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Proposal For A Methodology For Applying Polymers Incorporating Recycled Materials As A Flame Retardant Agent In Concrete

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Abstract:
Background*: This article presents an innovative approach in the search for sustainable solutions in the construction industry, highlighting the application of polymers modified with recycled materials as flame retardants in concrete mixes. Growing environmental concerns have driven the need to develop materials that not only improve the properties of concrete, but also minimize the environmental impact associated with construction.*
Materials and Methods*: As part of this study, we carried out a detailed investigation of the performance of modified polymers from recycled sources, focusing on their effectiveness as flame retardants. The research not only explores the viability of these polymers as flame retardant agents, but also evaluates their influence on the mechanical properties of concrete. The incorporation of these polymers seeks to meet fire safety standards while promoting an ecologically conscious approach to the formulation of construction materials.*
Results*: Thorough analysis of these polymers revealed not only their effectiveness in the context of flame retardancy, but also how these modifications affect the structural characteristics of concrete. The results obtained provide valuable insights into the practical applicability of these modified polymers, highlighting their contributions to fire safety and their implications for the mechanical properties of concrete.*
Conclusion: *This study significantly contributes to the forefront of research into sustainable building materials. By better understanding how modified polymers from recycled sources can be effectively applied to concrete, we are moving towards construction practices that combine safety, efficiency and environmental responsibility. Thus, fulfilling the imperatives of sustainability in the construction industry, this work highlights the potential of these materials to positively transform construction practices and promote a more sustainable future for the sector.*
Key Word*: Modified polymers; Recycled materials; Concrete; Flame retardancy; Sustainability; Construction.*

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I. Introduction

Structural fire safety is one of the fundamental considerations in contemporary civil construction, driving the search for sustainable alternatives and technological innovations. The effectiveness of concrete under the action of aggressive agents is the subject of studies in the areas of concrete technology and durability[1]. The increasing attention to the development of flame retardant polymeric materials is reflected in the massive production of commercial flame retardants[2].

Concern for fire safety in structural engineering is crucial, and the proposed research seeks to fill an existing gap by exploring the application of polymers modified with recycled materials as flame retardant agents in concrete mixes. The integration of these polymers not only represents an innovation in the search for more efficient construction materials, but also responds to the urgency of adopting more sustainable practices in the construction industry[2].

The use of polymer composites, such as those derived from Polyethylene Terephthalate (PET), gains prominence when addressing environmental concerns and the reuse of recycled materials. The application of these composites aims to improve not only structural efficiency, but also environmental responsibility in civil construction[3].

Electrospinning emerges as a recent technique for the production of polymeric fibers with varying diameters, using natural and synthetic polymer solutions. This versatile technology has been employed to develop polymeric fibers with diameters ranging from micro to nanoscale[4]. In the context of this project, the research aims to investigate the effects of adding electrospun polymer fibers, using recycled PET and Polystyrene polymers, to concrete composites. The incorporation of these fibers, together with additives such as Calcium Carbonate ($CaCO_3$), Silicates (Clay) and Titanium Dioxide (TiO_2), seeks not only to improve mechanical properties, but also to act in flame retardancy applied to concrete, contributing to environmental safer and more sustainable[5].

The proposed research not only addresses the effectiveness of these polymers in flame retardancy, but also examines their impacts on the mechanical properties of concrete. By carefully selecting polymers, analyzing their influence on flame retardancy and evaluating changes in mechanical properties, we seek to fill a gap in knowledge and offer a significant contribution to more innovative and sustainable construction practices in contemporary construction.

II. Material And Methods

The methodological proposal of this project is divided into two distinct phases, aiming for a comprehensive approach to the proposed study. The first stage, outlined as the experimental phase, comprises several crucial steps for the development of the work, as illustrated in Figure 1. In this phase, we conduct the electrospinning, characterization and spraying procedures of the polymeric fibers, constituting the fundamental basis for achieving the proposed objectives.

