Fire behaviour of a Carbon/Nomex honeycomb sandwich composite used in aircraft interior

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Abstract. Fire behaviour of a carbon/Nomex honeycomb composite, used as ceiling panel in aircraft interiors, was investigated in Cone Calorimeter at different incident heat fluxes, ranging from 20 to 70 kW/m². The material exhibited good fire performance with relatively low amount of heat release and long ignition times. Combustion of the material at 40 kW/m² proceeded in one stage, while at higher heat fluxes two stages were observed. The burning mechanisms and char formation during thermal decomposition at different heat fluxes was also examined. The long tail after flame-out in heat release curves and the significant increase of CO production and mass loss were analysed with respect to char residue.

1. Introduction
Sandwich structures which are used commonly in aircraft interiors are composed of light weight core and high strength face sheets. The sandwich core can be in the form of honeycomb (such as Nomex paper, aluminium), plastic foam (such as PVC, polyurethane, phenolic) and balsa [1]. Carbon/Nomex honeycomb composites are usually found in sidewalls, floors, and ceiling panels of aircraft cabins. Although, they have high stiffness and strength, low weight and density, low thermal expansion and thermal insulation [1], their involvement in a fire event, especially in a small compartment, such as the aircraft interior, can potentially increase fire hazard due to the release of heat and toxic gases as a result of pyrolysis and combustion processes.

Although, research focusing on the fire performance of laminate composites and sandwich composites with foam core or balsa is commonly found, limited studies are reported on the investigation of fire behaviour and thermal properties of carbon/Nomex honeycomb composites. Nyden et al. [2] examined a sandwich composite with Nomex honeycomb core, fibre backing and phenol-formaldehyde resin in Cone Calorimeter at incident heat flux 50 kW/m². Heat release rate (HRR) curves demonstrated that the material followed one step burning whilst the long tail after flame-out implied that material continued to smoulder. Zhou et al. [3] conducted a series of experiments to examine the effect of intumescent coating on post-fire performance and fire retardancy of sandwich composites. They included tests in Cone Calorimeter at 35 kW/m² on a carbon/epoxy prepreg with Nomex honeycomb core and found that combustion proceeded in two steps while the formation of a char residue at the end of the first stage decreased HRR.

Koštial et al. [4] investigated sandwich composites in Cone Calorimeter at 50 kW/m², considering the effect of the thickness of the laminating layers (glass/fabric sateen and aramid/fabric linen) with or without surface treatments, as well as the effect of the Nomex honeycomb core density. Constructions
with higher core density showed a lower maximum average heat release rate (MAHRE) while combustion process proceeded in two stages. Najmi et al. [5] investigated the thermal decomposition of sandwich structures with Nomex honeycomb core sandwiched between glass fibre laminates, with and without paint at 35 and 50 kW/m². They investigated the combustion process of the individual parts separately (glass laminate, honeycomb core, and paint) and their different assemblies and found that honeycomb and L.H structure (laminate + honeycomb) decomposed in two steps. The effect of the laminate covering as well as the contribution of the honeycomb core on burning was also investigated.

Recent research efforts are not mainly focused on the investigation of thermal behaviour, pyrolysis, and combustion of carbon/Nomex honeycomb composites. Studies oriented to the characterization of burning behaviour and fire performance of these materials are rather limited. Therefore, it turns out that research in this direction is particularly important, given that these materials are extensively used in aircrafts interiors and therefore the knowledge on their burning characteristics is the basis for improving fire safety.

2. Methodology
A sandwich composite with Nomex honeycomb core sandwiched between two carbon sheets was tested. An additional white layer was also attached to the side facing the inboard compartment as shown in figure 1. The material, used as ceiling panel in the aircraft interior, was provided by the aviation industry and due to confidentiality requirements limited information on material composition has been disclosed. Test specimens were 100 x 100 mm (-2 mm) according to ISO 5660 [6], with an average thickness and mass of 17.5 mm (+0.2 mm) and 26.8 gr (+1.8 gr) respectively. Samples were pre-conditioned for 72 hours in a controlled environment chamber with 50% ± 5% relative humidity and 23 ± 2 °C temperature.

![Figure 1. Ceiling panel front side (left) back side (right).](image)

Test on the back side of the specimen were performed in a Cone Calorimeter, at incident heat fluxes in the range 20 to 70 kW/m², in horizontal orientation according to ISO 5660 [6]. A customized sample holder was constructed with three layers of insulation paper (Isofrax 1260 °C Paper, k = 0.13 W/m K at 600 °C) of 3 mm thickness, on the sides and back of the sample to minimize side and back face heat conduction losses and enforce 1D heat transfer. The insulation material was protected by an aluminium foil of 0.08 mm thickness and the retainer frame was also used since cracking and deformation was possible to occur. Three samples were tested at each heat flux and average curves are presented in the following.

