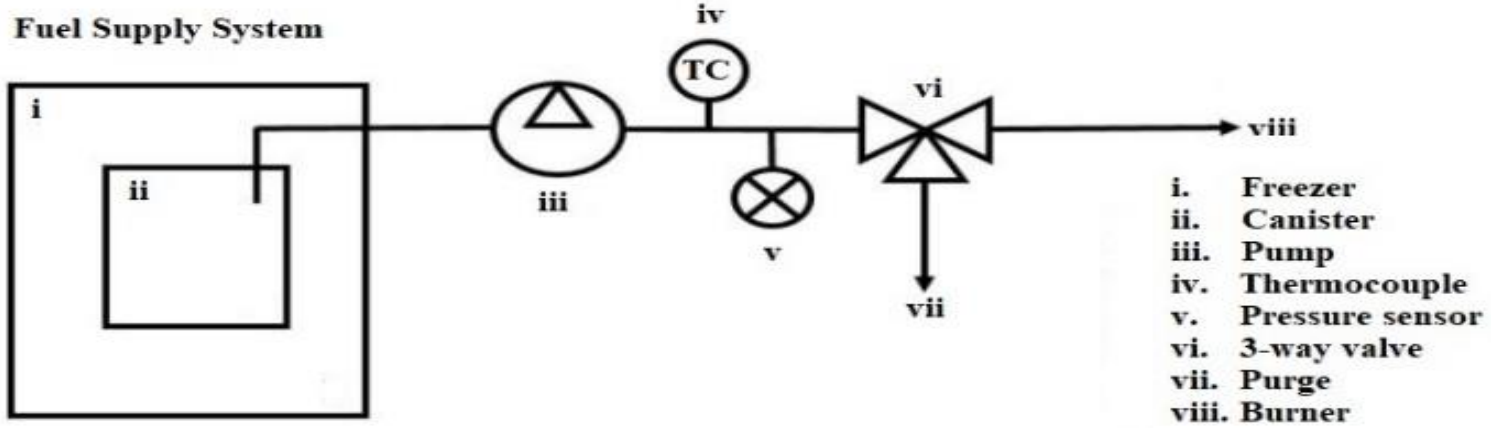
- ✓ High performance structural composites that require high temperature and increased toughness.
- ✓ Melting temperature T_g = 250 °C and T_m = 300°C.

PEKK

- ✓ The monomer of PEKK resin is characterized by three aromatic groups in the main chain with ether and ketone linkages.
- ✓ Application for cabin interiors and external structures in aerospace.
- ✓ High mechanical performance, T_g = 162 °C and T_m = 338 °C.

Methodology





✓ Delavan brand Injector :

