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Flame Retardant Polymer Nanocomposites: An Overview

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The overwhelming use of polymer as substitutes for metal, glass, wood, and ceramic has posed the challenge to develop polymer with flame retardant behavior after chemical modification and making composites for effective use of polymer in a wide range of applications. In this context, the present review article describes the advances in the preparation of flame retardant polymer nanocomposite (FPNC) along with the mechanism and properties. The evolved properties of FPNCs are discussed along with illustration and applications such as coating, sheet, and films for different applications in the light chemical composition, size confinement, and dimension alignments.

1. Introduction

Over several decades, polymeric materials have been widely employed in a range of applications consumer goods, buildings, automobiles, transportation, aeronautical devices, and molded products, due to their sustainability, stability, lightweight, and low cost.[1] However, the presence of huge carbon and hydrogen bonds in polymer makes the polymer prone to catch fire and causes serious fire hazards worldwide along with limited use of plastic in electronic and electrical devices. Therefore, it is of utmost importance to integrate flame retardancy in polymer to make it suitable for high-temperature applications along with fire safety.[2] The basic strategy adopted to develop flame retardancy is adding fillers, chemical modifications like halogenation, and making hybrid structures like blend and composite.[3] In all the above strategies of making a flame retardant polymer, making composite is more facile and promising for commercialization. Flame retardant polymeric nanocomposites have received extensive attention over the last decades because of their exceptional flame retardancy and mechanical robustness. Flame retardant polymer nanocomposite (FPNC) is used as paint for coating, processable polymer granules, and electrically conducting for use in building, automobile, textile, and electronic devices. In this regard, several findings are reported by worldwide scientists with the potential to improve existing plastic parts with several challenges like toxicity and evolution of polluting gases.[4] The significant finding of the area has been also compiled by the researchers in the review articles and books, however, the exponential increase in publication frequency needs to be updated for updated information to the common researchers. Therefore, in the context of the above development and need, the present review article describes the updated information about the basics of flame retardant polymer composites, synthesis, characterization, and significant applications in building construction, automobile, and electronic devices. The suitable scheme and illustrations are added to the subject clearly and understandable for common researchers and chemists.[5]

2. Overview of Flame Retardant Polymer Nanocomposites (FPNCs)

Flame retardant polymer nanocomposites (FPNCs) are the hybrid for polymeric materials, comprised of polymer and a filler with size in the nano range, i.e., 1–100 nm. The presence of multi-component composition has evolved several improved synergized properties for advanced applications of polymer and fillers.[6] In general polymer nanocomposites are different types and a summarized classification of polymer nanocomposites is shown in **Figure 1**.

Further, the presence of flame retardant groups like halogen and fillers is called flame retardant polymer nanocomposite and has been explored for advancing applications of polymer nanocomposite with safety from fire. The strategy adopted to develop flame retardancy is reinforcing flame retardant additives, incorporating flame retardant compounds in the polymer backbone, and adding intumescent property in the polymer matrix.[7] The incorporation of nano confinements in reinforcing agents improves mechanical strength and thermal stability along with fire resistance nature due to better dispersion and interaction with polymer matrix. For example, the use of nano clay in a matrix of nylon 66 has significantly improved the thermal stability and flame retardant properties of the pristine polymer, however, similar micro-sized polymer composites do exhibits the improved stability and flame retardancy. The other significant reason for flame retardancy in polymer nanocomposite is detoured path during the spreading of heat and thermal conductivity.[8] The use of chemically modified monomers during polymerization and copolymerization is another important strategy to develop flame retardancy in pristine and hybrid polymeric struc-

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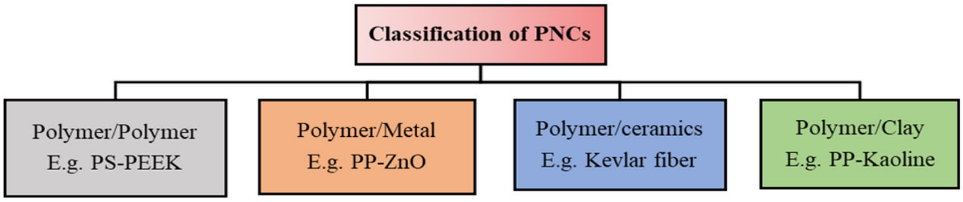

Figure 1. Classification of FPNCs.

Table 1. List of flame retardant additives, properties, and applications.

S. No.	Additives	Properties	Applications	References
1	ATH (metal based)	Heavy, non-toxic, excellent thermal and mechanical properties, reduced dripping, and better FRs.	Automobiles industries, space craft, air craft. Construction and building applications	[10]
2.	Melamine (nitrogen based)	Good thermal stability, better FRs, reduced dripping, toxic nature.	Textiles industries, resigns, electrical application, paint, and coating industries	[11]
3.	Hydroxyl carbonates (minerals based)	Good FRs, easy processable, good mechanical, and thermal properties.	Circuit breaker, construction, and building applications.	[12]
4.	Tetrabromobisphenol-A (halogen based)	Toxic, poor processability, excellent thermal, and mechanical properties.	Cables, wiring, siding, space craft, air craft, and construction and building applications.	[13]
5.	Ammonium polyphosphate	Excellent mechanical and thermal stability, toxic in nature, costly.	Print circuits board, and textiles industries.	[14]
6.	Polydimethylsiloxane (silicon based)	Anti-dripping properties, better processability.	Air purifier, circuit breaker, LED light, textiles industry, and cable.	[15]
7	Vinyl chloride	Flexible, thermal stability, toxic, poor thermal properties	Cables, wires, pipes, wirings, textiles	[16]
8	Ethylene chemical modification with HCl	Flexible, thermal stability, poor thermal properties	Packaging, cables, general goods, wires	[17]

tures. For example, the polymerization of brominated monomers like 2, 4, and 6-tribromophenyl methacrylate yield flame retardant polymers with an increase in limiting oxygen index.[9] Some of the more important flame retardant additives, monomers, and tools used to develop flame retardancy are listed in **Table 1**.