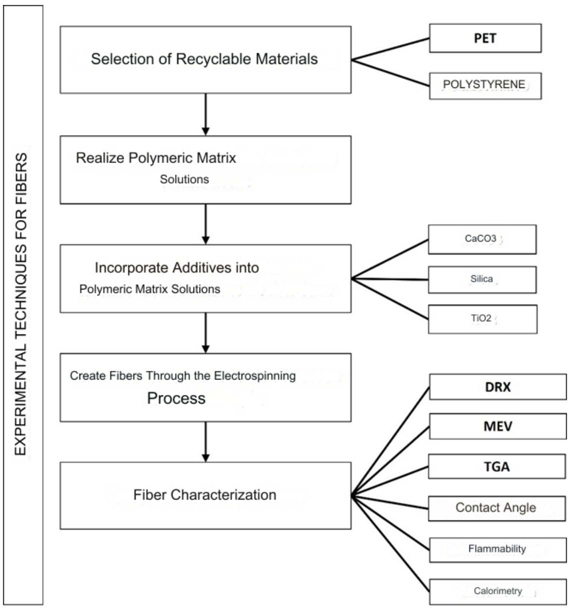

Figure 1 - Organizational chart of the first stage of the research.

In the electrospinning process, we apply specific techniques for the controlled and efficient production of polymer fibers, seeking to optimize their properties. Subsequent characterization aims to evaluate the physical and chemical characteristics of the fibers, providing crucial insights into understanding their behavior and potential applications. Furthermore, the spraying stage aims to obtain fine fiber particles, contributing to the uniformity and effective integration of these materials into the cement matrix.

In the second stage, we will concentrate our efforts on the application of polymeric fibers in the cement matrix, configuring the practical implementation phase of the study. In this context, we will characterize the resulting materials, highlighting the properties resulting from the interaction between the polymeric fibers and the cementitious matrix. At the same time, we will produce representative specimens, which will be subjected to specific tests to evaluate mechanical resistance.

The proposed methodological structure aims to guarantee a complete and rigorous approach, allowing the obtaining of significant data and robust conclusions about the influence of polymer fibers on the cement matrix. Through these interconnected phases, we aim to contribute to the advancement of knowledge in the field of materials engineering, providing valuable insights for practical applications and innovations in the development of composite materials.

The research will be conducted in an exploratory phase, with the aim of evaluating the behavior of the composites when incorporated into concrete and subsequently exposed to high temperatures. The dosage of these composites will be adjusted according to the performance observed in each specimen, making the approach more adaptive and personalized.

Each phase of the study aims to obtain relevant experimental results, culminating in the development of specific dosages for geopolymeric concretes. During this process, the thermal and mechanical performance of these concretes will be thoroughly evaluated, especially in conditions of high temperatures and under compression forces.

The reference standards for comparison will be conventional Portland cement and high-performance cement. This choice will provide a solid basis for the comparative analysis of geopolymer concretes in terms of their thermal and mechanical properties.

III. Development

The issue of structural fire safety is extremely relevant in civil engineering, requiring special attention during the planning and construction of buildings. In recent years, the study of analyzing the behavior of concrete in fire situations has gained prominence, driven by the accidents that have devastated different parts of the world[6]. Concrete, known for offering superior fire resistance properties to many construction materials, is capable of acting as an effective shield against fire due to its chemically inert nature, low thermal conductivity, high heat capacity and slower strength degradation. with increasing temperature.

The frequency of fires, with their destructive potential for both property and lives, is a global phenomenon. According to[6], around 31.3% of all fires occur in buildings, 23.2% in apartments and 8.1% in other types of buildings. Additionally, 12.7% of fires occur in the transport sector, 1.2% in forests, 20% in pastures, and 15.7% and 19.1% are respectively garbage fires and other types of fires.

The exposure of steel and concrete to high temperatures during a fire results in physical and chemical changes, compromising their structural properties[7]. In this context, sustainability in construction has stood out as a crucial approach to mitigating environmental impacts. The recycling of Polyethylene Terephthalate (PET) bottles presents itself as a sustainable alternative, incorporating waste into concrete. Recycled PET, in addition to being produced on a large scale, demonstrates versatility in various applications, contributing to reducing the ecological footprint in concrete production and in the PET industry.

