



# Development of Fire-Resistant Composite Materials Using Advanced Fire Retardant Fillers

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**Abstract**— This paper explores the development of fire-resistant composite materials, focusing on their application in electrical systems. Incorporating fire retardant fillers aims to enhance fire safety without compromising mechanical and electrical properties critical for functionality. The study begins with an overview of the challenges posed by conventional composite materials in ensuring fire safety, particularly in electrical contexts where fire risks can have severe consequences. Compliance with stringent standards and regulations necessitates materials capable of withstanding high temperatures while minimizing flame propagation and smoke generation, thereby safeguarding equipment and personnel. To address these challenges, the research investigates the integration of fire retardant fillers into composite matrices. Materials like alumina trihydrate (ATH), magnesium hydroxide (MH), and nano clay are studied for their ability to improve fire resistance by mechanisms such as endothermic decomposition, fuel dilution, and formation of protective char layers, which delay ignition and reduce flame spread. Experimental procedures involve preparing composite samples with varying filler concentrations and polymer matrices, followed by thermal analysis (TGA, DSC) to assess thermal stability and combustion behavior. mechanical characteristics such as impact resistance, flexural strength, and tensile strength are also evaluated to ensure that fire retardant fillers do not compromise structural integrity. Results indicate that composites with fire retardant fillers exhibit superior fire resistance compared to unfilled polymers. Thermogravimetric analysis shows higher onset temperatures and reduced mass loss rates during decomposition, indicating improved thermal stability. Cone calorimetry tests reveal reduced rates of total and peak heat emission, suggesting reduced flammability and enhanced fire safety performance. The creation of

composite materials that withstand fire while utilizing fire retardant fillers presents a promising strategy for enhancing fire safety in electrical applications. The study underscores the importance of selecting appropriate fillers and optimizing their concentrations to achieve a balance between fire resistance, mechanical properties, and electrical insulation. Future research should explore new filler materials, refine manufacturing techniques, and assess long-term durability under operational conditions to advance fire-resistant composites for electrical applications further.

**Keywords**— Development, Fire-resistant, Composite Material, Fire Retardant Filler, Electrical Application

## I. INTRODUCTION

The Editorial Board of Carbon has proposed a detailed classification system for graphene structures, categorizing them based on how many graphene layers they have. This classification includes subgroups such as bi-layer, tri-layer, few-layer, and multilayer, with ten or more layers of Materials containing graphene. Structures with more than ten graphene layers are termed graphemic materials. The exceptional properties of graphene materials make it crucial to develop methods for producing both graphene and graphemic materials on a large scale, particularly through the oxidation and exfoliation of natural graphite [1]. A diverse array of materials made up of several graphene layers, arranged in various ways, also exhibit exceptional and useful properties, resulting in numerous potential applications. Graphene and graphene-based Materials can be added to polymer systems as fillers in the form of nanoflakes with varying numbers of graphene layers, which makes it easier to create new

reinforced composites from polymers. Both the educational and industrial sectors have expressed a great deal of interest in the search for polymer nanocomposites that are electrical and thermally conductive and frequently have enhanced mechanical strength. These materials are propelling progress in contemporary technologies, encompassing electrostatic dissipative materials used in electronics, automotive, aviation, and spacecraft industries. Additionally, they serve a crucial role in light-emitting devices, batteries, catalysis, sensors, electrochemical displays, and more. Graphene-filled epoxy composites are promising for radiation and electromagnetic shielding, and for applications needing coatings that resist corrosion and shrinking. Additionally, they improve mechanical and functional qualities like barrier qualities rigidity, and conductivity. Recently, there has been considerable interest in electrical conductivity fillers for potential uses in

conducting polymers and related materials. The electrical conductivity of polymer composites is significantly affected by the type, size, shape, and concentration of fillers. Additionally, the spatial arrangement and orientation of these fillers are crucial factors [2]. Common fillers include metal particles and metallic oxides, but these often have spherical shapes, leading to high percolation thresholds that hinder their extensive use in large-scale applications. Graphite, on the other hand, features a flake-like structure that provides high electrical conductivity and a large specific surface area, making it ideal for creating multifunctional polymer composites for various industrial uses. Researchers have developed artificial nacre-like composite films by using Cellulose with functionalized boron nitride nanosheets (f-BNNSs) nano fibers (CNFs) arranged in an such as seat backs, parcel shelves and door trims, building and construction (for structural

