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GFRP as a Sustainable Material in Construction

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ABSTRACT: Glass Fiber Reinforced Polymer (GFRP) materials are increasingly used in household appliances, sports equipment, automotive industry, construction, shipbuilding, transportation, and energy sectors. However, their disposal at the end of their service life poses a significant environmental challenge due to the thermoset matrix, which prevents easy melting and recycling.This paper surveys disposal, recycling, and reuse options for recycled GFRP (glass fibre reinforced polymer) or waste composite materials, with an emphasis on using both original and recycled materials in construction. Globally—and particularly in Europe—the production and use of GFRP products are growing rapidly, leading to increasing volumes of waste that must be disposed of or recycled. In construction, large quantities of materials are used, where resistance to corrosion, moisture, salt, and related factors is highly desirable. This paper provides an overview of modern GFRP disposal and recycling methods (mechanical, thermal, and chemical), as well as an analysis of the potential for reusing recycled GFRP materials (RGFRP) in construction and other fields.As the production of GFRP becomes more affordable, its expanding use in construction necessitates thoughtful consideration of its reuse.

KEYWORDS: life cycle ofcomposites; GFRP; waste; disposal; recycling; reapplication.

I. INTRODUCTION

Composites are, in most cases, a combination of polyester resin and embedded glass fibres. Typically, they are referred to as reinforced polymers in the form of panels, hence also called plate-like materials, with the common abbreviation GFRP, for the English term "glass fibre reinforced polymer." [1].The glass fibres are arranged in layers, and their arrangement can vary, Figure 1. The use of glass fibre reinforced polymers generally offers advantages such as reduced structural weight while maintaining high load-bearing capacity. Additionally, they provide resistance to moisture, aggressive liquids, corrosion, and freezing.

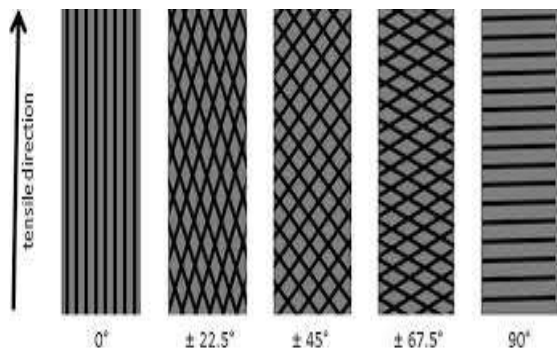

Figure 1. Schematic illustration of the composites with different fibre orientation

What is highly important for construction is the ability to adhere well to other materials, such as steel, aluminium, and concrete. [2, 3].For this reason, the original role of GFRP was as a replacement for steel reinforcement in reinforced concrete elements. In addition, widely used polymer reinforced with glass fibres are found in the production of modular buildings and mobile homes, electrical and electronic assemblies, transportation, marine vessels, and aircraft. A large portion of the plate-like GFRP material production goes into manufacturing wind turbine blades. [4].These materials also have long-lasting resistance to external influences, and as such are generally used in fluid transport, i.e., in hydrotechnics, such as inspection openings and pipelines.

II. ORIGIN OF THE LARGEST AMOUNTS OF GFRP WASTE

In broad use, the life cycle of GFRP material is always important, including its potential applications in construction. [5].During the production process using recycled materials, costs are significantly reduced, and recycled materials often exhibit better characteristics than the original material. Because of the growing widespread use of GFRP composites, production worldwide is becoming increasingly cost-effective. Like any material, GFRP is subject to various stresses such as fractures and wear, as well as exposure to water, climate change, and generally aggressive environments. It is estimated that the service life of a GFRP product is about 15–20 years, which results in a large amount of waste. One of the major applications of GFRP materials is the production of wind turbine blades, and it is estimated that by 2025 around 66 thousand tons of waste will be generated. [6].This is because wind energy production with turbines is expected to rise significantly in the future, and the amount of recycling from this product alone could reach about 40 million tons, which is very substantial. One possibility is repurposing GFRP products, and a particularly interesting example of repurposing wind turbine blades can be seen in Figure 2 as a bicycle shelter in the city of Aalborg, Denmark.

