Application of Residual Fibers of Polyethylene Terephthalate - PET in Structural Composites: A Systematic Review

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Fiberglass is the most commonly used material in the manufacturing process of wind turbine components, as it meets the basic requirements of the final product. However, as the market for wind turbines expands, industries must keep up with the demands of increasing blade efficiency at a reduced cost. As a replacement for fiberglass, poly (ethylene terephthalate) - PET textile fiber is an option, which has better tensile strength, elongation rate, and low density. However, it has low wettability and poor interfacial bonding with resin matrices. This study aims to perform a literature review of existing scientific studies using PET fiber from the tire industry or not applied as reinforcement in structural composites.
Keywords: PET Textile Fiber. Structural Composites. Wind Turbines. Wind Blades.

Introduction

The way energy has been, since the last century, and has been generated, still in significant volume, brings to the fore the constant search for renewable energy generation methods that do not pollute the environment and are economically and socially beneficial. According to the Global Wind Report (2022) [1], Brazil is the 6th country in the world ranking in terms of installed wind power (with 21.5 gigawatts), and this is a promising market since the economy has been circulating greener technologies driven by renewable and globally competitive energies, which brings us, also, the bias of biodegradability and the reuse of natural and synthetic waste from industries and agribusiness, capable of application in the technological development of greener materials, with longer life cycles and susceptible to recycling [2].

Manufacture wind blades are commonly used fiberglass, which, although highly versatile, presents some intrinsic negative points to the process as the unhealthy during the lamination of the blades and the challenges of increasing the efficiency of the blades since this is related to the increase of its length under a low weight (density of fiberglass equivalent to 2.54 g/cm³) and cost [3,4]. Therefore, the study regarding the replacement of fiberglass by residual and clean textile fibers of PET-poly (ethylene terephthalate) from the tire industry fills an existing gap around this technological perspective, presenting itself as an innovative idea in the sphere of development of new materials and their application in wind turbines.

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PET Fiber Application

The civil industry is one of the central and oldest holders of the development of composite materials using fibers as reinforcement components in cement matrices since these materials, when applied, tend to improve the initial properties presented by its matrix, especially the structural ones related to traction, bending, and impact.

Moreover, composite materials with fibers, whether synthetic or natural, tend to improve the ratio between the strength and final weight of the material since the strengthening mechanism is associated with the transfer of stress from the fiber to the matrix [4,5]. However, it is noteworthy that natural fibers present a low structural strength response when applied to polymeric or ceramic matrixes, which is not ideal for applications requiring extreme structural stresses. Thus, synthetic fibers become the most employed when high structural characteristics are required [4].

The study developed by Dias and colleagues (2019) [5] used textile waste from the Vale dos Sinos - RS tire industry. This study aimed to incorporate this waste as fibers in concrete, using it as a promising alternative to sustainable technologies in construction. The tests and validation of the study showed feasibility in the application since the incorporation of textile fiber in the cement matrix reduced localized cracks and improved impact absorption by concrete; however, because it still presents itself as a technological gap in the civil industry, it requires further studies around the application of this composite for more practical application in the sector.

The study prepared by Araujo (2019) [4] applied clean residual PET textile fibers from the tire industry (Kordsa) as reinforcement in a polyester matrix to be later applied as a coating element in civil construction. The results showed an increase in impact strength 10x higher than that established by NBR 15575-3. However, the morphological analysis showed an irregular distribution of fibers as the fiber concentration in the matrix increased, which contributed to the formation of voids and bundles, resulting in decreased adhesion strength between fiber and matrix, and the cited study did not perform any pre-treatment on the fiber. In addition, PET fibers have some drawbacks, such as low wettability and poor interfacial bonding with resin matrices. However, many studies have focused on solving these problems. When subjected to physical or chemical treatments to improve its properties, PET fiber is used as a reinforcement material and produces composites with low weight and high structural strength [6,7].

