INFLUENCE OF CLADDING AND INSULATION MATERIALS ON FAÇADE’S EXTERNAL FIRE SPREAD

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INTRODUCTION

There are thousands of existing buildings constructed using an aluminium composite panel (ACP) as combustible cladding, which creates a pathway for façade external fire spread. In Australia, a typical layered façade system consisting of ACP with various compositions of its core and different insulations (stone wool or polymeric batt) could lead to very different fire spread via external façades. Understanding the contribution of major combustible factors (i.e. cladding and insulation) is critical in assessing the fire risk of these façade systems and determining the appropriate rectification methods.

There are existing works in literature[1,2] on the burning behaviours of façades addressing the difference in cladding and insulation types. A study by Guilaume et al.[1] studied three ACPs with combustible cores of dominated polyethylene (PE), flame retardant-PE (typically not more than 29 wt.% of polymer) and non-combustible material. The studied specimens also include three types of insulations: phenolic foam, polyisocyanurate (PIR) foam and stone wool. The experimental design in this paper partially adopts the method used in this study on materials that are more relevant to the construction context in Australia. In this study, apart from ACP with PE-dominated and 29 wt.% PE cores, a new core composition was tested with a flame retardant to polymer ratio of 1:1 in line with the new guideline[3]. In addition, a thermoplastic batten, popularly used in Australia’s construction, is also studied.

EXPERIMENTAL DESIGN

The test protocols were designed based on the medium-scale ISO 13785-1:2002[4]. The burner was tested with a varied heat output of 100 kW in the first 15 minutes and increased to 300 kW for another 25 minutes. Thus, the total duration of each test is 40 minutes. As the purpose of these tests is to identify the contribution of cladding and insulation materials in facilitating significant fire spread beyond the fire of origin, the fuel source that sufficiently and directly ignites cladding/insulation proximately next the burner was selected.

The test was conducted under a calorimetric hood in accordance with ISO 9705-1:2016[5] to measure the heat release rate during the test. The effluents were also collected for Fourier-Transform Infrared Spectroscopy (FTIR) in accordance with ISO 16405:2015[7] and ISO 19702:2015[7]. A similar approach was used in previous research[1]. A set of 10 tests was conducted - including one baseline test with non-combustible cladding, as shown in Table 1.

Table 1 – Specimens

Test No.	Specimen	Cladding material	Insulation
1	PE-RW	Aluminium Composite Panel with its core consisting mainly of polyethylene (PE)	Rock wool
2	PE-PET	Aluminium Composite Panel with its core consisting mainly of polyethylene (PE)	Polyethylene terephthalate (PET)
3	PE-Air	Aluminium Composite Panel with its core consisting mainly of polyethylene (PE)	No insulation
4	FR45-RW	Aluminium Composite Panel with its core consisting of ~45% flame retardant (FR45)	Rock wool
5	FR45-PET	Aluminium Composite Panel with its core consisting of ~45% flame retardant (FR45)	Polyethylene terephthalate (PET)
6	FR45-Air	Aluminium Composite Panel with its core consisting of ~45% flame retardant (FR45)	No insulation
7	FR70-RW	Aluminium Composite Panel with its core consisting of 70% flame retardant (FR70)	Rock wool
8	FR70-PET	Aluminium Composite Panel with its core consisting of 70% flame retardant (FR70)	Polyethylene terephthalate (PET)
9	FR70-Air	Aluminium Composite Panel with its core consisting of 70% flame retardant (FR70)	No insulation
10	Baseline	Autoclaved Aerated Concrete (AAC)	-

Three types of ACPs with different core materials were used as the cladding: Type 1, hereafter referred to as PE, comprising of 97 wt.%. polymer; Type 2, hereafter referred to as FR45, comprising of approximately 45 wt.%. flame retardant and 44 wt.% polymer; and Type 3, hereafter referred to as FR70, comprising of 70 wt.% flame retardant and 29 wt.% polymer. Type-K thermocouples and a water-cooled heat flux gauge were used to measure the temperature along the exposed side of the specimen and in the cavity, and the heat flux was measured at the top of the specimen (Figure 1). There were five thermocouples at the centre line along the height of the specimen with a spacing of 500 mm. The sixth thermocouple was at the top of the specimen next to the heat flux gauge, both of which were installed flush with the front surface of the cladding. There were another three thermocouples at 500 mm, 1,500 mm and 2,500 mm height at the middle of the insulation. A similar location was maintained with specimens without insulation.

