

FIRE HAZARD RISK ASSESSMENT OF CLADDING MATERIALS USED IN FACADE SYSTEMS IN MALAYSIA

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ABSTRACT

In the era of modernization, the façade construction industry places increasing emphasis on producing buildings that are visually appealing to consumers. To meet these aesthetic demands while ensuring constructability, engineers have developed a range of lightweight façade materials, among which aluminium composite panels (ACP) are particularly prominent. ACPs are widely used and highly valued for their customizability, allowing them to be tailored to the specific requirements of clients. However, achieving a lightweight design often involves trade-offs in material composition. One such compromise is the incorporation of a polyethylene (PE) core a cost-effective and low-density alternative to more fire-resistant materials. This substitution has been linked to several catastrophic façade fire incidents globally, as the PE core can significantly accelerate fire propagation across building exteriors. In light of these concerns, this study conducts a thermal performance analysis of ACPs manufactured from various combinations of two grades of aluminium 3000 series and 5000 series and three types of PE cores: low-density (LD), high-density (HD), and fire-retardant (FR). The thermal analysis was conducted in accordance with the British Standard BS 8414 Part 1 (2017) using Finite Element Modelling (FEM) through the ABAQUS software platform. The results reveal that none of the tested ACP configurations satisfied the thermal performance criteria established in BS 8414 Part 1 (2017), regardless of the aluminium grade or PE core type. This finding highlights the urgent need to integrate additional fire-preventive layers or materials in ACP-cladded façade systems to ensure compliance with safety standards. Furthermore, the study explores the prevalent use of ACP in ongoing construction projects, as well as the preventative strategies implemented by BOMBA Malaysia (the Malaysian Fire and Rescue Department) to mitigate the risks associated with flammable façades. These insights were gathered from a local façade consultancy firm, offering a practical perspective on how the construction industry in Malaysia is responding to the ongoing fire safety challenges posed by ACP systems.

Keywords:

ABAQUS, Aluminium Composite Panel (ACP), Thermal Analysis, BS 8414 Part 1 (2017), Façade Fire, Flammable cladding

INTRODUCTION

The use of cladding materials in façade systems has raised significant concerns regarding fire safety, particularly in high-rise buildings located in urban centres such as Malaysia. This issue has gained increasing attention following a series of high-profile fire incidents worldwide, prompting engineers and architects to reassess the fire performance of commonly used construction materials. According to Sifat et al. (2024), fire hazard risk assessments are essential to ensure that façade materials do not contribute to the spread of fire or compromise the safety of building occupants. Their study revealed that although certain cladding materials are popular for their aesthetic appeal and insulation properties, they often demonstrate inadequate fire resistance, making them hazardous during fire events. Specifically, the research identified commonly used materials in Malaysia, such as polyethylene (PE) and aluminium composite panels (ACP), which exhibited variable fire performance, thereby highlighting the urgent need for stricter fire testing protocols and regulatory oversight.

The issue of façade fire safety in Malaysia is further exacerbated by the lack of comprehensive local regulations addressing the fire performance of cladding materials. As Abdullah (2021) notes, while some international fire safety standards are referenced in practice, there is a

pressing need to localize these standards to reflect the environmental and construction conditions specific to Malaysia. Abdullah emphasizes the development of context-appropriate national codes, especially for densely populated urban areas where high-rise buildings are prevalent. Similarly, Redzuan (2020) found that despite the existence of national guidelines, enforcement and compliance remain inconsistent. The study also observed that cost-efficiency is often prioritized over safety, with developers opting for cheaper, fire-prone materials without conducting adequate fire risk assessments posing a serious threat to public safety. The combination of substandard material selection, the absence of localized fire regulations, and weak enforcement mechanisms has contributed to a growing fire risk in Malaysia's urban construction sector. To address these challenges, Sifat et al. (2024) advocate for the implementation of rigorous fire testing procedures and the establishment of regulatory frameworks tailored to local conditions. They further stress the importance of raising industry awareness and promoting education on façade fire safety. By enhancing the fire resistance of cladding materials and ensuring compliance with both national and international safety standards, the risk of fire-related disasters in Malaysian buildings can be significantly mitigated.

