Fire Hazards by Aluminum Composite Cladding in High-Rise Buildings

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Abstract

Recent fire incidents have caught the attention of authorities, engineers, architects, and other stakeholders in the construction industry regarding the application of aluminum composite panels. Major high-rise buildings worldwide have experienced fire incidents associated with aluminum composite panels necessitating research in regulatory requirements. The UK, the UAE, France, Australia, and South Korea are countries whose high-rise buildings have experienced fire incidents associated with fire spreading through ACPs. An investigation of specific incidents revealed substantial fire spread by ACPs, leading to losses. Aluminum composite panels are a group of sandwich panels that have hardwired applications in the construction industry in the last three decades. This research identifies glaring gaps in the regulatory framework for applying aluminum composite panels in the construction of high-rise buildings. It investigates the contribution of gaps in the regulatory framework today regarding safety and fire incidents associated with ACPs in different countries. After ascertaining the gaps, the research makes appropriate recommendations for the safe application of ACPs in the construction industry.

Keywords

Aluminum composite cladding, aluminum composite planes, fire propagation, flame retardant nano coating

1. Introduction

Advancements in technology a call for continuous discovering and development of new and versatile building and construction materials. The newly developed materials are usually compatible with traditional building and construction materials while being used in different construction systems and buildings. The versatility and flexibility in emerging construction materials influence evolution in architectural thinking. Furthermore, the emerging materials impact the architectural field by modifying the environment, aesthetic, political, and cultural aspects of construction and building. Aluminum composite planes (ACP) emerged in the architectural field to influence material selection based on building characteristics such as shape, size, and geographical location. ACP materials fulfill architectural characteristics such as building shape, location, setting, construction and building methods. The supply of ACP materials comes with different characteristics and flexibility in architectural designs and implementation. ACP materials impact on the construction industry manifests through high-speed automated implementation and the emergence of modern construction systems. Thus, ACP's impact on the construction industry renders it critical in the current and future designs and construction, warranting an extensive examination to ascertain its characteristics, advantages, and limitations.

1.1 Objectives
The paper objectives are, first to study the aluminum composite cladding flammable characteristics. Second, to study and analyze the accidents where aluminum composite cladding was identified as a cause. Moreover, the loses of these accidents will be analyzed in terms fatalities, injuries, and property damages. Following that, the paper will then provide systematic mitigation plan to reduce the risk on existing high rise aluminum composite cladding buildings.

2. Literature Review
Modern building technology has seen the introduction of aluminum composite panels (ACP) as materials for covering the building's exterior and interior. Cladding is the application of materials to a building's exterior surface. It is used to provide thermal insulation, weather resistance, aesthetic appeal, and energy efficiency. Materials are layered one on top of the other to make a skin or layer of the building's interior and exterior aims at enhancing its aesthetic appeal while necessitating the other building aspects such as heating, ventilation, and air conditioning. The discovery of aluminum composite panels transformed the building and architectural industry while covering the increased demand for construction materials, Armstrong and Allwinkle (2017). The architectural industry has undergone extensive research due to technological enhancements triggering the production of modern, flexible, and versatile materials. The discovery and use of aluminum composite panels facilitate architectural creativity, particularly design.

Architects utilize aluminum composite panels in designing facades of structures from the numerous options of diesel design provided by aluminum composite materials characterized by different colors. Construction designers and architects adopt aluminum composite panels due to their flexibility in design and construction compared to traditional materials, Armstrong and Allwinkle (2017).The building and construction industry exhibits design variations of building shapes and facades. As a result of flexibility in building shape and facades, the demand for aluminum composite planes has increased worldwide. Aluminum composite planes give buildings and structures a distinctive contemporary appearance to the building's interior and exterior as claddings. Furthermore, aluminum composite planes offer thermal insulation to building interiors, Armstrong and Allwinkle (2017). Aluminum composite plans are economical and elegant in application in architecture compared to traditional materials providing similar roles. Besides being economical, ACP exhibits low cleaning and maintenance costs when utilized for cladding the building's interior and exterior.
According to the trends and advancements of technologies in systems of architecture and construction, metamorphosis is inevitable, particularly in shaping the trend in new methods of architecture and the construction industry. Technological advancements are instrumental in humankind's contemporary life, Armstrong and Allwinkle (2017).The architectural and construction industries must tap into the international advancements in technology to generate sustainable designs and models for the city environment Armstrong and Allwinkle (2017). Aluminum composite panels have emerged out of technology to transform the architecture and construction industry through buildings that displace the original fabric of cities and induce sustainable and eco-friendly structures.

Aluminum Composite Planes
ACPs consist of two aluminum sheets that sandwich polyethylene material and are pre-manufactured and ready for architectural and construction purposes. Aluminum plates utilized in the preparation of ACP have a thickness of 0.5 mm. The polyethylene material occupying the call between two aluminum sheets has a thickness of 3 mm, Sulaiman, (2021). ACP has an overall plane width of 4mm, encompassing the aluminum plates and polyethylene core. Deviations in the sizes of ACPs occur depending on construction requirements, location of buildings and type of construction. Aluminum planes in the ACP have inner and outer faces. Inner faces occupy the hidden side of the ACP and always attach to the building after cladding, Sulaiman, (2021). On the other hand, the outer surface of the ACP is visible and displays the intended aesthetic appeal. Plating the outer aluminum sheet using polyvinylidene fluoride (PVDF) is the first process in pre-manufacturing ACP. Due to variations in ACPs sizes depending on application and manufacturing factors, standard thickness sizes exist to promote uniformity. Standard thickness sizes of 6, 4 and 3 mm exist worldwide, Sulaiman, (2021). Aluminum plate sizes usually remain constant in size variation, while the polyethylene size varies with specific standard thickness sizes. Three primary processes of core extrusion, precast adhesive laminating and extrusion lamination produces complete ACPs during manufacturing, Sulaiman, (2021). Its application in the architecture and construction industry is in the covering of interior and exterior walls. The application involves fixing the aluminum or iron structure as cladding material.