Although, the designing of flame retardancy is a very old technology as fabric, entertainment, military good, protecting curtains, and fire-resistant roofs. However, the current advancement in materials with environmental concerns along with desirable mechanical, thermal, and optical properties expanded its horizon of applications even in smart electronic devices and gadgets after using suitable methods.[18]

3. Methods of Preparation of FPNCs

Historical evidence is revealing the exploration use of different materials to develop the flame retardancy properties like hides of animals for developing fabric, contaminated asbestos, and plaster of Perris. However, the blending of alum, ferrous sulfate, stannic oxide, borax, ammonium phosphates, and borax for absorption heat to protect against the spread of fire and cooling purposes. However, the infusion of money and polymeric materials advances the innovation of different hybrid materials for use in fire safety. In general, the both Ex situ and In situ method are used for the preparation of FPNCs after employing an optimized composition and condition.[19] The in situ method is a method of preparing polymer nanocomposites, in this method the nanomaterials are originally dispersed in a liquid monomer. Furthermore, to control the agglomeration of fillers and control geometry, different surfactants are used during in situ polymerizations. The incorporation of fillers in the liquid phase during the polymerization process swells due to interactions with solvents and makes the composite lighter due to increased porosity. Ex situ methods are another major method for preparing polymer nanocomposites, in which the method disperses pre-made nanoparticles directly into the polymer to make PNCs.[20] The improved dispersion of filler was carried out after using different external energy like heat, solvent, and microwave irradiation. A summary of both methods is given in **Table 2** along with comparative features.

The incorporation of different materials advances other properties like antimicrobial and improved mechanical strength for use as a coating on furniture and medical devices. In this regard, Song et al. mechanically dispersed the copper organo-phosphate and MXene in epoxy resins as reactive functional materials in the presence of a curing agent. Thus, the prepared composite exhibits extraordinary antimicrobial properties against *E. coli* and *S. aureus* and flame retardancy. The observed flame retardancy is

Table 2. Comparison between the preparation methods of polymer nanocomposites.

S. No.	Methods		Advantages	Disadvantages	Ref.
1.	Ex-situ method	Solution casting	High production,	Solvent required, more impurity	[21]
		Melt compounding	The more pure final product, high production	High viscosity, cleaning problem	[21]
2.	In situ method	Chemical synthesis	Micro indentation, easy control	Costly and time-consuming	[22]
		Photochemical synthesis	Better compatibility, pure products.	Higher reactivity, costly, control environment required.	[23]
		Electrochemical synthesis	Synthesized in a moderate environment, i.e., at normal room temperature and pressure.	Reactions are restricted to the working electrodes' surfaces.	[24]

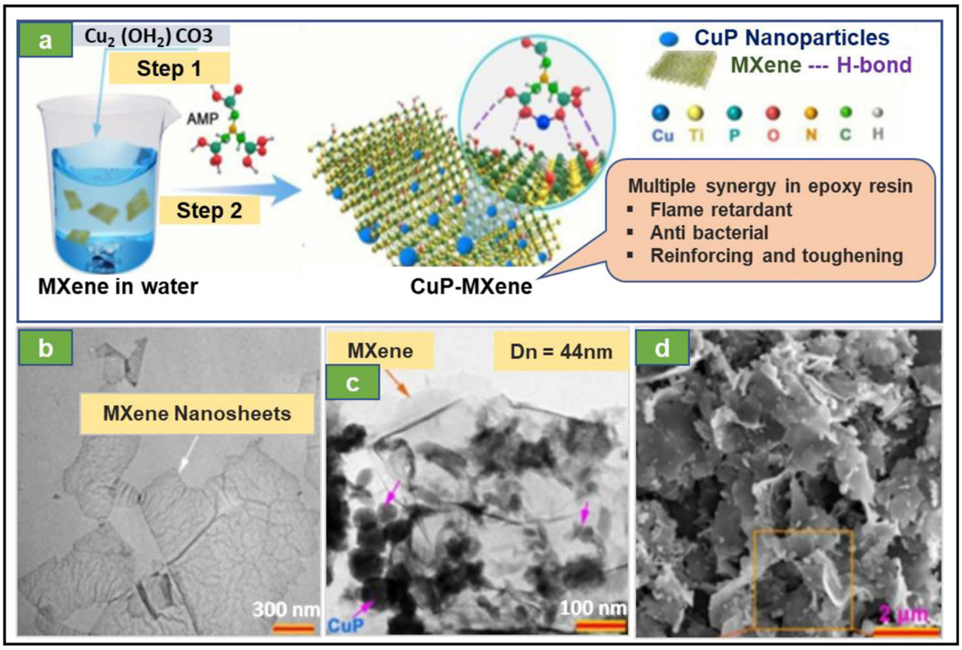

Figure 2. Design and synthesis of CuP-MXene. a) Schematic illustration for the preparation process of CuP-MXene; b) TEM image of MXene; c) TEM image of CuP-MXene; d) SEM image of CuP-MXene.