LITERATURE REVIEW

Façade and Cladding

Derived from the French word *face*, the term "façade" refers to the external appearance or outer surface of a building. With significant advancements in construction technology, it is now possible to manufacture complex façade elements with high precision. This development has expanded the range of façade products available, allowing for customised solutions to suit diverse architectural projects. Beyond enhancing the visual appeal of buildings, façade components also serve various functional roles, including waterproofing, ventilation regulation, thermal and acoustic insulation, and UV protection. Additionally, façade systems can be constructed using various methods, such as ribbon window systems and curtain wall systems, which incorporate high-performance materials (Kim, 2011).

While the continuous curtain wall system is a common and visually striking feature in high-rise buildings, various cladding materials may also be used as alternatives. These include perforated panels, timber, fibre cement, terracotta, stucco, aluminium solid panels, and aluminium composite panels (ACP) (Bradtmueller & Foley, 2014). However, the selection of materials must be made with careful consideration of both the design requirements and the local climatic conditions. Certain materials may be unsuitable for extreme environments. For instance, due to its lightweight and low-density characteristics, ACP may not be ideal for regions with extremely high temperatures. In such cases, materials like terracotta, which have higher melting and boiling points, may be more appropriate (Cohen, 1992). In the Malaysian context, ACP cladding has gained widespread popularity, largely due to its ability to withstand the country's consistently hot and humid climate while requiring minimal maintenance (Byrnes et al., 2019).

Aluminium Composite Panels, ACP

Aluminium composite panels (ACP) are widely favoured in façade design due to their high degree of customizability and the wide variety of available configurations. These features enable ACPs to fulfil diverse client specifications while significantly enhancing a building's aesthetic appeal, often creating a more visually striking effect than traditional paint finishes (Abdullah, 2018). Additionally, ACPs are considered a cost-effective solution, particularly when purchased in bulk, which further contributes to their popularity in the construction industry. A standard ACP panel typically has a total thickness of approximately 5 mm, comprising a polymer core (2–3 mm) sandwiched between two

aluminium sheets (each 0.5–1.0 mm thick). Both the aluminium layers and the core are available in various grades and compositions. The aluminium sheets are commonly manufactured from the 3000- and 5000-series alloys, each offering distinct mechanical and chemical properties (Latsa, 2015). The polymer core is typically composed of polyethylene (PE), available in three main variants: low-density PE (PE-LD), high-density PE (PE-HD), and fire-retardant (FR) PE. However, alternative configurations also exist, such as ACPs with an aluminium honeycomb core inserted between the aluminium layers. This type of ACP offers enhanced structural integrity and improved fire resistance (Yuen et al., 2021).

Properties of 3000 and 5000 Series Aluminium

As noted by Latsa (2015), both the 3000-series and 5000-series aluminium alloys exhibit very similar mechanical and chemical properties, with the primary difference being their chemical compositions. Table 1 presents the chemical compositions of the two alloys, while Table 2 illustrates the thermal conductivity values for both aluminium grades.

Table 1: Chemical composition of 3000 and 5000 series aluminium alloy (EN 573-3 Aluminium and Aluminium Alloys - Chemical Composition and Form of Wrought Products - Part 3: Chemical Composition,2003)

Alloy designation	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Alloy 3000 (EN AW-3105)	0.6	0.7	0.3	0.3-0.8	0.2-0.8	0.2	0.4	0.1
Alloy 5000 (EN AW-5005)	0.3	0.7	0.2	0.2	0.5-1.1	0.1	0.25	-

Table 2: Thermal Conductivity of 3000 and 5000 series aluminium alloy (BS EN 1706 Aluminium and Aluminium Alloys - Chemical Composition and Mechanical Properties, 2020)

Alloy designation	Thermal Conductivity (W/m°C)
Alloy 3000 (EN AW-3105)	171
Alloy 5000 (EN AW-5005)	200

Properties of Polymer Cores used in ACP

Although there are various options for manufacturing Aluminium Composite Panels (ACP), such as using Bakelite or polyester as the core material, polymer cores remain the most commonly available option in the market. As mentioned earlier, these polymer cores are typically classified into three variants: PE (LD), PE (HD), and FR, with FR being the most recent to be introduced commercially. The thermal conductivities of the three core types are presented in Table 3 below.