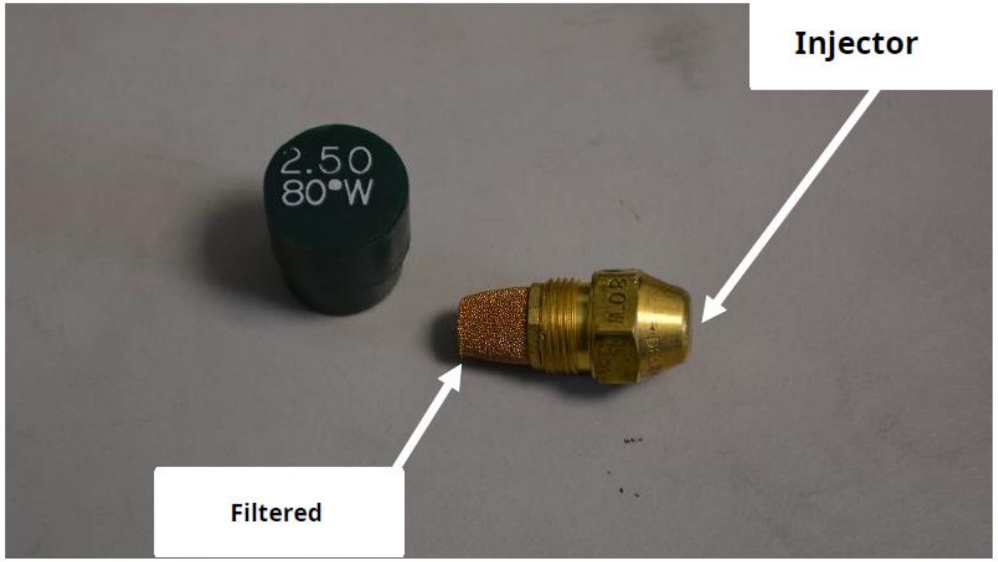
2.5 GPH output rate

80° spray angle

Jet A-1 kerosene fuel

Combustion energy = 42.8 MJ/kg

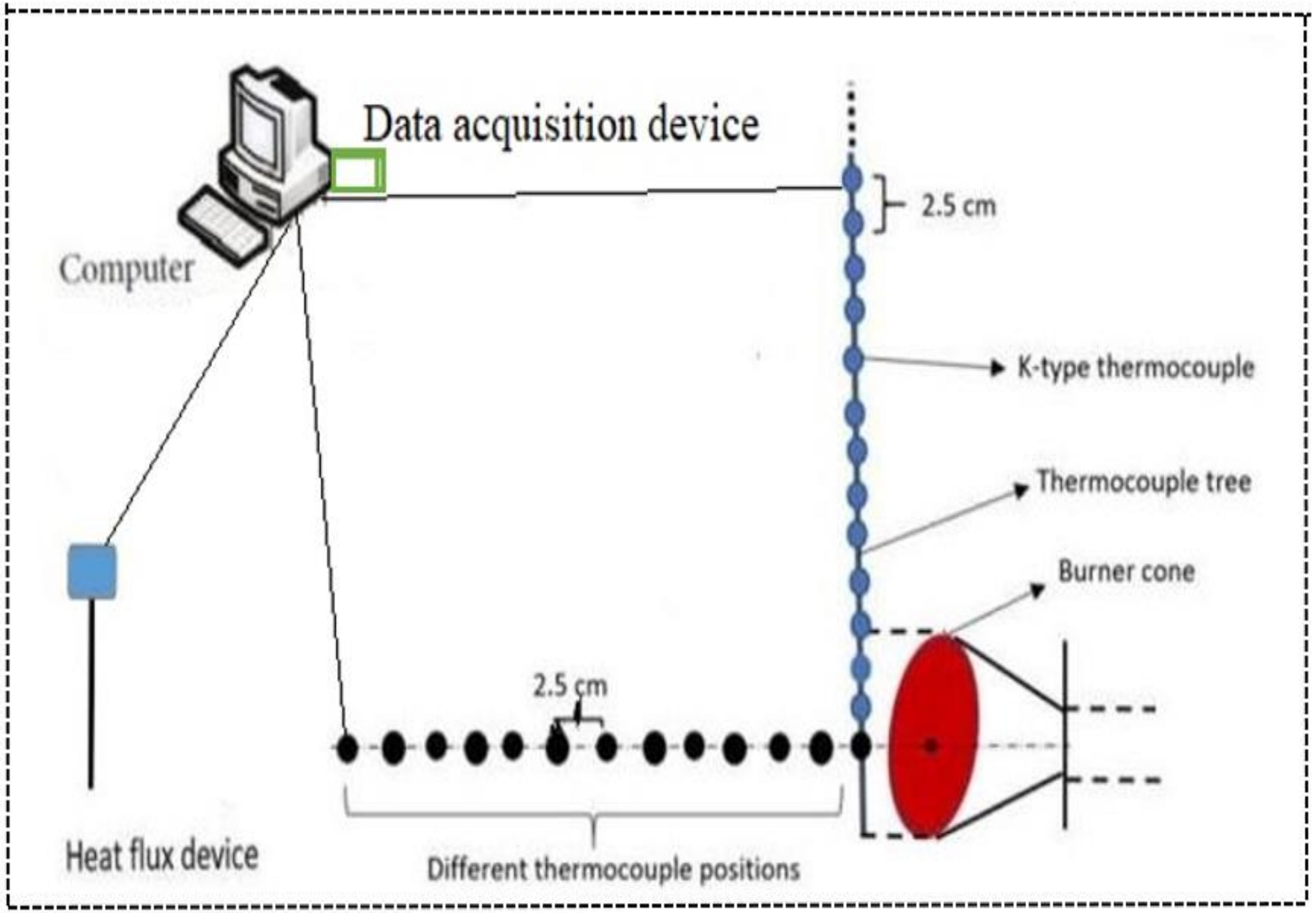
Density = 775 kg/m^3



✓ The ignition of the kerosene/air mixture is ensured using a spark plug fixed to the upper part of the cone located at the burner outlet. This is powered by a current of 10 kV for 3 seconds at the start of the test procedure.

Methodology cont'd..

- ✓ Labview data acquisition device
- ✓ Captec heat flux sensor
- ✓ FLIR Infrared thermal camera
- ✓ Ecom Pro gas analyzer



Side view of the NexGen burner with the installation of thermocouples

Methodology cont'd..

$$C_{12}H_{23} + 17.75\,(O_2 + 3.76N_2) \rightarrow 12CO_2 + 11.5\,H_2O + 66.77\,N_2 \qquad (1)$$

$$\text{Equivalent ratio, } \varphi = \frac{(FAR)_{\mathbf{Experiment}}}{(FAR)_{\mathbf{Stoichiometric}}} \qquad (2)$$

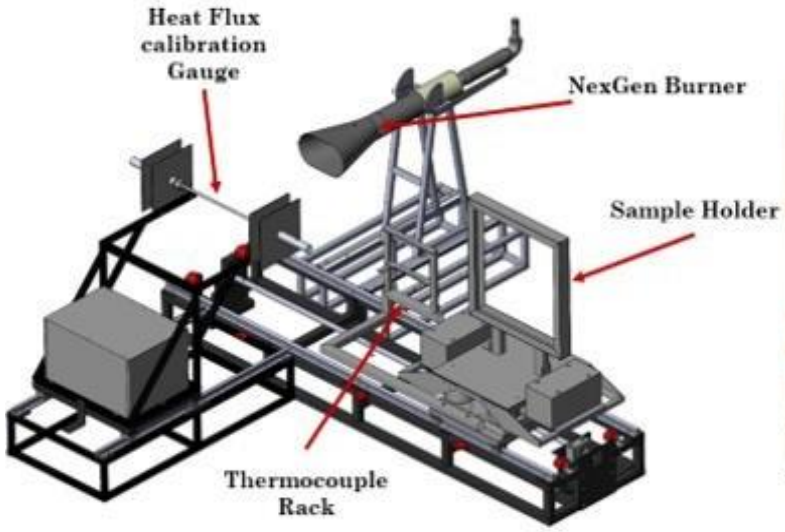
Table 1. Air flow variation

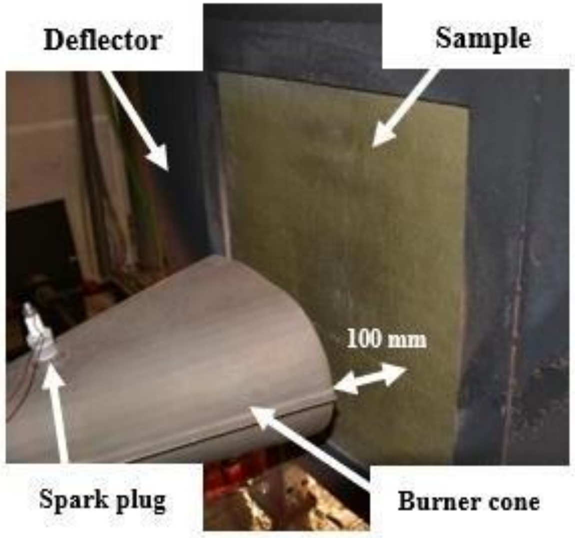
S/N	$Pressure\ (bar)$	$\dot{m}_a$ (Kg/s)	φ
1	4.30	0.03937	0.75
2	4.15	0.03815	0.77
3	3.85	0.03591	0.82
4	3.60	0.03405	0.86
5	3.45	0.03292	0.89
6	3.15	0.03069	0.96
7	3.05	0.02994	0.98
8	2.85	0.02845	1.03
9	2.75	0.02770	1.06
10	2.45	0.02547	1.15
11	2.30	0.02435	1.20
12	2.15	0.02322	1.26

NexGen Burner Description

- The tests must represent the realistic fire conditions, close to those encountered in real-life accidents.

- Fire protection standards used in the aerospace industry: ISO 2685





Before test

During test

After test

INSTITUT NATIONAL
DES SCIENCES
APPLIQUÉES
CENTRE VAL DE LOIRE

Results and Discussion (1/2)

- Effect of the thermocouple positions on the flame temperature for different equivalent ratio

- Effect of the equivalence ratio on heat flux and temperature evolution

- Thermal stability pyrolysis test of the three composite materials

Results and Discussion cont'd.

- From the results, it can be observed that the flame temperature decreases as the thermocouple position increases.
- Also, flame stratification can be observed from the temperature results
- The regime of **continuous flame** (region of the highest temperature value), the **intermittent regime** and the **plume regime** (unburnt gas region which is mainly characterized by smoke and soot).

