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Review

Glass Fibre-Reinforced Composite Materials Used in the Aeronautical Transport Sector: A Critical Circular Economy Point of View

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Abstract: Progress in composite materials has led to their use in applications where improved mechanical and resistance characteristics are required. Most composites are obtained in such a way that they present specific mechanical properties and/or have the role of both a thermal conductor and insulator; these properties are important, specific, specialized, and useful. The advantages of these materials compared to the classic ones are as follows: low weight, high resistance to wear and corrosion, and mechanical characteristics consistent with the subsequent use of the product. The slightly high costs of these materials are justified by their precision, the quality of the products obtained, and the fact that their use leads to increased reliability, maintenance, and, in the cases of the automotive and aeronautical industries, reduced energy consumption. This paper aims to bring to readers' attention the latest research related to glass fibre-reinforced composite materials in transport-related applications, such as automotive and aeronautic applications, including the manufacturing of unmanned aerial vehicles (UAVs). Considering the long period of use, the recycling and reuse of composite materials used in aeronautical transport is a must considering the environmental aspects and the need of achieving a circular economy. In recent years, considerable efforts have been made to find new alternatives to improve the performance and durability of materials in the aeronautical transport sector.

Keywords: glass fibres; UAV; surface modification by silanization; circular economy; aerospace industry

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Citation: Săftoiu, G.-V.; Constantin, C.; Nicoară, A.-I.; Pelin, G.; Ficai, D.; Ficai, A. Glass Fibre-Reinforced Composite Materials Used in the Aeronautical Transport Sector: A Critical Circular Economy Point of View. *Sustainability* **2024**, *16*, 4632. https://doi.org/10.3390/su16114632

Academic Editor: Zhibin Ye

Received: 1 April 2024
Revised: 16 May 2024
Accepted: 20 May 2024
Published: 29 May 2024

1. Introduction

In recent years, fibreglass-reinforced composites have emerged as a material that offers eco-friendly alternatives to traditional materials. In this context, the matrix–reinforcing agent's complementarity is important, along with the challenges and potential solutions for the development of advanced composites that meet international standards and environmental norms while replacing the traditional materials that are currently in use.

The choice of the topic is motivated by a personal interest in chemical engineering and the development of fibre production methods that can be used, as it is a vast and lucrative field that many would like to explore, but the strategies to be developed are complex and often do not provide immediate results. It should be noted that achieving the most favourable methodology requires the initiation of a series of practical actions as well as the involvement of financial and human resources [1].

Fibre-reinforced composite materials are a particular class of composite materials with superior mechanical properties that are used in a number of high-tech applications, such as the automotive and aerospace industries. It is important to mention that improvements were made in recent years by improving the matrix, reinforcing the fibres/fabrics, and also by improving the compatibility between the phases. These composites should have high structural, thermomechanical, and/or tribological performances. For industrial applications, there are several resins and fibres that are extensively used depending on the requested applications and this will be discussed along with the improvements which can be obtained by functionalization [2]. The use of recycled glass is an essential way to obtain circularity by reusing the glass fibres. Such a principle is expected to achieve essential improvements in the integrity, reliability, performance, testability, robustness, and cost-effectiveness of next-generation materials for specific applications in households, the automotive industry, and even the aircraft industry.

The functionalization of the glass plays an important role because it can improve the compatibility between the phases and this can lead to important improvements in the mechanical performances of the materials. Bahar A. et al. [2] functionalized glass fibres with APTES ((3-Aminopropyl) triethoxysilane) and obtained improved mechanical properties (compression, tensile, and bending strength) for the samples based on EPOLAM 2000 Resin and glass fibre. Table 1 shows the differences between the simple material and the chemically functionalized material for the given mechanical tests.

Table 1. The difference in mechanical tests between a simple and a functionalized sample [2].

Sample	Treatment	Compression Strength	Tensile Strength	Bending Strength
1	-	4608.54 [N]	405,744 [N]	240.21 [N]
2	APTES	5209.68 [N]	439,301 [N]	251.56 [N]

This review summarizes the latest research progress in glass fibre-reinforced composite materials including different glass fibre surface modifications. Through continuous innovation in the composite materials, composite materials are being used in civil engineering; in automotive and aerospace applications, including UAVs; and also in energy- and medical-related applications in a more cyclic economic model.

2. Materials Used in Aero-Applications

Fibres in this class are produced on a large scale and in various combinations, denoted by capital letters such as C, A, D, E, S, R, etc. They are distinguished from one another by the percentage of oxide compounds in their composition, of which silicon dioxide (SiO_2) makes up the majority (55–73 wt%) [3].

The following types of glass are considered to be the most important for manufacturing composites [4]:

C-glass has outstanding chemical resistance and is suitable for composites that have to work in aggressive environments.

A-glass fibre has certain similarities to window glass and is resistant to chemicals. Process equipment is made with it outside of the United States.

D-glass has a high SiO_2 content, which gives it low density, good heat resistance, and very good dielectric qualities (close to those of silica); it is widely used in the electronic components industry.

E-glass is characterised by very good processability, high mechanical strength, electro-insulating properties, and stability under humid conditions; it is vulnerable and can degrade in strongly alkaline or acidic environments.

S-glass (North American version) and R-glass (Western European version) have the best mechanical performance of all types (including at high temperatures up to 750 °C due to their Al and Mg silicate contents; they are widely used in combination with polymer matrices in industrial applications in the aerospace and military sectors [4]. As a material, glass has been known since antiquity (the Etruscans are believed to have been the first to use it, at least in Europe), but its spread as a structural material occurred in the 17th century, with ever wider use, until its global expansion in the last century; the manufacture and marketing of glass fibres is thought to have begun in 1931, linked to their use in the production of electrical insulation for high temperatures; a decade later, in 1943, a composite of epoxy resin and glass fibres was first used in the construction of the fuselage of a fighter aircraft [5] and, nowadays, glass fibre-reinforced polymer composites are used in reinforced concrete, with the iron being replaced with these composite analogues.

In the early days of reinforced plastic manufacturing, fibres in this large category were the most commonly used reinforcement material. This was a groundbreaking period in which they successfully replaced metal in high-performance engineering applications [6]. Even with the remarkable growth of graphene, or carbon fibres, this is still the case for glass fibre-reinforced polymers, which still account for more than four-fifths of the market for polymer matrix composites; widely cited and widely accepted estimates state that 85% of the glass produced worldwide each year is used to reinforce plastics [6]. The main qualities of glass fibres fully explain and contribute to their supremacy in the composites market: they have very good tensile strength (around 4.6 GPa, but they also have resistance to compression and shock stress, dimensional stability, and corrosion resistance; they are malleable and relatively easy to process into braids; and they have very competitive specific strength (because they have a low density of about 2.5×10^{-3} kg/m^3); a low price compared to other fibres, plus a wide variety of presentation forms; for many applications, it is also important that they are non-hygroscopic (they do not absorb water from the working environment); they do not rot and burn, which makes them stable, but this can also lead to concerns related to their removal from the environment when they become waste or when they are hard to reuse in other applications [7].

The fact that raw materials for glassmaking are readily available and can be made from them, such as limestone, boric acid, and sand (one of nature's most abundant resources), explains their widespread use. There are possibilities for different combinations and ratios of these ingredients, which result in a variety of glass types with a wide range of mechanical and physical properties [8].

2.1. Materials Used in the Construction of Aircraft Parts

Carbon Fibre-Reinforced Polymers are probably the most important class of composite materials utilized in the aircraft business. Carbon fibre is viewed as fibres with a content of at least 90 wt% carbon. The term graphitic fibre is utilized to portray fibres with a content of close to 100% carbon. Today, carbon fibre is the dominant fibre in the advanced composite materials industry. In the last two decades, the properties of carbon strands have increased spectacularly as a consequence of the demand for more grounded and lighter materials, especially from the aerospace business. As a solidarity-to-weight ratio, carbon fibre is the best material that can be delivered on an industrial scale on any occasion. Carbon fibres are more expensive than glass fibres but offer a better combination of good strength, light weight, and high modulus values. The breaking strength of carbon fibre is equal to that of glass, while its modulus is three to four times that of glass [9].

The materials used in the Boeing 787's body design are displayed in Figure 1. More than half of modern aircraft, including the Boeing 787 Dreamliner, are composed of carbon fibre composites [10]. Every generation of Boeing aircraft has seen a rise in the percentage of composite materials used, with the largest being the 50 wt% of composite materials used in the next 787 Dreamliner [10]. As with the 787 Dreamliner, the weight of the composite elements of the aircraft is reduced by about 20 wt%. In the early 1980s, Airbus also used composites in primary architectural structures [10]. The company created the first carbon fibre fall beam for a large commercial air conditioner, the A340, in the late 1990s; composite materials are used throughout the new A380 [10]. A new conductive composite material was required to address the increased risks associated with the air conditioner, such as lightning strikes and ice accumulation, which resulted in a significant decline in its performance. Presently, air conditioners are manufactured using composite materials that do not lead power well, leaving them vulnerable to repeated destruction by weather [10]. Following the discovery and development of nanoscale fortifications, graphene, carbon nanotubes (CNTs), and nanofibres are now regarded as essential elements of next-generation built-up composites [10]. Without the need for extra fillers, the mechanical support and other important characteristics like electrical and thermal conductivity can be enhanced by including these nano-fortifications in polymer metrics. Therefore, these problems will be resolved when these conductive materials are used in the aviation industry [10].