limiting oxygen index (LOI) 27.3 along with a self-extinguishing nature after ignition by 2 s. The basic preparative mechanism is shown in **Figure 2** along with morphology.[25]

4. FPNCs Characterization

Thermal analysis (DSC, DTA, TGA, TMA, and DMA), microscopes (TEM, SEM, and AFM), spectroscopy (UV-Visible, FTIR, and Raman), and X-ray diffraction techniques are used for chemical characterization of FPNCs.[26] **Table 3** shows the basic information derived from various characterization techniques.

The mechanical properties of FPNCs are determined for structural stability and sustainability to ensure the suitable applications with an ensured life span. Techniques used in this regard are universal testing machines, dynamic mechanical analyzers, impact, and surface analyzers. The weathering effect and electrical properties of FPNCs are determined by a resistivity meter and dielectric strength analyzer. Further, hybrid techniques like thermal analysis and gas chromatography, microscope, and X-ray diffraction techniques derive better information about polymer composites. For example, the simultaneous use of chromatography and mass spectroscopy was used for the identification of pyrolyzed products polyamide 6 and clay nanocomposite. The results are shown in Figure 2, which indicates the formation of a more linear compound of pyrolyzed than pristine polymer. It revealed the rapid chain scission along with interchain aminolysis as well as acidolysis of polymer in the presence of clay. The technique has been also used to study the effect of clay on the decomposition of different polymers like polystyrene, poly(styrene-*co*-acrylonitrile), acrylonitrile-butadiene-styrene and polyethylene, and polyacrylonitrile to correlate the burning behavior and its impact and gas chromatogram traces of polyamide 6 and nanocomposite are given in **Figure 3**.[39]

Assessment of flame Retardancy is most important for FPNCs before recommending its applications. The technique used for the estimation of flame retardancy is cone calorimeter, LOI mea-

Table 3. Brief applications of characterization technique.

S. No.	Methods	Techniques	Information collected	Ref.
1.	Thermal analysis	DSC	Reversible and irreversible change, characteristic energy, and transition temperatures.	[27,28]
		TGA	Thermal stability, ash content, phase change temperature	[28]
		TMA	Stress, strain, phase shift, softening temperature, state change.	[29]
		DTA	Thermochemical transition and associated energy.	[29]
2.	Microscopic techniques	SEM	Surface morphology, microstructure study, surface fracture study, contamination study, corrosion study	[30]
		TEM	Internal structure study, contamination study, inside bubbles study, texture study	[31]
		AFM	Adhesion strength, magnetic forces, mechanical properties study, surface roughness study.	[32]
3.	Spectroscopic techniques	FTIR	Functional group, sample identification, and chemical interactions.	[33]
		Raman	Chemical composition, chemical structure, and functionality.	[34]
		UV-visible	Functional groups, unsaturation, and chain structure	[35]
4.	X-ray techniques	XRD	Phase analysis, practical size analysis, crystalline study, cell dimension study.	[36]
		XRF	Chemical composition	[37]
		EDAX and WDAX	Elemental composition and mapping	[38]

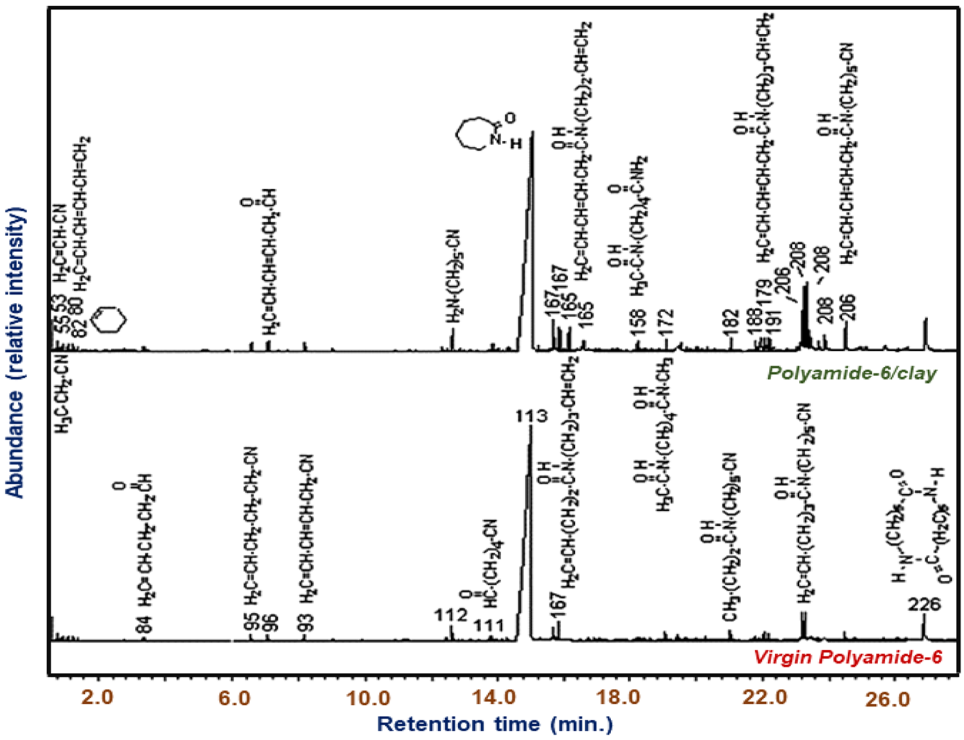

Figure 3. Gas chromatogram traces of polyamide 6 and its clay nanocomposite.

surement, and Ul-94, which are fabricated on the basis of different standards. The basic principles of techniques used for flame retardancy are shown in **Figure 4**.