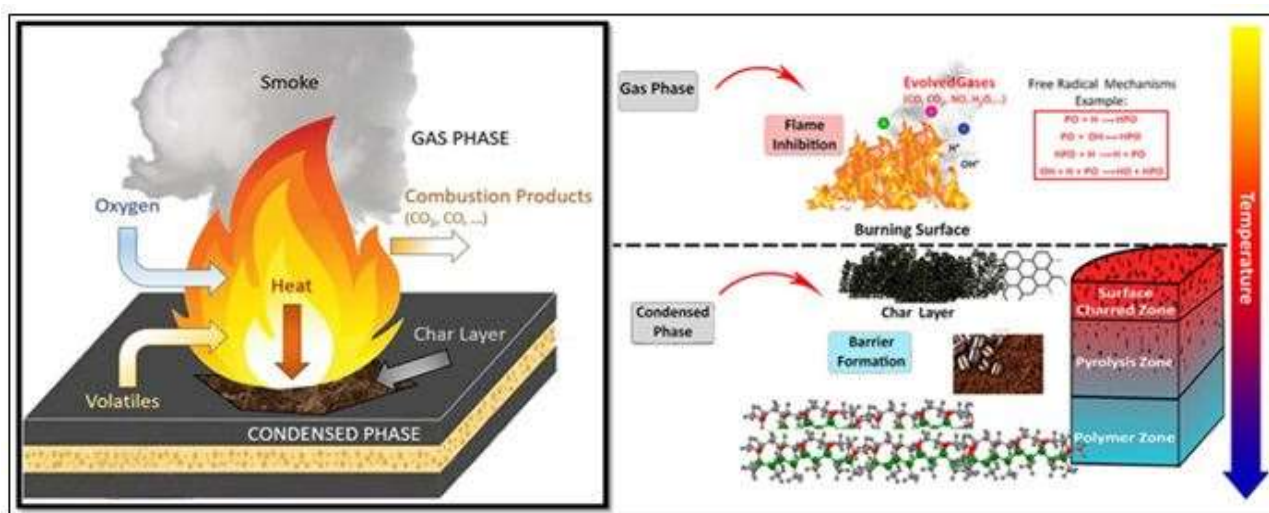


Figure 1: Fire retardants mechanisms in composites [3]

orderly structure by means of filtration assisted by vacuum. The film containing 70% f-BNNSs by weight not only shows outstanding in-plane thermal conductivity (TC) of 30.25 W m<sup>-1</sup> K<sup>-1</sup> in addition to its flexibility. In contexts where effective thermal management is needed, it's vital to uphold high thermal conductivity and consistent heat transfer rates. This ensures devices can operate within safe temperature ranges despite sudden heat shocks or changes in ambient temperature. However, polymer-based thermal conductive composites encounter notable hurdles such as Because of their intrinsic temperature sensitivity and insufficient flame retardancy, they have unstable thermal conductivity and pose a fire risk. Developing thermal conductive films that are both flexible and fire-resistant while maintaining high in-plane thermal conductivity is a significant challenge. Bio-based composites are increasingly used in various industries, including automotive (for components elements like formwork and facades), and aerospace. These composites often incorporate fibers like sisal or bamboo, providing durability in applications such as tanks and roofing. Despite differences in their raw material sources,