Working Rationale

Aluminum composite panels emanate from aluminum and polyethylene materials combined to form a sandwich. The resulting panel exhibits characteristics of aluminum and polyethylene. Aluminum is metallic and has mechanical properties, has low-density corrosion resistance and excellent heat and electrical conductivity rendering it useful in wide-ranging industrial applications, Sulaiman, (2021). These characteristics necessitate the combination of two aluminum sheets and a thermoplastic (polyethylene). The two aluminum shapes sandwich the thermoplastic base at the core to generate a material that finds broad application in the construction industry. The primary purpose of manufacturing aluminum composite panels is to offer buildings and aesthetic appeal. However, aluminum composite panels serve other additional purposes, such as enabling ventilation and cushioning in the building's interior against extreme external temperatures (thermal and acoustic insulation), Sulaiman, (2021). A continuous lamination process produces composite panels where the thermoplastic makes the core through extrusion and compaction between two aluminum sheets. The material attains flatness through perfection and compaction with the addition of protective film.

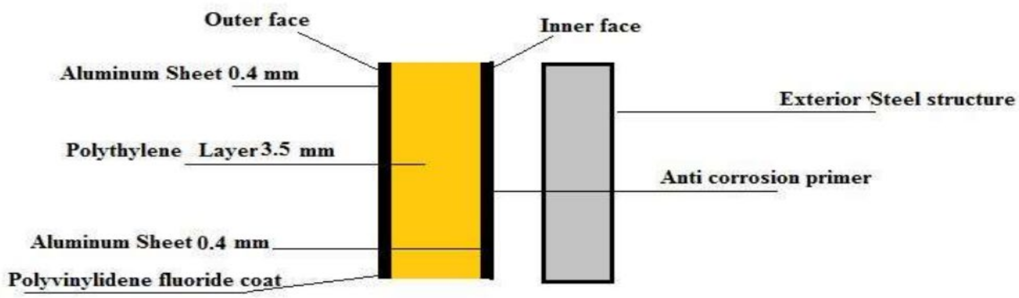

Figure 1. A cross-section of ACP material

The primary role of aluminum composite planes on the building's interiors and exteriors (cladding) is to offer aesthetic appeal through a modern, distinctive outlook. This application is relevant for the building's facade with a defective wall or with traditional materials that undermine its aesthetic appearance, Mohaney and Soni (2018). The flexibility of ACPs manifests in their various supply shapes and their several types, sizes, and colors. These characteristics of aluminum composite planes provide architects with an unlimited design range for modern residential and commercial buildings. The versatility of aluminum composite planes manifests in their application to different types of buildings regardless of the traditional materials used in construction, Mohaney and Soni, (2018). Furthermore, aluminum composite planes align with different finishing techniques, including wooden, marble, polished, and matte finishes.

The synthesis of aluminum composite planes with other traditional and modern building materials such as glass, ceramics, and metals is possible, expanding its flexibility range, Mohaney and Soni, (2018). The cladding of buildings using a combination of aluminum composite plans and glass is a common modern-day characteristic in architecture. For example, Dubai's "Burj Al Arab" building has a cladding for its interior and exterior comprising aluminum composite planes synthesized with glass.

Here are some the advantages of ACP cladding other than it's look.

1- It is a very cost-effective cladding material when compared to other options on the market.
2- Despite its small weight, it is an extremely hard, robust, and strong substance.
3- The application procedure is simple and straightforward. The material is easily available in standard sizes, making on-site transportation relatively straightforward.
4- It is indestructible, stain-resistant, and weather-proof.
5- They come in a variety of colors and finishes. Aluminum cladding panels could be utilized to effectively simulate the color and texture of real stone and wood.

Chemical Composition

The discovery and application of aluminum composite panels resulted from the necessity to incorporate sustainable building materials and construction systems. Architectural design incorporates sustainability principles to safeguard the surrounding environments against degradation from construction activities, Mohaney and Soni (2018). Aluminum is the primary component in aluminum composite planes. The construction and building industry consider aluminum 100% recyclable without significant loss in quality and quantity. This characteristic classifies aluminum as a sustainable material when utilized in architectural design, building, and construction. Additionally, its high durability index justifies its broad application in the building and construction industry, Mohaney and Soni (2018). The use of aluminum in ACP materials aims to enhance the materials' properties of solar heating, control airtightness, and have energy-efficient capacity elevations.

Aluminum composite planes have improved properties giving them more advantages over traditional construction materials. They exhibit excellent mechanical properties through their chemical and weather-resistance characteristics and lightweight property. In addition, ACP exhibits other properties that render them appropriate in modern-day architectural designs George et al. (2019). For example, they have excellent thermal and acoustic isolation properties, while their flatness, ease of shaping and rigidity justifies their applications in different building types and construction styles. These properties render aluminum composite planes cost-effective, durable, and reliable in the architectural and construction industries compared to other traditional construction materials, George et al. (2019). Furthermore, aluminum composite planes have a high recyclable potential and durability, resulting in a long life.

The longevity of its application leads to a low impact on the environment and justifies its classification as an eco-friendly construction material. The outer plate of the aluminum composite plane is more durable than the inner core and inner aluminum sheet George et al. (2019). The high durability of the outer aluminum plate makes the resulting ACP have a high performance. Additionally, the outer aluminum plate is durable to prevent frequent maintenance, lowering maintenance costs. The outer aluminum sheet is susceptible to interference from adverse weather conditions, aberrations from human activities and other forms of surface attack, George et al. (2019). As a result, the aluminum plate consists of durable material preventing frequent maintenance.

Application of ACPs

Studies associate the widespread application of aluminum composite panels due to the materials' excellent energy efficiency and low maintenance. Besides energy efficiency, aluminum composite planes find applications in buildings requiring controlled heating, air conditioning and ventilation, George et al. (2019). Ventilation systems in high-rise residential and commercial buildings consist of a divided external facade and internal wall. A division between the external facade and internal wall enables air passage leading to a flow that facilitates ventilation in the building's interior. The separation between the external facade and internal wall performs additional functions other than ventilating the building's interior. These functions include facilitating acoustic and thermal protection of the building's interior against external hot conditions, Khan et al. (2021). Due to these functions and applications of ACP, the material's external covering is critical to the design of the building. The exterior covering comprises excellent material that fosters energy conservation and ventilation while enhancing the building's structural stability and protecting against adverse weather, Khan et al. (2021). Therefore, ACPs' are effective architectural and building design cladding materials regardless of location, building shape and type of construction utilized.

