REDUCING THE FLAMMABILITY OF RECYCLED POLYETHYLENE

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Abstract. *The widespread use of recycled polyethylene in various industrial applications is significantly limited by its high flammability, which poses serious safety concerns in the construction, automotive, and electrical industries. This comprehensive review examines existing strategies and emerging technologies to reduce the flammability of recycled polyethylene by incorporating flame retardant systems. The study analyzes metal hydroxide-based approaches, swelling formulations, phosphorus-containing additives, and nanomaterial reinforcements, evaluating their mechanisms, effectiveness, and impact on mechanical properties. Metal hydroxides, such as aluminum hydroxide and magnesium hydroxide, work by endothermic decomposition, releasing water vapor that dilutes flammable gases and cools the fire zone. The swelling systems create protective carbon layers through synergistic interactions between acid sources, carbonization catalysts, and blowing agents. Future research directions include the development of biobased flame retardants, multifunctional additives that provide fire resistance and mechanical reinforcement, and improved compatibility strategies for recycled polymer matrices.*

Keywords: *recycled polyethylene, flame retardants, fire safety, polymer composites, thermal stability, sustainable materials*

Introduction. Polyethylene represents the most extensively produced thermoplastic polymer worldwide, with annual global production surpassing 100 million metric tons, generating enormous quantities of post-consumer waste that presents significant environmental management challenges [1]. The inherent flammability of polyethylene, characterized by a limiting oxygen index of approximately 17-18%, severely restricts its application in sectors requiring compliance with stringent fire safety regulations, including building construction, transportation infrastructure, electrical cable insulation, and consumer electronics [2]. This limitation becomes particularly problematic for recycled polyethylene, which already suffers from degraded mechanical properties due to thermal-oxidative damage accumulated during previous processing cycles and service life [3].

The circular economy paradigm demands efficient recycling and valorization of plastic waste streams, transforming environmental liabilities into valuable resources [4]. However, successful implementation of recycled polyethylene in fire-sensitive applications necessitates development of effective flame retardant strategies that do not further compromise already weakened mechanical performance [5]. Traditional halogenated flame retardants, while highly effective, have been largely phased out due to toxicity concerns, environmental persistence, and generation of corrosive acidic gases during combustion [6]. This regulatory landscape has accelerated research into environmentally benign alternatives including metal hydroxides, phosphorus compounds, intumescent systems, and emerging nanomaterial approaches [7].

The challenge of imparting flame retardancy to recycled polyethylene involves multiple interconnected considerations. The degraded polymer matrix exhibits reduced molecular weight, increased carbonyl group content, and altered crystallinity compared to virgin material, potentially affecting flame retardant dispersion, interfacial adhesion, and overall system performance [8]. Additionally, contamination from mixed waste streams, residual additives from previous applications, and variable feedstock composition create processing complexities that must be addressed through appropriate compatibilization and stabilization strategies [9]. Economic viability represents another critical factor, as flame retardant formulations must remain cost-competitive with virgin materials while delivering comparable performance [10].

Metal Hydroxide Flame Retardants

Aluminum hydroxide and magnesium hydroxide represent the most widely used non-halogenated flame retardants for polyethylene applications, valued for their low toxicity, minimal smoke generation, and cost-effectiveness [11]. These inorganic hydroxides function primarily through endothermic decomposition reactions occurring at elevated temperatures characteristic of polymer combustion. Aluminum hydroxide decomposes at approximately 200-220°C according to the reaction: $2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$, releasing 34.6% by weight of water vapor while absorbing 1.3 kJ/g of heat. This dual action simultaneously cools the combustion zone and dilutes flammable volatile concentrations in the gas phase. Magnesium hydroxide exhibits higher thermal stability, decomposing at 320-340°C through the reaction: $Mg(OH)_2 \rightarrow MgO + H_2O$, releasing 31% water while absorbing 1.4 kJ/g.

The higher decomposition temperature of magnesium hydroxide provides advantages for polyethylene processing, which typically occurs at 180-220°C, avoiding premature decomposition during melt compounding that can cause porosity and processing difficulties. However, achieving adequate flame retardancy with metal hydroxides generally requires high loading levels of 40-65% by weight, which significantly impacts mechanical properties including tensile strength, elongation at break, and impact resistance. The large volume fraction of rigid inorganic particles disrupts polymer chain mobility and continuity, creating stress concentration points that facilitate crack initiation and propagation.

Conclusion. The development of effective flame retardant systems for recycled polyethylene represents a critical enabling technology for expanding applications of recycled plastics into fire-sensitive sectors while simultaneously addressing environmental sustainability imperatives. Current research demonstrates that multiple approaches including metal hydroxides, intumescent systems, phosphorus compounds, and nanomaterials can successfully reduce polyethylene flammability, though each involves distinct tradeoffs between fire performance, mechanical properties, processing feasibility, and cost considerations. The unique challenges posed by recycled polyethylene, particularly degraded baseline properties and variable contamination, necessitate careful optimization and potentially acceptance of narrower application scopes compared to virgin material systems. Future advances will likely emerge from synergistic multi-component formulations that maximize flame retardant efficiency while minimizing loading levels and associated property degradation.

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