The UL-94 test is an extensively used preliminary test for industry and academic research institutes, to meet industrial criteria as well as categorize polymeric materials according to their fire retardancy.[40] UL94 covers both vertical burn testing, horizontal burn testing, and testing thin films. All the techniques differ in terms of fixing of samples and sample holders, i.e., horizontally or vertically at requisite testing angles and dimensions.[41] The results qualify the polymer to grade in different categories like V0, V1, and V2 on the basis of burning time, burning rate, and dripping behavior. Cone calorimetry is an advanced method for determining a material's fire resistance in terms of the profile of heat release.[42] Its working is based on the monitoring of change in oxygen consumption rate during the combustion

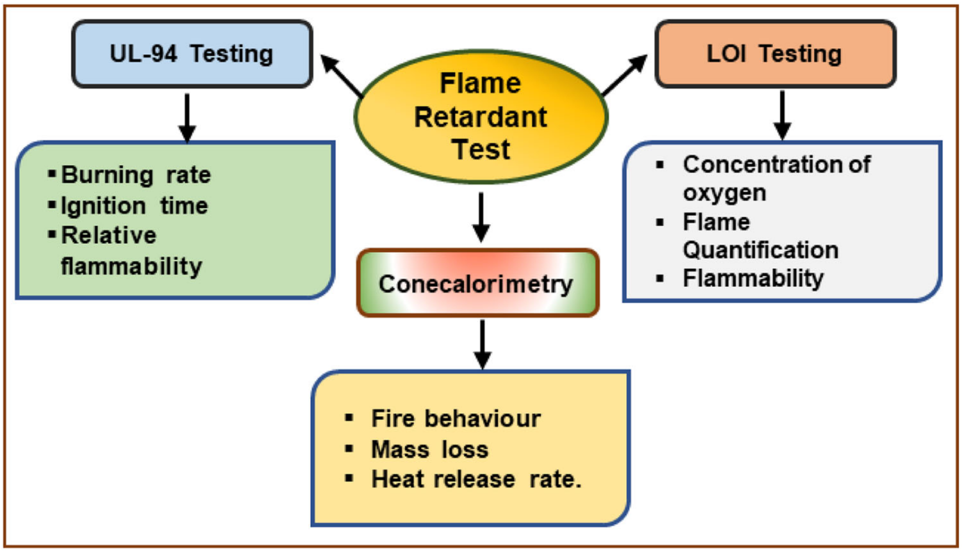

Figure 4. Showing the various techniques that are used for flame retardancy.

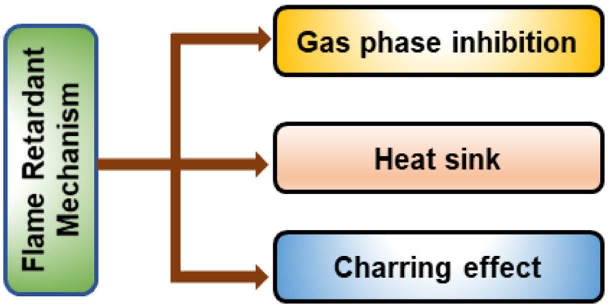

Figure 5. Showing the various flame retardancy mechanism.

of a sample after being subjected to a given heat flux. Initially, the test specimen's surface is heated with a cone-shaped heater ranging from 0 to 100 kW m^{-2} to generate. Further, the generated vapors from the heated specimen are ignited by an electrical spark igniter to combust in the exhaust hood. Further, released gas through the hood is analyzed for needful calculation of heat release profile as well as the assessment of produced dangerous gas.[43,44] LOI testing is based on the minimum oxygen concentration required to burn a polymer sample in a closed atmosphere.[45] The dimensions of the testing specimen are used with dimensions of 9.80 mm width, 162 mm length, and 1 mm thickness. The better flame retardant materials are consuming higher oxygen concentrations than the atmosphere.

5. Mechanism for Flame Retardation

The mechanistic inhibitions of FPNCs are gas phase inhibition, heat sink, and generating insulating layer or charring effect and various flame retardancy mechanisms are given in **Figure 5**.

