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Toxicity Assessment of Aircraft Interior Materials (Fabric Seat Cover and Wall/Floor Cover) Using the Cone Calorimeter and FTIR Analysis

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Abstract: Aircraft fires are more critical than building fires as there is no means of escape when in flight. Fire smoke can impair the movement and the reaction of the victims and hence impair the means of escape. Aircraft interior fire loads, fabric seat covers and wall/floor coverings, have been investigated in this paper in terms of the toxic emission produced in a fire. The specimens were tested using an enclosed restricted ventilation at 15 air changes per hour (ACH) cone calorimeter with a heat flux of 40 kW/m². The fire effluents were analysed using a heated online FTIR (Fourier Transform Infrared) analyser which determines 60 species in the fire products. Different burning patterns were found for each of the materials with the Fabric seat cover sustaining a flaming fire for 27 minutes while the wall/floor cover had only 33seconds flaming period. The major contributing toxic emissions for the fabric seat cover was SO₂ and for the wall/floor cover were HCN, CO and SO₂.

Keywords: Toxicity, Cone Calorimeter, Aircraft Fire loads, SO₂, FTIR, Aircraft Compartment fires.

1. INTRODUCTION

Inhalation of toxic emissions released from fires is the major cause of death for casualties from fire incidents (Purser, 2002). Released smoke in compartment fires reduces visibility and contains irritant gases, which causes impaired vision and respiratory problems (Stec and Hull, 2010). Toxic emissions cause impairment of escape, as acidic and irritant gases slow movement through reduced lung functions. The risk from a fire on aircraft is larger than for a building fire due to evacuation not being possible in flight. It is important to use materials in aircraft that are difficult to ignite and have poor flame propagation characteristics with low toxic emissions. However, current fire test for selecting material for aircraft interiors only looks at ease of ignition and speed of flame propagation, there is no standard to assess the toxicity once the material is engulfed in a fire (FAR 25.863). This work was aimed at showing that the cone calorimeter could be modified to assess fire toxicity using samples of aircraft materials.

Saudi Arabian Airline flight 163 in 1980 (Presidency of Civil Aviation, 1980) is an illustrative example of the important role of fire toxic gases in aircraft interior compartment fires. The pilot managed to land the aircraft but that was not enough time to save the life of anybody onboard, as everybody was incapacitated by toxic gases and nobody managed to open the airplane door to escape,

In terms of the dynamics of fire in building compartments and aircraft compartments, there are three factors to be taken into account: ventilation, compartment size and ceiling height. In

aircraft there is no fire compartmentation in the passenger compartment, but there is compartmentation between the hold and the passenger compartment above. Thus if a fire starts there is no limit to its propagation throughout the passenger compartment, apart from the availability of air. Aircraft passenger compartments have forced ventilation at a restricted rate of typically 15 ACH. This air is bled off the engines through an air conditioner and is recirculated, which in a fire scenario will result in smoke and toxic gas recirculation. The restricted ventilation will lead to a limit on the growth of the fire, but an increase in toxicity due to lower fire air supply. This was found in the present work and the present ventilation of 15 ACH was not the worst case for toxicity. The low ceiling height in the aircraft cabin can affect the mixing dynamics in the fire as well leading to faster smoke logging, which would increase the intensity of fire spread due to heat radiation from the smoke.

In air starved fires in aircraft compartments, if the fire occurs on the ground and the external door is opened this can lead to a backdraught. This occurred in Air Canada flight 797 (Board, 1986) The fire propagated in the cavity ceiling generating unburnt hydrocarbons resulting a backdraft only 90 seconds after opening the door for evacuation.

2. Experimental Equipment

A CE Flash EA2000 elemental analyser was used to determine the C, H, O, N and S content of the fire materials. A Mettler Toledo TGA/DSC 1 instrument was used to perform Thermogravimetric Analysis for the determination of sample volatile, fixed carbon and ash content. The sample was heated in a nitrogen atmosphere to evaporate any volatile components then in air to combust any carbon and the remaining weight was the ash.