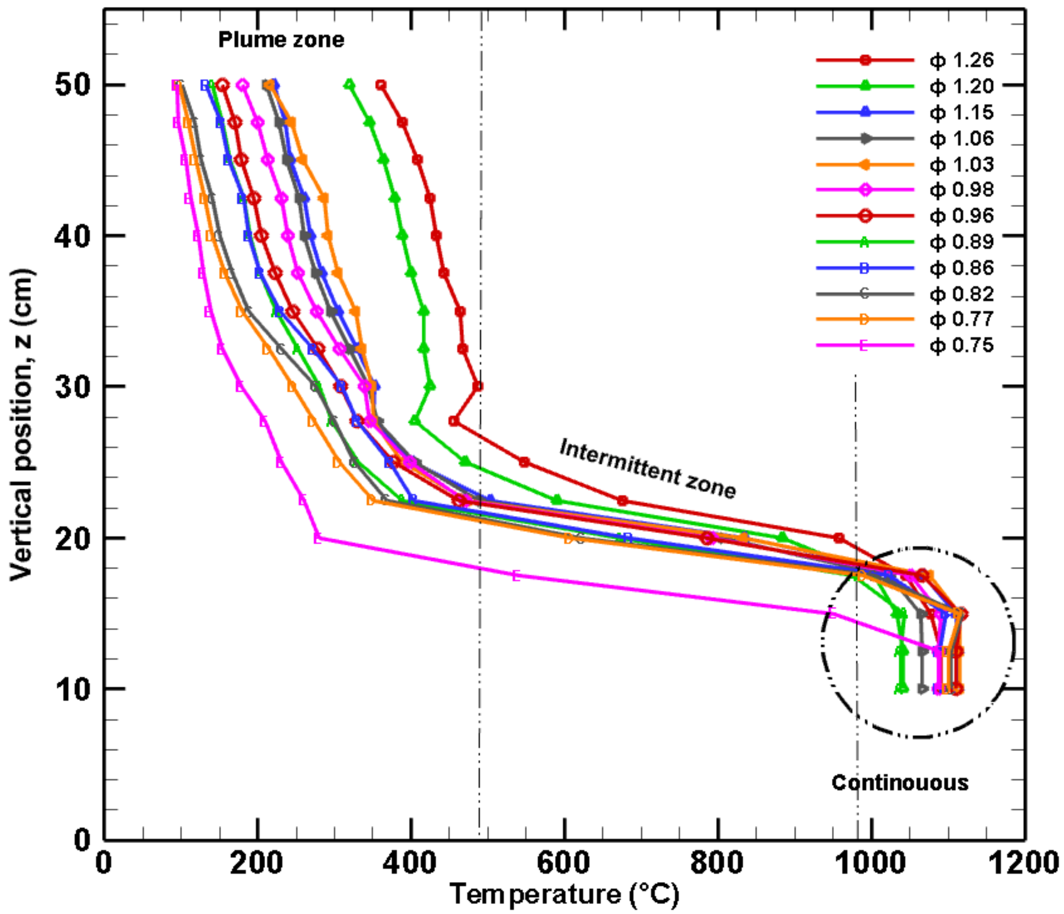
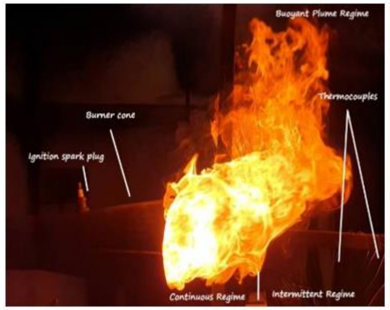


Fig 3. Effect of the vertical thermocouples from burner on the flame temperature

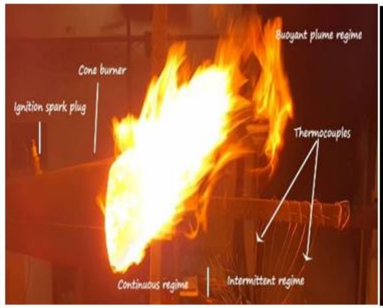
Results and Discussion cont'd.

- The flame temperature decreases with increasing thermocouple position along the horizontal direction in a similar pattern.

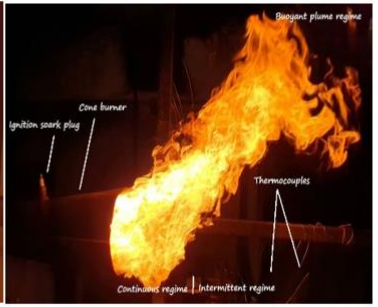
- The highest temperature reading was found at the position 10, 12.5 and 15 cm having almost constant average value of ~1101.5 °C.