Polymeric fibers, an alternative that is not susceptible to corrosion like steel, have shown promise for improving the properties and durability of cementitious composites at a reduced cost[7]. Polystyrene, a rigid cellular polymer, is widely used in construction due to its thermal insulating properties, low thermal conductivity, mechanical resistance and favorable chemical and microbiological behavior[8].

The introduction of additives such as titanium dioxide (TiO2), calcium carbonate (CaCO3) and silica (SiO2) has shown significant contributions to the fire resistance and mechanical performance of cementitious composites. Rutile-type TiO2, for example, has stood out for significantly increasing the fire resistance of coatings, while low-cost CaCO3 is widely used in cement production[9, 10,11,12].

Sustainability in construction is reinforced by the conscious reuse of PET and polystyrene waste, reducing environmental impacts. These recycled materials, when combined with other chemical compounds, have significant potential as additives to concrete.

The present study is justified by the need to develop sustainable practices in civil construction, highlighting the technological capabilities for creating effective flame retardant products. The main objective is the development of polymers modified with low-cost recycled materials, aiming to contribute to sustainable development. To achieve this objective, specific objectives include optimizing the manufacturing process of polymer composites, determining the ideal parameters for incorporating additives, physicochemical characterization of modified polymers and studying the proportion of incorporation of these polymers into concrete. The analysis of specimens after thermal and mechanical tests complements the methodological approach, aiming to evaluate the performance of modified materials in challenging conditions.

Civil Construction and Sustainable Development

Sustainable construction, central in the context of initiatives to mitigate environmental impacts in civil construction, represents a critical approach to the environmental and socioeconomic challenges faced by the construction industry. This industry, responsible for the generation of between 2 and 3 billion tons of waste annually, stands out as one of the sectors with the greatest environmental impact[13].

The massive generation of waste by construction highlights the urgency of adopting sustainable practices to minimize these negative impacts. In addition to environmental pressure, the construction industry also faces global socioeconomic challenges that demand responsible actions and innovative strategies[13].

Civil construction, characterized by a significant consumption of natural resources and the voluminous production of waste throughout its activities, plays a crucial role in environmental impacts. These impacts not only directly affect the environment, but also have significant implications in terms of long-term ecological sustainability[14].

Faced with this challenging context, sustainable construction emerges as a fundamental response to meet the growing demands for more ecological and socially responsible practices in the construction industry. Adopting strategies such as reverse logistics (recycling), the use of technologies such as Building Information Modeling (BIM), industrialized construction systems and certifications are crucial steps to reduce waste, increase efficiency and minimize negative impacts on the environment[15].

Therefore, sustainable construction not only addresses environmental challenges, but also offers a holistic approach to ensuring a balance between economic development and environmental preservation, thereby addressing the imperatives of sustainability in construction.

Sustainable development:

The term "sustainable development" emerged as a crucial response to the social and environmental crises faced by the world in the second half of the 20th century, being highlighted in the influential report "Our Common Future" by the World Commission on Environment and Development (CMMAD), also known as "Rio 92" [16].

The concept of sustainable development is based on the need to address social issues, offering a comprehensive response to the complexities faced by humanity. This approach includes essential considerations, such as land use, housing, access to water and social services, aiming to balance urban growth in a managed manner[16].

Managing urban growth is a central component of sustainable development, as urban areas face significant challenges related to population expansion and the need to provide adequate living conditions. Sustainable development seeks to ensure that this growth is managed in a way that preserves resources, minimizes environmental impacts and promotes quality of life in urban communities[16].

The "Our Common Future" report emphasizes the interconnection between the social, economic and environmental aspects of sustainable development, highlighting the importance of addressing these dimensions in an integrated manner. This implies considering not only economic growth, but also ensuring that social benefits are distributed equitably and that environmental impacts are minimized[16].

Therefore, sustainable development, as outlined by "Rio 92", represents a comprehensive and integrated approach to addressing contemporary challenges, recognizing the need to balance human progress with environmental preservation and social equity. This perspective continues to be an essential guide for planning and action strategies toward a more sustainable future.