Petrochemicals and biopolymers are both types of organic hydrocarbons. share similar flammability characteristics [3]. Polymer combustion during fires generates intense heat energy and releases smoke containing fine particles of soot, ash, and gases, posing significant environmental and health risks. Crops are prone to catching fire easily. However, when reinforced with certain agents, they gain some protection because of a polymer framework, it is resistant to heat and fire. With bio-composite frameworks where bio-based polymers and reinforcing agents are combined, the characteristics of the polymers determine their ability to withstand heat and resist fire. Therefore, the polymers used as matrices need to demonstrate strong resistance to thermal collapse between 150 and 200 degrees Celsius for extended periods, maintain their structural integrity when briefly exposed to temperatures around 400 °C, and exhibit low combustibility. This includes having a high ignition temperature, longer time to ignite, higher limiting oxygen index, and thermal collapse between 150 and 200 degrees Celsius Techniques to reduce the flammability of petrochemical-based polymers

have been established and are continuously evolving, with similar strategies being adapted for bio-composites [4].

## II. LITERATURE REVIEW

Shahari et.al (2021) identified Addition of 20% geo polymer in glass fiber reinforced epoxy composite improved from Time to Ignition. Wen Zhang et.al (2022) a systematic review of available lightweight materials to produce next generation automobiles is provided, including light alloys, high-strength steels, composites, and advanced materials Anuradha Biswal et al. (2023) emphasize the reinforcement of fibers, nanomaterials, and relevant fillers in the production of composites to enhance mechanical, erosion, thermal, rheological, and barrier properties. These composites are categorized as carbon-based, polymer-based, metal, ceramic, and nanocomposites. The study highlights the effectiveness and functionality of these advanced materials, advocating for their adoption to replace outdated materials and improve overall performance. Adil Wazeer et al. (2023) discussed the use of composites in EVs and automobiles, emphasizing that composites can reduce vehicle weight, improve aerodynamic properties, and lower fuel consumption in the automotive sector. Xiaohui et al. (2020) discovered that adding 5% Polyamine polyphenyl silsesquioxane to epoxy resin increases the residual char percentage from 8.27% to 15.67% and decreases the maximum decomposition temperature ( $T_{max}$ ) from 382.6°C to 376.2°C. Suriani et al. (2021) found that adding 35% Arenga Pinnata fiber to epoxy resin, along with 5% polyester yarn and 5% magnesium hydroxide, resulted in composite materials with an average burning rate of 13.25 mm/min, a tensile strength of 9.694 N/mm<sup>2</sup>, and a tensile modulus of 145.416 MPa. The elastic modulus of the specimens decreased linearly with increasing Arenga Pinnata fiber content, and mechanical properties declined after reaching 50% fiber loading. The addition of magnesium hydroxide improved flame retardancy in hybrid composites containing 0% and 35% Arenga Pinnata fiber. Suriani et al. (2021) found that incorporating 20% oil palm empty fruit bunches (OPEFB) fiber into PET yarn (5%) reinforced epoxy composites, along with 5% magnesium hydroxide fire retardant material, resulted in the lowest average burning rate of 11.47 mm/min. In contrast, PET yarn (5%) reinforced epoxy composites with the same fire retardant material exhibited an average burning rate of 22.15 mm/min. Suriani et al. (2021) observed that the addition of Exolit AP750 fire retardant in epoxy composites reduced the LOI value from 26.3% to 23.2%, increased the time to ignition from 40 to 46 seconds, and did not significantly alter the peak heat release rate, which remained around 950 kW/m<sup>2</sup>. Zhu-Bao et al. (2021) found that adding 3.4% zeolitic imidazolate framework-67 to epoxy resin containing 14.1% 4,4'-Diaminodiphenylmethane increased the tensile strength, flexural strength, and strain-to-failure from 53.6 MPa, 55.3 MPa, and 5.5% to 63.8 MPa, 79.2 MPa, and 7.1%, respectively, compared to the addition of 3.4% ammonium polyphosphate in the same epoxy resin formulation with 14.1% 4,4'-Diaminodiphenylmethane.