Figure 2. Possibilities for repurposing of wind turbine blades

Some estimates indicate that by 2025 the amount of GFRP composite waste could reach nearly 700 thousand tons. [7].Figure 3 shows the sectors of the economy that are the largest consumers of GFRP and thus the primary producers of waste worldwide. The construction and electronics/electrical engineering sectors lead. Following them, a large share of GFRP use is in transportation, ports and marinas, as well as the aforementioned wind turbine production.

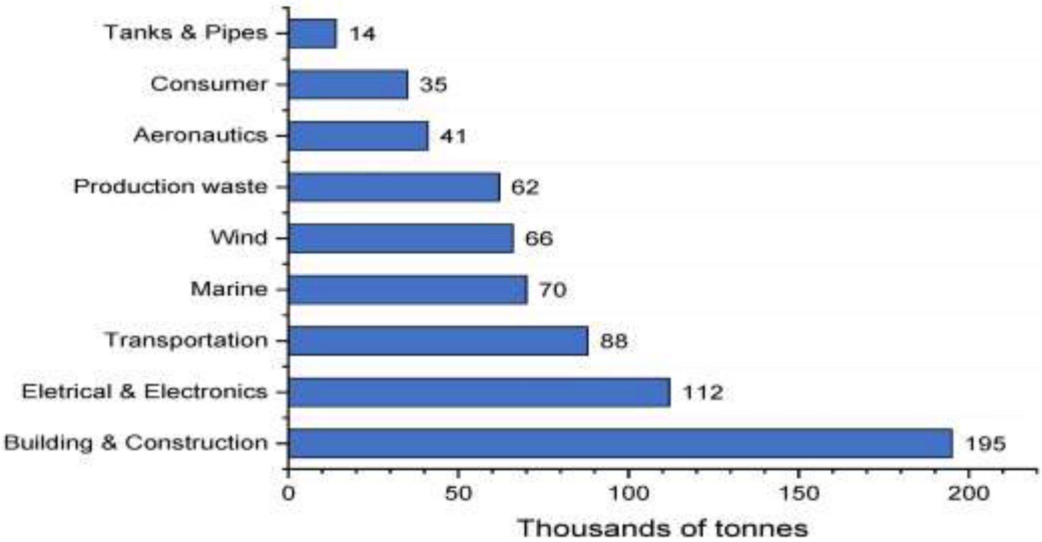

Figure 3. The biggest sources of GFRP material waste

The quantity of GFRP material will continue to increase over time, which means that waste management and environmental protection regulations will become increasingly stringent, and disposal and recycling technologies will become more advanced.

III. DISPOSAL OF GFRP MATERIALS

[8].It is estimated that over 250,000 tons of GFRP waste are generated globally each year, primarily from the wind turbine and marine sectors. Most of this waste ends up in landfills because there is no widely applied recycling technology. [9].The combination of glass fibers and thermoset resin makes separation costly and technically complex.The big problem arises because, with the increasing use of composites and similar materials worldwide, many countries and industries largely neglect GFRP waste. [6].There is a justified concern that several tons of material, due to a lack of awareness and adherence to disposal recommendations, may never reach appropriate channels for reinvestment and creation of new resources, including recycling. The most important task of waste management and environmental protection legislations is to ensure that all such materials are properly disposed of, recycled, or reused after the end of their initial use. In Europe, and worldwide, Germany and the United Kingdom are among the most active. In these countries, regulations rapidly align with official disposal recommendations for waste materials. One of the prevailing disposal methods in these countries—and the largest among them—is repurposing, as shown in Table 1: disposal of GFRP materials.