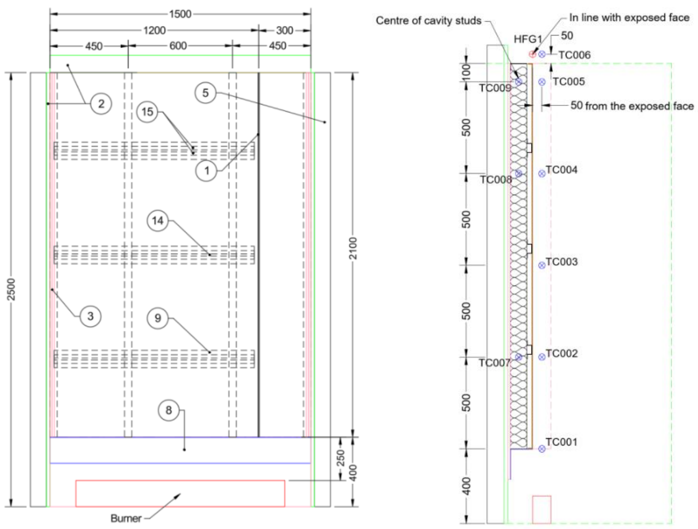

Figure 1 – Test rig (left) and instrumentation (right)

RESULTS AND ANALYSIS

The heat flux at the top of the specimen and the heat release rate (HRR) (inclusive of burner's) are presented in Figure 2 and Figure 3, while the gas evolved analysis is included in Table 2. HRR and heat flux curves of PE, FR45 and FR70 are shown in orange, purple and green respectively and the baseline's curve is black. In the gas evolved analysis (Table 2), each gas was coded with green as the lowest and red as the highest concentrations. Further data from the thermocouple measurements will be presented at the conference.