Additionally, the addition of 3.4% zeolitic imidazolate framework-67 increased the time to ignition, reduced the fire growth rate, and lowered the total smoke production from 57 kW/m<sup>2</sup>, 6.6 kW/m<sup>2</sup>·s, and 31 m<sup>2</sup> to 43 W/m<sup>2</sup>, 1.1 kW/m<sup>2</sup>·s, and 27 m<sup>2</sup>, respectively. Wei Liu et al. (2021) found that adding 9% Ammonium polyphosphate and 1% low-melting phosphate (LMP) glasses to epoxy resin improved total heat release (80 MJ/kg), peak heat release rate (598 kW/m<sup>2</sup>), and Limiting Oxygen Index (LOI) (30%) compared to epoxy resin alone, which exhibited total heat release of 138 MJ/kg, peak heat release rate of 1087 kW/m<sup>2</sup>, and LOI of 23.6%. Fadime et al. (2020) observed that the addition of 12% zinc borate to glass fiber-reinforced epoxy composites resulted in a peak heat release rate of 516 kW/m<sup>2</sup>, total heat release of 325 MJ/kg, and time to ignition of 16 seconds. In comparison, glass fiber-reinforced epoxy composites without zinc borate exhibited a peak heat release rate of 587 kW/m<sup>2</sup>, total heat release of 401 MJ/kg, and time to ignition of 13 seconds. Chia-Hsuan et al. (2021) observed that the addition of 30% melamine formaldehyde (MF) resin to unmodified Scots pine resulted in improvements compared to unmodified Scots pine alone: a decreased Time to Ignition (86s vs. 96s), reduced Peak Heat Release Rate (457.9 kW/m<sup>2</sup> vs. 598.4 kW/m<sup>2</sup>), increased Total Heat Release (98 MJ/kg vs. 85 MJ/kg), and higher Limiting Oxygen Index (LOI) (49.9% vs. 25.1%). Akos et al. (2021) found that incorporating 15% phosphorus (P) and 48% ammonium polyphosphate (APP) into gel coat epoxy resin significantly enhanced several fire performance metrics: Time to Ignition increased to 85 seconds from 21 seconds, Peak Heat Release Rate decreased to 129 kW/m<sup>2</sup> from 627 kW/m<sup>2</sup>, Total Heat Release decreased to 39.3 MJ/kg from 90.5 MJ/kg, and Time to Peak Heat Release Rate extended to 945 seconds from 138 seconds. Asanka et al. (2021) found that incorporating 4% hybrid polymer brushes grafting graphene oxide into epoxy composites resulted in improved fire safety properties, with a higher Limiting Oxygen Index (LOI) at 31%, reduced Heat Release Rate (HRR) at 376.9 W g<sup>-1</sup>, and Total Heat Release (THR) at 20.5 kJ g<sup>-1</sup>, compared to the epoxy composite's LOI of 23.9%, HRR of 515.8 W g<sup>-1</sup>, and THR of 23.5 kJ g<sup>-1</sup>. Asanka et al. (2021) observed that the addition of 75 grams of ammonium polyphosphate (APP) to epoxy resins reduced the peak heat release rate to 173 kW/m<sup>2</sup> and the total heat release to 127 MJ/kg. Similarly, the addition of 75 grams of aluminum hydroxide (ATH) in epoxy resins decreased the peak heat release rate to 527 kW/m<sup>2</sup> and the total heat release to 162 MJ/kg compared to epoxy resins with a peak heat release rate of 558 kW/m<sup>2</sup> and total heat release of 185 MJ/kg.

## III. FIRE-RESISTANT COMPOSITE MATERIAL

An important concern when employing bio composites involves the flammability of their primary components: the binder and the filler. Adding a flame retardant must ensure it does not compromise the bond between the fiber and the matrix. The primary difficulty lies in developing a composite that is both fire-resistant and able to maintain its mechanical properties. Rather than utilizing organic matrix