Table 3: Thermal Conductivity of polymer cores used in the production of ACP (Askeland & Wright, 2016;Hansen & Bernier, 1972)

Polymer Core	Thermal Conductivity (W/m°C)
PE(LD)	0.33
PE(HD)	0.45
FR	0.50

Flammability risk of ACP

Due to the nature of Aluminium Composite Panel (ACP) cladding, it has been shown to be highly combustible in recent years. This is primarily attributed to the material properties of the polyethylene (PE) core and the behaviour of fire, especially in high-rise buildings where wind loads intensify flame spread. Since PE cores begin to melt at approximately 370°C, the molten material subsequently ignites and contributes to the rapid propagation of fire (Askeland & Wright, 2016). Moreover, when burned, PE cores release toxic fumes, making evacuation more difficult and hazardous. In addition, research has shown that a higher organic content in the ACP core correlates with an increased peak heat release rate during façade fires (McLaggan et al., 2021). As a result of these factors, the number of fire incidents exacerbated by ACP cladding has increased in recent years, following the rising demand for the material.

Cases of Fire Outbreaks Caused by Flammable Façade

The cases of building fires influenced by flammable façades worldwide are highlighted in Table 4 below. The façade fires listed in the table date back to the early 1990s, during the initial adoption of Aluminium Composite Panels (ACP). At that time, ACP was primarily manufactured to replace heavier and more expensive building materials, offering the advantage of bulk transport and easier on-site installation (Chen et al., 2019). Furthermore, it is evident that in most of the cases cited, ACP with a polyethylene (PE) core was used as the cladding material. However, the occurrence of these incidents demonstrates that, despite the apparent advantages of ACP such as cost efficiency and ease of installation it also poses significant risks, leading to substantial damage and loss.

Table 4: Cases of Building Fire Outbreaks Exacerbated by Flammable ACP

No	Location	Year	Cladding Material	Cause of fireoutbreak	Casualties
1	Knowsley Heights, Liverpool, United Kingdom	1991	Aluminium composite panels with a mineral core were installed in an unventilated façade system.	Arson. The lack of a horizontal cavity within the system led to the rapid spread of fire, causing the building to burn like a "furnace," according to eyewitness accounts.	0 casualties, all 60 occupants were evacuated in time.
2	Garnock Court, Irvine, Scotland	1999	PVC cladding	A lit cigarette that was improperly disposed of set fire to the cladding.	5 injured, 1perished
3	Television CulturalCentre (CCTV Complex), Beijing, China	2009	Mixture of Titanium and Zinc alloy	The use of illegal and unregulated fireworks caused flames to propagate from the lower floors, eventually engulfing the entire 34-storey building within 20 minutes.	7 individuals were injured, and 1 perished of the 8 people involved, 7 were firefighters, including the individual who lost their life.

4	Shanghai Apartment, China	2010	Aluminium composite panels (ACP) were fitted in a system that used polyurethane (PU) as insulation.	Welding sparks from untrained workers during renovation works ignited the bamboo scaffolding, which then spread to the cladding, engulfing it in flames within four minutes.	71 people were injured, and there were 58 fatalities. The incident holds the title of the second deadliest façade fire on record.
5	Tecom Building, Dubai, UAE	2012	ACP with PE core	Undetermined	2 people sustained minor injuries; falling debris damaged vehicles and caused a pedestrian to suffer minor burn injuries.
6	Lacrosse Tower, Melbourne, Australia	2014	ACP with PE core	A lit cigarette, improperly disposed of, ignited the cladding.	There were 0 casualties, and all 400 occupants were evacuated safely due to the activation of the high-pressure water sprinkler system.
7	The Marina Torch, Dubai, UAE	2015 & 2017	ACP. Core of ACP was undisclosed	A lit cigarette or coal from a shisha, left unattended on the balcony, ignited the cladding.	There were 0 casualties
8	Address Downtown Dubai Hotel, Dubai, UAE	2016	ACP with PE core	A short circuit in the floodlights installed on the external façade between the 14th and 15th floors triggered the incident.	15 injured
9	Grenfell Tower, North Kensington, West London, United Kingdom	2017	ACP with PE core	The fire was traced to a faulty refrigeration unit located on the fourth floor. Despite the swift response from emergency authorities, the blaze had already spread throughout the entire building, trapping a significant number of occupants.	72 people perished, and the number of injuries remains unreported. It holds the title of the deadliest façade-related fire.
10	Employees Provident Fund (EPF) Building, Petaling Jaya,	2018	ACP with PE core	Sparks generated during maintenance work on the façade, combined with hot weather conditions, resulted in the rapid spread	There were 0 casualties, and 527 employees and

	Selangor, Malaysia			of flames.	customers were evacuated in time.
11	Neo200, Melbourne, Australia	2019	ACP with PE core	A lit cigarette that was improperly disposed of ignited the cladding.	1 injured

METHODOLOGY

The workflow of this study is illustrated in Figure 1. This chart provides an overview of the methodological steps undertaken to conduct the research. The specific steps used to obtain the results through ABAQUS simulation software are presented in Figure 2.