A)	Prevention	- extend the service life of structural components (products) - design products to enable easy disassembly and potential recycling - reduce the quantity and variety of materials in production,
B)	Reuse	- inspection, cleaning, repair, and maintenance - ensure spare parts availability - reduce environmental impact,
C)	Re-purposing	- enable the use of proper (more durable) parts in products for other applications, with a lower cost compared to the original part,
D)	Recycling	- recycling of materials and the use of recyclates,
E)	Remendation	- repair of products and components.

Table1. Waste disposal methods by importance

IV. SOME OF THE RECYCLING OPPORTUNITIES

If none of the repurposing options for products and components is feasible, recycling becomes necessary. Worldwide, certain recycling methods for GFRP materials dominate, with careful attention paid to cost and energy consumption to ensure sustainability and environmental protection. [10].Figures 4 and 5 show the costs and energy consumption for individual recycling methods of this material.

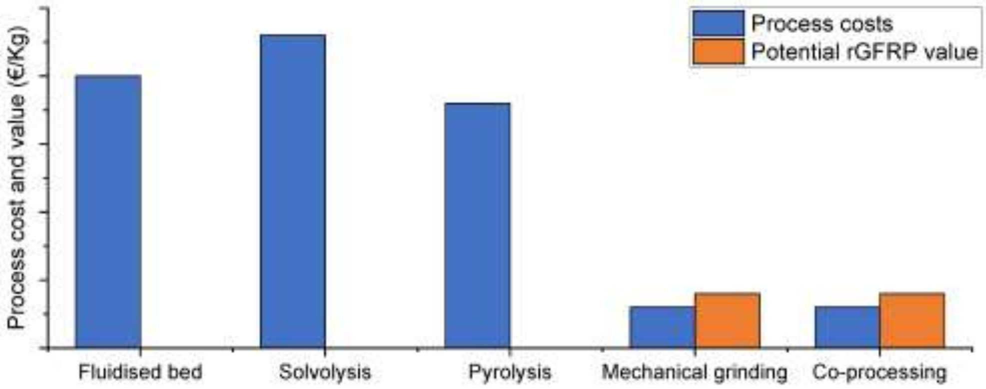

Figure 4. The cost (euro per kilogram) for the individual recycling methods

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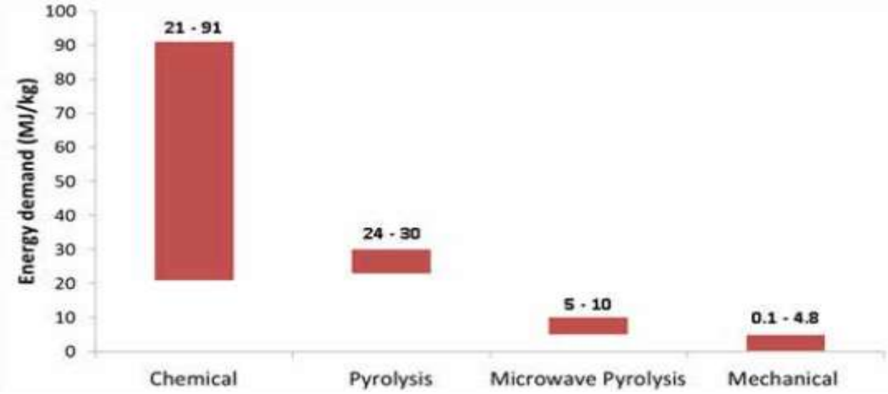

Figure 5. Energy consumption in MJ per kilogram for the individual recycling methods

[10].On the simplified representation of recycling methods in Figure 6, in addition to the basic recycling methods, three methods of thermal recycling are also visible.