Suitable application areas for aluminum composite planes are regions with high fire protection necessities. These regions require non-combustible materials utilized in the building's exterior, Khan et al. (2021). Moreover, applications of aluminum composite panels occur in high-rise residential buildings and commercial buildings exhibiting high-fire risks. Fire exit points and stairs are potential areas in commercial and high-rise residential buildings where aluminum composite panels find application. Aluminum composite panels have wide application in residential and commercial buildings due to their flexibility with several finishes, Khan et al. (2021). In addition, the materials have excellent processing and installation properties justifying their ease of application in new buildings and during refurbishments.

Safety Concerns of ACPs

Aluminum composite panels harbor fire risks due to the composition of polyethylene in their structure. HDPE (High Density Polyethylene) is a typical ACP case where fire spreads quickly due to the materials characteristic of providing adequate heat for ignition. These materials can ignite surrounding materials due to their highly flammable characteristic, Srivastava et al. (2020). Another shortcoming of using aluminum composite panels is their likelihood

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to crumble when exposed to heat (pyrolysis mechanism). Polyethylene comprises elongated hydrocarbon chains tightly packed together to form a plastic structure. The resulting structure renders the material stiff and susceptible to fire outbreaks. The aluminum component aids HDPE (type of ACP) in spreading the heat that causes ignition. Aluminum is an excellent heat conductor and absorbs maximum heat to red hot levels. These properties enable aluminum to propagate heat throughout the aluminum composite panel, Srivastava et al. (2020). It allows heat to reach layers beneath the panel's surface, leading to continuous and complete combustion.

Several architectural and construction studies have indicated insignificant safety concerns of the aluminum composite plane materials. According to study findings, aluminum composite planes do not have risks to buildings occupants' health or significant environmental consequence, Srivastava et al. (2020). The majority of alloys integrated into the manufacturing and installation of aluminum composite plans are neutral regardless of the anodizing and covering methods. Aluminum components do not negatively affect groundwater, land, and buildings' interior air, Srivastava et al. (2020). Thus, the toxicity levels of aluminum composite planes are insignificant to the building uses and surroundings. Despite several studies exonerating aluminum composite plane materials from significant toxicity levels, the process of polyethylene represents a substantial toxic level, Srivastava et al. (2020). Polyethylene has a chemical composition comprising hydrocarbons that have substantial toxicity to users and the environment. However, the toxicity levels associated with polyethylene composition depend on the atmospheric conditions and the amount of polyethylene in ACP, Srivastava et al. (2020). Architectural designs and constructions in hot areas utilize ACP materials with less polyethylene thickness, leading to low impact toxicity.

Incidents Associated with ACPs

Incidence of aluminum composite panel fire outbreaks involves Dubai's torch Tower, whose thermoplastic core material propagated heat throughout the building. Beijing's TVCC and London's Grenfell Tower were other fire instances associated with aluminum composite panels, Khan et al. (2021). In the three instances, the polyethylene panel core contributed to the spread of fire and ignition of other surrounding materials. Aluminum's excellent heat and electrical conductivity property cause an increase in heat propagation, facilitating the combustion of layers beneath the panels. These instances triggered widespread regulation in the aluminum composite panels, particularly the thermoplastic core, Bjegovic et al. (2016). The thermoplastic core must pass a non-combustibility test for the different grades to fulfill regulatory requirements for construction.

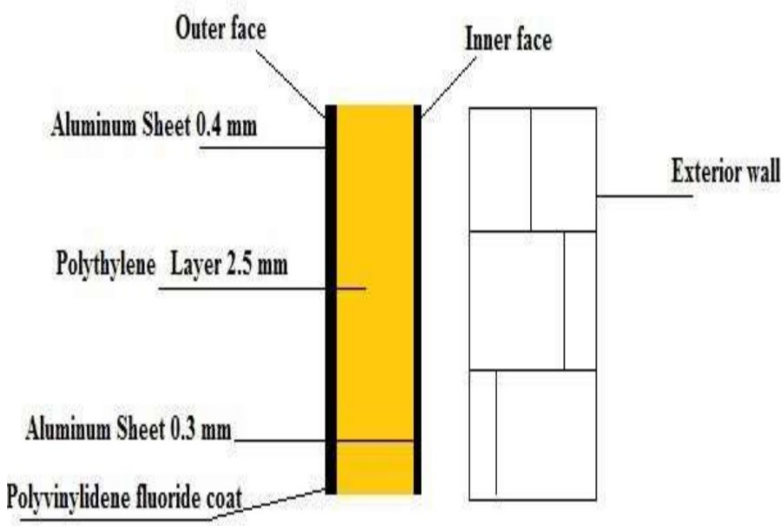

Figure 2. ACP Structure

The "North Bank building" in Sulaymaniyah presents a case of ACP application where adjustments were necessary to limit the toxicity levels of polyethylene. During the construction of the building, potential concerns of polyethylene toxicity levels existed. The building's location in hot climatic conditions increases the likelihood of polyethylene emitting toxic chemicals to the environment, Bjegovic et al., (2016). This toxicity situation is due to the ACP composition of polyethylene necessary adjustments. The design resorted to an ACP standard comprising less polyethylene (3mm) to reduce the potential of toxicity to the building's occupants and surrounding environment. However, the application of aluminum composite plane materials encounters resistance in specific regions worldwide.

Opponents of the material attest to its alteration to local architecture and construction style, Bjegovic et al. (2016). Instead of enhancing aesthetic appeal, ACP degrades the character of local architecture by imposing an international style on local buildings. This perception is apparent in northern Iraq, where architects and designers contest the suitability of the materials' characteristics such as form, shape, and patterns to the building's outcome.