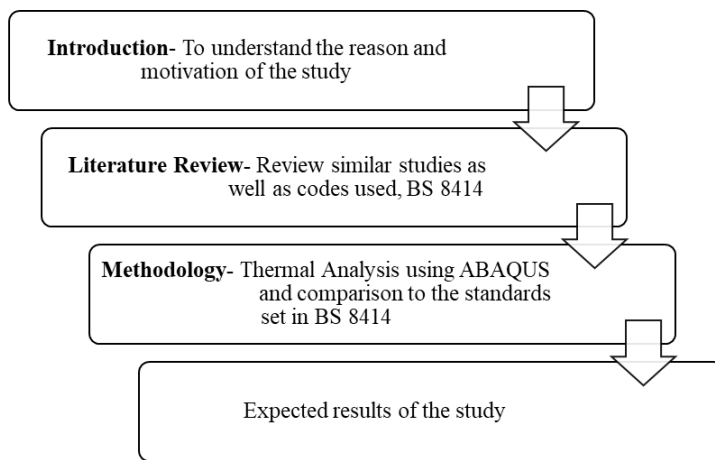


Figure 1: Flow chart of work of study

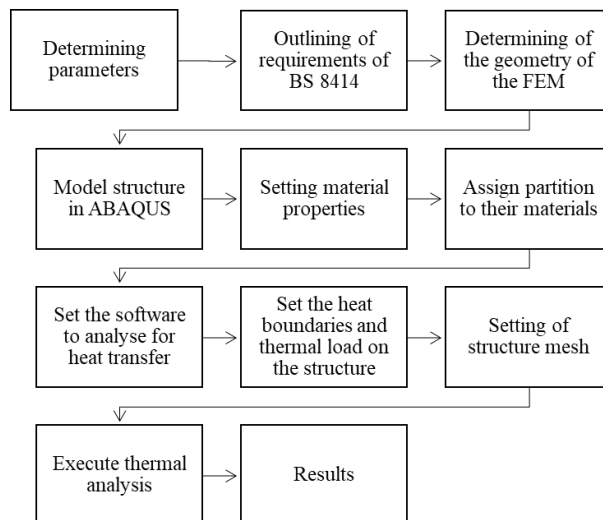


Figure 2: Flow chart on conducting thermal analysis using ABAQUS

Before the thermal analysis could be conducted, the ACP wall model was first developed in ABAQUS. The full-scale façade fire test outlined in BS 8414 Part 1: Fire Performance of External Cladding Systems (2017) was used as a reference for modelling the ACP wall, as it is the industry-standard method for testing flammable façade materials. Figure 3 presents the schematic diagram of the cladded wall mock-up unit used for façade fire testing.

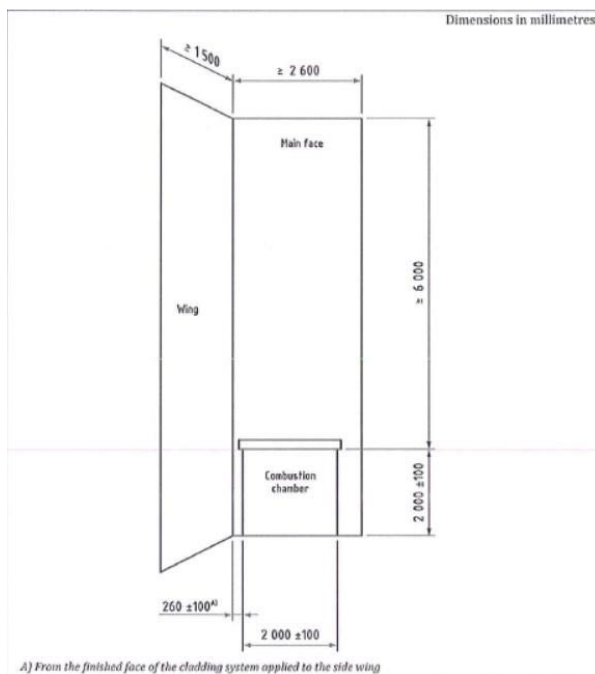


Figure 3: Schematic diagram of external cladding mock-up for fire testing (BS 8414 Part 1: Fire Performance of External Cladding Systems, 2017)