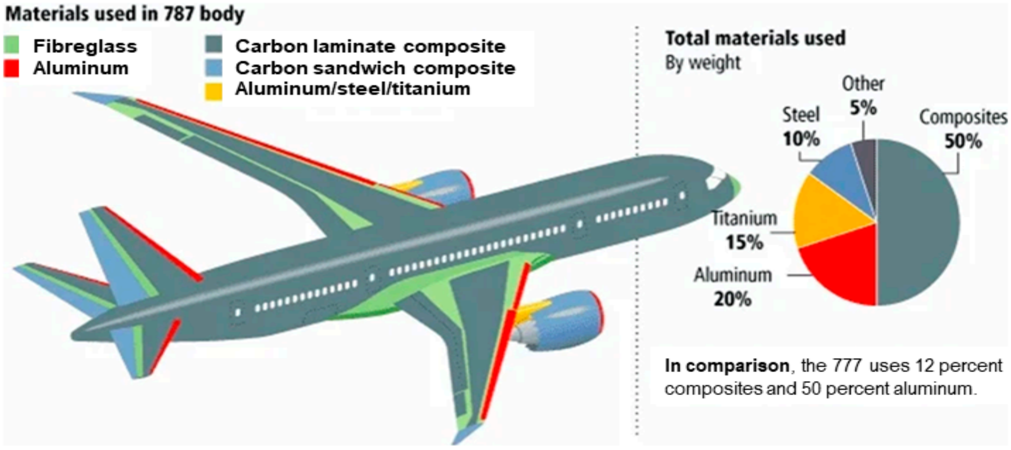

Figure 1. Various materials used in the Boeing 787 Dreamliner [10].

As very flexible reinforcing materials, carbon and graphite fabrics have very high mechanical resistance, relatively low density, and some of them have a special resistance to high temperatures (2300 °C) [10].

A wide variety of fibres are accessible for aircraft manufacturing. When creating custom furniture, three types are most commonly utilized. These are Kevlar, carbon fibre, and fibreglass. Fibreglass is produced with a range of physical attributes and price points. E-glass filaments are ideal for making composites because they offer the best physical characteristics at the lowest cost [10]. When a fabric is bidirectional, it means that the same number of filaments cross it crosswise as well. Next, the factory type is described. Based on the fibres' arrangement, there are several fabrics available, including satin, twill, bahtin, and so on [11]. Additionally, fibre fabrics are available in a range of densities, ranging from less than one ounce per square yard to over ten ounces per square yard [11]. Graphite fibre, often known as carbon fibre, is a really remarkable material used in aeronautics and in golf clubs, sailboats, etc. [11]. Critical areas, like the rear, are where carbon-based materials are used in custom aircraft design. Working with carbon fibres and fabrics can be a bit difficult, and, when they break, they snap like a carrot snapping in half. It is obvious that there is a very high failure point at which this occurs [11]. Another interesting choice is related to Kevlar fibres produced by the DuPont Corporation [11]. Because of the linear structures and the strong hydrogen bonds which can be developed between the fibres, it is a highly resistant and extremely hard material and thus is used in developing composite materials, including boats, tactical armour, etc. When it comes to applications that need to withstand abuse and cut resistance, Kevlar is quite persuasive [11].

The heat resistance, shear, and compressive strength of a composite are more dependent on the structure of the reinforced material, whereas firmness, flexibility, and rigidity are more influenced by the reinforced material. Polyesters, vinyl esters, and epoxies are the polymers that are the most commonly used as matrixes in Carbon Fibre-Reinforced

Polymers (CFRPs). In the aircraft industry and for industrial purposes, polyesters are typically used [11].

In the aircraft industry, the most used materials are vinyl esters. Vinyl esters are a hybrid of epoxy and polyester. They are far more scalable in terms of chemical resistance, strength, and adhesion than polyesters. Vinyl esters are simple to use because of their low consistency. It is also simple to shorten their relieving time by adding extra hardener, which shortens the restoring time. Despite the restoration period, the alleviated vinyl ester typically exhibits consistent strength and flexibility characteristics. Vinyl esters are less expensive than epoxies and are not subject to moisture problems during application. A drawback associated with the use of vinyl esters is the mixing of chemicals. Before use, the vinyl ester resin is typically activated using copper naphthalenate (CONAP). Methyl ketone peroxide (MEKP) is added as a hardener that actually initiates the relieving system shortly before the fibres are added, and dimethyl aniline (DMA) is added as an accelerator that determines how quickly the mix will polymerize. Some concerns have to be considered in the processing because, for instance, if MEKP is combined directly with DMA or CONAP, the mixture may become unstable [12].

Epoxies are the resins of choice used in the majority of expertly completed aircraft repairs and have come to dominate the aerospace industry. Epoxies are heat-cured and the polymerization occurs by "cross-connecting". Essential components of epoxies are lengthy atom chains that, when released, interlock to form significant strength regions for a network of cross-connected chains. This lends the matrix an internal structural coherence. Epoxies are used in composite designs that are unmatched in strength and delicateness when combined with the proper reinforcing agent materials. In contrast to polyesters and vinyl esters, the mix of hardener and resin needs to be very strictly dosed. Adding extra hardener will not shorten the cure time; in fact, it may even delay the process [12].

It is important to pay attention to the manufacturer's recommendations regarding their processing and application. At normal temperatures, most epoxies cure, but the final properties (including strength) are obtained in a "post-curing" process which is mainly based on a thermal treatment at a higher temperature. Usually, this entails increasing the temperature for a period of time to above 60 °C. Epoxies have a far longer work time than polyester and vinyl ester because specific heaters with customized work times can be used. Some of them require as short as four minutes; others require up to twenty-four hours at seventy degrees [12,13].

2.2. High-Performance Materials Used for UAV Manufacturing

Multirotor and fixed-wing unmanned aerial vehicles (UAVs) are the most often used types of UAVs. Their capabilities, which essentially improve the mechanical, aerodynamic, and other aspects of vehicles, depend on the kind of electronics that are integrated into a vehicle as well as the material that was used to construct it. However, battery-powered UAVs are less durable and have a lower operational range [14]. It all comes down to using high-performance materials when building the drones. A high strength-to-weight ratio, non-corrosive properties, fatigue resistance, a low cost, easy access to raw materials, a low noise output, and environmental friendliness are important characteristics to look for in UAVs. Strong battery power is needed if the drone weighs too much in order to maintain flight and provide extended autonomy. Lightweight materials are essential to prevent this. Either less high-density (high-strength) material or less low-density material is utilized for lightweight drones [15]. Most UAVs nowadays are constructed from high-strength, lightweight carbon fibre instead of the nearly all-aluminum construction seen in the past. Not to mention, a variety of materials are employed for a range of tasks and missions, including military tasks, delivery, mapping, and even human rescue. The material should be selected based on the application, payload, and sensors it carries. For instance, drones with jet engines are now available on the market in addition to the battery-powered UAVs that are still in use today. In order to reduce fuel consumption and extend the lifespan of these aerial vehicles, certain materials need to be used. In their analysis of magnesium's use as a building material for drones, Chandramouli K. et al. [16] also presented potential uses for airborne, manned, and unmanned vehicles in the future. The components that magnesium can be employed for are those that are discussed because of its light weight and capacity to sustain impacts. Using Ashby plots, magnesium, titanium, aluminum alloys, and composites were compared. Ultimately, it was discovered that when magnesium-based components are manufactured by electrolysis, they can be more economically efficient, recyclable, and have a lower carbon footprint than aluminum. An aircraft's vertical take-off and landing (VTOL) process of the transition from vertical to horizontal flight was studied by Kaske H.K et al. [17]. Their goal was to create a compact, mobile, unmanned aerial system that combined the benefits of multirotor and fixed-wing designs. The finished prototype (canard) was made of carbon fibre-reinforced plastic. Because the canard shaft was a high-stress area, aluminum was utilized in it. The primary structural components were the steel rods that secured the hatch. The Unmanned Aircraft System's skin was made of aluminum alloy 6061-T6, which was chosen after taking the bending loads into account. Jesuarockiam N. et al. [18] looked into the uses of graphene-based nanocomposites in energy devices. Applications include thermoelectric conversion, solar cells, lithium-ion batteries, and fuel cells. It was demonstrated that graphene exhibits excellent thermoelectric energy conversion efficiency, low resistance, high power density, and high carrier mobility. Al-Khabsheh B.N. et al. [19] looked at how to create a novel composite using carbon fibre and epoxy resin LY5052. Using COSMOL software, Shivaji Lamani et al. investigated the creation and testing of sandwich composites composed of a balsa wood core and fibreglass or polyester resin. Tests for tensile, compression, and flexural strength were conducted with the use of a universal testing apparatus. According to the findings, a standard polyurethane core is not as thermally resistant or as structurally sound as a balsa wood core and fibreglass/polyester skin [1].