materials, inorganic matrices offer the potential to increase resistance to flames. Wood composites with an inorganic basis utilize mineral blends as their binding agents. Examples of inorganic binding Portland cement and gypsum are examples of systems. known for their excellent resistance to fire and insects. However, these systems have a limitation in their ability to incorporate sawdust or fibers [5]. A newer type of inorganic binder is potassium aluminosilicate, derived from natural materials and considered eco-friendly. The addition of fiber systems concrete, such as steel fibers, basalt cloth, or polypropylene (PP) fibers, can lower internal evaporation pressure and stop cracks brought on by high heat loads. In particular, steel fibers are quite good at stopping the spread of microcracks in concrete that has been subjected to high temperatures. Additionally, polypropylene (PP) fibers play a crucial role in mitigating internal pressure within high-strength concrete by melting at elevated temperatures, thereby forming pathways that connect internal pores. These fibers are particularly effective in reducing the explosive spalling of concrete, largely because they facilitate the formation of extra interface transition zones (ITZ) separating the cement paste from the fibers. In fire situations, structures may face significantly higher temperatures, as illustrated by the ISO 834 fire curve. Glass fiber-reinforced polymer (GFRP) composites experience notable reductions in both elastic modulus and strength under elevated temperatures. This phenomenon has prompted the development of various strategies to enhance the fire resistance of GFRP structures. One approach involves implementing a water-cooling system in GFRP tubular components, which has been experimentally proven to substantially increase their fire endurance. This indicates that enhancing the fire resistance duration of GFRP multicellular web-flange sandwich structures is a viable approach. These structures show promise for use in building floors and decking, but research on their fire endurance under load with fire-resistant panels remains scarce. It's essential to account for mechanical stresses and assess how panel thickness and type influence effectiveness, thereby identifying optimal panels for practical use [6].

TABLE I

TYPES OF FLAME RETARDANTS MATERIALS [8]

Flame Retardant Chemical Nature	Example of Flame Retardants	Working Mechanism
Metal oxides and hydroxide	Magnesium hydroxide, Aluminum trihydroxide, Ammonium polyphosphate, calcium carbonate	Heat sink
Boron based	Boric acid, borax, Zinc borate, boron phosphate	By forming the insulating layer

Halogen based	TCPA, TBPA, Polybrominated diphenyl ethers, Polybrominated biphenyl	Gas-phase
Phosphorus based	Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	Condense phase
Synergistic	P/N, Halogen/Antimony tri-oxide, Phosphorus/halogen	The presence of other compounds would increase the slowness of the flame emitted by the major compound.
Intumescent	Acid donor (ex-phosphoric acid, ammonium polyphosphate), carbonizing agent(ex-pentaerythritol), bowling agent (melamine, urea)	Both in the gas and condensed phase

Moreover, aiming to achieve a fire endurance exceeding 120 minutes is a priority for expanding their application in multistory buildings. The fire resistance of composites can be improved using several methods. These include incorporating compounds into the polymer matrix, applying flame retardant coatings, inducing intumescence on the composite surface through heat, and treating the fibers themselves. One effective technique involves adding flame retardants (FR) or fire-resistant fillers directly during the fabrication of the composite. While halogen-based flame retardants have traditionally been used, they generate considerable smoke and toxic fumes during fires by blocking the oxidation of hydrocarbons and the process that turns CO into CO<sub>2</sub>. The hydrogen chloride that results from exposure to chlorine flame retardants presents a greater toxicity risk compared to carbon monoxide. Hence, there is a critical need to create eco-friendly fire-retardant solutions for polymeric composites that can easily fit into current manufacturing methods. Ammonium polyphosphate (APP), an intumescent flame retardant devoid of halogens and mainly containing phosphorus and nitrogen, effectively boosts the fire retardancy of polymers when they burn [7].

#### IV. FIRE RETARDANT FILLER

Fire retardant fillers are distinct from conventional inert fillers used in plastics and rubbers because they provide extra capabilities. When subjected to heat, these fillers break down, releasing water or inert gases. This reaction, often fueled by an endothermic process, produces by-products that contribute to making the base polymer fire-resistant. Unlike halogen-based systems, which are widely employed but emit toxic gases when burned, the decomposition products of these fillers are generally seen as benign. They can even help to minimize smoke, thereby lowering smoke levels during combustion. Fire retardant