3. Findings
Heat release curves at different imposed heat fluxes are shown in figure 2a. It is obvious that the material exhibited a quite different behaviour as the heat flux increased. No ignition was observed at 20 and 30 kW/m². The combustion process proceeded in one stage at lower heat fluxes (<50kW/m²), whereas at higher heat fluxes in two distinct stages. The higher temperatures achieved at higher heat fluxes allowed further the thermal decomposition of the material and the production of flammable volatiles that were released and diffused into the fire zone, resulting in the second stage of combustion. As the heat flux increased, the heat gasification rate was accelerated, resulting in higher heat release rates. The transition from the first to the second stage of combustion was depicted by a decrease in the flame intensity at the end of the first stage followed by a gradual increase that marked the beginning of the second stage of combustion, as it was demonstrated in HRR curves (figure 2a) and visually...
observed (figure 3). The time elapsed for this transition was decreased with the increase of the heat flux.

![HRR and CO production rate graphs](attachment:figure_2.png)

**Figure 2.** HRR (a) and CO (b) production rate at different incident heat fluxes in Cone Calorimeter.

Prior to ignition, the major part of the surface was covered by white smoke probably due to the vaporization of water and the release of pyrolysis gases that escaped unburned from the composite. Mass loss curves (not shown here) indicate a larger loss prior to ignition at 40 kW/m$^2$, close to 7%, whereas at higher heat fluxes a relatively low amount of mass ~ 2-4% was lost before ignition. Snapshots of characteristic burning stages at 70 kW/m$^2$ are shown in figure 3. Soon after flame-out, smouldering combustion of the char and the unburned material residue that remained within the substrate occurred, with the release of a small amount of heat as it is illustrated in figure 2a.

![Characteristic stages](attachment:figure_3.png)

**Figure 3.** Snapshots of characteristic stages during Cone Calorimeter experiments at 70 kW/m$^2$.

The char formation on the surface during the first stage of combustion, as occurs in charring materials was probably responsible for that complex combustion process [7], [8]. The thickness of this char was possibly increased as the pyrolysis continued, acting as a thermal barrier preventing heat transfer to the underlying material and consequently diminishing the thermal decomposition process and the release of flammable volatiles in the reaction zone. However, the increase of the heat flux made it possible to overcome this barrier where a second stage of combustion occurred and time elapsed for the transition from the first to the second stage was also shortened as shown in figure 2a.

CO production was divided into three regions as shown in figure 2b. At lower heat fluxes (40 kW/m$^2$), where the heating time for the surface to reach the ignition temperature was longer, the first stage started just before ignition. Soon after ignition, CO production further increased with a different pace and achieved a peak slightly before HRR peak and then decreased as flaming combustion completed (second stage). Close to flame out, CO production increased again and obtained values...
much higher in comparison with the corresponding values of flaming combustion (third stage). At higher heat fluxes CO production prior to ignition was not observed, due to the shorter heating periods. The first two successive stages of CO production were associated with the corresponding stages of flaming combustion while a third stage was associated with the smouldering combustion that begun close to flame out. It was also observed that after flame-out CO production was significantly reduced with the increase of the heat flux, while mass loss was increased (17.6, 29.4% and 36.89 % at 50, 60 and 70 kW/m$^2$ respectively). It is possible that at lower heat fluxes a char residue with a more stable structure (less porous) was formed, that inhibited thermal decomposition of the substrate, which resulted in reduced mass loss compared to higher heat fluxes, while the oxidation of the char produced higher amount of CO.

4. Conclusions
Carbon/Nomex honeycomb exhibited a complex thermal decomposition and combustion process at different heat fluxes in the Cone Calorimeter. At low heat fluxes (<50 kW/m$^2$) combustion proceeded in one stage whilst at higher heat fluxes two stages were identified. The effect of char formation produced during thermal decomposition, inhibited heat transfer to the underlying material and the release of flammable volatiles in the fire zone as occurs in charring materials. This resulted in the decrease of HRR at the first stage of combustion and lower HRR at the second stage. After flame-out, a long tail on HRR curves demonstrated that material continued to smoulder releasing high amount of CO. The high heat flow of gases at higher heat fluxes produced a porous char that after flame-out allowed further decomposition of the substrate resulting in higher mass losses and lower production of CO.

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