The gas phase inhibition of combustion process is based on the addition of flame retardant addition in gases generated after heating of polymer sample. In this method vapor phase inhibiter traps the free radicals at molecular level to stop the combustion process. The halogenated flame retardants are often work on this mechanism.[46] The second important mechanism is the suppression of thermal feedback and is also known as char effect. In this method the flame retardant chemicals react with the surface of the material to generate a carbonaceous layer. This layer thermally insulates the polymer, reducing pyrolysis, and preventing the release of extra gases during fuel burning. Non-halogen systems that use phosphorous and nitrogen chemistries frequently use this approach.[47] The third mechanism exploits the cool and rehydrates the polymer after synchronizing the endothermic processes during pyrolysis. In the presence of fire, these systems use an endothermic reaction to release water molecules, which cool the polymer and dilute the combustion process. The different hydrated metal salts like aluminum tri hydroxide generates retards are works on this principles. The synergistic, additive, and antagonistic approach has been also explored in the development of effective flame-retardancy nature in polymer composites. In example use of antimony oxide along with halogen containing flame retardant increases the effective flame retardancy in polymer composite. The basic adopted strategy is formation volatile antimony oxide during heating, which inhibited the vapor phase combustibility of polymer composites.[48] Further, the endothermic release of antimony oxide is another steps to improve the effectiveness of flame retardancy after generating heat sink behavior in polymer composites.

6. Applications of FPNCs

In the era of globalization, privatization and liberalization FPNCs are used in various fields. The primary reason for using FPNCs in any application is because of their distinct properties like easy separation, physical adsorption, chemical degradation, good physical and mechanical properties, easy processable, control at atomic level, high aspect ratio, high surface area, and its availability.[1] The some major applications of FPNCs are given below in **Figure 6**.

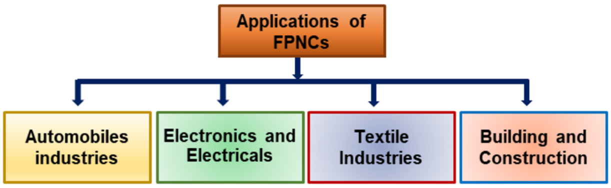

Figure 6. Showing various applications of FPNCs.

6.1. Electronic and Electrical Industries

The widespread usage of polymer components in electric devices and their components necessitate the development of various flame retardant polymer composites to protect electronic equipment from overheating, sparking, melting, and smoke.[49] The polymers serve as a backbone for the development of the electronic industry as resistive support materials in printed circuit boards and the outside cases of electronic devices such as telephones, they are also a hindrance. The integration of electrical conductivity, on the other hand, has expanded its use as active electronic components such as switches, devices, resistance, capacitors, and integrated circuits.[50] As a result, replacing traditional plastic with flame resistant polymer has significantly improved the life and effectiveness of electronic devices. For example, using flame retardant 1,3-dioxolane based polymer electrolytes improves working performance at higher operating temperatures, such as 20–50 °C and excellent cycle stability.

The integration of other properties like conductivity and responsiveness extends the applications of polymer composite in electronic devices. In an example the composite comprised of polystyrene, carbon nano tube and chemically modified silane was prepared by mechanical mixing and hot pressing in controlled atmosphere. The composite exhibits high charring effect for significant decrease in heat release rate by 33.9% due to presence of carbon nano tube along electrical conductivity and absorption capacity of electromagnetic radiation in X band region of 8.2–12.4 GH. Thus, the synergized behavior of MWCNT, modified silane, and polystyrene towards increasing the flame retardant nature has been explained in **Figure 7**.[51]

Furthermore, the active processable polymer for active components in electronic devices such as capacitors and batteries has been created for safe and extended usage by combining conductivity and flame retardancy.[52] **Table 4** shows the basic applications of various flame retardant polymers in the electrical and electronic sectors.

6.2. Textile

FRs polymers are most commonly used for the development of a variety of sophisticated textiles for personal, community, and industrial purposes. The first step in this process is to develop flame retardant fiber after using different synthetic and natural polymers such as cellulose, polyamide 6, polyamide 6:6, polyolefin, and acrylate.[61] The important used strategies are grafting, nano confinement, coating of textile fiber, and addition of char-promoting chemicals. Multifunctionality in flame retardant polymers, such as antibacterial and electrical conductivities, provides additional dimension for the usage of flame retardant fabrics. In this direction, the development of polymer based textile with metals like silver and Mxene based conductive network found its advanced applications in wearable heater due to electro and photo thermal performances. These kind of textiles are projected as potential to convert the energy involved in physical motion into open circuit voltage along with flame retardancy and antibacterial nature.[62]

Chemical modification of polymers along with inclusion of different micro particles such as silver, gold, zinc oxide, and tin oxide are among the reported procedures investigated in this respect. The generation of flame retardancy in textiles using in situ chemical surface modification is another successful technology for expanding the horizon for applications. Thus, the prepared cotton fabric exhibits the limiting oxygen value of 160 g L^{-1} (42%) with sustainability of 23.9% after 50 cycles of laundry, along with lower heat release rate.[63] Vasiljević et al. reported the insitu polymerization method for the development of flame retardant fiber of polyamide 6 and 9-10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide in an optimum concentration. The produced fiber showed high flame retardant properties along with minimal toxicity for human even in direct contact.[58] Multifunctional fiber from alginate has been prepared using wet spinning methods using 7% urushiol by weight. The functionalization and spinning mechanism has been exhibits in **Figure 8**, along with working mechanism for deactivation of microorganism and flame retardancy.[64]

Different types of applications of flame retardant polymer nano composites (FPNCs) in textiles are given in **Table 5**.