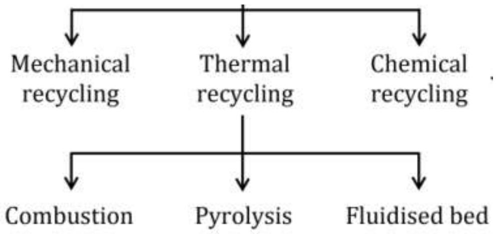

Figure 6. Simplified overview of how to recycle GFRP materials

[10].Recyclates obtained by mechanical recycling methods are most interesting for further use in construction, both in the production of new materials and in the production of load-bearing elements in structures.Thermal methods include pyrolysis and oxidation. [11].These methods remove the polymer matrix at high temperatures and allow the recovery of soluble silicates and clean glass fractions.Chemical methods use solvents, acids, or peroxides to break down the matrix. [12].The combination of microwave energy and oxidizing agents enables the extraction of high-purity glass fibres.

An interesting figure shows a comparison of the effectiveness of different methods in terms of the quality of the recovered fibres, specifically the proportion of preserved mechanical properties, Figure 7.

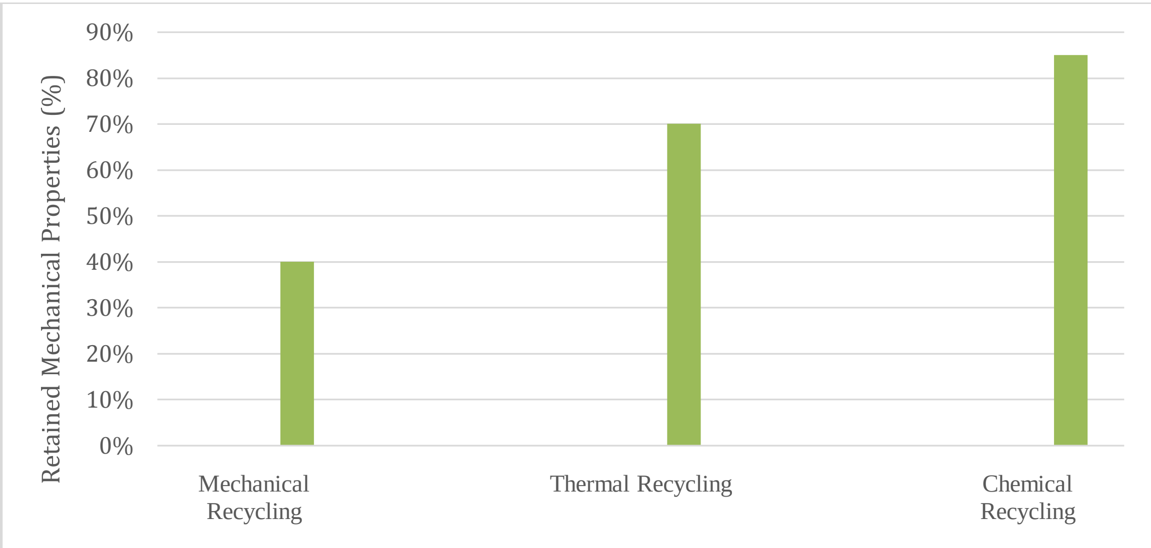

Figure 7. Comparison of Recycling Methods by Fiber Quality

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A comparative analysis of the main recycling methods shows a comparison of the quality of the recyclate, recycling costs, environmental impact, and the potential for industrial application of each method.

Method	Recyclate Quality	Cost	Environmental Impact	Industrial Applicability
Mechanical	Medium	Low	Moderate	High (concrete, fillers)
Thermal	High	Medium	Moderate–High	Limited (depends on energy input)
Chemical	Very High	High	Depends on reagents	Moderate (with post-treatment)

Table2. Comparative analysis of methods

V. PRODUCTION AND USE OF MECHANICAL RECYCLED GFRP MATERIAL

The most common use of mechanically obtained recycled GFRP material is in the field of civil engineering and structural elements, which is the subject of research by numerous researchers. [10].The production of mechanical recyclate can be roughly divided into crushing and grinding methods, Figure 8.