φ = 0.77



φ = 1.03



φ = 1.20

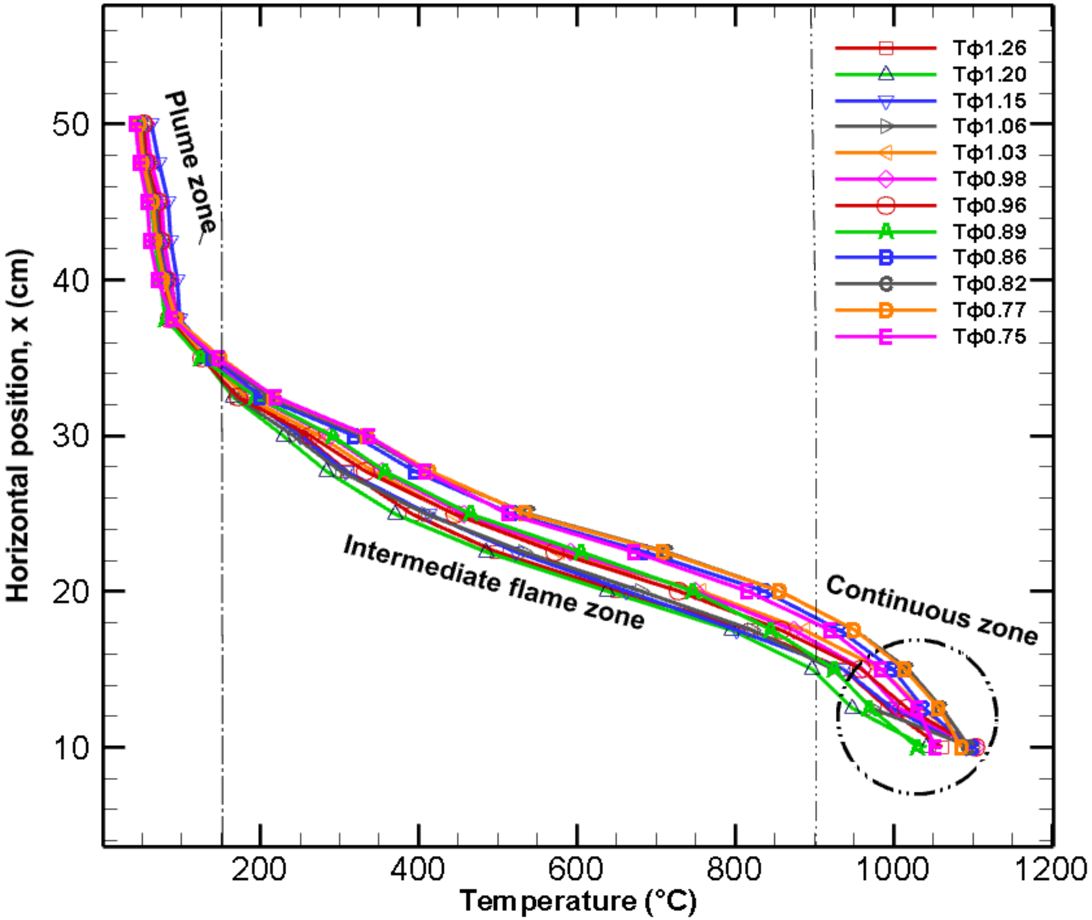


Fig 4. Effect of the horizontal thermocouples from burner on the flame temperature