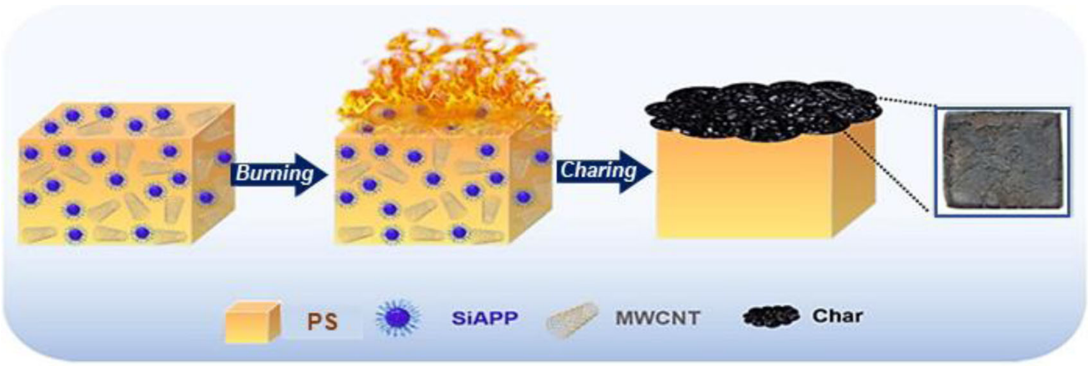

Figure 7. Schematic illustration for the flame retardant nature.

Table 4. Flame retardant polymer composites in electrical and electronics.

S. No.	Composition	Properties	Applications	Ref.
1.	P and chlorinated PE	Specific gravity, tensile strength, elongation, thermal stability	Cables and wiring siding	[52]
2.	Epoxy, polyamides, PET	Non-conductive, flame retardancy, good insulator	Print circuits board	[49]
3.	Polyacetylene, polythiophene, polyaniline	Conductivity	Air purifier LED light	[53]
4.	PVC	Thermoset, thermal stability, rigid, tensile strength	Circuit breaker	[54]
5.	Specialty polymers	Stability, longer life time, strength, rigid	Capacitors	[55]
6	Liquid phosphate and polycarbonate	High Li^+ conductivity, i.e., 4.4 mS cm^{-1}, Young's modulus, i.e., 12.4 GPa and electrochemical window	Battery	[56]
7	PU and Xenon	Self-extinguishing and reduced heat release rate.	Sensor	[57]
8	Polyacrylonitrile and graphene oxide	Self-extinguishing, exceptional charge transfer characteristics, potential difference 80 V, and current density 25 μA m^{-1}	Triboelectric nanogenerator	[58]
9	Polystyrene, ammonium polyphosphate, and reduced graphene oxide	Free radical captured matrix and 10DB shielding	Electromagnetic shielding	[59]
10	Unsaturated polyester and aluminum diethylphosphinate.	Moisture and electric insulation	Electric insulation	[60]

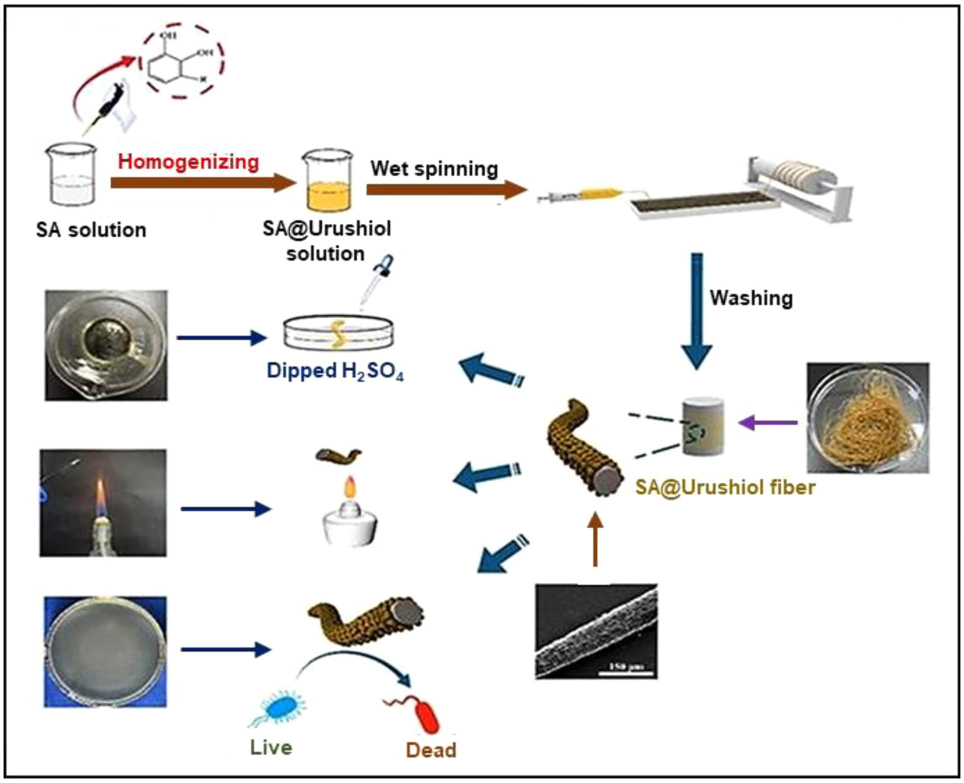

Figure 8. Shows the other important applications of flame retardant polymers in the textile and related industries.