Lightweight aircraft materials such as titanium alloys, aluminum alloys, high-strength steel, composites, and some intelligent materials like shape memory and self-healing materials were studied by Lassila, L. et al. [20]. They also talked about using computer-aided structural optimization to improve UAV performance and save costs. Additionally, the amount of material weight reduction that additive manufacturing techniques may achieve was evaluated. Manufacturability methods and high costs are still problems [20]. Their model consisted of three primary materials: glass fibre for the propellers, carbon fibre for the entire fuselage and stabilizers, and Kevlar 49 for the area beneath the fuselage. The application of composite materials and their benefits and drawbacks were the primary topics of discussion. The non-destructive test revealed that the UAV's motor mount, wing joint, and landing gear were all free of defects [21]. In order to improve the mechanical qualities and elastic modulus of acrylonitrile butadiene styrene (ABS), Hui Y. et al. looked into the manufacturability of an ABS matrix with sandwich layers of CFRPs. Three alternative ABS printing material densities—high, medium, and low—were selected. Applications of the GFRP composite in the engineering and aeronautical domains were investigated by Babaee M. et al. [22]. The composite was made using the hand lay-up technique. The technique of fused deposition modeling for 3D-printed RC airplane wings and fuselage was studied by Hashim, M.F.A. [23]. The materials explored included PET, ABS, and PLA. Before 3D printing, each part's weight was determined. The wing and empennage were connected by a carbon fibre beam. Different materials were employed for different parts: the fuselage surface was made of glass and carbon fibre, the wing surfaces were made of carbon fibre, and the ribs were made of balsa wood. The performance of employing morphing (adaptive) wings for UAVs with a maximum take-off weight of 15 kg was examined by Ridzuan M.J.M et al. [24]. In order to reduce potential effects on aerodynamic drag, the morphing wing was designed to be "adaptive," which means it may "shape-shift" smoothly and automatically during flight, without slots or steps on wing surfaces, employing a control system without requiring any direct pilot engagement [24].

Using selective laser sintering (SLS), nylon was used for the inside components while polystyrene foam was used to create the wings. Utilizing computational fluid dynamics

(CFD), the roll rate performance was assessed. Transforming wings were assumed to outperform traditional ones.

2.3. Fibreglass Manufacturing

Essentially, laminates consist of layers of fibres (such as glass, carbon, etc.) assembled with resin (particularly epoxy) to provide superior mechanical, electrical, and chemical performance, as well as better design flexibility in the final panels. Composite materials made of fibreglass-reinforced polymers (GFRPs) come in several varieties, including flat, twill, and satin. These materials are commonly used because of their excellent mechanical properties, thermal properties, corrosion resistance, ultimate strength, and stiffness-to-density ratio in comparison to conventional engineering materials, such as strength, ease of fabrication, etc. [25].

As a result, scientists raced to investigate their mechanical, thermal, acoustic, fatigue, and impact properties. Furthermore, numerous models have been created to replicate their failure and rupture modes by incorporating small materials (PZT piezo elements) and various forms of nonlinearity. Despite all of the above benefits, their low recycling potential has proven to be a significant obstacle, particularly because these waste materials contain a high concentration of bromine, which can lead to numerous health and environmental issues [26,27]. Five fundamental steps make up the manufacturing process: mixing, melting, fibreing, coating, and drying [28–30]. A chemical coating or size is applied in the final stage. Size is the proper term for the applied coating, and sizing is the process used to apply this process, despite the fact that the terms binder, size, and sizing are frequently used interchangeably in the industry. Coatings are typically added at a weight percentage of 0.5 to 2.0. Coupling agents and/or binders are examples of lubricants [31–33].

Glass fibres are considered suitable for low- to medium-performance composites, typically used in applications considered non-critical, such as filter installations, various types of piping, electrical and thermal insulators, and vehicle components (including military and aerospace applications where a high specific strength is important) [34]. If, on the other hand, composites (with a polymer matrix) are introduced into a structure where high stiffness is expected, then they are combined (i.e., hybrid reinforcement is achieved) with stiffer fibres such as carbon, boron, or Kevlar; there is another practical way of achieving this—using the composite in a sandwich structure, where the glass fibre composite alternates with layers of metal, wood, or even impregnated paper. Similar in nature to glass fibres are silica fibres, characterised by a much higher content (between 96% and 98%) of SiO_2, and quartz fibres, which are produced from highly pure silica crystals (up to 99.95% SiO_2); both types are characterised by lower density values than glass, insensitivity to moisture, and remarkable resistance to chemical agents [35].

The mechanical strength of glass fibres depends on the technological process by which they are obtained and their cross-sectional size, but they generally have mediocre values, which decrease even more when the working temperature increases. Quartz fibres are comparable to glass fibres in terms of tensile strength, and their modulus of elastic activity (varying from 70 to 120 GPa based on diameter) is marginally higher than that of glass fibres. It is worth noting that quartz fibres have the highest specific mechanical strength of all fibres that can withstand high temperatures, including silicon carbide and aluminum fibres [36].

Quartz fibres are also prized for their high resistivity and the best dielectric properties of the common reinforcing fibres, so much so that they have found numerous applications in high-tech areas such as the aeronautical industry (a spectacular example is their use in the outer skin structure of aircraft that are 'invisible' to radar—known as stealth) [36]. Because of their purity (which also makes them relatively expensive compared to E- and S-glass fibres), they have very good resistance to radiation (they are transparent to radio waves and ultraviolet and ionising radiation) and high temperatures; they also have remarkable dimensional stability, thanks to their low coefficient of thermal expansion, which has the same values in both the radial and axial directions, so that they are also highly resistant to thermal shock. Lastly, quartz fibres have the advantage of being able to be used in the manufacturing of composites in conjunction with a variety of ceramic materials and resin types. If the fibres are treated with a silane coupling agent, this ability to work with various resin types can be further enhanced [37].

2.4. Safety

Since most products were banned after it was discovered that asbestos causes cancer, the popularity of fibreglass has increased. But since asbestos and fibreglass are both silica in nature, there are concerns about similar behavior, raising questions about the safety of fibreglass as well [38]. Considering these, numerous researchers have been started to clarify these aspects; some of these studies and especially their conclusions are summarized below. Fibreglass is regarded as safe as long as the appropriate safety gear is used during installation. The International Agency for Research on Cancer (IARC) summarized their 1988 review in a press release that was released in 2001. After examining man-made glass fibres used for insulation, such as fibreglass, they concluded that there was insufficient evidence of any cancer risk and no evidence of increased risks of lung cancer or mesothelioma (cancer of the lining of the body cavity) from occupational exposures during the manufacturing of these materials [38,39].

The Insulation Manufacturers Association of North America [40,41], the American Conference of Government Industrial Hygienists, and other organizations also note that conclusive research has not demonstrated that fibreglass is carcinogenic to humans. All biosoluble glass wool, including fibreglass used in non-insulating products and home and building insulation, was eliminated from the National Toxicology Program's 2011 "Report on Carcinogens" [40,41]. The Proposition 65 list has been amended by the California Office of Environmental Health Hazard Assessment ("OEHHA") to remove all items other than "Grass wool fibres (inhalable and biopersistent)". The fibres used to make building insulation products are not included in this. Because of this research, the biosoluble fibreglass packaging used in today's fibreglass insulation does not need a cancer warning label [41,42].

Wearing the appropriate safety gear is advised when installing fibreglass or coming into contact with it during home renovations to prevent skin contact-related irritation or inhalation of the fibreglass. It is advised to wear gloves, a suitable head covering, and loose-fitting, long-sleeved, long-legged clothing. The Insulation Manufacturers Association of North America offers a set of suggested work practices for handling fibreglass, rock wool, and slack wool products. In order to prevent the insulation from entering the vents and spreading throughout a building or house, it must also be properly sealed. It is not recommended to leave it out in a busy area, as per the American Lung Association. Inhaling fibreglass particles does not appear to cause long-term harm, and employees who regularly come into contact with fibreglass insulation are not thought to be at an increased risk of respiratory and lung issues, especially if they take appropriate safety measures [43–46].

Although fibreglass is thought to be safe when handled correctly, there are some environmentally friendly substitute insulation options available. These consist of materials derived from soy, such as hemp, fleece, and recycled denim. Despite accounting for a relatively small share of the USD 9.5 billion US insulation market in 2022, the use of these niche products is anticipated to increase [47].

Since there are not many suppliers of substitute insulation, it is hard to find these products in many markets, which restricts their ability to grow. To make matters worse, these substitutes are frequently more expensive than more established forms of insulation, which limits their market potential. But as consumer demand for eco-friendly products grows, demand for eco-friendly substitute insulation may rise, and suppliers may choose to capitalize—at least partially—on the trend by increasing their investments in R&D to cut production costs and give the customer a more favourable return on their investment [48].