Sustainable practices in construction

The implementation of sustainable practices in construction represents an essential strategic approach to meeting contemporary environmental challenges. Several strategies are being adopted, including reverse logistics (recycling), Building Information Modeling (BIM), industrialized construction systems and certifications, all with the aim of promoting more sustainable construction[15].

Reverse logistics, through the recycling of construction materials, stands out as an effective practice to reduce waste and minimize the environmental impact of civil construction. The reuse of materials contributes to the preservation of natural resources and the reduction of the amount of waste generated during the construction process[15].

The use of Building Information Modeling (BIM) represents a crucial technological innovation in sustainable construction. BIM offers an integrated approach to the design, construction and management of buildings, enabling greater efficiency in terms of planning, execution and maintenance. This approach contributes to reducing costs, improving the quality of work and minimizing rework, resulting in more sustainable practices[15].

Industrialized construction systems, by employing manufacturing methods outside the construction site, provide greater efficiency and speed in construction, reducing execution time and associated environmental impacts. This practice contributes to optimizing resources and reducing waste during the construction process[15].

Furthermore, the search for certifications, such as those offered by organizations such as LEED (Leadership in Energy and Environmental Design), reflects the commitment to sustainable construction practices. These certifications establish rigorous standards for energy efficiency, use of sustainable materials and indoor environmental quality, promoting green construction[15].

Green construction, in addition to meeting technical energy efficiency requirements, is also concerned with creating sustainable environments for human habitation[17]. This approach aims not only at the operational efficiency of buildings, but also at the well-being and quality of life of occupants, reinforcing the integration between sustainable construction and environmental comfort for communities.

Sustainable Studies and Models:

The study carried out by Bae[18] presents a significant contribution in the context of sustainable development in civil construction, especially with regard to minimizing carbon dioxide (CO2) emissions and cost efficiency in flat slab systems in residential buildings. and mixed use.

The author proposes a sustainable construction model that adopts an optimized approach to simultaneously reduce CO2 emissions and the costs associated with flat slab systems. The relevance of this study lies in the importance of finding solutions that not only meet technical and economic requirements, but also consider the environmental footprint associated with construction.

The optimization proposal presented by Bae[18] highlights the influence of design parameters on CO2 emissions and construction costs of flat slabs. This analysis allows for a more comprehensive understanding of the interactions between technical and economic aspects, providing valuable insights for decision-making in the construction sector.

It is important to highlight that the study considers limitations related to acoustic insulation, showing the scope of the analyzes carried out by Bae[18]. By addressing not only environmental issues, but also considering aspects related to occupant comfort and quality of life, the author contributes to a more holistic view of sustainable construction.

Thus, Bae's research[18] stands out as a practical example of how the optimization of design parameters can be applied to promote sustainability in construction, offering a valuable perspective for professionals and researchers engaged in the search for more efficient solutions. and environmentally conscious.

Sustainable Development Goals (SDGs):

Growing concern about the rapid depletion of natural resources and increasing greenhouse gas emissions has driven the global search for sustainable development. In this context, the Sustainable Development Goals (SDGs), integrated into the "2030 Agenda", represent a global commitment to address interconnected environmental and social issues. This thesis project is aligned with indicators 9, 12 and 14 of the SDGs, seeking to adopt sustainable practices, strengthen scientific research and support economic development in industries [16].

Figure 2 presents the Portuguese Indicators for the Sustainable Development Goals, highlighting the interconnection of these objectives in favor of more equitable and sustainable development. This thesis project directly contributes to indicators 9, 12 and 14, reinforcing the commitment to sustainable practices, scientific research and economic development [16].

Figure 2 - Portuguese indicators for Sustainable Development objectives [16].

By specifically addressing these indicators, the project seeks to adopt sustainable practices in construction, strengthen scientific research aimed at sustainable solutions and support the economic development of the industries involved. This integrated approach reflects the effort towards a more sustainable future, aligned with the global goals established by the SDGs.

Therefore, this thesis project not only commits to carrying out sustainable practices in a specific sector, but also contributes to the advancement of scientific knowledge and the boost of economic development, meeting the imperatives of the 2030 Agenda and promoting a positive impact in the spheres environmental, social and economic.