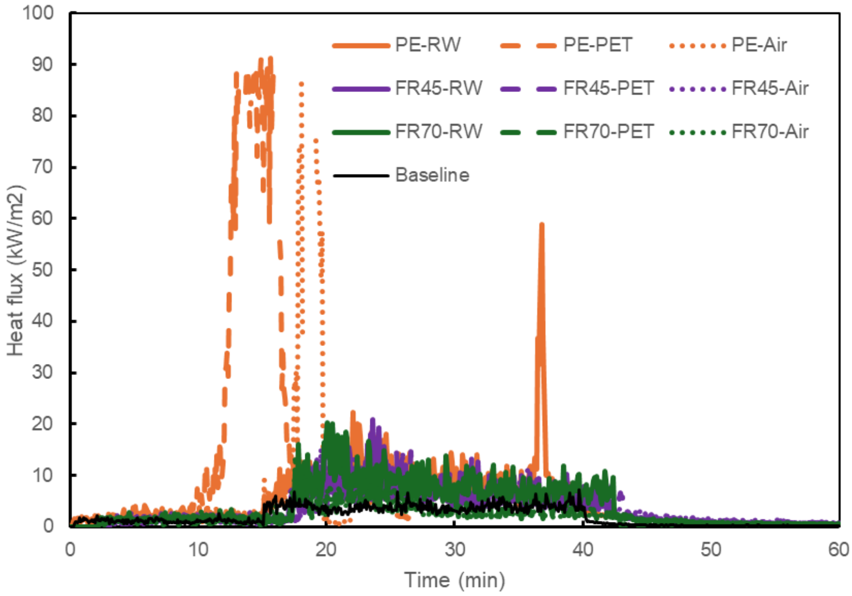

Figure 2 – Heat flux measured at the top of the specimen

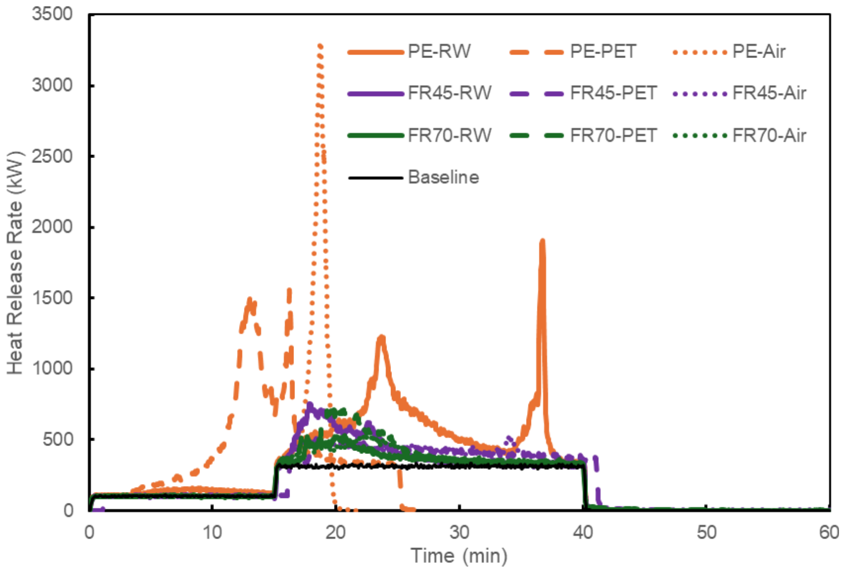

Figure 3 – Heat release Rate (HRR) including burner

Table 2 – FTIR measurements

FTIR measurement (ppm)	Baseline	FR70-Air	FR70-RW	FR70-PET	FR45-Air	FR45-RW	FR45-PET	PE-Air	PE-RW	PE-PET
Carbon dioxide CO2	0.69	0.94	1.09	2.14	1	1.39	1.69	9.29	3.24	4.75
Carbon monoxide CO	0	0.02	0.01	0.03	0.02	0.02	0.01	0.17	0.03	0.04
Nitrous oxide N2O	0.92	1.31	0.86	1.15	0.52	0.82	0.69	43.69	2.1	1.44
Nitrogen monoxide NO	3.1	4.33	3.56	5.81	7.34	10.01	6.98	139.65	18.89	22.3
Nitrogen dioxide NO2	7.78	27.04	27.67	31.24	26.65	39.64	73.87	298.16	71.64	164.04
Sulfur dioxide SO2	2.33	3.88	3.92	11.03	4.22	4.58	7.67	141.06	6.15	26.53
Ammonia NH3	1.06	1.17	1	1.25	0.9	0.61	0.81	17.47	0.99	2.14
Hydrogen chloride HCl	0.59	1.93	2.99	7.7	2.92	3.17	4.52	9.37	3.63	5.79
Hydrogen fluoride HF	1.67	1.14	1.2	1.74	1.65	3.14	3.99	5.46	4.73	7.26
Methane CH4	8.16	23.69	27.67	32.06	52.36	39.02	22.6	63.25	19.48	61.63
Hydrogen cyanide HCN	1.61	4.66	4.53	6.41	12.94	9.04	1.65	117.02	2.45	11.06
Ethylene C2H4	2.14	17.46	16.81	15.07	37.64	36.07	9.36	48.35	13.68	44.87
Hydrogen bromide HBr	0	12.52	17.74	18.36	14.79	12.4	8.33	10.23	0	2.22
Acrolein C3H4O	1.18	0.12	0.33	21.86	0	0.37	15.42	1.37	0.18	14.08
Formaldehyde CHOH	1.22	3.04	2.26	6.91	5.12	4.69	4.79	27.1	3.95	9.43

There is a general trend in line with previous studies that the presence of PE cladding results in a significant increase in both HRR and the heat flux. Particularly, FR45 and FR70 result respectively in an increase of heat flux by up to 1.77 and 1.87 times higher than that of the baseline, while PE cladding could lead to a heat flux 11.6 times higher than the baseline. The HRR (excluding burner) peaks at 413 kW and 454 kW for FR70 and FR45, while PE cladding could reach 3.01 MW. The gas evolved analysis shows a significant increase in most gas species with PE cladding, especially with air cavity and PET insulation.