A Temet Gasmeter FTIR instrument was used for toxic gas analysis. This was connected to the cone calorimeter exit chimney raw gas analysis with heat sample lines, heated pump and filter and the FTIR measurement cell was heated. This ensured no loss of toxic species due to condensation or solution in water. The FTIR had a 2 meter path length multi-pass sample cell with a volume of 0.22 l. The FTIR sample cell was coated with gold. To produce a time-averaged spectrum, a liquid nitrogen cooled MCT detector was used to scans 10 spectra per second and several scans were used. The longer the time average, the more improved has the signal to noise ratio and more species can be resolved in each analysis. The FTIR was calibrated to detect 60 species simultaneously and if all the gases were analysed it has a 2 seconds response. The FTIR was calibrated for all the significant species that were present in the sample. The Temet FTIR had a 2 ppm resolution, for acrolein as an example, it has a COSHH value of 0.3 ppm (HSE, 2007) which is consequently below the sensitivity of FTIR. The FTIR reported values for acrolein as low as 1 (ppm), and below this the instrument could not resolve any concentration and it has been reported as zero. The instrument gave a warning if parts of the measured spectrum were unaccounted for in the calibrated gases. All in the fire products were calibrated for in this work.

The materials were tested for toxic gas release using small specimens on a cone calorimeter, modified to enable ventilation controlled combustion and direct undiluted sampling of the products of combustion. The standard cone calorimeter dilution was still used for the determination of the heat release rate (HRR) by oxygen consumption. The cone calorimeter can also determine the smoke generation for furniture and building materials. The cone calorimeter has a conical radiator with a range of heat fluxes 10-100 kW m⁻² applied as a constant heat flux across the surface of 100 mm square specimen with a thickness of (5-50 mm) planted on a load cell below the cone. The smoke generated is collected by a hood and duct directly above the cone where O₂ concentrations and smoke density are measured (BSI,

1993). The apparatus original set-up is freely ventilated which makes it able to meet the ISO fire stages 1b for non-flaming tests and stage 2 for flaming tests.

The cone calorimeter was modified in this work for under-ventilated tests using an enclosure containing the specimen and the radiator. Air was metered to this chamber to achieve the desired ACH. The equipment was also modified to enable raw product gases from the ventilation controlled chamber to be sampled by the heated sampling system and pump to connect the raw gas sample to the FTIR analyser. This modification consisted of a 210mm long extension tube on the conical heater central hole with the same internal diameter (80mm) as the hole. This acted as a chimney and enabled a gas sample probe to be inserted into this outlet 'chimney', without influencing the entrainment of air into the conical outlet. This prevented any toxic gas oxidation in the downstream air entrainment. Oxygen consumption calorimeter was also used to determine the HRR in the ventilation controlled compartment as a fraction of the total heat release measured in the cone calorimeter after dilution of the product gases with air. Essentially these modifications of the cone calorimeter convert it into an equivalent apparatus to that of ASTM E2058 where a fire sample on load cell is placed in a vertical quartz tube with an external conical heater and metered airflow up the quartz tube. This equipment has not previously been used for fire toxicity measurements as it is a fire propagation test.

These modifications make the apparatus able to meet ISO fire stages 3a & 3b (ISO19706, 2007) for under ventilated flaming tests. The standard HRR measurements use the diluted sampling in the cone calorimeter. Toxic gas concentration in the diluted fire products has been criticised in that the fire gases passing through the conical radiator may modify the effluent components. Another criticism was that the concentration of toxic gases may be effected by the relatively high dilution and the fact that unburned combustion products may continue to burn as it emerges from the ventilation controlled enclosure giving ultimately a well ventilated fire (Hull and Paul, 2007). The present modification to the equipment enabled this problem to be avoided. This would still leave the fire gases in contact with the conical heating element, but this is considered to be a negligible effect as the temperatures are too low for significant reaction.

3. Results and Analysis

Two aircraft interior materials were tested: fabric seat covers and wall/floor coverings. The modified cone calorimeter was used with 15ACH restricted ventilation. This simulates the ventilation conditions in the aircraft cabin in accordance with a survey conducted in 1994 on commercial airlines (Foundation, 1998). The heat flux was set at 40kW/m² which represented a surrounding flaming fire, as suggested by the classification of fires in the ISO19706.

3.1. Samples:

1. Fabric Seat Cover: the elemental composition was 48.20% C, 6.23% H, 26.06% O, 14.98% N, and 4.53% S giving a stoichiometric air to fuel ratio of 6.47. The N content indicates that this was an acrylic type material and toxic HCN would be expected and was found in the outlet gases. The relatively high sulphur content, due to the presence of S containin flame retardants, would result in SO₂ emissions and these were found to be a major factor in the overall toxicity. The TGA analysis showed that the volatile content was 69%, which resulted in flaming combustion. The fixed carbon was 25%, the ash 2% and water 5%. A 300×300 mm cut of the fabric was folded to fit the sample holder and to have a thickness of 7 mm and initial mass of 44.6 g.