Methodology

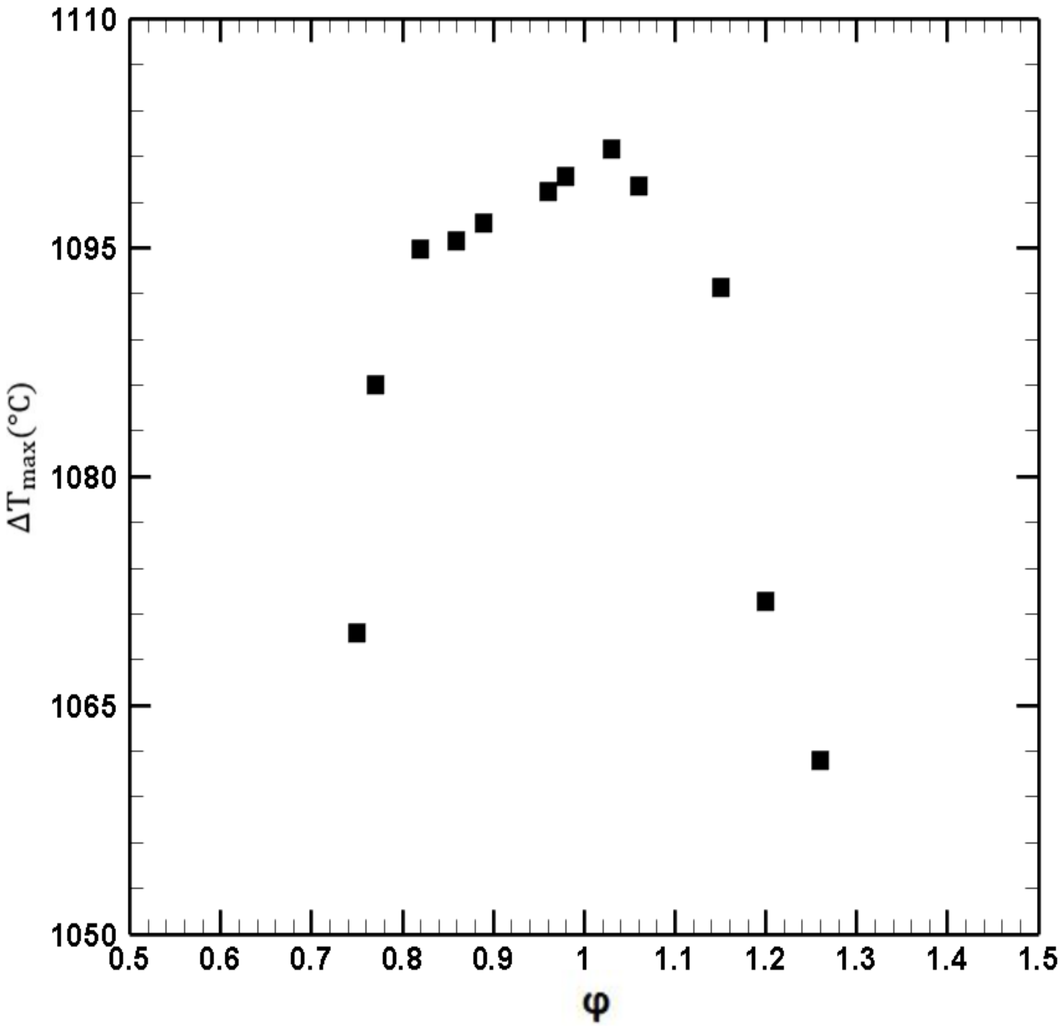


Figure 5. Effect of equivalent ratio on the maximum flame temperature

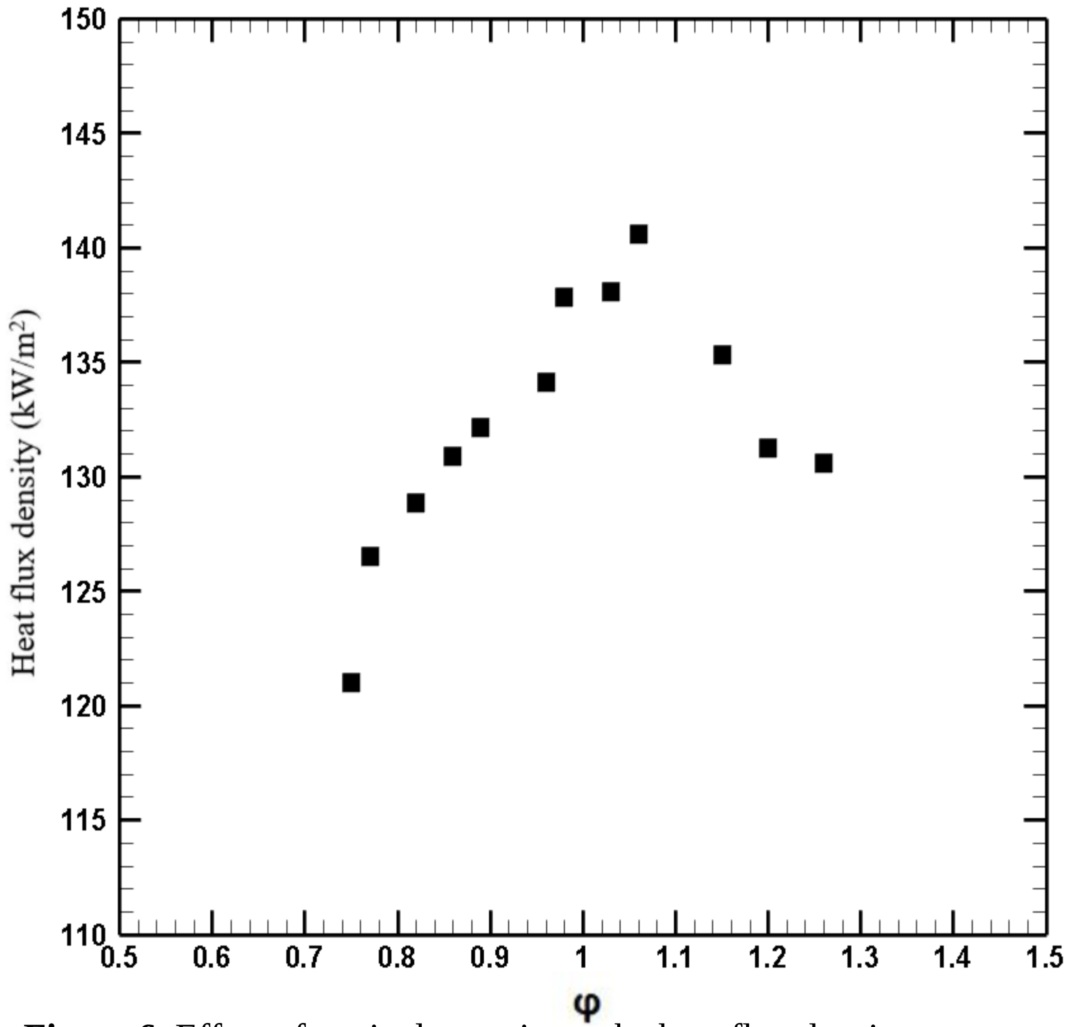


Figure 6. Effect of equivalent ratio on the heat flux density

Results and Discussion (2/2)

- The full-scale fire test was carried out in two stages. Firstly, a preliminary test experiment of three wood samples of the same source.

- This is to examine the precision and repeatability of the bench set up. Thereafter, the three composites samples of Carbon-BMI, Carbon-PEKK and Carbon-Phenolic were tested.

- The fire-resistant tests of the 500 mm X 500 mm samples were performed for 5 minutes

- The following parametres were measured; back-faced temperature (FLIR Camera), mass loss (SCAIME AG3 center support load cell) and the gas emissions (Ecom-Pro gas analyser).

Results and Discussion cont'd.

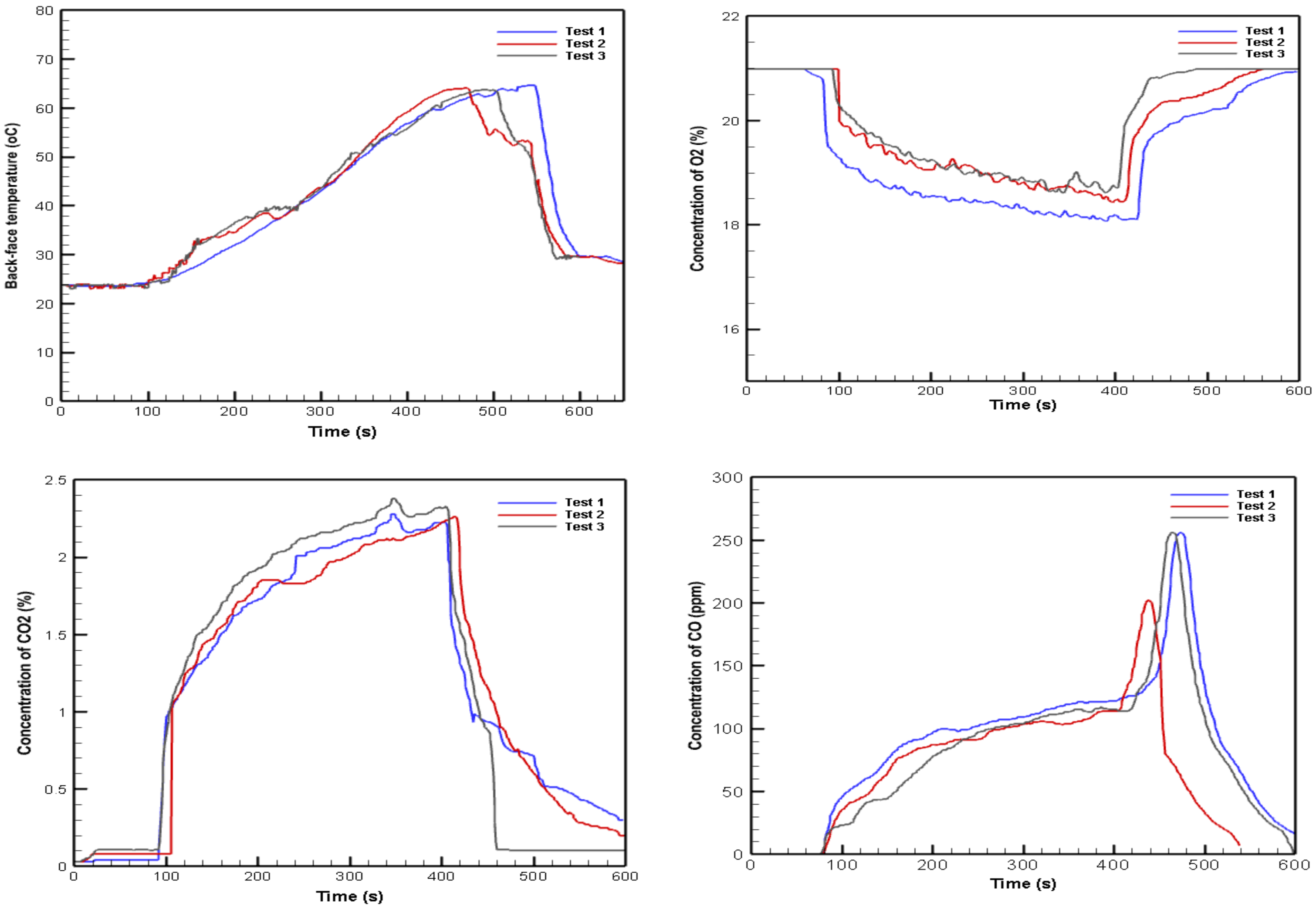


Figure 7. Repeatability test of known wood sample

- The back face temperature of the wood test samples were pretty close to one another with similar pattern having an average peak values of 65 °C.
- It can also be seen that the results of the peak concentration of oxygen, CO2 and CO emissions of the three test samples are in close agreement to one another.
- Therefore, validating the repeatability of the experiment.