2.5. Future Materials

The advancement of UAV technology has made it imperative to design improved materials. New materials must be developed in the aircraft industry in the future to increase endurance, speed, dependability, and reduce cost. The goal of future engineering is to make everything controlled. This is where self-engineering enters the picture, in which the material restores any changes it makes on its own without the need for human intervention [45]. Shape memory alloys (SMAs) function based on the theory of temperature-dependent deformation. Their lift can be adjusted by modifying the form of the airfoil using the SMA wires [49]. When far-end scanning is required, this can be utilized in UAV wings. The delosperma cooperi plant, which alters its body wounds when sliced to stop water loss, is one example of a shape memory material that was inspired by nature [49]. There have been cases when debris has struck the airframes and long-term exposure to moisture and wind has caused corrosion to the material. Self-healing materials are being developed to combat this and extend their lifespan up to five years [49]. In addition, innovations such as printing electronics directly onto carbon fibre, which conducts electricity, have left many in awe [49]. Biodegradable materials are moving forward with sustainability as a trend. After serving their purpose, these materials will be able to return to nature and break down. This will be especially helpful for military operations where it is imperative to remove evidence [45]. Self-adapting materials are available to enable UAVs to adjust to changing environmental conditions, including temperature variations [49]. In order to be used in warfare, stealth UAVs need to "hide" from enemy radar. For radiation protection, materials that absorb radar are even positioned at the engine's inlet [50]. These new materials are paving the way for an exciting future filled with cutting-edge inventions and technologies.

3. Current State of Glass Fibre-Reinforced Composite Materials and Functionalization

The silanization process is frequently used for the functionalization of oxide surfaces because of its beneficial characteristics, which can be induced easily, such as having good reactivity, while its bifunctional nature means that it can be bound to the oxide surface, usually while introducing an organic moiety with specific characteristics. Moreover, it is important to mention that their reasonable/low cost makes them suitable for industrial applications. Optimizing the deposition process, common silanization agents such as 3-aminoprypyl triethoxysilane (APTES) can be used to coat the glass surface with a continuous monolayer, which is important to generate a stable surface with improved compatibility with the polymer phase [51].

In Figure 2, the structure of APTES and the method of binding to the surface are presented.

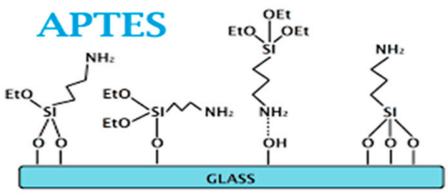

Figure 2. The silanization process with 3-aminopropyltriethoxysilane (APTES) [51].

Typically, thin films of 3-aminopropyltriethoxysilane (APTES) are employed to promote adhesion between silicate substrates and organic materials, with uses ranging from biomolecular lab-on-a-chip to advanced composites. Unfortunately, there is misunderstanding regarding the reaction conditions that will inevitably lead to allergic reactions. Researchers often employ a variety of contradictory experimental techniques, such as the creation of self-assembled smooth monolayers. For the APTES system on silica, the effects of reaction temperature, solution concentration, and reaction time were investigated [51].

The two phases, the matrix's nature, and the reinforced material's morphology were taken into consideration when classifying the composite materials into various categories. The mechanical properties are strongly influenced by the morphology of the reinforcing agent. Figure 3 shows the structural representation of the matrix composites reinforced with various kinds of reinforcing agents. Generally speaking, the basic metals are copper, steel, aluminum, and titanium. Additionally, there are three types of matrix-reinforced composites: continuous matrix-reinforced or sheet-reinforced composites, short-fibre/whisker-reinforced composites, and particle-reinforced composites [52]. These are more rigid, more durable, and have a high tensile strength. It is important to note that the anisotropic nature of the fibre/fibre-reinforced composites causes a notable variation in the mechanical properties along or perpendicular to the fibre direction on the three axes.

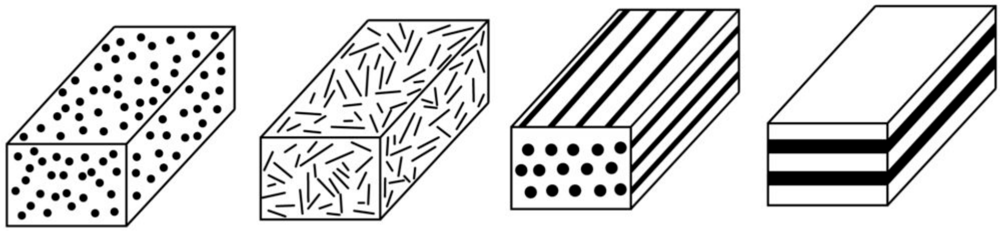

Figure 3. Mechanical behavior of composite materials [52].

The most common fibres used to reinforce composites, particularly polymer matrix composites, are glass fibres. The main benefits of employing these kinds of fibres are their reasonable prices and practical mechanical attributes. Low and unsatisfactory resistance to absorption, structural sensitivity during mixing, and, in some situations (such as low adhesion to the polymer matrix in the presence of water), decreased adhesion to the matrix are also disadvantages. The instability of ordinary glass fibres in an alkaline environment limits their use in the case of ceramic materials like concrete, mortar, and cement paste [52].

Figure 4 shows how 3-methacryloxypropyltriethoxysilazane (3-MPTMS) was used as a silane coupling agent to functionalize the silica filler. The primary purpose of Modesti, M. et al.'s research [52] was to look at the effect of filler silica on the mechanical, chemical, and physical properties of experimental composite resins. When compared to non-silanized filler, silanization enhances the surface area of the silica filler and allows it to be more equally dispersed in the organic matrix. Furthermore, the silicone coupling agent prefers a chemical interaction or even a chemical bond with the acrylic resins. The mechanical properties of non-silanized silica-reinforced composites were compared to the mechanical properties of siliconized composites. Depending on the chemical bonding between the filler and the organic matrix, the mechanical and chemical properties of siliconized composites were better than those of composites containing non-siliconized filler structures [53].

The composites, which contained varied weight segments of pineapple leaf fibres and polyester resin, were found to be fairly biodegradable. Their mechanical properties, including their impact strength, tensile strength, and tensile strength, as well as their bending and water absorption behavior, were investigated. It was feasible to efficiently manufacture a new class of polyester-based composites reinforced with short pineapple leaf fibres. The addition of fibres raised the Young's modulus, which raised the tensile strength as the percentage of fibre content increased (short pineapple leaf fibres). It was discovered that flexural stiffness increased as the fibre content increased. The material's impact resistance at 40% fibres was determined to be 41 kJ/m^2. When it comes to moisture absorption, the composites' water consumption rose as the weight fraction of pineapple leaf fibres decreased. At 30 weight percent, the biocomposites' mechanical characteristics improved. Short pineapple leaf fibre loading can serve as a suitable replacement for cementitious composites in structural applications that require low strength. On the basis of these encouraging findings, research on the strengthening impact of various chemical treatments on pineapple leaf fibres in terms of tribological and thermal characterization is possible [54].

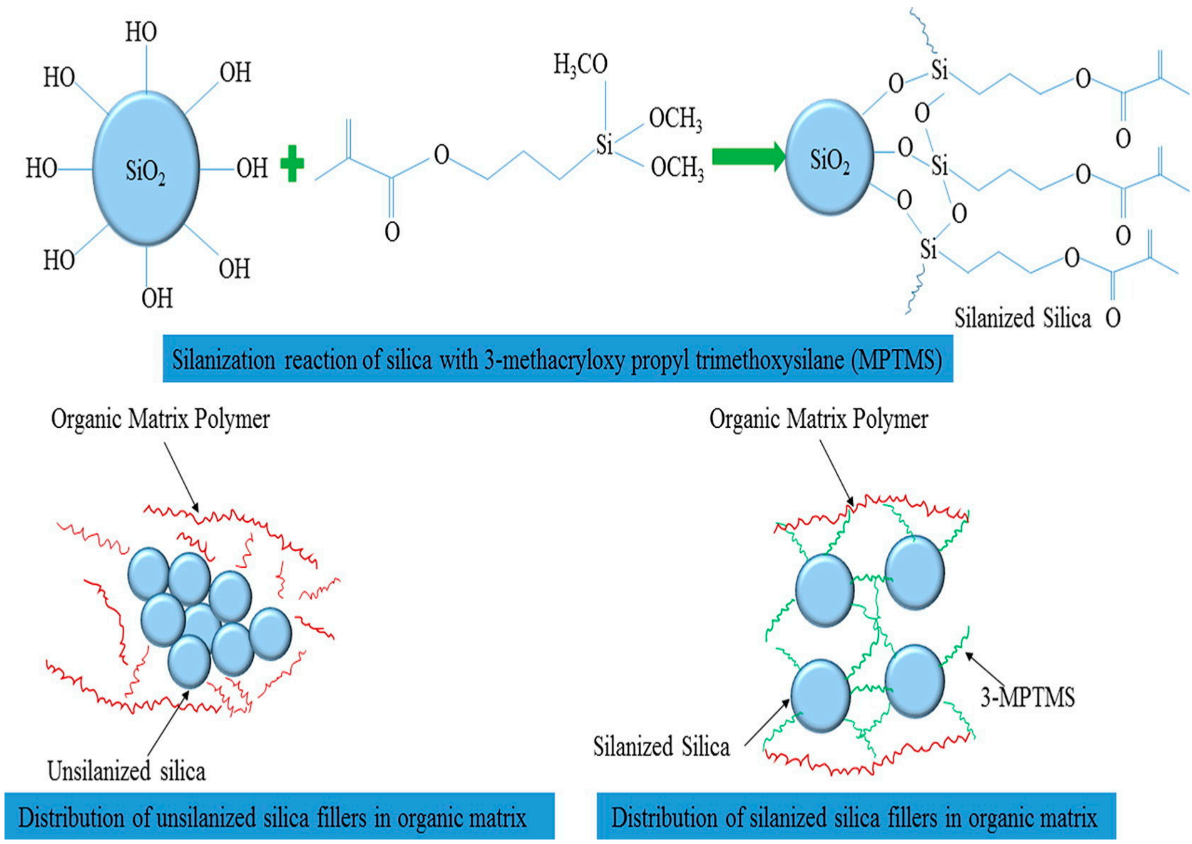

Figure 4. Properties of composite resin affected by fillers modified with silane [53].