To sum up, aluminum composite plane materials have a crucial role in the current trend of sustainability approach architecture and building industry. The resulting buildings can offer excellent performances while enhancing the integration between architectural design attributes and ecological requirements—the aluminum composite plan materials technology influences architectural forms and construction systems deployed in different geographical locations. Buildings with ACP claddings modify the original cities' fabric by inducing new construction styles and architectural designs.

3. Methods

The economy of the UAE is dependent on urban planning. Thus, the UAE has significantly focused on buildings and skyscraper development the last few decades, which dramatically increased the demands for the use of the ACP. ACPs are considered a high quality and cost-efficient material however they are very combustible and propagate rapidly. There is an alternative material that does not spread fire, but it is expensive and the reinstallation for the existing buildings will cost even more. These are proposed interventions and solutions relevant to alleviating and combating fire outbreaks in high-rise buildings. The methodologies discussed below are practical and feasible alternatives as they offer technologically-savvy alternatives that should be considered in enhancing the safety of high-rise buildings. The use of bio-inspired-retardant technology and the façade sprinkler system is relevant in limiting the propagation of fire, while the hydraulic elevator and escaping slides offer evacuation platforms for the high-rise buildings.

The bio-inspired DMA co-monomer and polymers (bio-inspired catecholic flame retardant nanocoating)

In high rise buildings, the recent advancements in the bio-inspired DMA co-monomer and polymers offer solutions to high-rise buildings as they provide alternative means of alleviating fire outbreaks and combating their spread. Nam et al. (2020) explain that this technology is informed by bio-inspired catecholic flame retardant nanocoating. The benefit of this technology is that it makes polyacrylonitrile (PAN) flame retardant. It relies on halogens and heavy metals to increase fire resistance. Thus, high-rise buildings can benefit from this technology s it offers the platform and avenue for ensuring the surfaces are integrated with polyacrylonitrile (PAN), which are flame retardant. In addition to halogens and heavy metals, other materials that help to bolster the ability of these sources to reduce their affinity to the fire include transition metals and phosphorous-organic compounds, Nam et al. (2020). As much as these solutions have been widely explored, they are costly. They are also toxic alongside related ecological issues/concerns. Nam et al. (2020) state that a green flame-retardant PAN based on bio-inspired dopamine methacrylamide (DMA) co-monomer is the most recent and effective alternative. The practical, cost-effective, and highly effective flame retardant technology can be leveraged to construct high-rise buildings.

Alongside limiting the related high-cost implications, it offers an ecological-friendly solution to inhibiting the outbreak and spread of fire. Nam et al. (2020) also mention that the synthesis of this polymer is through free radical polymerization. The process entails polymerizing AN alongside acetonide-protected dopamine meth-acrylamide (ADMA), Nam et al. (2020). The next stage of the process features the deprotection of ADMA. The DMA has a kinetic advantage which initiates cyclization. The heat generated as a result of this process can be controlled. These are features that improve these materials' ability when used in construction as they can regulate the incidence and intensity of heat at all levels and standards while also mitigating the possibility of outbreaks. PAN's improved flame-retardant performance is attributed to the formulation of the carbonaceous layer on the polymer surface, Nam et al. (2020). The DMA's effective radical scavenging capability also contributes to the ability of such surfaces to show resistance to fire outbreaks.

Therefore, the use of conventional additives is unnecessary for applying this intervention. Other features which illustrate the effectiveness of bio-inspired DMA co-monomer and polymers include the low-heat release capacity. It is a property that distinguishes these materials when used for surfaces to limit fire outbreaks, although they bolster the functional abilities of these elements. An additional property is the high limiting oxygen index. Bio-inspired DMA co-monomer and polymers can limit the spread of flames as there is limited oxidation which undermines the ability of these elements to spread fires. Cao et al., (2022) indicate that flame–retardant nano coatings improve flame retardancy of surfaces. High-rise buildings should thus leverage these components and incorporate them into the construction processes.

Façade sprinkler system

Sprinkler systems are very essential in fire extinguishment, cooling, containing, and stopping the fire from spreading. However, the use of a sprinkler system to the façade of commercial and high-rise building could compromise the full glass and luxurious look of the building. Figure 4, illustrate an external sprinkler system used to cool a tank. The external sprinkler system is a very useful application, however, for luxurious building the below external sprinkler system will not be applicable because it will make the building looks unattractive.

Figure 3. External Sprinkler system

Consequently, the sprinkler system should be places in such a way that will be invisible thus it will not compromise the façade of the building. Burj Khalifa is one of the most luxurious buildings in the whole world, and the mechanism and placement of the powder gun on its façade to shootout the fireworks from Burj Khalifa are well hidden and does not ruin the building look. Figure 5 shows the façade of Burj Khalifa with the invisible powder gun.

Figure 4. Façade of Burj Khalifa

Thus, the placement and the mechanism of installment of the gun powder of Burj Khalifa should be adopted to install an invisible external sprinkler. To install the external sprinkler system for buildings using ACP, some requirements should be planned in an effective way in the design stage such as placing a heat detector inside each panel in the ACP and directly connected to the building alarms and the external sprinkler system. Other parameters to be considered are type, size, geometry classification and volume of the water, foam, or special agent to be released. The sprinkler will be placed perpendicular to the building and the suggested type is the side-sprinklers which will allow the water to fall into the glass not away from it. Figure 6 shows an illustration of the placement of external sprinkler system.

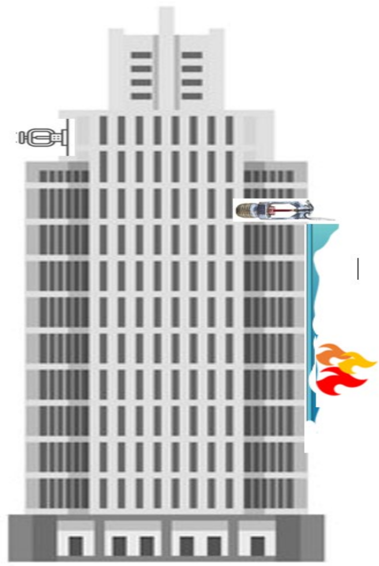

Figure 5. Illustration the proposed external sprinkler system

Hydraulic Elevator

To ensure a redundant system of evacuation in high rise buildings, it is recommended to not rely on one method of occupant evacuation in any building containing ACP, especially that the fire can easily propagate into the higher floors in minutes. Therefore, for building containing ACP material, it is recommended to use both the stairs as well as the elevators to evacuate the building occupants in case of fire, Ronchi and Nilsson, (2013). The number of required stairs is already discussed in the egress design section of the paper. Whereas for elevators, typically their use is avoided during fires for safety reasons that include electrical hazard, entrapment, and engulfment. To avoid these safety issues, the hydraulic elevator system is recommended.