6.3. Building and Construction

This industry uses a lot of FRs plastics to make various structural components for buildings and constructions. The important use of FR plastics in construction as concrete, asphalt, fake sealing, drainage pipe, insulation cables, coating, flooring, and adhesive due to their superior adhesion and strength-to-weight ratio.[70] Different polymer composites are employed with flame retardant qualities after optimizing properties, such as the strength optimized polymer composite mortar with appropriate adhesive

Table 5. Applications of flame retardant polymer nano composites (FPNCs) in textiles.

S. No.	Composition	Properties	Application	Ref.
1.	Polyesters, nylons, acrylic	Tearing strength, thermal stability	Yarn industries	[65]
2.	Silk fiber	Flexibility, compatible, tearing strength, UV stability	Silk cloths and Cotton clothes	[66]
3.	Natural polymers, SBR, carboxylated SBR	Flexibility, compatible, tearing strength, UV stability	Carpet backing	[67]
5.	Polyamides, cottons, polyesters	Body compatible, anti-bacterial properties, flexible	Protective clothing (undergarments)	[63]
6.	Nylons, polyester	High strength, modulus, tearing strength, water resistance, UV stability	Tents	[68]
7.	LDPE, vinyl polymers	Adhesion properties, durability, conformability, stability, UV stability, tearing strength	Banners	[69]

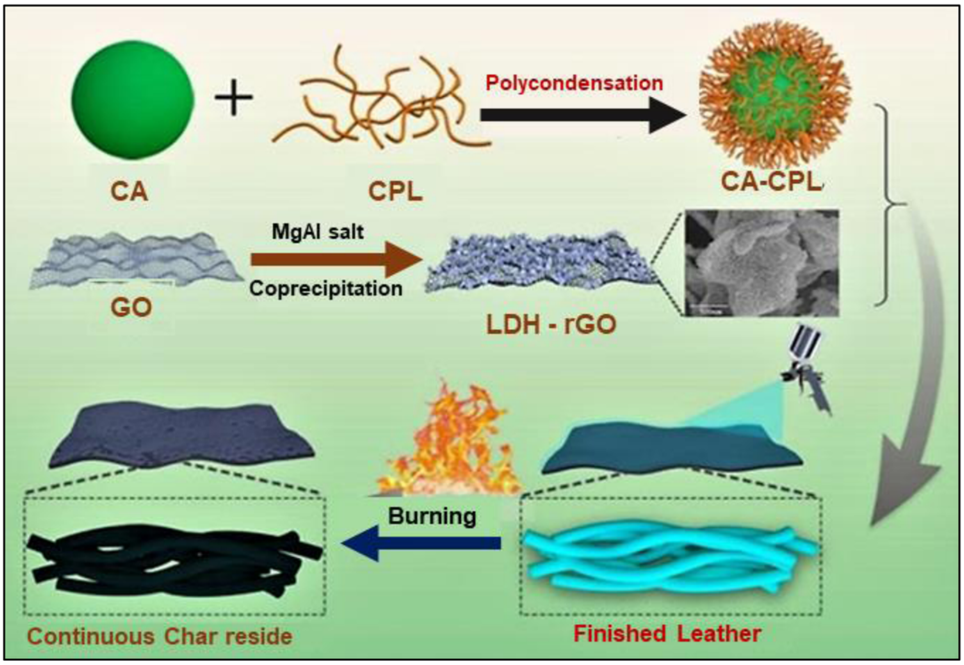

Figure 9. Synthesis and application of hetrostructured filler-based flame retardant bio-composite.

and strength.[71] Ribeiro et al. developed a flame retardant polymer epoxy composite comprising nano size dispersed alumina, as well as mechanical qualities such as flexural strength and compressive strength. Another notable advancement in smart construction is designing and manufacturing of flame retardant polymer composites to replace wood. The reinforcing of multiple fillers optimizes the hardness and strength for use in place of ordinary plastic.[72] Rocha et al. created a polyethylene composite with lignocellulosic fibers as a potential substitute for real pine wood. The HDPE composite combining sponge gourd fiber and 10% magnesium hydroxide, which demonstrated the best impact resistance and flame retardant nature with potential to replace natural wood.[20]

The use of biodegradable polymer in construction with flame resistance behavior is another essential requirement for materials scientists. In this context, An et al. has reported the hetero structured filler, i.e., layered double hydroxide-reduced graphene oxide-based bio composite of latex through precipitation and solution blending (**Figure 9**). Thus, the obtained composite exhibited 27.4% limiting oxygen index, of 27.4%, 146.18 kW m^{-2} of heat release rate and a good smoke production rate of 1.48 m^{-2} s^{-1} with potential to use for coating of vehicle and furniture. The schematic for synthesis and application of composite is shown in figure along with charring effect.[73]

The evolution of water molecules along the char generation is responsible to optimize the burning rate and flame retardancy. A flame retardant polymer–polymer composite are also optimized to reduce released hazardous and improved thermal stability.[74] **Table 6** shows the basic applications of several flame retardant polymers in architecture and construction.

Table 6. Flame retardant polymer composites in building and construction.