3.1. The Main Characteristics of Fibreglass

The most widely used fibres are C-, A-, D-, S-, R-, and E-glass, which are weather-resistant in addition to having a high electrical resistance and good mechanical strength. Type C glass is recommended in some situations because it resists corrosion better than type E glass but has a weaker mechanical strength. When compared to the other materials, S-glass is more expensive than type E glass but has better mechanical strength, elastic modulus, and resistance to high temperatures. The decrease in adhesion forces at the polymer-reinforced interface with rising water content is indicated by the surface and fibre breakage [37]. It is also important to remember that glass fibres are typically amorphous. However, after extended exposure to high temperatures (>40 °C), some crystallization may happen, which will reduce the material's strength by up to 50%. Composite materials are extremely elastic and found in many different applications (buildings, aircraft, etc.) [55]. Composite parts provide very pure strength and the structure becomes lighter and can be molded into any shape. The main use of fibreglass is to make sheets and coatings. It is primarily utilized in the automotive and aerospace industries, as well as in numerous home applications. Fibreglass is typically combined with polyester to create fibreglass sheets. This includes a system made up of two or more distinct phases separated by a characteristic platform, whose combination produces summed squared properties that are superior to their individual components in many ways.

Glass fibres are excellent because of their high surface-area-to-weight ratio. They are, however, significantly more sensitive to chemical attacks due to their larger surface area. By trapping air inside, fibreglass blocks provide good thermal insulation and a thermal conductivity of about 0.05 W/(m*K). Gloss strength is typically evaluated and reported for "virgin" or clear fibres, which have recently been manufactured. Because thinner fibres are more ductile, the strongest fibres are the freshest and thinnest. With increasing surface scratching, the resulting hardness diminishes [56–58]. Because glass is amorphous, its properties stay constant both along and throughout the fibre [58]. Moisture is a crucial element in determining tensile strength. Moisture is readily absorbed, aggravating microscopic cracks and surface imperfections while weakening toughness. There are several works evaluating the effect of moisture on the mechanical properties of different GFRPs. In accelerated conditions, namely in boiling water for 24 h, the glass fibre-reinforced vinyl ester resin composites absorb water and become saturated after ~8 h, while significant mechanical property degradations are observed especially in the first 4 h [59]. Based on some previous works, water enters the composite materials according to three mechanisms: (i) the diffusion of water molecules directly into the matrix; (ii) the preferential flow of the water along the fibre–matrix interface, followed by diffusion; and (iii) water penetration within the defects, microcracks, pores, etc. Based on the study realized by Roy R et al. [59], the variations in the flexural strength and toughness are dependent on the composition, and they vary according to Table 2. It is obvious that by increasing the content of the fibreglass, the influence of the water absorption is lower and both flexural and toughness variations are lower.

Table 2. Variations in mechanical properties over time of conditioning in boiling water [59].

Fibre Content %	Flexural Strength Variation (MPa)				Toughness Variation (kJ/m^2)			
	0 h	**4 h**	**8 h**	**24 h**	**0 h**	**4 h**	**8 h**	**24 h**
27.48	444.5	399.0	374.8	365.9	20.29	18.04	15.03	11.99
38.63	475.9	452.7	437.3	430.5	29.10	27.50	23.58	22.11
48.48	519.9	486.9	465.7	463.8	34.16	33.63	31.27	29.90
55.75	554.9	527.4	503.2	495.8	39.79	37.54	35.40	35.20
63.50	658.9	602.8	565.5	548.4	49.02	45.35	40.52	39.32

The elongation at break of carbon fibres is approximately one-third that of the fibre [58]. Reinforcing thermoplastic polymers, such as polyesters, polyamides, and polypropylene, with glass fibres results in materials with very appealing characteristics [60,61]. Fibreglass's thermoplastic compositions have a high level of impact resistance, great strength, and stiffness. These materials are widely used in residential, automotive, and industrial applications due to their low specific gravity, simplicity of production, and adjustable features [62].

3.2. Properties of Composite Material Reinforced with Fibreglass

The varied chemical makeup of raw materials results in a comparatively wide range of materials with highly disparate properties. Table 3 [62] presents these compositions as well as the primary characteristics of the kinds of fibre that are most frequently used in composites.

Particularly well suited for laminates with high strength and low weight is type E fibreglass. In these applications, continuous filament glass is favoured because of its higher strength and lower bulk factor. The thickness of continuous filament glass fibres ranges from 0.002 to 0.02 inches. Generally speaking, the type of fabric and web configuration employed determine the laminate's directional qualities. Among many applications, the material used to produce airbrush radiators is a good example of fibre-reinforced plastic because it keeps the radiator free from outside influences that could interfere and alter the desired outcome. A material that enables the radar beams to transmit and receive information without distortion from the radar sending equipment in the target to the radar receiving equipment in the aircraft is needed for this application [62]. Along with withstanding air pressure, it must also maintain subsonic or supersonic speed. Low-pressure plastic resin (POLYLITE 440-M888) and glass fibre combine to provide a great answer to these needs [62]. This material is also used for fittings, the low-pressure manufacturing of large items like boilers, hollow rods (where the unidirectional factory lends itself to wrapping around a solid handle), and many other products. Glass fibres and flame-retardant polyester resin are combined to create high-strength patterned and flat laminates for aircraft parts like floors, shelves, ducts, panels, noses, wingtips, rudder points, hoods, and decks [63].

Table 3. Characteristics and composition of glass fibres utilized in composites [62].

Characteristics	Type E	Type C	Type S
Composition [wt%]			
SiO_2	52.3	64.2	64.5
$Al_2O_3 + Fe_2O_3$	12.5	4.4	24
CaO	17.3	13.2	-
MgO	4.6	3.3	10.3
$Na_2O + K_2O$	0.80	9.6	0.3
B_2O_3	10.6	4.7	-
BaO	-	0.9	-
Properties			
Density—ρ [g/cm^3]	2.6	2.49	2.48
Surface tension—σ [GPa]	3.45	3.3	4.6
The modulus of elasticity—E [GPa]	76	69	85.5
Dip Temperature—T. max [°C]	550	600	650

Table 4 presents the characteristics of the materials in the above table, which were composed of AERO glass fibre fabric with a density of 80 g/m^3 and POLYLITE 440-M888 orthophthalic polyester resin. To start the process of free radical polymerization and cross-linking the polyester molecules with the styrene, 1.5% Norpol peroxide (98.5% ethylic alcohol) was mixed with POLYLITE. A manual processing method was used at room temperature to create a composite laminate consisting of fourteen layers of glass fibre with an equal stacking sequence and a total thickness of 1.3 mm [63].

Table 4. Mechanical characteristics of composite materials [62].

Property, Unit	Value
Tensile strength (90 °C), MPa	135 ± 10
Young's modulus (90 °C), GPa	11.8 ± 0.8
Shear strength, MPa	40 ± 2
Shear modulus, GPa	2 ± 0.2
Tensile strength (0 °C), MPa	165 ± 10
Young's modulus (0 °C), GPa	13.8 ± 0.5
Poisson's ratio	0.2 ± 0.03

Glass fibres have isotropic properties, in contrast to carbon fibres. As a result, the transverse and longitudinal moduli of elasticity have different values. Due to water absorption on the surface in the case of E-type glass, resistance decreases even in humid air; additionally, a greater decrease in resistance may be observed if the surface is exposed to mineral acids [64]. But one more significant factor affecting the strength of all kinds of glass fibres is the damage caused by processing operations [64]. Glass fibres are typically treated by spraying a thin layer of an aqueous film-forming polymer solution, such as polyvinyl alcohol, in order to reduce this damage [64].

This polymer treatment has several benefits, including the following [64]:

- Preventing damage to the fibre surface;
- Binding the fibres to speed up processing;
- Ensuring fibre lubrication;
- Boosting wear resistance during additional processing operations;
- Providing anti-static properties;
- Increasing the adhesion force at the interface and forging a stronger chemical bond between the glass surface and the composite matrix [64].

Because of their improvements and light weight, glass fibre-reinforced composites have been extensively studied in numerous research projects. These materials have also found application in a wide range of engineering settings. As evidenced by the construction industry, the use of polymers in materials has been shown in numerous engineering applications to increase corrosion resistance and strengthen a variety of structures. Fibre loading and orientation are the main factors affecting these composites' properties. Considering a fibre loading of 20, 30, and 40 wt% and four different orientations of the fibres and of the successive layers of glass (15, 30, 45, and 60°), Debiasi et al. showed that the mechanical properties are strongly dependent on these two parameters [65]. The variation is a complex one; there are situations when the mechanical properties are higher at 30% (intermediate) glass fibre loading but, also, there are situations when the sample with the lowest loading (20% glass fibre in the epoxy resin) has higher mechanical properties. For instance, the maximal flexural strength was obtained for the composite containing 20% glass fibre and the orientation of the fibres at 30°, which is much higher than any of the other 11 samples considered in this study. Moreover, the erosion rate was also evaluated and the sample with 20% fibre loading showed a maximal erosion rate for the samples with 30° fibre orientation while, for the other two composites with 30 and 40% loading, the maximum erosion rate was found for the samples with 15° fibre orientation.