2. Wall/floor cover: the elemental composition was 33.4% C, 5.2% H, 45.6% O, 9.1% N, 3.4% S and 2.5% Al with a stoichiometric air to fuel ratio of 3.39. The N and S content would also lead to HCN and SO₂ in the toxic gases. The presence of Al indicates that AlOH fire retardant was used in this material. The TGA analysis showed that there was 49% volatiles, 30% fixed carbon, 17% ash and 4% water. The high ash indicates the present of mineral based fire retardants such as carbonates and the CO₂ results confirmed this. Six 100×100 mm pieces were cut and put over each other to form a thickness of 6.6 mm and initial mass of 46.2 g.

3.2. Fire Development

The mass loss of the samples in the fire is shown in Fig. 1. The fabric seat cover had a significant flaming stage for 27min losing 75% of the original mass before the non-flaming smoldering stage started, which continued for 22min losing an additional 7% of mass by the end of the test. The wall/floor cover sample had a brief flaming stage for only 33sec and lost less than 4% of its initial weight before the specimen entered the non-flaming smoldering stage where 74% of the original weight was lost in 39min. The mass loss rate was stable in the range of 0.9-1.2 g/min until the 1500th second when half of the material was lost, then the mass loss rate dropped to lower values. These results indicate that the 49% volatiles with this material was not hydrocarbons and hence did not give rise to extensive flaming combustion. It is considered that the volatiles measured in the TGA was from the decomposition of AlOH and carbonates to give H₂O and CO₂ respectively. The heat absorbed in this decomposition and the release of CO₂ was the mechanism of non-flaming smoldering combustion.

Fig. 2 shows the Heat release rate (HRR) The fabric seat cover's flaming stage reached a peak HRR of 50 kW/m² before it reduced to less than 20 kW/m² after flameout in the smoldering stage. The wall/floor cover had a peak HRR in the brief flaming stage of 10kW/m² then no heat release detected by the instrument. This demonstrates good flame retardancy in the wall/floor covering, but a lack of effective flame retardancy in the fabric seat cover.

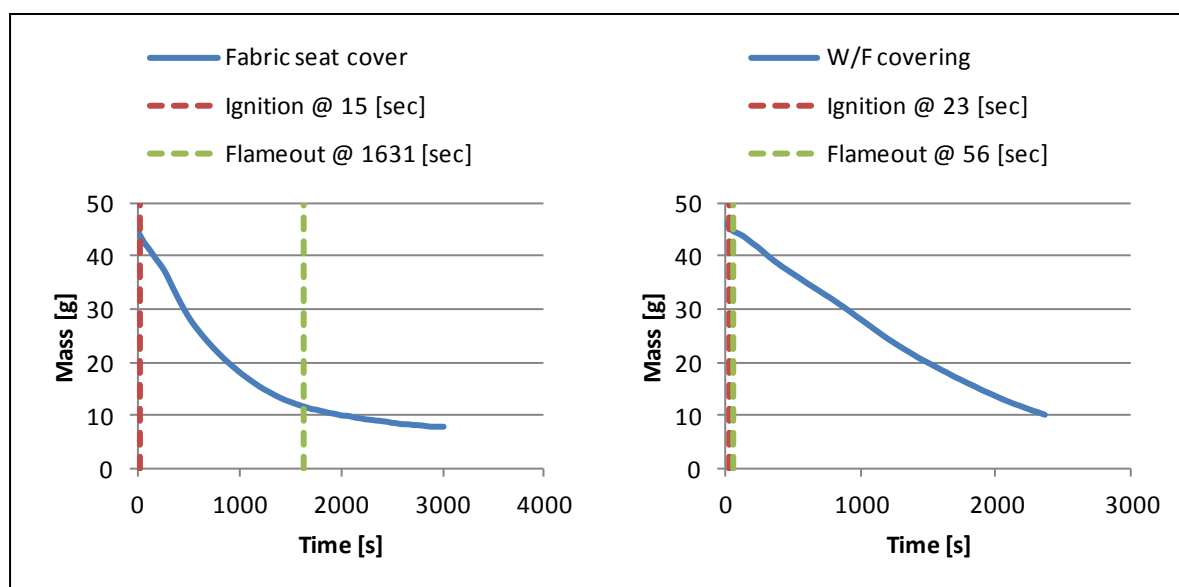


Fig. 1: Mass V Time, flaming and non-flaming stages of fire shown for (Left: fabric seat cover, Right: wall/floor cover)

The very low HRR for the wall/floor cover was unexpected as there was a significant mass loss as shown in Fig. 1. However, the HRR by oxygen consumption shows that the mass loss was not primarily by combustion. In the elemental analysis the oxygen was determined by

difference and not by direct analysis. If there was another significant element present the CE elemental analyser would not detect it and would assume it was oxygen. A FEG-SEM material analysis was used to analyse for other metals and Al was measured at 2.5% indicating the presence of AlOH fire retardant. However, this was too low to give all the weight loss and it was concluded that the presence of a carbonate fire retardant was present which would yield CO₂ on heating. This was confirmed by high CO₂ measurements in that test, which act to inert the flame from preventing flaming combustion. The low HRR region was one of smouldering combustion and it will be shown below that there were significant toxic gas emissions in this phase of combustion.