The hydraulic elevator is a fire safe elevator system that operates independent of the building's electrical system. It is considered a safer rescue option when compared to motor powered rope elevators. The hydraulic elevator operates by two systems: pressurized fluid or electricity fluid system. In both systems, it is recommended that this elevator's electrical system is independent from the building to ensure safe operation in the event of fire. The hydraulic elevator requires low maintenance and is easy to incorporate into the architectural design of the building.

The correct placement of the hydraulic elevators is important to ensure it can be used in case for fire. Therefore, it is recommended to have a hydraulic elevator in the middle of the building, away from the exterior architectural designs. By this, it is ensured that if a fire propagates at any end of the buildings, occupants will be able to escape. Moreover, the hydraulic elevator will be of high benefit to occupants with special needs.

Spiral Slideway/Shunt Valve

The rapid evacuation in high-rise buildings in the event of fire outbreaks has become an integral part of safety and risk management intervention. Emergency evacuation from these tall buildings could feature the use of a spiral slide way and shunt valve, Zhang (2017). There are various factors which validate the use of this intervention. Firstly, its efficacy is associated with the use of gravity. It has been noticed that there is no use of electric power. Occupants are evacuated with ease, including mobility-impaired persons. Using the spiral slideway and shunt valve ensures that the

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evacuation integrates the clockwise and anticlockwise movements. Hence, those evacuated will not feel lightheaded or dizzy. As opposed to using a traditional staircase, the spiral slideway is faster. It also accommodates mobile-impaired individuals.

Within high-rise buildings, the benefits associated with a spiral slideway for evacuation during fire outbreaks include ease of installation. These buildings are not subjected to structural changes. It is also cost-effective when compared to bio-inspired catecholic flame retardant nanocoating. The use of bio-inspired catecholic flame retardant nanocoating has high-cost implications as it entails the additional adoption of materials to be used for the construction processes. Moreover, this evacuation avenue entails using stainless steel which is durable and can service the high-rise buildings for longer periods. Winter maintenance with the application of this alternative will also not be required. Therefore, there are no additional expenses incurred to ensure they remain operational. They remain in the state in which they were instituted, making them highly effective and operational. Any evacuation aims to ensure that individuals can depart from regions and areas with high risk. In turn, they can be allowed to vacate safe zones. The spiral slideway makes this goal with limited cost implications.

To sum up, these interventions offer an avenue through which the high-rise buildings can address the issue of fire outbreaks. In addition to promoting the swift and effective evacuation of individuals, these interventions offer a construction technology that makes it easier to advance at levels of construction with special consideration for flame retardancy and a developed suppression system that effectively suppress or extinguish the ACP fire. Each of these interventions offers a unique outlook that can be leveraged to create and sustain an ecosystem that prompts successful outcomes in risk management in case of fire outbreaks.

4. Data Collection

Aluminum composite panels have found a broad spectrum of applications in the global construction industry. These panels exist in varying compositions and components, including aluminum sheets and polymer materials. The variable composition of elements and their sizes dictates the type and rating of the aluminum composite panel. Despite wide-ranging applications in cladding buildings using aluminum composite panels, the threat of fire spread has gotten the attention of authorities worldwide and particularly in the United Arab Emirates (UAE). The risk of fire spread in buildings fitted with aluminum composite panels has necessitated revisions and banning of particular types and sizes of aluminum composite panels in building construction. Consequently, it is imperative to explore the incidence of fire risks and fire spreads associated with aluminum composite panels. Thus, an explorative method is necessary to investigate fire incidents associated with aluminum composite panels while establishing gaps in the regulatory framework.

Under its construction industry department, Dubai civil defence (2018), the UAE is cautious about the cladding systems of high-rise buildings following recent incidents of fire propagation throughout the building's exterior walls. Fire risks and incidents forced the department to conduct surveys examining the quality of materials used to make external facades, Šadauskienė et al. (2016). As a result, high rise buildings and towers in UAE underwent examination to establish the safety of balconies and facades before devising the 2018's UAE fire and life safety code. According to the new code requirements in UAE, buildings containing cladding systems whose sandwich materials have combustible materials are illegal following the ban on such materials, Šadauskienė et al. (2016).

Despite this regulatory framework in UAE and other jurisdictions worldwide, they do not meet complete fireproof requirements in construction facades. The composite aluminum panels contain auxiliary parts such as sealants and gaskets, which must adhere to safety standards, Osvaldova et al. (2021). However, these auxiliary parts contain combustible materials and retain the risk of fire ignition and spread through the ACP material. Additionally, the fire and safety code in UAE requires testing the entire facade system to ascertain adherence to safety standards for new buildings, Osvaldova et al., (2021). Testing criteria require performing test procedures on the entire system scale. This criterion involves testing the system and its components before being eligible for approval.

Authorities in UAE and other jurisdictions worldwide engage construction departments and stakeholders at the material design stage. The interaction between the authority and manufacturer aims at establishing test requirements and installers in the material to ensure compliance with the standards as enshrined in the fire and life safety code, Osvaldova et al., (2021). Consequently, the fire and life safety code contain 10-point advisory criteria outlining the testing procedure of the facade's core when testing the facade system and entire ACP panel, Osvaldova et al., (2021).