Results and Discussion cont'd.

- Once the degradation temperature of the resin is reached, composite material decomposition commences.

- Carbon-PEKK material exhibits the least mass loss as a result of high yield of stable carbonaceous char and relatively higher T_g and T_m.

- Carbon-Phenolic and carbon-BMI reveal high mass loss. This could be attributed to the scission reaction between carbon polymer chain.

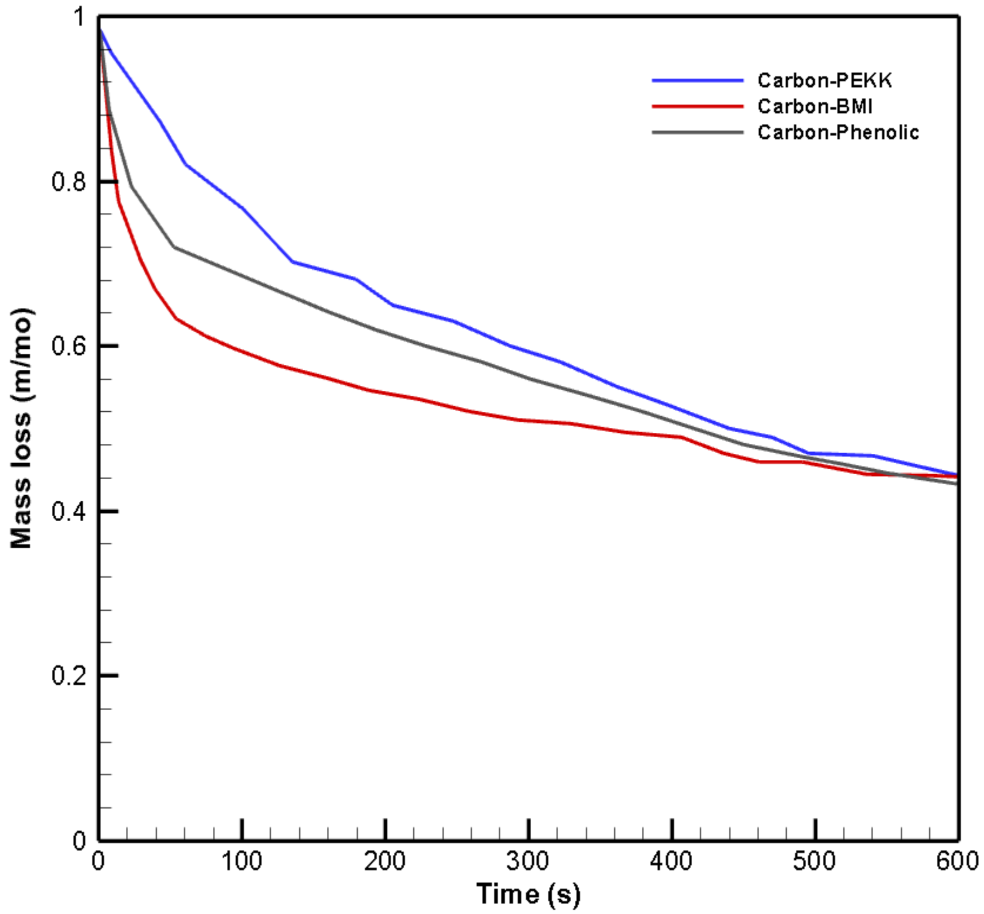


Figure 8. Mass loss of the polymer composites

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Results and Discussion cont'd

- The thermal decomposition process of the composites involves the following five stages:

- ✓ A short period of about 10 seconds of no loss in mass
- ✓ The period where the material just begins to be exposed to fire
- ✓ The beginning of thermal degradation with gas emission and mass loss of sample
- ✓ The period of increased concentration of the emission gases and acceleration of the mass loss to the peak value and finally
- ✓ The period of decline.

INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Results and Discussion cont'd.

- The Carbon-PEKK revealed the highest back face temperature of 302 °C than carbon reinforced BMI and phenolic.

- This could be attributed to the fact that the monomer of PEKK resin is characterized by three aromatic groups in the main chain with ether and ketone linkages, providing high thermal stability (Nathan grange *et al.,*).

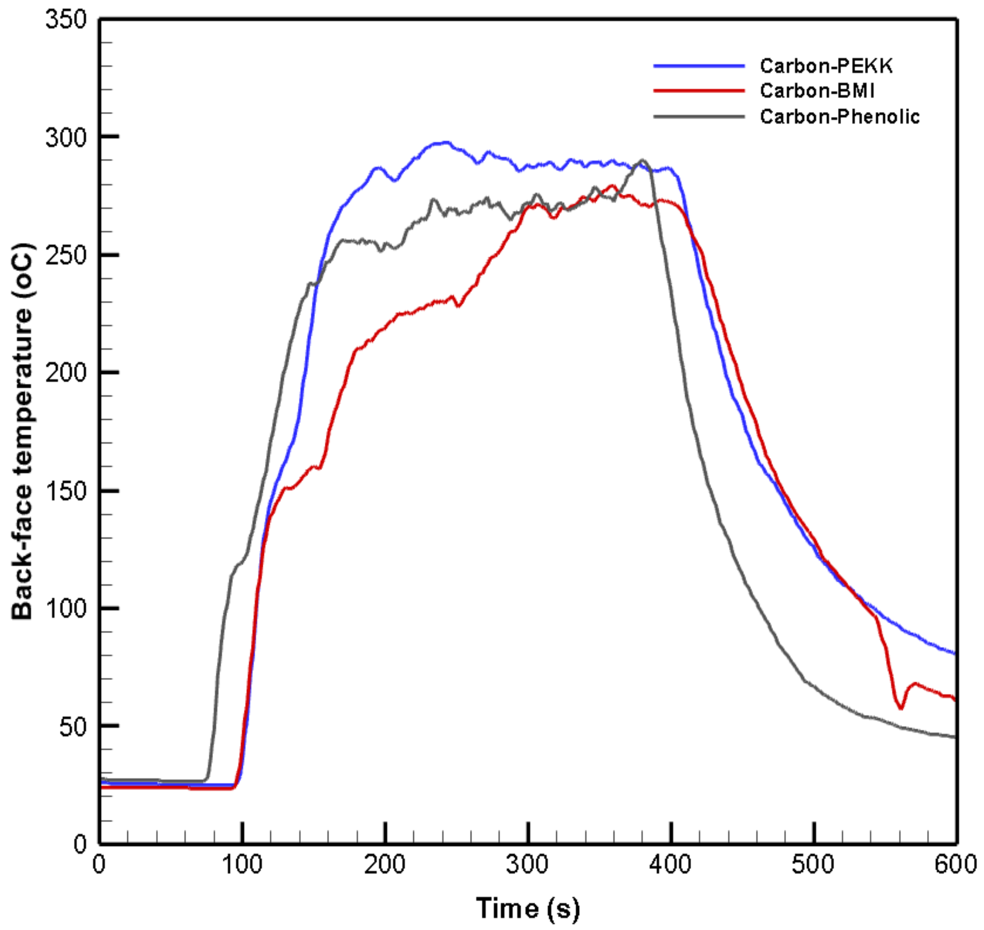


Figure 9. Back face temperature of the polymer composites

Results and Discussion cont'd.