Teh and colleagues (2004) [8] performed surface treatment with NaOH on PET fibers that were used as reinforcement in an epoxy composite, which, when purchased with the pure resin, showed excellent fracture toughness with only 1% loading since the adhesion between matrix/fiber treated showed excellently. The studies developed by Mao and colleagues (2019) [6] validated a new method of surface treatment on residual PET textile fibers via immersion in a hybrid solution of tetraethylorthosilicate (TEOS)/KH550/polypropylene (PP)-g-MAH (MPP) synthesized (TMPP). The results were highly positive for interfacial properties, mechanical strength (flexural and tensile), and the modified fiber's thermal and physical-chemical properties.

However, the structural performance of fiber-reinforced composites is also affected by the total volume fraction of the fibers relative to the matrix, the distribution of the fiber in the matrix, the length of the fiber strands, and the orientation of the fiber in the matrix [9,10]. Manjunath and colleagues (2019) [7] performed static (flexural tensile and impact) and dynamic (temperature effects, damping properties, storage frequency, and loss modulus) experiments, validated by morphological analyses, on unidirectionally distributed PET textile fiber composites in epoxy resin, evidencing impact resistance and better dynamic mechanical behaviors compared to glass fiber/epoxy composites. Dan-mallam and colleagues (2015) [11] used PET fibers interlaced with kenaf fiber in a hybrid composite of epoxy resin manufactured via a vacuum infusion process, obtaining improved mechanical properties (bending and impact), morphological (interfacial bonds) and physical (water absorption), enabling the application of the hybrid composite in various sectors that require high structural stresses and exposure to weather such as rain, considering mainly the percentage of fiber/matrix distribution as responsible for the improvements cited.

We did not find studies applying the residual PET textile fibers from the tire industry in the epoxy matrix in the application of wind turbines, either in wind blades or other components. It presents a technological gap amenable to investigation in the renewable energy industry sector.

Materials and Methods

The method aimed to build a systematic review of works that have used PET fiber from, or not, the tire industry as a reinforcement material for structural composites, improving the performance of these materials and considering the processes inherent to this improvement (chemical or physical surface pre-treatments, fiber distribution, percentage of fibers distributed in the matrix, fiber orientation and distribution of fiber strands. Tables 1 and 2 listed the studies considered in our research sources and keywords.

Table 1. Databases used in the search for scientific articles.

Sources of Research
Science Direct
MDPI
Academic Google

Table 2. Keywords used in the search for articles in the databases.

Keywords
Wind turbines
Wind blades
Structural composites
Composites materials
PET textile fiber
PET fiber

In the Science Direct database, a filter was performed with the keywords in English to obtain the most relevant articles—the selected publications dated from 2018 to early 2022. Figure 1 presents the steps for filtering the publications.

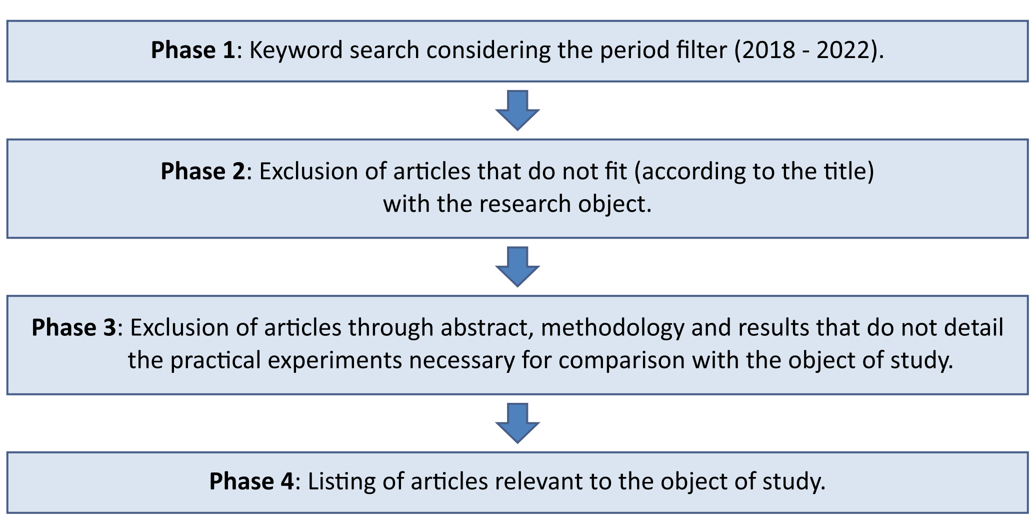
Results and Discussion

Phase 1 ended up performing a relevant filter, using combinations of keywords and Boolean operators, for example, „structural composites AND wind turbine blades“ or „PET fiber AND wind turbines“. When selecting the period (2018 - 2022), the number of articles reduced considerably, mainly in the MDPI and Google Academics databases, since the articles presented in the latter were forwarded to other sites such as Science Direct, Research Gate, or MDPI itself. Table 3 presents the results.