Testing and inspection require the entire ACP panel and facade system throughout the installation and maintenance stages. Furthermore, the fire and safety code outline the responsibilities of specific stakeholders, manufacturers, consultants, engineers, architects, owners, installers). It contains additional chapters guiding ACPs' design, installation, and maintenance stages, Osvaldova et al., (2021). The European testing standards and the national fire protection association of the United States provide a comprehensive framework guiding fire and safety codes for aluminum composite panels and other sandwich panels.

Fire incidents associated with composite panels
Fire incidents involving combustible external composite panels have existed in the construction industry since the inception of sandwich panels three decades ago. Industrial buildings adopted composite panels as materials whose characteristics of lightweight, cost-effectiveness and ease of installation, making them appropriate for external cladding and serving as facade systems' materials, Calabrò et al., (2021). As a result, composite panels have found wide applications in the present construction industry. The primary advantages are flexibility in my dimension size color while lightweight and inexpensive, which favors construction industry materials' requirements. Additionally, composite panels accommodate various surface finishes suitable for several architectural designs, Calabrò et al., (2021). However, despite this design and architectural advantages associated with composite panels, the risk of combustibility in commercial and residential buildings has necessitated reviewing and updating their grade quality and application in different buildings.

1991, UK's Knowsley Heights Fire
This incident involved a fire ignition and spread in a residential building characterized by external walls with thermal insulation refurbishment Calabrò et al., (2021). A case involving an external fire source ignited the building's external cladding system spreading rapidly throughout its face. The incident sparked concerns about the external wall cladding system triggering the introduction of horizontal cavity barriers on the buildings' floors.

Scotland's Garnock Fire of 1999
The fire outbreak in the 14-floor building involved fire spreading through its external cladding system. Its effects spearheaded the devising and implementation of building regulations that enforce using materials resistant to fire spread in Scotland in 2015 Calabrò et al., (2021). But unfortunately, it caused one death and injured four people.

2009's Television Cultural Center Fire in China
Investigations into the fire incident revealed its source as the fireworks on the building's roof. The building's cladding materials consisted of metal panels and strips of titanium zinc alloy at its southern facade, while the northern facade consisted of glass curtain walls on the façade, Badam (2017). Fireworks generated sparks at the roof of the building that penetrated through cavities of metal panels igniting combustible materials used for insulation. The properties of metallic panels for the building contained extruded polystyrene (XPS foam) and EPDM rubber as waterproof material, Badam (2017). Facades provided passages for the downward flowing of burning and melting XPS droplets. It took the Tower less than 20 minutes for a full-blown engulfment supported by strong winds. An examination of the fire case revealed the extensive highly combustible materials in the cavities without sectional breaks as the primary cause of the fire Badam (2017). It resulted in the death of a firefighter while several civilians suffered injuries and wounds.

Shanghai's Apartment Fire in 2010
This fire incident associated with composite panels was catastrophic due to the number of casualties and deaths. It resulted in 58 casualties, with 71 people suffering injuries. The fire at the residential building took place when undergoing refurbishment (renovating external walls) of the insulation and cladding system using polyurethane (PU) foa,m Badam (2017). Bamboo and wood were other materials utilized for the scaffolding of the building. Since the insulation materials were highly flammable, sparks ignited from welding works on the building's 10th/9th floor triggered the ignition. The fire spread in the external walls rapidly due to the flammable materials and excellent air supply, Badam (2017). The fire spread to adjacent buildings and several apartment rooms with automatic sprinklers equipped up to the 4th floor, proving ineffective.

The UAE's 2012 Tecom Building Fire in Dubai
The fire incident was destructive since it damaged nine-building floors and injured two people. Moreover, the incident injured bystanders and damaged five vehicles in the vicinity. Investigations associated the fire propagation in the building with its cladding system, Tech Talk. The cladding systems contained aluminium composite panels containing

a combustible material (polyethylene) at the core. The fire ignition point was burning debris consisting of sweets and twisted metal rods.

Australia's Lacrosse Building in 2014

The incident involved a fire outbreak and the destruction of a 23-storey building in Melbourne, Australia. Investigations into the incident established the cause as a discarded cigarette on the 6th floor spreading wood-made table, Tech Talk. The fire spread rapidly outwards after igniting the cladding system of the external walls and engulfed floors upside of the building. Composite panels used in the building's cladding system contributed to the rapid-fire spreading, Tech Talk. The composite panels contained a polyethylene material whose role in the fire spread was immense and caused the burning of the external and internal parts of the building, Tech Talk. Despite the failure of alarming systems and requiring floor to floor alerting of occupants of total evacuation, no severe injuries and casualties emerged from the incident.

Dubai's Torch Tower incident in 2015

The cause of the fire incident on the 79-floor building was a discarded shisha coal on the 50th-floor balcony. This incident was among several skyscraper fire incidents between 2015 and 2017 ("Tech Talk, Volume 20," n.d.). Torch Tower's fire entailed burning over 40 floors on one side and exhibiting the falling of massive combusting materials. In addition, it involved high-level fire on higher floors engulfing floors beneath by triggering secondary fires, Tech Talk. Composite panels supported the secondary fire incidents and contributed to several floors' massive burning and engulfing.

UK's Grenfell Tower Incident in 2017

The incident involved the engulfing of a 24-storey building in London, causing the death of 80 people. The Grenfell Tower and Shanghai's apartment incidents of 2010 were destructive fire incidents associated with composite panels. They contributed to revising standards dictating building materials choice on its interior and exterior walls, Chen et al. (2019). Grenfell Tower had undergone refurbishments entailing ventilation, heating and air conditioner systems while installing rain screens, windows and doors and insulation made of cladding systems on the exterior walls, Chen et al. (2019). Investigations revealed a refrigerator fire on the building's 4th floor to be the fire's genesis. 4th-floor residents alerted the fire brigade immediately after the fire outbreak. The arrival of the fire brigade within the 6 minutes of information could not prevent fire from spreading throughout the building through the exterior cladding systems, Chen et al., (2019). The fire spread rapidly through the exterior cladding system, overpowering firefighters. It re-entered the building's floors and trapped several people leading to a high casualty rate.