- The graph shows that oxygen is used up during combustion, releasing combustion products such as carbon dioxide and carbon monoxide in the enclosure.

- Well ventilated enclosure

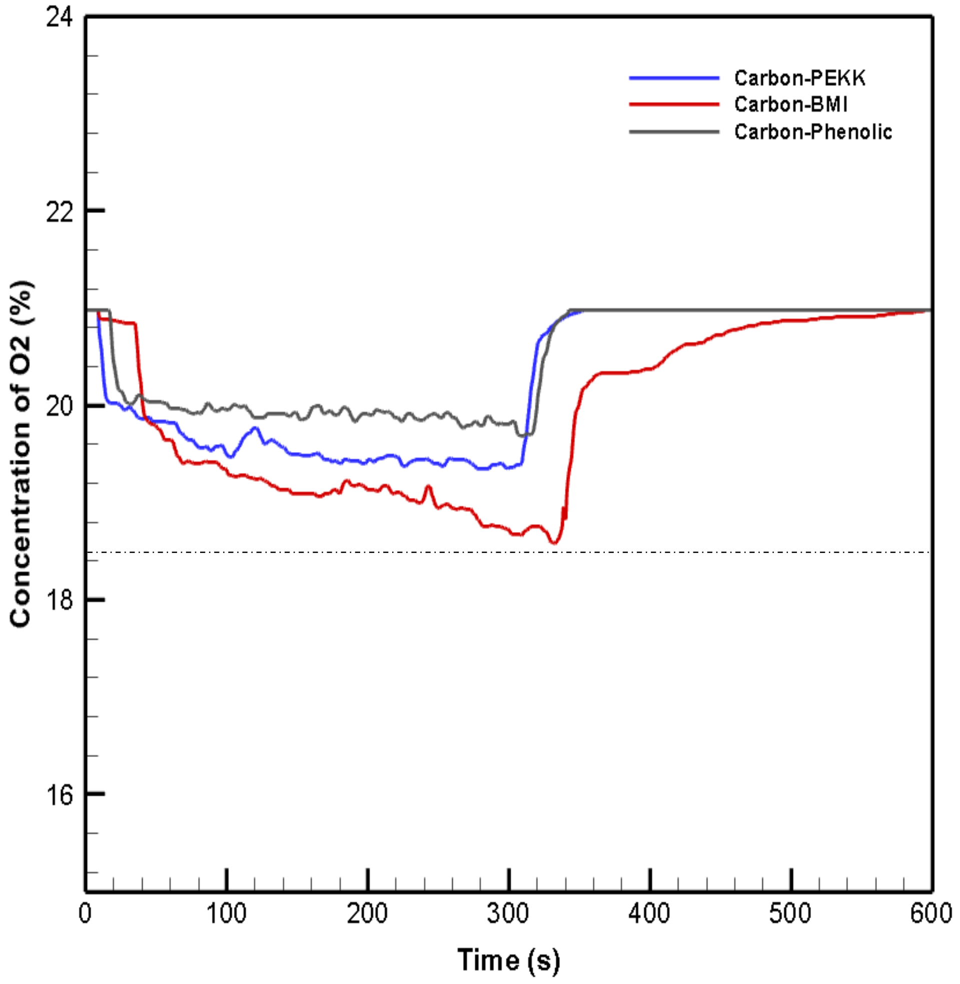


Fig 10. Oxygen reduction evolution

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Results and Discussion cont'd.