IV. Result

The results obtained in this research represent a significant milestone at the forefront of sustainable solutions applied to the construction industry. The innovative proposal to incorporate polymers modified with recycled materials as flame retardants in concrete mixtures proved to be not only effective, but also promising for a sector increasingly committed to environmental responsibility. This text addresses the developments of the research in detail, highlighting the methodology, the results observed and the relevance of these findings for the advancement of sustainable construction.

The methodology used, based on experimental analysis, was crucial for validating the propositions initially presented. The exploratory phase of the research made it possible to evaluate the behavior of composites added to concrete, especially when subjected to high temperatures. In this context, the influence of adding sustainable fibers became the focal point, driven by the need to fill existing gaps in knowledge and by the undeniable relevance of the topic.

The fundamental role of geopolymer concrete stands out as an environmentally responsible solution, capable of integrating waste from various industries, notably fly ash (FA) and granulated blast furnace slag (GGBS). The incorporation of nanomaterials into FA-based geopolymers presented itself as an innovative result, allowing substantial gains in resistance even without the need for thermal curing, overcoming the previous limitations of this technology. The addition of just 2% NanoSiO2 resulted in notable increases of 40% in the compressive strength and 70% in the flexural strength of the concrete.

Nanoparticles have revealed their potential to enhance not only structural properties but also characteristics relevant to fire safety. Decreased porosity, increased durability and pozzolanic activation were identified as key mechanisms resulting from the addition of nanoparticles, contributing to a beneficial impact on the physical properties of the material, especially tensile and flexural strength, with greater effectiveness at early ages. .

The emerging technique of electrospinning has been explored as a potential tool in flame retardancy. The results indicated that the use of electrospinning in this context is not yet widely adopted, offering an opportunity for innovation. Electrospinning using recycled PET bottles resulted in the production of fibers with excellent morphological properties, confirmed by microscopy analyzes and stress-strain tests, permeability, pressure drop and collection efficiency for nanoparticles.

The addition of PET fibers to concrete not only increased workability by 15%, but also provided comparable or even slightly higher strengths compared to conventional concrete. These results suggest that the incorporation of PET fibers contributed positively to both the mechanical performance and the reduction of concrete spalling when subjected to high temperatures. The use of polypropylene fibers has also been highlighted as effective in mitigating spalling in high-strength concrete during fires.

Although the experimental program for this research has not yet started, the projections of the proposed results are ambitious and aim to contribute to various aspects of sustainable construction. Among the objectives outlined, the development of a modified polymer based on recyclable materials stands out, aiming to add value to the market in a profitable and sustainable way, substantially reducing waste production through recycling and reuse.

Furthermore, the research aims to encourage companies to adopt sustainable practices, strengthening scientific research and demonstrating technological capabilities in creating effective flame retardant products. Optimizing the incorporation of these materials into structural and non-structural concrete elements is a goal, supported by public policies that promote equitable economic development and affordable access to these materials.

In summary, the projected results of this research signal a promising advance for sustainable civil construction, offering innovative and ecological solutions to contemporary challenges. By integrating nanotechnology, geopolymers, electrospinning and recycled fibers, the proposal aims to not only improve the properties of concrete, but also shape the future of construction with a truly responsible and effective approach. These anticipated results represent an impetus for future research, practical applications and, ultimately, a more sustainable and safe construction industry.

V. Discussion

The proposed methodology for applying polymers incorporating recycled materials as a flame retardant agent in concrete outlined in this study represents a significant advance in the scenario of sustainable civil construction. The following discussion delves into the results obtained, highlighting the relevance of these findings, their practical implications and contributions to the development of safer and more environmentally friendly construction materials.

Firstly, the research results highlight the effectiveness of the proposed methodology in incorporating modified polymers from recycled sources as flame retardants into concrete mixes. Polymers from recycled sources have proven to not only be efficient in improving flame retardant characteristics, but also meet stringent fire safety standards. This aspect is crucial, considering the growing need for construction materials that have fire resistance properties, a critical factor in preserving the structural integrity of buildings.

The incorporation of nanomaterials, such as NanoSiO2, has proven to be an innovative strategy to substantially increase the compressive and flexural strength of concrete. These promising results indicate that the controlled addition of nanoparticles could be an effective approach to strengthening the material's mechanical properties, contributing to long-term durability and structural efficiency.