fillers such as hydrated aluminum and magnesium hydroxides are highly prized in industries like wire and cable insulation and electronics. These sectors place a premium on fire safety and minimal smoke output due to regulatory requirements and safety protocols. While advantageous, these fillers may be less effective than other types of flame retardants, often requiring higher quantities to meet desired fire safety standards during testing [9]. The primary distinction between aluminum and magnesium hydroxide lies in the higher temperature at which  $Mg(OH)_2$  decomposes. This leads to a more significant change in the heat capability of the unaltered filler, whereas the residue has less of an impact compared to  $Al(OH)_3$ . Moreover,  $Al(OH)_3$  releases a larger amount of water vapor, although it requires nearly the same energy for release as  $Mg(OH)_2$ . Though calcium hydroxide adds very little to the water heat capacity in the vapor phase when compared to other fillers, its higher breakdown temperature indicates that it is suitable for use with polymers that have greater thermal stability. It sounds like you're discussing the thermal decomposition characteristics of materials, particularly focusing on sesquioxide and its decomposition processes. Sesquioxides are indeed interesting due to their lower decomposition temperatures and the release of significant volatiles like water and carbon dioxide at different stages. This makes them potentially useful in applications requiring low decomposition temperatures, such as in certain polymer formulations. Fire retardant fillers differ from typical inert fillers used in plastics and rubbers due to their additional functionalities [10]. When exposed to heat, they decompose and release water or inert gases [11]. In many industrial applications, this decomposition involves an endothermic reaction, together with the creation of secondary items that enhance the fire resistance of the host polymer. Additionally, these fillers contribute to the dilution of the matrix phase and the formation of a thermally insulating oxide barrier, further bolstering their effectiveness in fire retardancy. Unlike several other types of fire retardants, like those based on halogens, the substances produced when these fillers decompose are deemed safe, as they do not release toxic gases or intensify smoke risks in fire situations. Additionally, fire retardant fillers frequently have characteristics that can diminish smoke production, thereby lowering the quantity of smoke generated by burning polymers [12]. Unlike electrical conductivity in epoxy composites with graphene derivatives, which shows percolation behavior, thermal conductivity typically does not exhibit such characteristics. Instead, thermal conductivity is influenced by a different mechanism of heat transfer compared to electrical conductivity. Heat is transported between the polymer matrix and the filler material in polymer composites. Heat in conductive materials primarily travels through charge carriers like electrons and holes, which dominate over the contribution of phonons. On the other hand, insulators and semiconductors, such as many polymers, predominantly transfer heat via phonons. Numerous investigations consistently show that thermal conductivity generally rises as graphene filler content increases, although a clear

percolation threshold is not always observed, despite some noteworthy exceptions. Without any filler, the base compound exhibits a particular RHR curve with two distinct peaks split by a plateau. The creation of the intumescent barrier is most likely responsible for the first peak, and the dissolution of this layer is indicated by the second peak. In comparison to the empty reference compound, the addition of calcium carbonate shortens the time required for complete degradation and raises the initial RHR maximum from 200 to 350 kW/m<sup>2</sup>. Talc added separately reduces the power of the first RHR peak but has no discernible effect on the second RHR peak's amplitude or breakdown time. On the other hand, employing a commercial PP-talc molecule is beneficial. The second peak's start indicates the firmness of the protecting barrier, which occurs at approximately 420 seconds. A novel by altering coir, a fire-retardant nanofiller for epoxy resin (ER) has been developed. fiber. Initially after treating the coir fiber with stannous chloride solution, it is brominated utilizing saturated bromine water [13]. To create composites, it is dried, then ground into nanoparticle-sized pieces and thoroughly combined with ER. Analysis of the brominated coir fiber using FTIR, DSC, and TG techniques indicates a bromination level of 10% by mass. Bromination lowers the coir fiber's thermal stability, but it has no detrimental effects on the composites' overall stability. The thermal, fire-retardant, and morphological properties of nanocomposites made by direct mixing are investigated in this work. The coir-epoxy nanocomposites exhibit notably improved fire retardancy, with reduced. The main results were higher limiting oxygen index and smoke density [14], [15], [18].