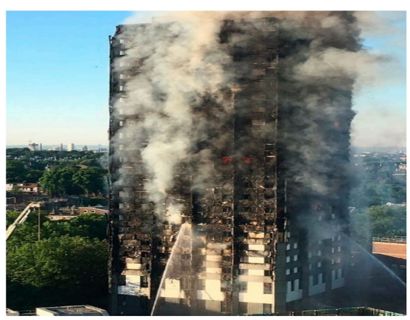

Figure 6. Picture of Grenfell Building on Fire

Fire incidents of the Grenfell Tower and UAE's skyscrapers involved rapid-fire spreading through the ACPs materials of the cladding system. These ACPs involved a sandwich of thermos-plastic material (mainly highly combustible polyethylene (PE)) in between two aluminum sheets, Health and Safety Executive. The PE core material of the ACP made them vulnerable to fire ignition and spreading throughout the building. The incidents exposed regulatory shortfalls and ACPs' vulnerability to fire incidents jeopardizing the safety of building occupants. Consequently, regulations from different jurisdictions underwent updates to raise bars on safety requirements of building materials, Health and Safety Executive. In addition, updates in regulatory frameworks focused on tightening loopholes and rectifying negligence and flaws inherent in safety protocols and building materials regulations.

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5. Results and Discussion

Compliance and enforceability have remained a challenge despite laws and regulatory frameworks in different jurisdictions offering guidance on fire safety ACPs and other external wall construction materials. Audits on buildings in countries such as Australia and Britain established buildings with banned ACPs. In Australia, a survey in NSW established 1184 buildings with ACPs without the approval of eligibility, Health and Safety Executive, (2021). An audit in Victoria State identified 87 buildings without appropriate ACPs among the audited 170 buildings. Similar data for the UK and the UAE reveals a trend of non-compliance with new legislation and existing building codes , Health and Safety Executive, (2021).

Consequently, The UAE and other jurisdictions have been sluggish in accompanying the new building codes with requirements for fire risk assessments in commercial and residential buildings. The UAE fire and life safety code and Australia's national construction code (NCC) lack clarity and consistency in assessing ACPs based combustibility levels, Health and Safety Executive, (2021). Additionally, regulations in using flammable ACPs in buildings have not accompanied updates in fire-fighting protocols. UAE has not approved and implemented the bio-inspired flame-retardant technology capable of enhancing fire safety solutions when using ACPs on external walls of buildings.

The fire and life safety building code and jurisdiction codes should contain innovative solutions and measures that encourage research and development in the building and construction industry while safeguarding properties and life. The UAE must consider economic viability before enacting policies and laws on building materials, Nishtha et al., (2020). The building and construction industry and experts should provide the criteria for UAE to establish and develop appropriate standards and guidelines. After examining expert and analyst opinions, the UAE should develop an accompanying assessment tool for evaluating underlying fire risks associated with building materials Nishtha et al. (2020). The asses sment tool should contain criteria for evaluating existing and ongoing constructions, developments and redevelopments of buildings and establish the level of compliance with safety protocols. Evaluation of the building's safety should incorporate other stakeholders, such as occupants and emergency responders, Nishtha et al., (2020). The emergency response department should offer binding opinions on material selection, quality and installation procedures.

Besides focusing on the manufacturer's point of view, an assessment tool should encompass the evaluation of residual risks related to cladding systems installation and resulting system integrity. Clients and designers should avail information on underlying residual risks after installation after selecting the appropriate quality and design of a cladding system material, Nishtha et al. (2020). The evaluation and establishment of residual risks in a building material require collection and examination of temporary loss of fire protection systems (temporary conditions occurring during construction), positioning of fire stops and vertical alignment (layout of insulation panels), flammability (adhesives specifications), Nishtha et al. (2020). In addition, regulations should guide replacements and fixings on the ACP cladding material for insulation.

Therefore, the assessment tool must encompass evaluations of repairs and maintenance to determine the quality, reliability and safety of the material used to replace broken portions of the cladding systems, Nishtha et al. (2020). Besides considering the quality of materials for fixings and replacements, fixing and replacement should have a standard design and procedure to guarantee safety.

Evaluation tools should guide clients and designers on removing previous cladding systems and protecting external walls against adverse weather before installing other cladding systems. Appropriate wallcoverings consist of temporary protective covers (LPS 1207/TS63) or scaffold sheeting (LPS 1215/TS62), Nishtha et al. (2020). Furthermore, building controls should apply whenever undertaking the re-cladding to align to best practices that comply with safety regulations. Designers, owners, and contractors must seek building permits by submitting applications for the works at the authorized local jurisdiction, Nishtha et al. (2020). The authorized local jurisdiction should consider details of the re-cladding plan and organize consultations with local rescue services, fire firefighters and responders. The local authority should consider these professional groups' opinions and comments on the work plan before inspecting the worksite, Nishtha et al. (2020). Building works commence on the site after the local authority certifies the work plan and issues a building regulation completion certificate.

Construction works are sources of fire outbreaks on the cladding systems, and the inclusion of regulations in the code is essential in eradicating the fire risk. Consequently, the local jurisdiction must conduct periodic inspections and assessments of construction works, Building Performance (2016). The code should guide the construction works on appropriate controls during cladding systems' construction works. Local authorities should inspect works to ensure implementation and maintain controls, Building Performance (2016). Construction controls should consist of preparatory works, stripping and dismantling defective and broken insulation systems and installing new ACP insulation systems.

During repairs, replacements and maintenance of cladding systems are fire risks, and controls are loopholes in the construction codes. These codes require addresses to eliminate potential sources of ignition and lower fire load in the stored construction materials, Building Performance (2016). Moreover, construction works should not occur at the worksite without precautionary requirements against fire. The codes should dictate the necessary precautionary requirements: a fire-fighting brigade, offering escape means, and installed alarm systems, Building Performance, (2016). The alarm system should guide the coordination of construction workers and building occupants on escape criteria during fire outbreaks on the cladding systems. Furthermore, the guidelines for responses and activities of building occupants and construction workers during fire outbreaks, Building Performance, (2016). Provisions for fire-fighting protocols and appliances to reach the fire points at the construction site. Accessibility of fire-fighting appliances and safe evacuation routes for occupants and construction workers is essential for preparation for fire outbreaks at the construction site.