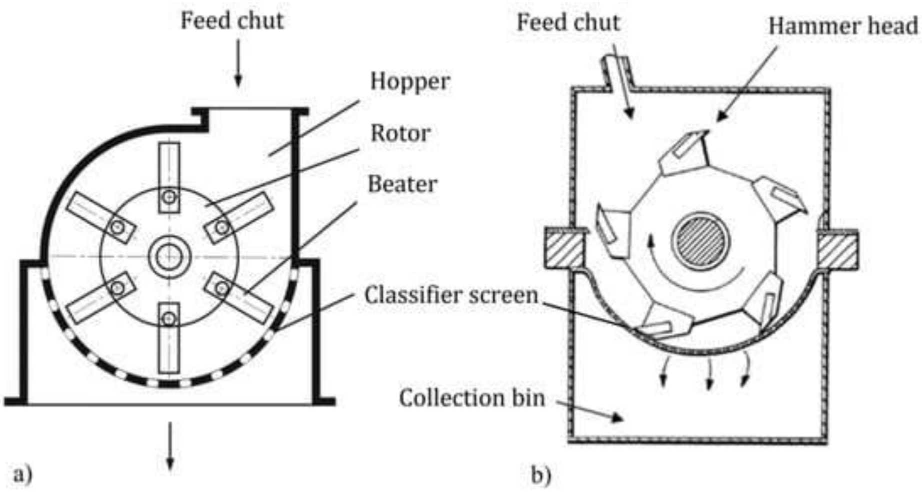

Figure 8. Methods of mechanical recycling of GFRP materials by crushing and grinding

Numerous examples of research on the use of mechanical recyclate can be divided into two groups, namely: application in the form of aggregates in concrete as a substitute for classic aggregates, and use in products of new construction elements of the original shape, i.e., from recycled GFRP material.

[13].Most common use of mechanical recycled GFRP material is as an aggregate in concrete as can be seen in Figure 9, where, for example, researchers examined compressive and tensile samples of concrete filled with mechanical recycled GFRP, which in this case largely replaces or supplements the classic aggregate. The researchers compared the bearing capacity of the samples according to the percentage of recycled GFRP material - aggregate in the concrete.

[14].Some authors have investigated replacing fly ash with GFRP powder in geopolymer concrete and found an increase in high-temperature resistance with a 10% content.

The use of GFRP bars as a replacement for steel reinforcement in concrete is common. [15].Experiments have shown that beams with reinstalled GFRP bars retain 95% of the load-bearing capacity of the original samples.

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Figure 9. Examples of mechanical recycling infill in concrete samples

Another method of using mechanical recycled GFRP material is as an additive to resin in the remanufacturing of GFRP sheet reinforcement for its original purpose.[16].Researchers have investigated the load-bearing capacity of bent beams with a rectangular cross-section, containing 50% recycled GFRP. By grinding glass fibre reinforced polymer, a recycled material was obtained, which was mixed with resin in the remanufacturing of sheet reinforcement. When testing the beams in bending, the load-bearing capacity was compared with the load-bearing capacity of beams made of the original material. Beams made of 50% recycled GFRP had a load-bearing capacity of about 30% compared to beams made of the original material. Figure 10 shows samples of beams made of partially recycled and original GFRP material.[17].One potential application of sheet-form recycled GFRP material is the production of lightweight panels for insulation. Such panels contribute to the reduction of CO_2 emissions.

Figure 10. Examples of beam patterns made from virgin and partially recycled GFRP material

VI. CONCLUSIONS

All indicators, both European and global, speak of the growing use of glass fibre reinforced composites (GFRP), which is present in a very wide number of products today. On the websites of the ministries dealing with waste management and environmental protection, both European and world countries, official data on the assessment of the increase in the use of fiberglass are updated daily. The result is the creation of a huge amount of waste and this is today's reality. As a result, the main task of the legislation of all countries in the field of waste management and environmental protection arises, and this is the urgent adoption of quality programs for the disposal of GFRP waste materials, both in the forms of conversion and in the field of recycling. In the field of construction, where this material is mostly used, the use of recycled material must also be present and is growing rapidly. Numerous scientists and researchers from all over the world are working intensively on this.

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