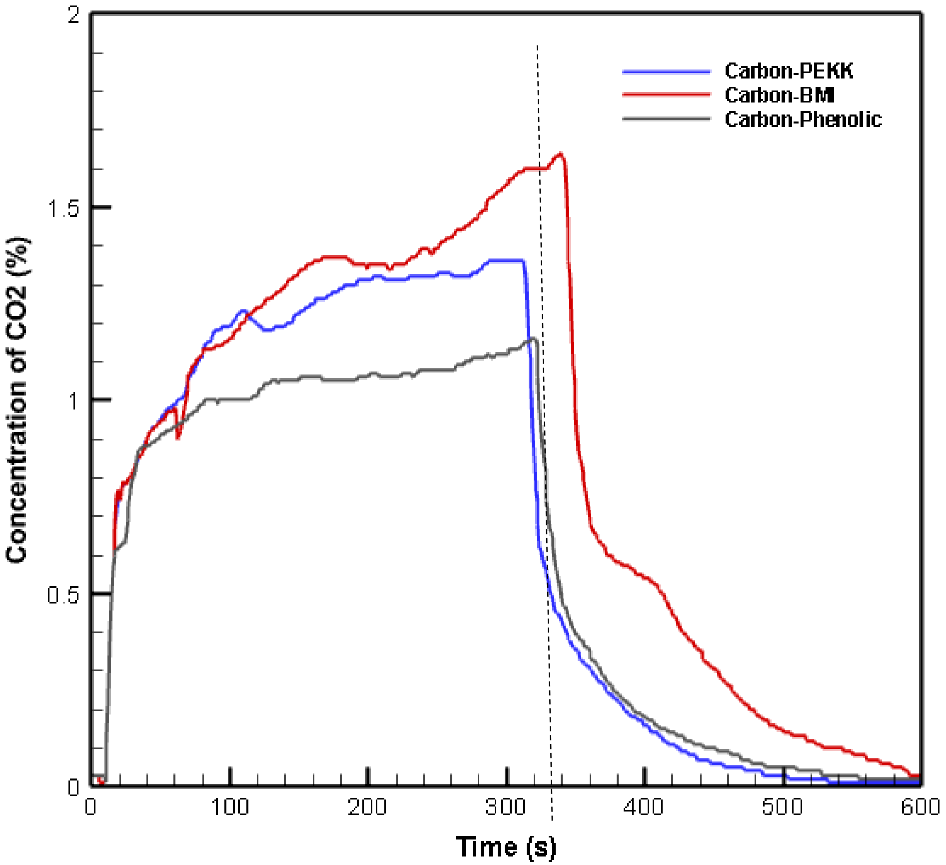


Fig 11. CO2 evolution

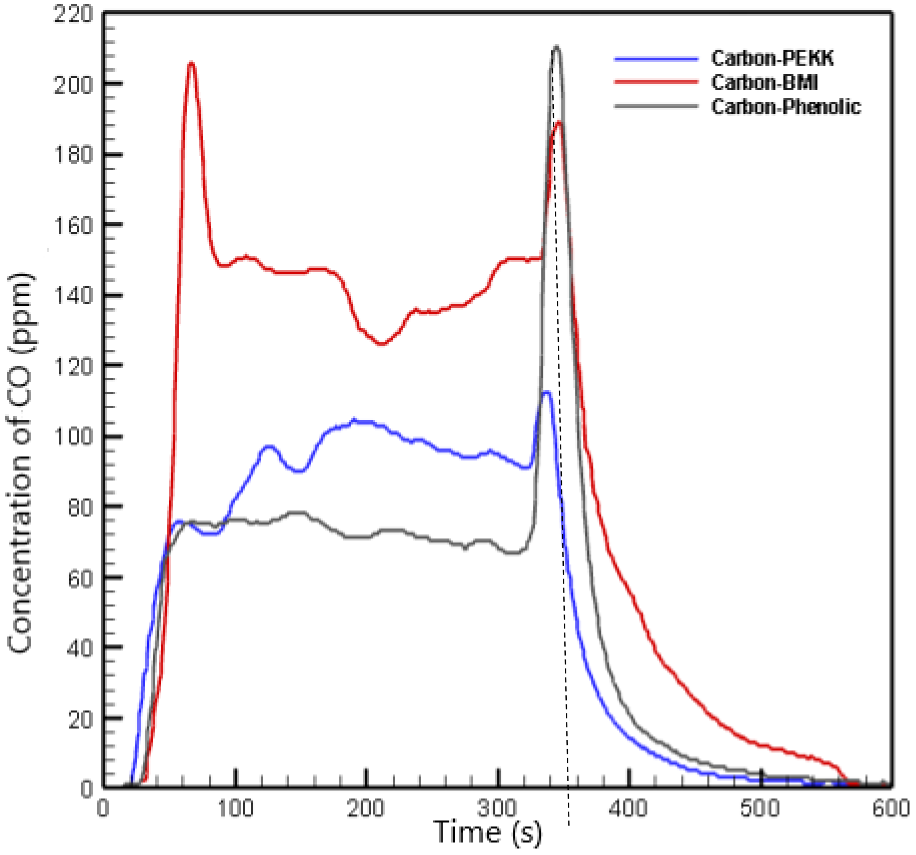


Fig 12. CO evolution

- ❑ **At about 345 s, CO and CO_2 attained a peak value, which indicates the process of fast oxidation flaming combustion.**
- ❑ **The peaks of CO gas released are 112 ppm < 189 ppm < 211 ppm for Carbon-PEKK, BMI and Phenolic respectively.**

Results and Discussion cont'd.

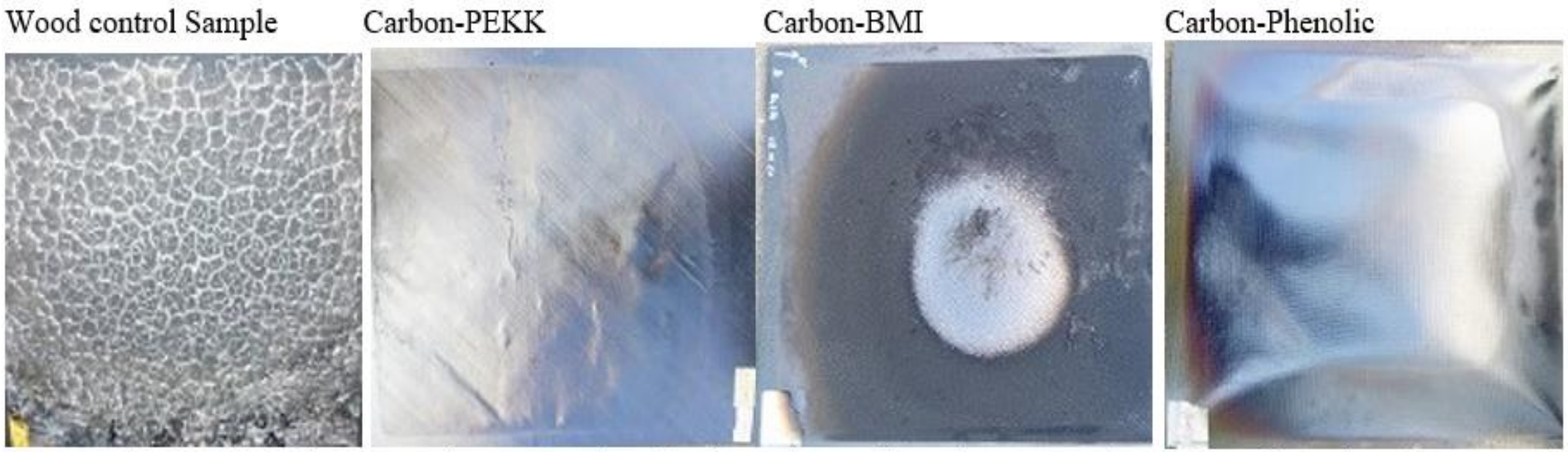


Plate 2. Photographs of the composite test samples after the 5 minutes fire resistance test (vertical configuration –face exposed to heat flux)

No swelling　　less swelling　　High swelling

- ❑ The most degraded sample is the carbon phenolic as a result of high concentration of gaseous emissions.
- ❑ Carbon-PEKK on the other hand have a superior thermal property as revealed by the mass loss and the high back face temperature results.

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Conclusion and perspectives

- In conclusion, the combustion diagnostic test revealed that temperature varies with positions in the vertical and the horizontal directions of the propagated flame .

- The equivalence ratio of the premixed flame significantly impacts the temperature and the heat flux parameters.

- The result shows that the optimum flame temperature and heat flux densities were obtained at the stoichiometric fuel mixture condition.

Conclusion and Perspectives

- ❑ Carbon-PEKK on the other hand shows superior thermal property based on the mass loss and back-face temperature results.

- ❑ MLR and HRR will the composites will be included.

- ❑ The data presented will be used to validate an FDS code (solver).

- ❑ Subsequent objectives include studying the effects of equivalent ratio on the flame frequency and morphology, front face temperature measurement and the use of FDS as a predictive tool for other flame parameters.

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

Thank you for your attention !