Table 3. Number of articles obtained after the phase 3 analysis.

Sources of Research	Phase 3
Science Direct	23
MDPI	16
Academic Google	7

Figure 1. Exclusion and prioritization phases of the scientific articles.



Four questions (Q) were defined that guided the relevance of the content of each article obtained in the previous phase to supporting the qualitative selection process of phase 4. This relevance was analyzed quantitatively following the logic of assigning values to the answers: "yes" (value 1.0), "in part" (value 0.5), and "no" (value 0). Thus, according to the questions, the higher the value of the selected article, the more its content is in agreement with the research developed.

The questions selected for the study were:

Q1: Does the study use residual PET fiber and epoxy resin for composite structural development?

Q2: Does the study present its results or quotes from the fiber and/or structural composite characterizations?

Q3: Does the study aim to apply the structural composite in the wind turbine industry?

Q4: Does the study define some pre-treatment on the fiber before using it as reinforcement in the polymeric base?

Table 4 presents the results for each article found in the databases, totaling 12 relevant articles.

Table 4. Listing of articles according to the prioritizations defined in phase 4.

Nº	Article Title	Questions					Databases/ Journal
		Q1	Q2	Q3	Q4	Total	
1	Structural optimization of a horizontal axis wind turbine blade made from new hybrid composites with kenaf fibers [12]	0	0	1	0	1	Science Direct - Composite Structures
2	Experimental Study on Mechanical Properties of Natural Fiber Reinforced Polymer Composite Materials for Wind Turbine Blades [13]	0	1	1	0	2	Science Direct - Materials Today: Proceedings
3	Performance analysis of wind turbine blade materials using nanocompWosites [14]	0	1	1	0.5	2.5	Science Direct - Materials Today: Proceedings
4	Development and characterization of PET flakes reinforced polyester resin composites [15]	0	1	0	0	1	Science direct - Materials Today: Proceedings
5	Recycling of thermosetting composites for wind blade application [16]	0	1	0	0	1	Science Direct - Advanced Industrial and Engineering Polymer Research
6	Fiber Orientation Effect on the Behavior of the Composite Materials of the Horizontal Axis Wind Turbine Blade (HAWTB) [17]	0	1	1	0	2	IEEE Xplore
7	Comparative Assessment of Static and Dynamic Mechanical Properties of Glass and PET Fiber Reinforced Epoxy Composites [7]	1	1	0	0	2	Science Direct - Materials Today: Proceedings
8	Experimental and Numerical Comparison of Impact Behavior between Thermoplastic and Thermoset Composite for Wind Turbine Blades [18]	0.5	1	1	0	2.5	MDPI – Materials
9	The Potential of Natural Fiber Reinforced Polymer Composites in Sandwich Structures: A Review of Its Mechanical Properties [19]	0	1	0	0	1	MPDI – Polymers
10	Performance Analysis of Reinforced Epoxy Functionalized Carbon Nanotubes Composites for Vertical Axis Wind Turbine Blade [20]	0	1	1	0.5	2.5	MPDI – Polymers
11	Simulation of Glass Fiber Reinforced Polypropylene Nanocomposites for Small Wind Turbine Blades [21]	0	0.5	1	0.5	2	MPDI – Processes
12	Surface Modification of PET Fiber with Hybrid Coating and Its Effect on the Properties of PP Composites [6]	0.5	1	0	1	2.5	MPDI - Polymers

Conclusion

Few articles were found that used PET fiber in an epoxy matrix, and only the article described in item 7 responded positively to this question. This point highlights the technological gap around using these materials to develop a new structural composite that can be applied in the wind turbine industry, replacing fiberglass in the manufacture of the blade and other components of the system. This project will undoubtedly contribute to advancing new technologies in the sector and assist in future studies involving the proposed theme.

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