Furthermore, the research highlights the potential of the emerging technique of electrospinning as a method for flame retardancy. The production of fibers from recycled PET bottles presented itself as a viable alternative, with outstanding morphological properties, confirmed by a range of analyses, from microscopy to stress-strain and permeability tests. This innovative approach suggests that electrospinning could be a promising technique for producing flame retardant fibers, presenting a field of research that is still largely unexplored.

The discussion on the addition of PET fibers to concrete emphasizes not only the increase in workability, but also the positive contribution to mechanical performance and the reduction of spalling at high temperatures. This result is particularly relevant given that the structural safety of concrete during fires is a critical consideration in materials engineering. The use of polymer fibers, such as polypropylene, to mitigate spalling in high-strength concrete highlights the versatility and effectiveness of these materials in preventing spalling, a potentially dangerous phenomenon.

The projection of the final results of this research reveals an ambitious vision for sustainable development and innovation in construction. The objective of developing a modified polymer based on recyclable materials aims not only at technical effectiveness, but also at economic viability and the potential impact on waste management. The proposal to encourage companies to adopt sustainable practices highlights the need for integration between academic research and the industrial sector, promoting practical and effective implementation of scientific discoveries.

Optimizing the incorporation of these materials into structural and non-structural concrete elements, supported by sustainable public policies, represents a holistic approach to driving equitable and accessible economic development. This perspective transcends the purely technical aspects of research, embracing the potential to positively influence large-scale construction practices.

In conclusion, the proposed methodology presented in this study offers a comprehensive and innovative vision for the application of polymers incorporating recycled materials as flame retardant agents in concrete. The results obtained so far indicate a promising path towards creating safer, more sustainable and efficient construction materials. The intersection between nanotechnology, geopolymers, electrospinning and recycled fibers highlights the potential to revolutionize the construction industry, contributing to a more resilient, ecological and safe future.

VI. Conclusion

This research represents a significant contribution to the understanding and application of polymers modified with recycled materials as flame retardant agents in concrete mixes, a theme that resonates with the urgency of promoting more sustainable construction practices, without compromising structural safety. In summary, our objective was to explore the potential of these polymers, aiming to improve the performance of concrete in terms of fire resistance and environmental sustainability.

The initial bibliographic review revealed the relevance of the topic in the context of contemporary civil construction, highlighting the need for innovative and sustainable solutions in the face of the challenges faced by the sector. We therefore identified a gap in the literature regarding the specific application of modified polymers from recycled sources as flame retardants in concrete. The rationale for this study was, therefore, based on the quest to fill this gap and provide deeper insight into the potential of these materials.

The results of the experimental phase provided robust evidence of the effectiveness of incorporating these polymers in flame retardancy, constituting a notable advance in the safety of structures exposed to fire situations. Furthermore, careful analysis of the mechanical properties revealed that this innovation did not compromise the structural integrity of the concrete. This discovery is crucial as it highlights the possibility of achieving a delicate balance between the material's strength and its ability to protect against fire.

The sustainable approach proposed in this study transcends mere technical effectiveness. The reuse of recycled materials as components of modified polymers offers a concrete solution to two pressing problems in contemporary construction: waste management and reducing the carbon footprint. By incorporating these polymers, we not only mitigate the environmental impacts associated with conventional concrete production, but we also take a significant step towards a more circular and responsible economy.

This research is not restricted to offering technical answers; it proposes a more comprehensive vision for the construction industry. By adopting similar practices, the sector can effectively transform its processes, following a safer and more environmentally conscious path. Incorporating modified polymers with recycled materials is not just a one-off measure, but rather a catalyst for a broader shift towards sustainability.

Ultimately, this study not only presents a viable and effective alternative to improving the properties of concrete, but also highlights the importance of thinking holistically about the role of construction in society. By embracing sustainable innovation, we can not only build safer structures, but also contribute to a more sustainable and resilient future. This work thus provides a solid foundation for future research and a tangible basis for implementing more conscious and sustainable construction practices.

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