S. No.	Composition	Properties	Application	Ref.
1.	HDPE, PU and clay	Oxidation, hydrolysis, poor conductivity, specific heat capacity, heat resistance, air permeability	Thermal insulation for roofs, sheeting for roofs, facades, and well	[75]
2.	PMMA, PU, and PVC	Adhesion properties, water compatible, strength, durability, corrosion, degradation resistance	Floor coverings ducting	[76]
3.	PP, PVC, fillers, and heat stabilizer	UV stability, heat stability, durability, rigid, tensile strength	Pipes and wiring pipes, and gate	[77]
4.	PVA and metal oxide based filler	Flame retardancy, UV stability, strength	Panels	[78]
5.	Red phosphorous and epoxy	Thermal resistance and reduced heat release rate value by more than 55%	Glass	[79]
6.	Basalt and polyoilefines	Improved LOI and heat release	Body cover	[79]

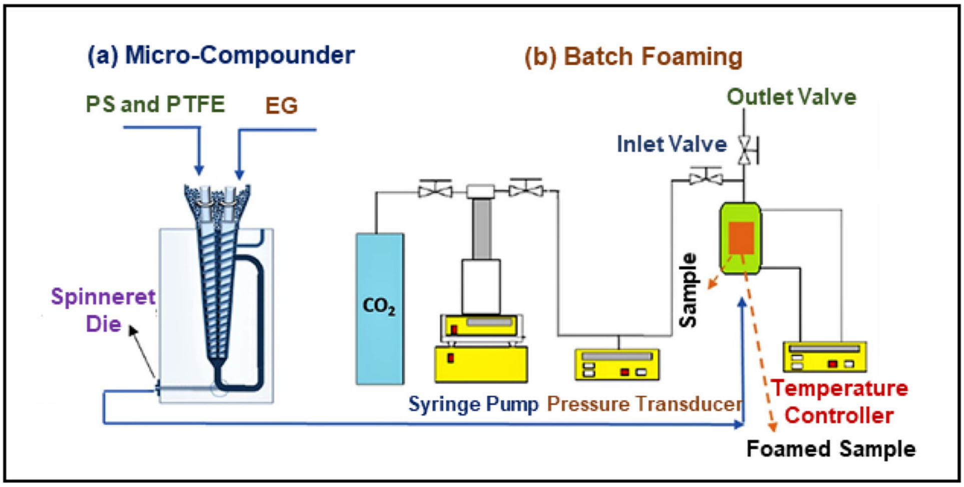

Figure 10. The preparatory tools for flame retard foam.

6.4. Automobiles

Flame retardant polymer nanocomposites are proposed to improve the manufacturing speed, environmental and thermal stability, facilitate recycling, and reduce weight of automotive parts and systems.[80,81] Although, the fire safety is main criteria for motor vehicle act for manufacturer and consumer but several fire hazard observed associated with great loss of humans and assets. In this regard, several innovations are integrated to advance the fire safety practices in automobile using different flame retardant polymer composites. The basic combustion principles like liquid fuel driven car and battery driven car demand different types of safety precautions against fire. In example, the liquid fuel car demands the use of blended thermoplastic to give more time to scape along lower burning rate and slow heat release rate. However, battery operated motors explore the FPNCs to control the blast, battery failure in limited area. However, the practice of blended fueled car like electric, liquid, and gas need more and more precautionary measures to control the fire safety. Fiber reinforced composite with flame retardant nature has potential to use for structural composite for automotive. However, FPNCs with intumescent properties are explored to reduce the temperature of part during fire accidents along with heat sink nature. The composite with cooling behavior also used as coating to control the fire damage due to heat sink effect during fire.[82] Further, the structural design flame retardant foam are other important form to use in automotive industries. In this regard, nanofibrillated polystyrene composite was reported by Park et al. in the presence of polytetrafluoroethylene and expandable graphite. The prepared foam properties are high cell density, the average cell size decreased from 103 to 10 lm, and excellent fire retarding properties along with stiffness.[83] **Figure 10** shows the preparatory tools for flame retard foam.

The other flame retardants polymer nanocomposite listed in **Table 7** along with the basic applications in the vehicle industry.

7. Conclusion

This review discusses the advances for the need and preparation of different types of flame retardants polymer nanocomposites after addition flame retardant additives and chemical modification of pristine polymers. The efficacy of different methods and

Table 7. Flame retardant polymer composites (FPNCs) in automotive industries.

S. No.	Composition	Properties	Application	Ref.
1.	PVC/PP-additives	Strong, hardness, excellent fire retardancy	Panels, carpets, flooring, seats	[84]
2.	HDPE/PP-additives	Easy processable, good mechanical	Automobiles dashboard	[82]
3.	PP-additives	Flexible, strength	Safety bags	[85]
4.	PC/PMMA-additives	Transparent, FRs properties, strength	Glass, lighting	[86]
5.	PP/HDPE-additives	Tensile strength, hardness, high MFI, good mechanical and thermal properties	Bumpers, door parts	[87]
6.	Rubber/PU-additives	Tearing strength, load bearing, tensile, flame retardancy.	Wheel and tire	[88]
7.	PP/PU/HDPE-additives	Good mechanical and thermal properties	Door handle, fuel systems	[89]

evolved properties are discussed after using suitable examples and illustrations. Further, the use of FPNC in building construction, automobiles, electrical and electronic equipment, electrical components, and textiles are discussed. Finally, the story of success and challenges has been established on the basis available literatures for researchers and entrepreneurs.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

additives and applications, flame-retardant, polymer nanocomposites

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