In Figure 5, Debiasi, M. et al. [66] present the effects of moisture absorption on the mechanical characteristics (elongation at break) and degradation mechanisms of a novel sandwich biocomposite based on flax fibres. Cork serves as the sandwich's core and linen composite serves as its skins. The experimental findings demonstrate that the mechanical properties of the sandwich biocomposites are positively impacted by the presence of a plug in the core and a paper layer in the shells. Based on a composition of aluminum, calcium oxide, and borosilicate, fibres produced from "E"-glass are considered the main reinforcement material for polymer matrix composites due to their good electrical insulation properties, low moisture affinity, and good mechanical properties. Other compositions include "S"-glass, which has better mechanical strength and heat resistance, as well as some specialized glass reinforcements with better chemical resistance, such as AR-glass, which has better alkali resistance [66].

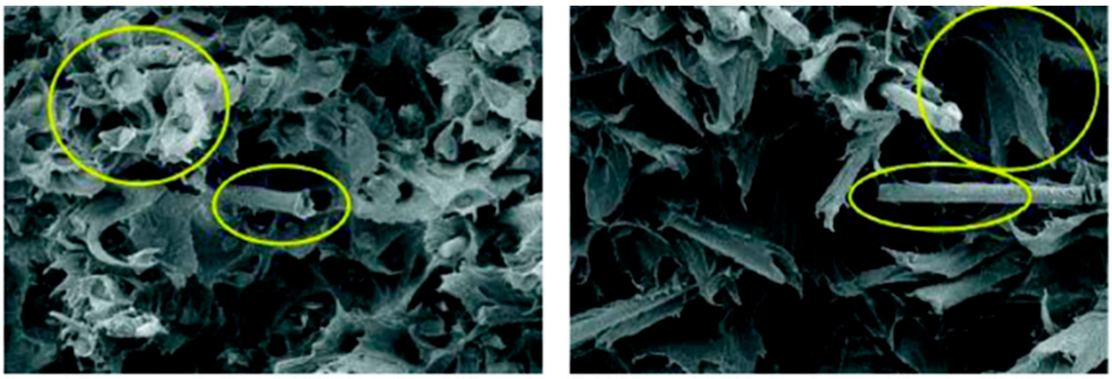

Figure 5. The impact of water absorption during the tensile test on the sample [66].

The glass fibres used in the reinforcement of thermoplastic and thermosetting resins were obtained from so-called textile glass made up of warped threads and twisted threads.

The most widely used textile glass used in the reinforcement of polymer composite materials is non-alkaline type E glass (with a composition consisting of calcium borosilicate and aluminum). This is utilized due to its excellent mechanical, electrical, and chemical qualities as well as its extremely affordable cost. The final form of the fibres can vary from discontinuous fibres (striated, short or long) to continuous fibres in twisted strips, woven fabric, non-crimped fabrics, and unidirectional pleats [67].

3.3. The Factors Influencing the Composite Materials' Qualities

The properties of the composite material and its anisotropy will depend on the kind, distribution, size, shape, orientation, and arrangement of reinforcement. When approaching the topic of the influence of aggressive environmental factors on composite materials, attention is focused on their action on the structural components: the fibres, matrix, and fibre–matrix bond [68]. This is because the destruction and rupture of composite materials can occur according to a variety of failure mechanisms and modes, including the following:

- Breaking of the fibres—this happens mainly under the action of traction loads;
- Microcracking of the matrix—this indicates the appearance of microscopic cracks in the polymer matrix;
- Matrix cracking—this is similar to microcracking;
- Destruction of the fibre–matrix connection—as a result of this, the reinforcing fibres detach from the matrix;
- Exfoliation—this refers to detachment of the layers of a layered composite material (delamination).

The aggressive environmental factors, previously presented, will influence the characteristics of the composite material at both the microscopic and macroscopic levels. This will obviously reflect the state of tension and deformation. Composite materials are nevertheless used extensively even if the hostile environment has a negative impact on their design [68]. The performance of composites can be impacted by hot and humid climates. For fibreglass/polyester and fibreglass/epoxy, where the surface sap was dissolved due to widespread weathering, a 10–20% decrease in stiffness was observed. Certain portions of the architecture, like ravines or leading edge pieces, may suffer from disintegration due to the impact of rain, snow, or ice.

Composite parts can be stronger against this kind of breakdown by using coatings like polyurethane. The effect of weathering on composites is dependent on the type of material used and if a protective layer was applied. Research showed that materials retained more than 90% of their original strength and 80–90% of their modulus in the areas where the paint was applied. The composite retained less of its original assets in the case where the paint was dissolved; for instance, in [69], only 68% of the original strength was retained. It is anticipated that composite components will pass dampness testing, which typically takes into account the design condition both prior to and during static and dampness saturation fatigue tests. After immersing the composite parts in liquids such as fuel, hydraulic liquids, cleaning agents, de-icing liquids, and so on, static tests are carried out. Cryogenic temperatures (−150 °C to −273 °C), elevated temperatures, and thermal cycling between these limits are among the temperature effects on composites. It does not appear that the mechanical properties of graphite/polyimides or graphite/epoxies are significantly impacted by cryogenic temperatures. However, they reduce the shear strength and render the composite material somewhat brittle. Elevated temperatures for a protracted period of time can significantly alter a composite's characteristics, with a more pronounced effect in the event that moisture is present [69,70].

In conditions of overheat, the heat produced by lightning strikes is known to cause matrix gums to vaporize and to cause large areas of fibre delamination and fracture on composite nose arches, wingtips, rudders, ailerons, and capillary casings. A cycle of thermal oxidation can completely destroy the gum's polymer fasteners when exposed to heated temperatures for extended periods of time. The use of heat-resistant adhesive coatings is one example of a preventive method [71]. Over the course of their estimated

30-year lifespan, the composites can be exposed to cold temperatures (−20 °C or less) and high temperatures (50 °C or more). It has also been explained that other mechanical characteristics, such as ultimate stiffness, compressive strength, and elasticity (which is dominated by the matrix), decrease at high temperatures. The analysis revealed that when the temperature rose from −50 °C to 100 °C, the laminar fracture energy decreased by 25% to 30%. The internal stresses caused by the various thermal coefficients of the constituent elements of the composite materials are what cause the influence of temperature on the mechanical properties of composites. These internal stresses vary in strength as temperature changes, sometimes resulting in matrix cracking at very low temperatures (−150 °C to −273 °C). Each polymer has a unique operating temperature range in practical applications. The problem has been found to be exacerbated by high temperatures combined with moist circumstances, among other factors, by further lowering Tg [72].

3.4. Impact of Materials in Design and Fabrication of Composite UAVs

In the present day, engineering and technology are advancing quickly. The development of aeronautical engineering technologies focusing on the design and modeling of drones, or UAVs, for both civil and military usage is one area where research is progressing more quickly. UAVs are aircraft without a human pilot or occupants. There is a lot of interest in creating UAVs that can operate in a variety of conditions and autonomously carry out a range of tasks in remote regions. The wings, horizontal stabilizer, rudder, and other aerodynamic surfaces of UAVs are made of composite materials [73]. Because composite materials are difficult to break, it might be challenging to determine whether the inside structure has been harmed in any way. Aluminum, on the other hand, bends and dents readily, making structural deterioration simple to identify. Should a hazardous situation arise, this could put you at greater risk. Additionally, repairing a damaged composite surface can be more challenging. Last but not least, although composite materials can be pricey at first, their long-term cost advantages and longer life cycle (even if the initial material is more expensive than the classic, existing material, which does not have the chemical silanization treatment, thanks to which its life can be extended by up to twenty years) than that of individual materials usually make up for this [73]. These fibres exhibit excellent dimensional stability, a high strength-to-weight ratio, appropriate resistance to high and low temperatures, little water absorption, and strong electrical insulation. Because fibreglass is a strong, durable, and lightweight material, it is employed in the manufacturing of airplanes [73].

Because of the fibres in the matrix system, this material is stronger than aluminum. Because fibreglass has a smoother surface, less surface treatment is required to eliminate roughness and save fuel due to the increased friction. All composite materials, including this GFRP, are resistant to corrosion. These materials can tolerate bending conditions and are also resistant to cracking. This material's design is more resilient than aluminum's, such that it does not need any additional upkeep or repairs while in operation [73]. In contrast to aluminum, which bends easily and allows internal flaws to be readily identified, damages in composite materials, such as GFRPs, are harder to identify, need more work to fix, and hence come with a higher price tag [73].