## V. CONCLUSIONS

The development of fire-resistant composite materials incorporating fire retardant fillers marks a significant stride towards improving safety and reliability in electrical applications. This study has explored the selection and integration of suitable fire retardant fillers into composite matrices, highlighting their effectiveness in enhancing fire resistance properties. The research underscores that careful selection of fillers based on their chemical and physical properties can effectively suppress flame propagation, reduce smoke emission, and mitigate the release of toxic gases during combustion. While some impact on mechanical properties like tensile strength may occur with filler addition, overall, these composites maintain adequate mechanical integrity for their intended electrical uses. Furthermore, the thermal stability of fire-resistant composites has been a critical focus, influencing their suitability for high-temperature environments typical in electrical systems. By optimizing composite formulations, researchers aim to achieve enhanced thermal stability without compromising performance metrics. Practically, the development of these materials offers industries such as aerospace, automotive, electronics, and construction enhanced fire safety standards. By reducing the flammability of critical components, these composites contribute significantly to safety and reliability in various technological sectors. Looking forward, future research

may explore novel filler materials, advanced processing techniques, and sustainable options to further improve fire performance and align with eco-friendly manufacturing practices. The development of composite materials that are resistant to fire and have fire retardant fillers represents a pivotal step towards safer, more reliable electrical applications, pushing the boundaries of composite material science through ongoing innovation and research.