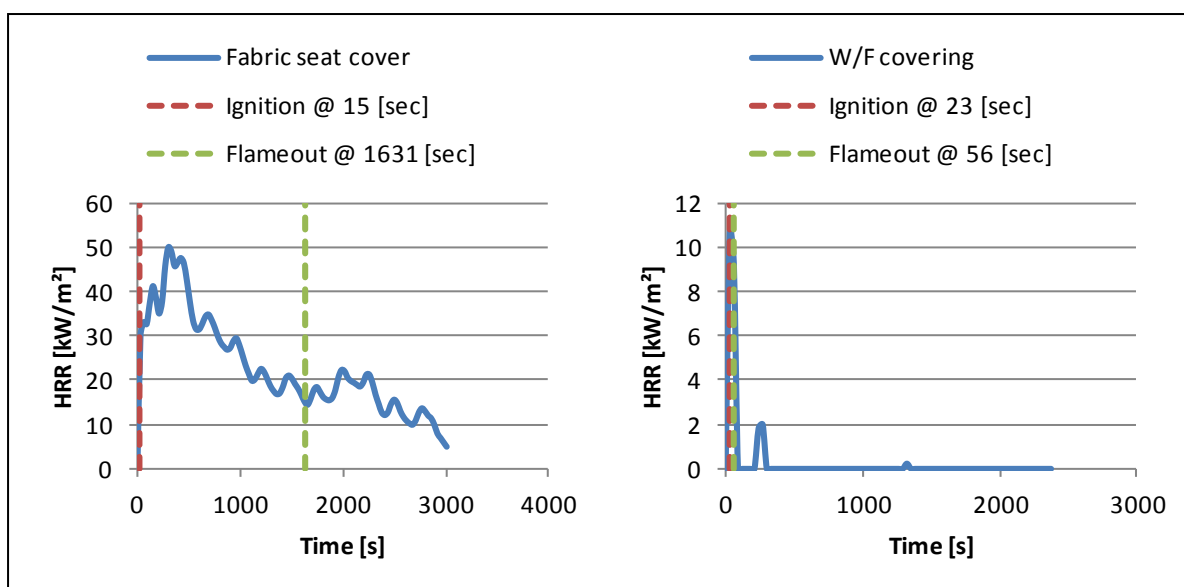


Fig. 2: HRR V Time, flaming and non-flaming stages of fire shown for (Left: fabric seat cover, Right: wall/floor cover)

3.3. Toxicity Results

The toxicity produced by the fire was evaluated using an modified N-gas model (Babrusukas et al., 1991). The N-gas was obtained by dividing the all 14 measured LC₅₀ toxic gas by its LC₅₀ exposure limit, then all these ratios were summed to produce the total toxic gas N ratio. A similar analysis can be done based on COSHH 15min or AEGL 10 min. which relates to impairment of escape The exposure limit used here is the LC₅₀ which represent the lethal concentration of a certain gas which kills half the test animals group (Purser, 2002).