The GFRP matrix is susceptible to weakening, particularly as temperatures rise above 150°. Smoke can be produced by fires started by composite materials, as is well known. Toxins from the smoke emission are dispersed throughout the atmosphere. People that breathe in the surrounding air may experience health issues as a result of this. However, as temperatures rise above 300 °C, there is a greater chance of structural failure, which puts the airplane as a whole at serious risk [73]. Fibreglass is apparently very pricey. However, long-term savings will come with high expenditures along with quality. In order to reap all the benefits, fibreglass and other fibres are being used more and more in the manufacturing of aircraft [73]. The behavior of the composite's components and the interfaces between the fibre and resin determine its properties [72]. The goal of combining the beneficial properties of reinforcement to increase performance while lowering weight and cost drives the development of composites comprising multiple types of reinforcement [74].

Because thermosets are easier to fill in the fibre than thermoplastics, they are more commonly utilized in aircraft applications, particularly UAVs [75]. Because of its strong chemical resistance, superior dimensional stability, strong fibre adhesion, and wet performance, epoxy is the most widely used thermoset resin. Lightweight materials such as graphite, carbon fibre, S-glass, E-glass, and aramid are required to extend the flying time of UAVs. More precisely, because of its greater specific strength-to-weight ratio, carbon fibre is the best material for UAVs [76]. However, using carbon-based fibres can increase costs and interfere with the transmission of radar signals during flights; for this reason, glass fibres are advised for some applications [77].

The following processing techniques can be utilized to create composites for UAVs: vacuum infusion, vacuum bag, hand lay-up, prepreg lay-up, resin transfer molding (RTM), and filament winding with autoclave or oven curing [78,79]. However, RTM and filament winding require specialized machinery, whereas prepreg and hand lay-up demonstrate poor reproducibility. In contrast, compared to manual lay-up methods, vacuum infusion and vacuum bag only require a basic machine and are easy to set up; however, they manage to provide good repeatability and an improved fibre-to-resin ratio with minimum voids, enhancing mechanical qualities [80].

3.5. The Possibility of Recycling Composite Materials

The benefits of composite materials, such as their light weight, specific strength and hardness, dimension stability, adaptability to various qualities like a high thermal conductivity and coefficient of expansion, durability in shape and size, and so forth, have led to a massive increase in their use. This is why a sustainable approach in line with the high need to develop a circular economy has to consider which solutions can be used to not generate waste during any of the development phases, which is especially important at the end of the products' life based on composite materials. Certainly, some of these composites can be repurposed, remanufactured, refurbished, repaired, or reused and, in these cases, better circularity is obtained [81].

The construction may be compromised by environmental effects on certain features; thus, it is important to take that into account when interacting with the plan. Early configuration stages should take into account the environmental effects on composite materials; otherwise, plan iterations and failures will result in a waste of time, energy, and money. Generally speaking, composites have a highly special level of awareness regarding individual environmental factors. The effects of environmental factors include fatigue, temperature and humidity, ultraviolet exposure [UV], biological attacks, and so forth. They are the most significant environmental degradation factors taken into consideration and can limit the utility of polymer composites by deteriorating mechanical properties during operation [82,83]. The two most significant factors that contribute to climatic deterioration are temperature and humidity. According to the review, their combination has more detrimental effects on the composite qualities than either one alone, and wetness molding allows for the adjustment of the failure mode at high temperatures. The matrix phase and potentially the interface are the primary environmental effects, whereas strands are often somewhat heartless in the molding process for polymer matrix composites [83,84].

To overcome this shortcoming, hybrid composite materials have been developed, such as a polymer that is additionally compounded with specific particulate reinforcing agents with stabilizing capacity. For example, particular attention has to be paid to the compatibility between phases, and this is mainly assured by surface modification in the particulate phase [85]. The conventional method of taking environmental factors into account is characterized by extreme apertures and closely evaluates the effects of such variables on material qualities through testing. Subsequently, these boundaries are considered variable for the duration of the design [86,87].

A vehicle includes many types of materials: metal, plastic, textile, etc. The percentages vary depending on the type of vehicle, its destination, the climatic zone in which it will be operated, the performance it develops, and the social class it is aimed at. More than 50 million cars are manufactured annually in the world, with 15 million in the USA, around 10 million in Europe, and the rest in Asia. Over 50 million tons of resources are consumed just to manufacture these vehicles. Raw materials are limited, though. It is expected that the current reserves will last for 45 years in the case of oil, 120 years for iron, 30 years for copper, and 21 years for lead reserves. In total, 75% of the total weight of the cars taken out of use is recycled, and 25% remains residual dust [88].

From a car, the recycled rate (wt) is 70.1% for the ferrous materials; 3.4% for the non-ferrous materials; and ~1.5% for the electrical equipment. Residual dust, which is not recovered from cars, is composed of 8.5% plastics; 4.6% rubber; 3.5% glass; 3% electrical equipment; 2.9% other materials; 1% oil and fats; 1% textiles; and 0.5% paper. Plastics and tires are recycled in small percentages. Fibres cannot yet be recycled. Glass represents 40 kg of the total weight of a car and its recycling percentage is low. It is expected that about 85% of the mass of automobiles (those that go out of service on the mentioned date) will be recyclable, and for newly designed ones the percentage will reach 90%. In the longer term, it is expected that 95% of the mass of a car will be recyclable. From this point of view, more and more car manufacturing companies are starting to rethink their product development methods [89].

Due to financial and technological limitations, commercial reuse operations for primary composite materials are currently quite limited. The primary challenge lies in extracting uniform pieces from the combined material. Composites cannot be reused because of strands, various types of support, and measurements or fasteners, particularly thermoset ones. Due to these difficulties, the majority of composite recycling activities are limited to cushion recycling, like fuel or energy recovery, with minimal material recovery, like strand building. The EUROPA End-of-Life Vehicles Mandate [88] and the Waste Electrical and Electronic Hardware Order [89] are two examples of relatively late environmental legislation that are creating a growing need for recycling techniques that lead to the actual recycling of materials [89]. Unfortunately, there are many issues which are correlated with recycling in general. Based on the thesis realized by Delphine Dantec, the Cost of Recycling Compliance for the Automobile Industry is dependent on several factors, such as the following: the type and manufacturer of the car, the country (labor and landfill costs greatly vary across the world), the desired recycling rate, etc. [90]. This tendency started in the 1990s and, since then, recycled plastics were used to protect chassis and to cover the front and back wheel arches. For instance, the Megane II model had, in 2014, 30% of its components made from recycled materials [91].

Mechanical, thermal, and chemical recycling are the three main categories in which numerous yet-to-be-commercialized breakthroughs have been produced as a result of extensive research and improvement efforts. In mechanical recycling, fibre-rich and sap-rich fractions are separated for reuse by cutting, crushing, sifting, and destruction (crushing is the step which requires the most energy). The mechanical step uses a lot of energy (for CFRPs, it is generally accepted to be within the range of 0.14–0.31 MJ/kg [92]), and the quality of the reuses is not very high. High temperatures (between 300 and 1000 °C) are used in thermal handling to break down the tar and separate the fillers and supporting filaments. Natural fillers or clean strands can be regenerated, and burning, gasification, or pyrolysis can produce secondary fuel or thermal energy. The pyrolysis, chemical recycling and high voltage fragmentation of polymers are quite energo-intensive processes consuming 3 to 30; 63 to 91; and 4 MJ/kg, respectively [92]. In any case, the quality of recuperated filaments or fillers degrades to a different degree during heat handling. By using organic or inorganic dissolvable materials, chemical reuse seeks to chemically depolymerize or remove the matrix and release the filaments for further reuse. There has not been any real progress in the situation thus far due to a lack of adaptation and concerns over the production of chemical waste from chemical reuse. However, a cleaner technique based on natural and supercritical liquid innovation—particularly water—has drawn increased interest from researchers and demonstrated intriguing potential [83–89].

Based on the recent work of Goncalves, R.M. et al. [93], there are several recycling technologies, including fluidized bed, solvolysis, pyrolysis, mechanical grinding and co-processing, but only mechanical grinding and co-processing can be used for glass fibre-reinforced polymers in an economically viable way (150–300 EUR/kg), while the other technologies are 4–5 times more expensive and, thus, are not yet suitable. Unfortunately, co-processing via the cement kiln route cannot process the existing demand, and the legislation in several states (such as the UK and the Netherlands) allows incineration and landfill deposition if the cost of recycling is higher than 200 EUR/t.

According to value, the two main application fields are aerospace (more than 20%) and automobiles (more than 30%). The use of composite materials was first promoted by the aerospace and security industries; currently, the majority of guard aircraft are composed of more than half composite material. Lately, composites have emerged as a key component for the next generation of commercial aircraft, including the Boeing 787 "Dreamliner" (half), the Airbus A380 (25%), and the next A350 (53%). Innovation in vehicle weight reduction is essential to advancing environmental friendliness. The automotive industry is seeing a rapid rise in the use of composite materials, particularly in the areas of body development, interiors, chassis, hoods, and electrical parts [89].

The research by Townsend, A. et al. [94] has led to the use of techniques such as milling, burning, and pyrolysis for glass fibre reprocessing. Reused fibreglass finds its way into various businesses and can be utilized in various completed items. For example, reused filaments have been successful in lessening shrinkage in concrete, accordingly increasing its durability. This substantial increase can best be utilized in frozen temperate zones for substantial floors, pavements, sidewalks, and checks [89]. There are different purposes for reused fibreglass filler in pitch, which can increase mechanical properties in certain applications. Reused fibreglass has also found use with different items such as reused tire items, wood and plastic items, asphalt, material tar, and shaped polymer ledges [94].