5.1 Proposed Improvements

Authorities and stakeholders should implement guides and requirements compelling manufacturers and owners to use non-combustible materials for building insulation systems. Possible non-combustible materials include stone wool and glass elements, Building Performance, (2016). In addition, the grade quality for cladding materials should be high (preferably Euro Class A1 and A2 rated panels). Consequently, jurisdictions should develop task forces to enforce, approve and list materials for building cladding and insulation, Building Performance, (2016). The task forces should adopt three approaches when undertaking their duties:

- Approving factory manuals for producing appropriate ACPs for insulation and cladding purposes.
- Provide certification for building materials, manufacturers, and buildings as enforceability for appropriate ACP materials.
- The task force should oversee the manufacturing, installation, maintenance, and inspection of the ACP material to ensure compliance with quality and implementation procedures.

Jurisdictions should assess existing buildings with insulation and cladding systems (applying ACPs) to establish their fire risk levels, Building Performance, (2016). Assessment should involve gathering information on the quality, approval status, and non-combustibility capabilities of the ACP material. Buildings in jurisdictions and particularly UAE, that fail the non-combustibility approval for the ACP cladding materials should undergo:

- Removal and replacement of the combustible materials with non-combustible materials under the owner's cost.
- Upon approval claims, the building owners should submit cladding systems' ACP samples for fire testing, Building Performance, (2016). Testing should adopt the ANSI fire testing and fire propagation method. The task force (ARC) should recommend appropriate actions after receiving test results for the ACP cladding materials.

Authorities should implement comprehensive loss control strategies in buildings whose removal and replacement of combustible materials is gradual due to their size and nature, Building Performance, (2016). Loss control strategies for these buildings consist of:

- Penetration into the ACP should take cautionary steps to avoid potential fire risks. Fire stopping is the ultimate protection requirement when penetrating the ACP.
- Limit external fire sources near the buildings. These limitations prevent exposing ACP cladding systems to external fires from yard storage, electrical appliances and equipment, automobiles, and heating equipment, Building Performance, (2016).
- Implement and oversee behavior change for the buildings' occupants. Behavior change for building occupants involves handling household equipment and power appliances and controlling social behaviors (smoking and housekeeping).
- Inspection and prompt repairing of damages and protrusions on the ACP of the insulation claddings.

6. Conclusion

Incidents of the Torch Tower (UAE), Grenfell Tower (UK) and others trigger the urge to review the existing regulatory framework in UAE's ACP materials and the fundamental safety requirements of the building and construction industry. A specific focus on the external facade system and ACP insulation is necessary for the UAE material requirements. The nature of fire spread with ACP cladding materials containing combustible core materials raises concern over the safety of building occupants and firefighters. Consequently, the UAE should implement new regulations in the fire and life safety code of 2018 to control ACP production quality and undertake tests and inspections during installation and maintenance. Focus on local and international manufacturers, and third-party certification is essential to enforce compliance and ensure reliability. Authorities should adopt a consistent certification criterion for local and international manufacturers to eliminate possible loopholes for non-compliance.

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Biography (12 font)

Saed Talib is Amer is an Assistant Professor at Khalifa University. His research focuses on computer integrated manufacturing and robot-controlled nondestructive testing. Dr. Amer also worked on sustainability metrics research and systematic measures to enforce engineering sustainability education. His previous work included seat comfort analyses for Boeing aircrafts and robotics solutions for Unexploded Ordnance (UXO) remediation. Finally, Dr. Amer worked on simulation solutions for hybrid renewable energy research. Dr Amer earned his Doctor of Philosophy in Computer and Information Systems Engineering with a concentration on Computer Integrated Manufacturing Systems in August 2012 from Tennessee State University, USA.

Amal Almarzooqi is currently enrolled in Master of Engineering in Health, Safety and Environment Engineering program (MEng in HSE Engineering) at Khalifa university as well. Amal has a very wide and rich knowledge of HSE and ergonomics and human factors, she has been chosen to present and publish a paper in AHFE2022 that will be held in New York in July 2022, the paper title is Toxic Work Environment, and it has been accepted and submitted. She has a lot of volunteering community hours in the civil engineering college at the university.

She is a civil engineer who graduated from Khalifa University with applied science and engineering in January 2020. Khalifa University has become the first and only university in the UAE to be placed among the top 200 universities in the world. She participated in solar decathlon 2020 for a sustainable critical house and greenhouse construction that was displayed in EXPO 2020 in Dubai, and this was the graduation project for her bachelor's degree. She published a paper about (Indoor Air quality in Abu Dhabi2018) and it was a collaboration with Abu Dhabi environment agency . The civil engineering background that she has includes the following fields: Geotechnical & Foundation Engineering, Concrete & Material & steel, Engineering management, Project control & construction management, Structural engineering, Wastewater engineering, Air pollution and environmental engineering, and Geology science.

Arwa Alzubaidi is a student in Khalifa university currently undergoing the Master of Engineering in Health, Safety and Environment program. Arwa has graduated with a degree in B.E (hons) in Chemical and Materials Engineering from the University of Auckland in 2016. She focused her graduate project on studying leeb hardness testing and material failing characteristics. She has then enhanced her practical skills by working as an HSE engineer in the heavy metal industry, which enhanced her knowledge and experience in HSE.

Safa Alkatheeri is currently enrolled in Master of Engineering in Health, Safety and Environment at Khalifa University. She holds a Bachelor of Science Degree in Electrical and Electronics Engineering form Khalifa University. During her undergraduate journey she participated and won the Best Lighting Presentation titled " Designing device that moves using EEG signals trained by deep learning" in the Undergraduate Research Conference held in Zayed University. 2019. In addition she participated and won the First Place in IEEE Circuits and System Society Competition Over European, the Middle Eastern and African Candidates. 2019. After joining the Oil and Gas field as an Electrical Engineer, HSE was one of the areas that grabbed her attention, including the Fire Protection Engineering course. As a result, her primary research interests are in fire incidents, causes, losses and proposing mitigation plans.

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