Flame Retardant Coatings for Plastics and Textiles

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Editorial

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The growing use of polymer-based materials in transportation, construction, electronics, and textiles presents a significant challenge due to their inherent flammability. To ensure safety and sustainability, the development of efficient, environmentally friendly flame-retardant (FR) coatings has become an active, interdisciplinary area of research. This Special Issue, entitled "Flame Retardant Coatings for Plastics and Textiles," contains ten contributions, including original research articles and reviews, which demonstrate recent advancements in surface-engineered strategies, novel composite coatings, and multifunctional materials that provide enhanced fire protection without compromising mechanical, optical, or environmental performance. The following summarizes these contributions.

An editorial review [1] opened the collection by summarizing the current state of surface modification strategies. The paper emphasized the effectiveness of sol–gel and layer-by-layer (LbL) coatings, as well as multifunctional gel coats, in minimizing heat and mass transfer when exposed to a flame or an irradiative heat flux. These approaches enable the production of thin, multifunctional coatings that preserve the substrate's properties while improving the fire behavior. This overview was complemented by a review paper focusing specifically on textile applications [2], detailing how inorganic–organic hybrid coatings derived from sol–gel chemistry and LbL deposition can provide cotton fabrics with durable flame-retardant features. The paper emphasized the role of phosphorus-, nitrogen-, and silicon-containing precursors and discussed multifunctional outcomes such as hydrophobicity, antibacterial activity, and electrical conductivity. Additionally, the review addressed the current challenges of durability in laundry cycles and the large-scale processing of coated textiles.

In their review [3], Pomázi and Toldy conducted an in-depth analysis of gelcoats as functional surface layers in composites. They described how tailored epoxy and polyester gelcoats can provide flame retardance, optimal mechanical performance, and an attractive finish. They also discussed recent innovations, such as UV-curable and in-mold gel coating methods, and addressed challenges related to additive dispersion, viscosity control, and adhesion. These findings provided a foundation for developing high-performance coatings for the transportation and construction industries.

Kovács et al. [4] conducted an experimental study comparing the performance of several phosphorus-containing formulations, including ammonium polyphosphate (APP) and resorcinol bis(diphenyl phosphate) (RDP), when applied to epoxy-based gelcoats. As evaluated through cone calorimetry tests performed at 50 kW/m^2 irradiative heat flux, the coating with the best performance, containing 15 wt.% APP, reduced the peak heat release rate by up to 89% for polypropylene substrates and by over 50% for polyurethane automotive parts. These results confirmed that surface-applied, halogen-free coatings are effective replacements for bulk flame-retardant additives and preserve mechanical integrity.

Abuhimd et al. [5] investigated the synergistic role of $MgAl_2O_4$ nanoparticles (at 2 and 4 wt.% loading) in an epoxy coating containing ethylenediamine-modified ammo-

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nium polyphosphate and a triazine-based charring agent. Incorporating the nanoparticles improved the limiting oxygen index and UL-94 rating, achieving V-0 classification. Moreover, for the coatings containing 4 wt.% of magnesium aluminate nanoparticles, cone calorimetry revealed a significant decrease in peak heat release rate (by about 77%) and total heat release (by around 70%) compared to the neat epoxy reference. This study demonstrated that inorganic nanofillers can reinforce the char layer and improve the thermal stability of intumescent formulations.

Laoutid et al. [6] developed transparent epoxy coatings incorporating aluminum hypophosphite nanoparticles ($\leq$60 nm) using a similar approach. When applied to poly(lactic acid) (PLA) sheets, these coatings significantly reduced the peak heat release rate (by around 20%, compared with the PLA sheets coated with the neat epoxy system), due to the formation of a continuous protective char. Remarkably, the coatings maintained optical transparency, opening prospects for decorative or optical-grade fire-protective applications.

Sun et al. contributed two complementary studies addressing flame-retardant coatings for thermoplastic composites. In the first paper [7], they examined intumescent flame retardant (IFR) systems in continuous glass fiber-reinforced polypropylene (PP) prepregs. Through optimizing IFR loading at 25 wt.% and incorporating high-flow PP to enhance impregnation, the authors attained a UL-94 V-0 rating while maintaining good mechanical properties. This work provided a scalable method for producing halogen-free FR composites for transportation and structural applications.

Furthermore, the authors extended this concept to sandwich structures, namely corrugated glass fiber/PP panels filled with thermally insulating materials (e.g., rock wool, polyurethane foam, and aerogel) [8]. The designed structures demonstrated enhanced heat resistance and mechanical strength. Moreover, the study identified key geometric parameters that influence heat transfer and demonstrated the feasibility of lightweight, multifunctional panels that combine structural and thermal performance.

Koštial et al. [9] experimentally evaluated various sandwich constructions made of phenolic-coated laminates with different core materials, such as Nomex®, aluminum honeycomb, and PET foam. Cone calorimetry tests revealed how core density, coating thickness, and adhesive layer affect the overall fire performance of the sandwich constructions. These results offered valuable design guidelines for sandwich panels used in railway and automotive interiors.

Maqsood and Seide [10] developed PLA/oxidized starch composites containing ammonium polyphosphate as a halogen-free intumescent system. The oxidized starch served as both a carbon source and a bio-based additive that improved melt spinnability. The resulting PLA fibers and nonwoven fabrics exhibited effective flame retardance and good mechanical properties, supporting their potential for eco-friendly textile and composite applications.

Overall, the ten papers collated in this Special Issue demonstrate the vitality of current research on flame-retardant coatings for plastics and textiles. Contributions range from fundamental studies on surface engineering and sol–gel chemistry to advanced applications of multifunctional gelcoats, nanocomposite systems, and sustainable, bio-based formulations.

The results presented here are expected to inspire further collaboration among polymer scientists, surface engineers, and industrial partners to develop safe, efficient, and sustainable FR materials for a wide variety of plastic and textile applications.

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Abbreviations

The following abbreviations are used in this manuscript:

APP	Ammonium polyphosphate
FR	Flame retardant
IFR	Intumescent flame retardant
LbL	Layer-by-Layer
PET	Poly(ethylene terephthalate)
PLA	Poly(lactic acid)
PP	Polypropylene
RDP	Resorcinol bis(diphenyl phosphate)

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