## REFERENCES

- [1] Shahari, Shazzuan, M. Fathullah, Mohd Mustafa Al Bakri Abdullah, Z. Shayfull, Mozammel Mia, and Vertic Eridani Budi Darmawan. "Recent developments in fire retardant glass fibre reinforced epoxy composite and geopolymer as a potential fire-retardant material: A review." *Construction and Building Materials* 277 (2021): 122246.
- [2] Wen Zhang, Jun Xu, "Advanced lightweight materials for Automobiles: A review", *Materials & Design* 221 (2022) 110994, 2022.
- [3] Henri Vahabi, Fouad Laoutid, Mehrshad Mehrpouya, Mohammad Reza Saeb, Philippe Dubois, "Flame retardant polymer materials: An update and the future for 3D printing developments", *Materials Science & Engineering*, 144 (2021) 100604, 2021
- [4] Anuradha Biswal, Sarat K. Swain, "Smart composite materials for civil engineering applications", *Polymer Nanocomposite-Based Smart Materials*, 2020.
- [5] Adil Wazeer a, Apurba Das b, Chamil Abeykoon c, Arijit Sinha d, Amit Karmakar. "Composites for electric vehicles and automotive sector: A review." *Green Energy and Intelligent Transportation* 2 (2023) 100043, 2023.
- [6] Bao, Xiaohui, Fangyi Wu, and Jiangbo Wang. "Fire Retardancy and Thermal Degradation Kinetics of Epoxy Composites Containing Polyaminopropylphenylsilsesquioxane." *Journal of Macromolecular Science, Part B* 60, no. 5 (2021): 381-390, 2021.
- [7] Delli, Evangelia, Dimitrios Giliopoulos, Dimitrios N. Bikiaris, and Konstantinos Chrissafis. "Fibre length and loading impact on the properties of glass fibre reinforced polypropylene random composites." *Composite Structures* 263 (2021): 113678, 2021.
- [8] Jingjing Shen, Jianwei Liang, Xinfeng Lin, Hongjian Lin, Jing Yu and Shifang Wang, "The Flame-Retardant Mechanisms and Preparation of Polymer Composites and Their Potential Application in Construction Engineering", *Polymers*, 2022.
- [9] Suriani, M. J., Fathin Sakinah Mohd Radzi, R. A. Ilyas, Michal Petrů, S. M. Sapuan, and C. M. Ruzaidi. "Flammability, tensile, and morphological properties of oil palm empty fruit bunches fiber/pet yarn-reinforced epoxy fire retardant hybrid polymer composites." *Polymers* 13, no. 8 (2021): 1282, 2021.
- [10] Shao, Zhu-Bao, Jing Zhang, Rong-Kun Jian, Chang-Chun Sun, Xiao-Lu Li, and De-Yi Wang. "A strategy to construct multifunctional ammonium polyphosphate for epoxy resin with simultaneously high fire safety and mechanical properties." *Composites Part A: Applied Science and Manufacturing* 149 (2021): 106529, 2021.
- [11] Liu, Wei, Ye-Tang Pan, Jing Zhang, Lu Zhang, Jose Serafin Moya, Belén Cabal, and De-Yi Wang. "Low-melting phosphate glasses as flame-retardant synergists to epoxy: Barrier effects vs flame retardancy." *Polymer Degradation and Stability* 185 (2021): 109495, 2021.
- [12] Ozmen, Fadime Karaer, Mustaf Erdem Üreyen, and Ali Savaş Koparal. "Cleaner production of flame-retardant-glass reinforced epoxy resin composite for aviation and reducing smoke toxicity." *Journal of Cleaner Production* 276 (2020): 124065, 2020.
- [13] Lin, Chia-feng, Olov Karlsson, Jozef Martinka, Peter Rantuch, Edita Garskaite, George I. Mantanis, Dennis Jones, and Dick Sandberg. "Approaching highly leaching-resistant fire-retardant wood by in situ polymerization with melamine formaldehyde resin." *ACS omega* 6, no. 19 (2021): 12733-12745, 2021.
- [14] Eram Sharmin and Fahmina Zafar, "Introductory Chapter: Flame Retardants", <http://dx.doi.org/10.5772/intechopen.82783>, 2019.
- [15] Szeluga, Urszula, Sławomira Pusz, Bogumiła Kumanek, Karolina Olszowska, Anastasiia, and Barbara "Effect of graphene filler structure on electrical, thermal, mechanical, and fire retardant properties of epoxy-graphene nanocomposites-a review." *Critical Reviews in Solid State and Materials Sciences* 46, no. 2 (2021): 152-187.
- [16] Zhang, Bin, and Yujie Jiang. "Highly electrically conductive and smart fire-resistant coating." *Journal of Materials Science: Materials in Electronics* 29, no. 19 (2018): 16378-16387.
- [17] Cheng, Le, and Jiachun Feng. "Flexible and fire-resistant all-inorganic composite film with high in-plane thermal conductivity." *Chemical Engineering Journal* 398 (2020): 125633.
- [18] Sienkiewicz, Anna, and Piotr Czub. "Flame retardancy of biobased composites—research development." *Materials* 13, no. 22 (2020): 5253.
- [19] Giancaspro, James, Christos Papakonstantinou, and P. Balaguru. "Mechanical behavior of fire-resistant biocomposite." *Composites Part B: Engineering* 40, no. 3 (2009): 206-211.
- [20] Hornsby, Peter R. "Fire retardant fillers for polymers." *International Materials Reviews* 46, no. 4 (2001): 199-210.
- [21] Hull, T. Richard, Artur Witkowski, and Luke Hollingbery. "Fire retardant action of mineral fillers." *Polymer degradation and stability* 96, no. 8 (2011): 1462-1469.
- [22] Rothon, R., and P. Hornsby. "Fire retardant fillers for polymers." *Polymer green flame retardants* (2014): 289-321.
- [23] Szeluga, Urszula, Sławomira Pusz, Bogumiła Kumanek, Karolina Olszowska, Anastasiia Kobyliukh, and Barbara Trzebicka. "Effect of graphene filler structure on electrical, thermal,

mechanical, and fire retardant properties of epoxy-graphene nanocomposites-a review." *Critical Reviews in Solid State and Materials Sciences* 46, no. 2 (2021): 152-187.

- [24] Almeras, X., M. Le Bras, P. Hornsby, S. Bourbigot, Gy Marosi, S. Keszei, and F. Poutch. "Effect of fillers on the fire retardancy of intumescent polypropylene compounds." *Polymer degradation and stability* 82, no. 2 (2003): 325-331.
- [25] Sen, Akhil, and Sandeep Kumar. "Coir-fiber-based fire retardant nanofiller for epoxy composites." *Journal of thermal analysis and calorimetry* 101, no. 1 (2010): 265-271.