Although the model described in BS 8414 Part 1 (2017) requires a complete façade system to be constructed, this study focused solely on modelling the cladding wall using aluminium composite panels (ACP). This is because the objective was to evaluate the performance of the ACP material in isolation. Furthermore, it was found that ABAQUS software is unable to accurately model the façade wall with all its intricate components and assemblies. Due to the various materials used in ACP production, a typical configuration was selected consisting of two 1 mm thick aluminium sheets and a 3 mm thick polymer core. The different ACP combinations used in the wall modelling, along with the thermal conductivity values of each material, are presented in Table 5.

Table 5: ACP configuration used for software modelling

Set	Aluminium Alloy	Thermal Conductivity (W/m°C)	Polymer Core	Thermal Conductivity (W/m°C)
A	3000 series	171	PE (LD)	0.33
B	3000 series		PE (HD)	0.45
C	3000 series		FR	0.5
D	5000 series	200	PE (LD)	0.33
E	5000 series		PE (HD)	0.45
F	5000 series		FR	0.5

Once all sets of ACP were modelled and partitioned in ABAQUS according to Figure 3, the material properties were defined and assigned to the cladding wall. After assigning the material properties, the analysis settings were configured, and expected outcomes were established to obtain the necessary data for this study. Next, the boundary conditions and thermal load on the ACP wall were applied. For the boundary condition, a room temperature of 20°C was used, in line with BS 8414 Part 1 (2017), which specifies that room temperature prior to a full-scale test should fall within the range of 15–20°C. Regarding the thermal load, since the combustion source in the full-scale test is a burning wooden crib, a thermal load of 5000 W/m² was applied, as referenced by Xu et al. (2007). Following the assignment of loads and boundary conditions, the model was meshed with a global mesh size of 0.00625. Once the meshing process was completed, thermal analysis was carried out, and the results were extracted and analysed accordingly.

ANALYSIS AND DISCUSSION

Results Obtained through the Thermal Analysis using ABAQUS

Once the data had been extracted from the point of heat load application to the topmost section of the ACP wall by selecting the relevant nodes it was tabulated for each ACP set, as shown in Figure 4. This data was also visualized using heat maps, providing a clear representation of temperature distribution across the wall, as illustrated in Figure 4 below.