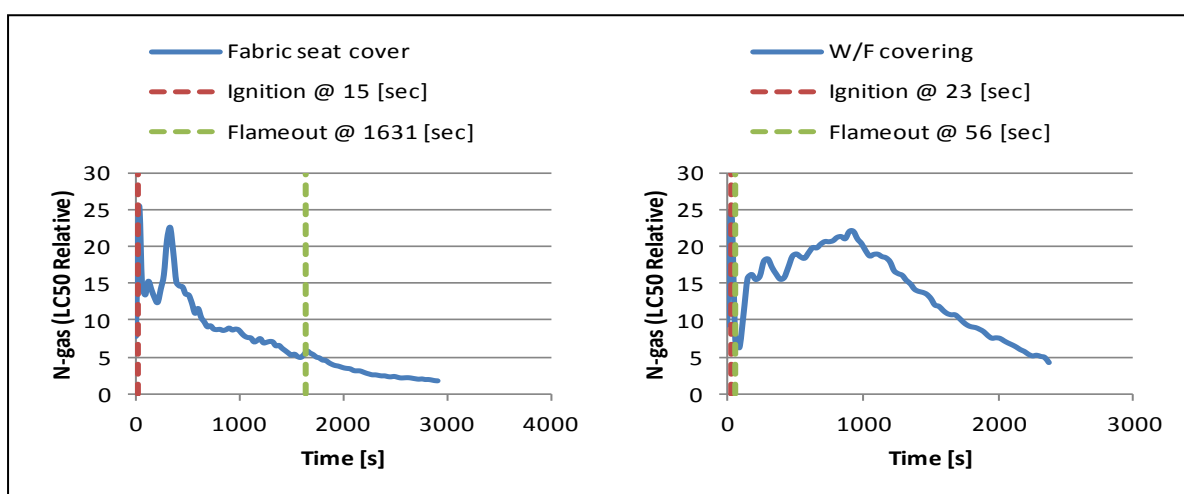


Fig. 3: N-gas (LC50 relative) V Time, flaming and non-flaming stages of fire shown for (Left: fabric seat cover, Right: wall/floor cover)

The N-gas based on LC₅₀ exposure limits for both samples is shown in Fig. 3. There were two peaks in the flaming stage for the fabric seat cover; 25 times the equivalent exposure limit LC₅₀ at the ignition time and 23 at 400th second. The dominant toxic gas was Sulphur dioxide (SO₂) as shown in Fig. 4. For the wall/floor cover sample the peak N-gas value was 22 and occurred late in the smouldering pyrolysis. The dominant toxic gas was HCN with 60% of the toxicity, then 25% for Carbon monoxide and 10% for Sulphur dioxide. This shows that different fire retardant compositions were used in those materials, as there were different burning characteristics and toxic emissions.

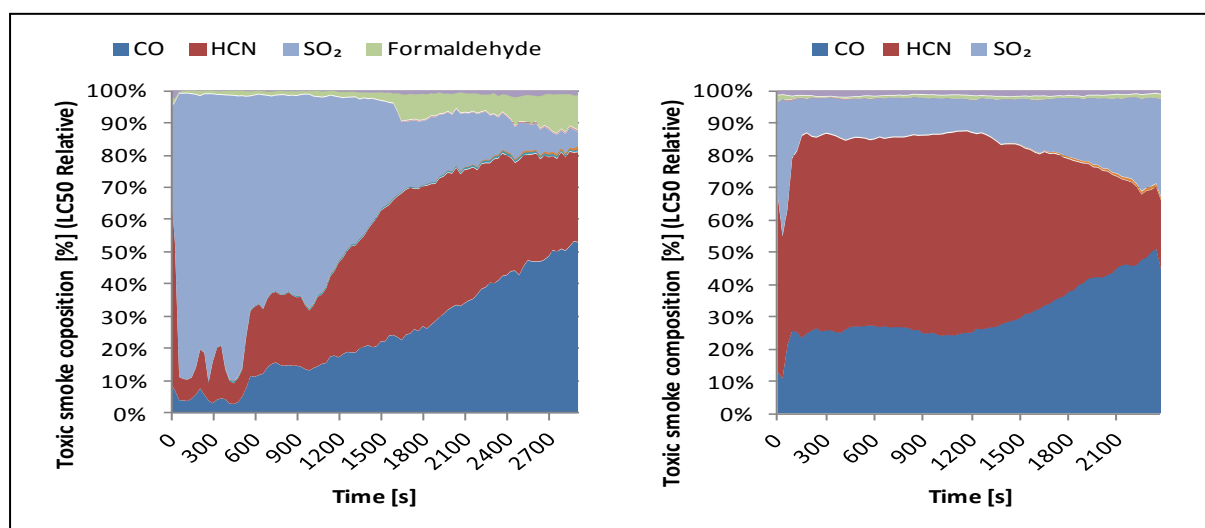


Fig. 4: Toxic composition of N-gas (LC50 relative) V Time shown for (Left: fabric seat cover, Right: wall/floor cover)

4. Conclusions

- The FTIR analysis showed that Sulphur Dioxide was the major toxic gas for the aircraft fabric seat covers and the wall/floor covers. The sulphur came from the fire retardant and this shows that these materials will not initiate a fire, but if there is a fire elsewhere then these materials will contribute significantly to the toxic gases. This is not currently recognised in the screening of materials for use in aircraft interiors.
- HCN was the second most important toxic gas and this was due to the use of acrylic fibres in the seat and wall coverings, which could easily be substituted for non-N containing materials.
- Carbon monoxide was not the dominant toxic gas, even though the materials were burnt under air starved conditions where CO is often the dominant toxic gas.
- Toxic gases from these aircraft materials was totally different from normal building materials such as wood, where the major toxic gases are acrolein, formaldehyde and carbon monoxide.

5. Acknowledgments

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