To further understand the significance of cladding and insulation on different fire performance properties, a two-way analysis of variance (ANOVA) and ordinary least square (OLS) regression analysis model is adopted. In this analysis, cladding and insulation types are two factors or the independent variables, while fire performance properties, including measurements of heat flux, peak of HRR (PHRR), the time that the peak heat flux or PHRR is obtained, and gas toxicity (carbon dioxide, carbon monoxide and hydrogen cyanide) are the dependent variables or responses.

The two-way ANOVA procedure[8] calculates the F-value based on a null hypothesis, stating that there is no difference between the means of the experimental populations. The P-value is calculated from the above F-value and represents the probability of achieving properties without invalidating the null hypothesis on the experimental conditions. As a result, any variable with a P-value equal to or lower than the significance level (selected as 0.05 in this study) will have a significant effect on the corresponding response. Table 3 presents the P-value of cladding and insulation factors with seven selected responses. Red cells correspond to those with a P-value equal to or less than the significance level, while green cells are the opposite. It is observed from Table 3 that cladding could be concluded to have a significant influence on most of the selected fire performance properties (five out of seven), while the influence of insulation is inconclusive.

In the next step, a comparative analysis with OLS regression is conducted. Owing to the size of the data, eta-square is used to identify the effect size measures – the strength of the relationship between the factor and the response. Eta-square value ranges from 0 to 1, with 0 meaning the factor explaining none of the variance and 1 meaning the factor explaining all the variance (presented in Table 4). The maximum heat flux response has the eta-square for cladding and insulation as 0.9361 and 0.006, respectively. It means that the cladding type explains 93.61% of the total variance in the maximum heat flux, while insulation only accounts for 0.6% of the variance. Table 4 also reports the residual, which means other factors apart from the two factors in this study. It is also observed that the analysis results from Tables 3 and 4 align well, showing the significant contributions of cladding compared to insulation in the selected fire performance properties.

Table 3 – P-value of cladding and insulation factors from ANOVA

	Cladding	Insulation
Max Heat Flux	0.004976	0.766396
Time to Max Heat Flux	0.027758	0.404938
Peak of Heat Release Rate	0.041811	0.514440
Time to PHRR	0.107971	0.368834
Carbon dioxide	0.019566	0.730869
Carbon monoxide	0.039505	0.375474
Hydrogen cyanide	0.227482	0.393102

Table 4 – Influence of cladding and insulation factors on responses from OLS regression (Eta-square is displayed as a percentage)

	Cladding	Insulation	Residual
Max Heat flux	93.61%	0.60%	5.79%
Time to Max Heat flux	69.96%	7.82%	22.22%
PHRR	67.54%	6.45%	26.01%
Time to PHRR	53.01%	13.29%	33.70%
Carbon dioxide	76.82%	2.30%	20.88%
Carbon monoxide	65.81%	9.52%	24.66%
Hydrogen cyanide	41.30%	15.70%	43.00%

CONCLUSIONS

A series of 10 mid-scale tests was conducted to investigate the contribution of cladding versus insulation to façade external fire spread. Results show a significant difference between cladding and insulation, where the presence of PE cladding dominates the variance of the fire spread. Particularly, the variance of the maximum heat flux at the top of the specimen is strongly influenced by the cladding type (over 90%), while the insulation type only accounts for less than 1% of its variance. The gas evolved analysis also shows a similar trend in the toxicity of combustion products.

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