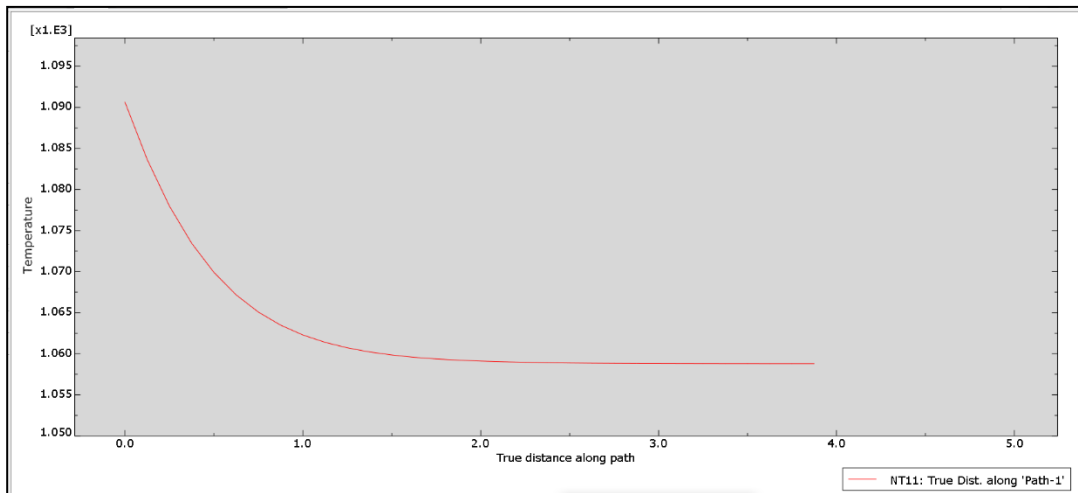


Figure 4: Temperature versus distance from point of impact of Set A ACP

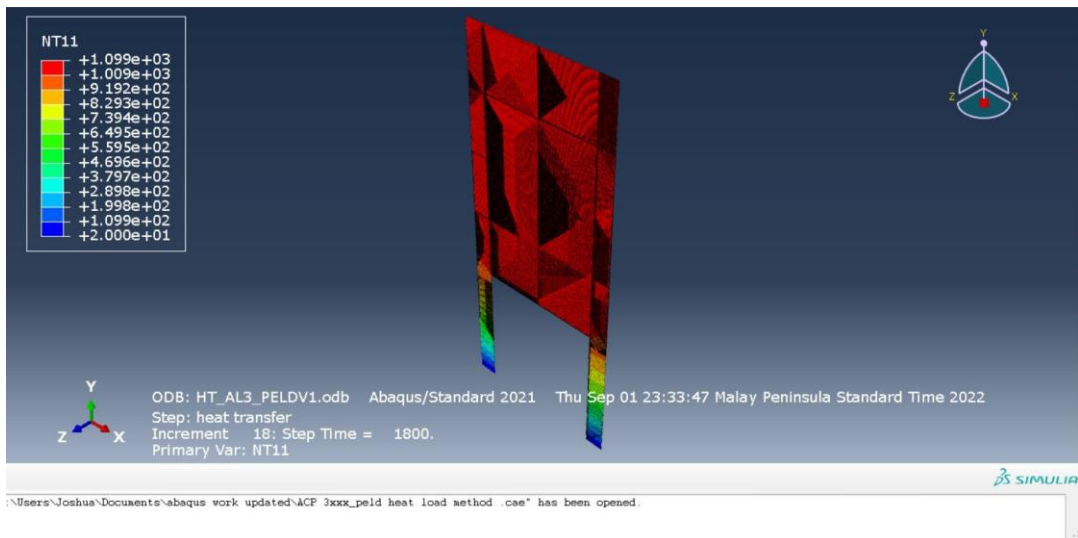


Figure 5: Heat Map of Set A ACP wall

This analysis was conducted at the conclusion of the 30-minute thermal simulation. The data from each table was then condensed into Table 5 by extracting the temperature value of the topmost node. This step was taken to align with the guidelines outlined in BS 8414 Part 1 (2017), which require assessing whether the temperature at the topmost thermocouple, in this case the node exceeds 600°C at the 30-minute mark. Exceeding this threshold indicates a failure in material safety compliance.

Table 6: Temperature recorded at the topmost section of each set of ACP wall after 30 minutes of thermal load.

Set	Temperature at 6m at t=1800s (°C)
A	1058.80
B	1058.79

C	1057.71
D	908.541
E	907.744
F	907.412

As shown in Table 6, the ACP in Set F, which is modelled using 5000 series aluminium and an FR core, performs the best among the six sets. However, the temperature recorded at the topmost section of the ACP wall exceeds the 600°C threshold specified in BS 8414 Part 1 (2017). In fact, none of the six ACP sets, regardless of material composition, meet the requirements outlined in BS 8414 Part 1 (2017). When comparing the two aluminium grades, the results indicate that the 5000 series aluminium outperforms the 3000 series across all tested sets. Regardless of the core material paired with it, ACPs using the 5000 series consistently show better thermal performance. For instance, comparing the best-performing 3000 series set (Set C) with the lowest-performing 5000 series set (Set D), Set D still recorded a temperature 141.559°C lower after 30 minutes of exposure to thermal load.

Regarding core material, the FR core clearly demonstrates the best performance, irrespective of the aluminium grade used. This is evident from the fact that in both the 3000 and 5000 series sets, the ACPs with FR cores Set C and Set F, respectively recorded the lowest temperatures. However, temperature differences between core types within the same aluminium grade are relatively marginal, suggesting that the aluminium grade has a more significant impact on thermal performance than the core type.

Types of ACP Used in Current Construction Projects

To identify the types of ACP cladding currently employed in the façade industry, a consultation was conducted with Pintar Jaya (M) Sdn Bhd, a façade engineering consultancy. The company provided detailed information on the types of ACP panels used in three ongoing projects for which they are responsible for both the design and installation of façade components. The list of these projects, including their current status and the type of ACP cladding used, is presented in Table 7 below.

Table 7: Current projects and the types of ACP panels used as provided by Pintar Jaya (M) Sdn Bhd

Name of Project	Status of Project	Type of ACP Panel
Sunway South Quay CP2, Bandar Sunway, Subang Jaya	Under construction	Brand of ACP has yet to be determined but has been decided to be an FR core with either 3000 or 5000 series aluminium
Pavilion Damansara Heights (Parcel II), Kuala Lumpur	Under construction	Alpolic FR ACP 3000 series
IOI City Mall, Putrajaya (Phase II)	Completed (August 2022)	Alcopla FR ACP 3000 series

As shown in Table 4.7, all three projects prioritize the use of FR (Fire-Retardant) cores over the grade of aluminium. This practice aligns with the updated guidelines issued by BOMBA Malaysia, specifically the Performance Criteria for External Cladding System in Malaysia (FPST/DOC/14-1, Version 1:2019), developed in response to the 2018 EPF building fire (Performance Criteria for External Cladding System in Malaysia FPST/DOC/14-1, 2019). According to the guideline, the use of PE (both LD and HD) cores in external and internal façades is restricted to instances where the ACP system does not exceed 18 meters above platform level. Additionally, PE cores are permitted for internal applications that are not integrated with the primary façade structure. The guideline further mandates that ACP panels installed in systems exceeding 18 meters in height must incorporate fire

barriers and utilize FR cores to ensure enhanced fire safety.

Although the newly implemented standards introduced by the relevant authorities effectively mitigate façade fire risks in new constructions by establishing enhanced safety requirements, they do not extend to existing buildings already fitted with aluminium composite panels (ACP) containing polyethylene (PE) cores. This oversight poses both safety and economic challenges. In relatively new buildings, the premature replacement of ACP panels imposes a substantial financial burden, as building owners may be unwilling to undertake costly upgrades shortly after project completion. Nonetheless, retrofitting may still be a feasible option for these newer structures, given that their building systems remain in good condition and would likely require only minor adjustments to existing fixtures. In contrast, older buildings may demand more extensive and costly renovations to comply with current fire safety standards, making retrofitting less economically viable.

CONCLUSION AND RECOMMENDATION

A total of six different combinations of aluminium sheets and polyethylene (PE) cores were modelled in ABAQUS to represent six types of aluminium composite panel (ACP) wall assemblies. Following a 30-minute thermal simulation, the results indicated that none of the assemblies met the performance criteria outlined in BS 8414 Part 1 (2017). This failure is primarily attributed to the material being assessed in isolation, rather than as part of a complete façade system. This limitation arises from ABAQUS's inability to simulate complex assembly components, such as insulation panels, intumescent coatings, brackets, and fire barriers, elements that are crucial for fire compartmentalisation within ACP systems. Fire compartmentalisation at each level of an ACP-cladded wall plays a vital role in delaying vertical fire spread, thereby reducing the rate of heat transfer from the source to the uppermost parts of the wall (Jensen, 2013).

Moreover, the software's limited capacity to model realistic fire dynamics may have contributed to the failure. In ABAQUS, heat is applied uniformly as a thermal load across the material, which does not reflect the erratic and uneven spread of actual fire behaviour over time. Additionally, data obtained from Pintar Jaya (M) Sdn Bhd confirms that current façade construction projects utilize fire-retardant (FR) cored ACP, which consistently outperforms other ACP variants, regardless of aluminium grade. This practice aligns with guidelines set by BOMBA Malaysia in response to the 2018 Employees Provident Fund (EPF) building fire incident. However, the updated BOMBA guidelines do not specify any directives or policies concerning the replacement of non-compliant ACP cladding on existing structures.

As demonstrated by the simulation results, ACP panels should not be installed as standalone materials, but must be paired with fire-protective components such as intumescent materials, insulation, and fire barriers. This was evidenced in a full-scale test conducted by Façade Resources Sdn Bhd, where an ACP wall integrated with their proprietary fire barrier, Façade Shield™, was tested under the supervision of SIRIM QAS International Sdn Bhd. After 30 minutes of fire exposure, the thermocouple at the topmost level of the wall recorded a peak temperature of only 320°C, which is 280°C below the maximum limit stipulated in BS 8414 Part 1 (2017). This clearly demonstrates that incorporating fire-retardant components significantly improves the fire resistance and safety performance of ACP cladding systems.

AUTHORS BIOGRAPHY

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