4. Conclusions

Composites are now manufactured for more than just luxury, defense, and aerospace goods. They are quickly becoming a path to achieve improved structural performance at reduced prices. They are now part of the cars we drive, in all buses and trains, in recreational and sports equipment such as skates and boats, and also in buildings. Glass fibre-reinforced epoxy bars are nowadays being used to develop reinforced concretes with high durability and mechanical performances. The objective of this study was to synthesize the latest research on composite materials, which represent the most innovative and high-performance options available today for new applications in transport, especially in the aeronautical industry, such as the improvement of materials used in the construction of airplanes and drones. Considering special applications, which are required to last and operate for longer times, even in aggressive environmental conditions (differences in temperature, pressure, humidity, and other atmospheric conditions), their design is important. Nowadays, increased amounts of composite wastes are available worldwide and consequently solutions have to be identified because the two radically different components are difficult to be separated and reintroduced in a new life cycle, and thus their recyclability and reuse rates are still below expectations. Worldwide, scientists are looking for solutions for better recycling, especially because of more legislative initiatives. In the automotive industry, the current recycling rate is ~85% and is expected to become 90% in the middle-term and 95% in the long-term. Similar milestones can be reasonable for the aerospatial industry even if airplanes and drones have some specificities compared to automotives.

Funding: This research was funded by the national project "Functionalization and decoration with nanoparticles of the glass surface. A promising approach to inducing new applications"-PN-III-P1-1.1-TE-2021-1242, Ctr. No. TE95/2022.

Conflicts of Interest: Author George-Valentin Săftoiu was employed by the company Romaero S.A. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Ahmad, J.; Gonzalez-Lezcano, R.; Deifalla, A.F.; Majdi, A.; El-Shorbagy, M.A. Glass Fibers Reinforced Concrete: Overview on Mechanical, Durability and Microstructure Analysis. *Materials* **2022**, *15*, 5111.
2. Bahar, A.; Saffari, M.; Kaafi, P.; Afsoosbiria, H. A review of advantages of using glass fiber reinforcemment in construction. In Proceedings of the International Congress on Durability of Concrete (ICDC2012), Trondheim, Norway, 18–21 June 2012.
3. Kopecskó, K. Durability of glass fibers. In Proceedings of the 6th International RILEM Symposium on Fiber-Reinforced Concretes, Varenna, Italy, 20–22 September 2004.
4. Bath, B.; Deo, S.; Ramtekkar, G. Durable Glass Fiber Reinforced Concrete with Supplimentary Cementitious Materials. *Int. J. Eng. Trans. B Appl.* **2017**, *31*, 1012–1019.
5. Thakur, A.; Sharma, T. Glass fiber strength properties. *Int. J. Manag. Tech. Eng.* **2018**, *8*, 175–179.
6. Wang, X.; Wu, G.; Xie, P.; Gao, X.; Yang, W. Microstructure and Properties of Glass Fiber -Reinforced Polyamide/Nylon Microcellular Foamed Composites. *Polymers* **2020**, *12*, 2368. [CrossRef]
7. Thomason, J.; Jenkins, P.; Yang, L. Glass Fiber Strength-A Review with Relation to Composite Recycling. *Fibers* **2016**, *4*, 18. [CrossRef]
8. Sherif, G.; Chukov, D.; Tcherdyntsev, V.; Torokhov, V. Effect of Formation Route on the Mechanical Properties of the Polyethersulfone Composites Reinforced with Glass Fibers. *Polymers* **2019**, *11*, 1364. [CrossRef] [PubMed]
9. Kazemi, M.; Fini, E. State of the art in the application of functionalized waste polymers in the built environment. *Resour. Conserv. Recycl.* **2022**, *177*, 105967. [CrossRef]
10. Rodrigues, A.; Luís, F.; Wandscher, V.; Pereira, G.; Valandro, L.; Rippe, M. Surface treatments of a glass fiber reinforced composite: Effect on the adhesion to a composite resin. *J. Prosthodont. Res.* **2020**, *64*, 301–306. [CrossRef]
11. Issa, A.A.; Luyt, A.S. Kinetics of Alkoxysilanes and Organoalkoxysilanes Polymerization: A Review. *Polymers* **2019**, *11*, 537. [CrossRef]
12. Antoniou, M.; Tsounidi, D.; Petrou, P.S.; Beltsios, K.G.; Kakabakos, S.E. Functionalization of silicon dioxide and silicon nitride surfaces with aminosilanes for optical biosensing applications. *Med. Dev. Sens.* **2020**, *3*, e10072. [CrossRef]
13. Aissaoui, N.; Bergaoui, L.; Landoulsi, J.; Lambert, J.F.; Boujday, S. Silane Layers on Silicon Surfaces: Mechanism of Interaction, Stability, and Influence on Protein Adsorption. *Langmuir* **2012**, *28*, 656–665. [CrossRef] [PubMed]
14. Arnfinnsdottir, N.B.; Chapman, C.A.; Bailey, R.C.; Aksnes, A.; Stokke, B.T. Impact of Silanization Parameters and Antibody Immobilization Strategy on Binding Capacity of Photonic Ring Resonators. *Sensors* **2020**, *20*, 3163. [CrossRef] [PubMed]
15. Silva, T.; Correia, L.; Dehshirizadeh, M.; Sena-Cruz, J. Flexural Creep Response of Hybrid GFRP-FRC Sandwich Panels. *Materials* **2022**, *15*, 2536. [CrossRef]
16. Chandramouli, K.; Srinivasa, P.; Narayanan, P.; Tirumala, S. Strength properties of glass fiber concrete. *ARPN J. Eng. Appl. Sci.* **2010**, *5*, 1–6.
17. Kaske, H.K.; Melesse, G.; Yabasa, G. A Study on Using Glass Fiber -Reinforced Polymer Composites for Shear and Flexural Enhancement of Reinforced Concrete Beams. *Adv. Civ. Eng.* **2022**, *2022*, 5995103.
18. Jesuarockiam, N.; Sathishkumar, T.P.; Satheeshkumar, S. Glass fiber -reinforced polymer composites—A review. *J. Reinf. Plast. Compos.* **2014**, *33*, 1258–1275.
19. Al-Kharabsheh, B.N.; Arbili, M.M.; Majdi, A.; Alogla, S.; Hakamy, A.; Ahmad, J.; Deifalla, A.F. Basalt Fiber Reinforced Concrete: A Compressive Review on Durability Aspects. *Materials* **2023**, *16*, 429.
20. Lassila, L.; Garoushi, S.; Vallittu, P.; Säilynoja, E. Mechanical properties of fiber reinforced restorative composite with two distinguished fiber length distribution. *J. Mech. Behav. Biomed. Mater.* **2016**, *6*, 331–338. [CrossRef] [PubMed]
21. Hui, Y.; Men, G.; Xiao, P.; Tang, Q.; Han, F.; Kang, A.; Wu, Z. Recent Advances in Basalt Fiber Reinforced Asphalt Mixture for Pavement Applications. *Materials* **2022**, *5*, 6826.
22. Babaee, M.; Jonoobi, M.; Hamzeh, Y.; Ashori, A. Biodegradability and mechanical properties of reinforced starch nanocomposites using cellulose nanofibers. *Carbohydr. Polym.* **2015**, *132*, 1–8. [CrossRef]
23. Hashim, M.F.A. Reinforced Alkali-Activated Composites Design, Mechanical Properties and Durability. *Adv. Fiber* **2023**, 381–413.
24. Ridzuan, M.J.M.; Majid, M.S.A.; Afendi, M.; Mazlee, M.N.; Gibson, A.G. Thermal behaviour and dynamic mechanical analysis of Pennisetum purpureum/glass-reinforced epoxy hybrid composites. *Compos. Struct.* **2016**, *152*, 850–859. [CrossRef]
25. Wang, X.; Yu, Z.; McDonald, A.G. Effect of Different Reinforcing Fillers on Properties, Interfacial Compatibility and Weatherability of Wood-plastic Composites. *J. Bionic. Eng.* **2019**, *16*, 337–353. [CrossRef]
26. *Toxicological Profile for Synthetic Vitreous Fibers*; U.S. Department of Health and Human Services, Public Health Services, Agency for Toxic Substances and Disease Registry: Atlanta, GA, USA, 2004; pp. 1–11.
27. Review of the, U.S. *Navy's Exposure Standard for Manufactured Vitreous Fibres*; National Academy of Sciences, National Research Council, National Academy Press: Washington, DC, USA, 2000.

28. Quinn, M.M.; Smith, T.J.; Youk, A.O.; Marsh, G.M.; Stone, R.A.; Buchanich, J.M.; Gula, M.J. Historical Cohort Study of US Man-Made Vitreous Fiber Production Workers: VIII. *Exposure-specific job analysis. J. Occup. Environ. Med.* **2001**, *43*, 824–834. [CrossRef]
29. Hull, D.; Clyne, T.W. *An Introduction to Composite Materials*, 2nd ed.; Cambridge University Press: New York, NY, USA, 1996.
30. Yuan, F. Properties of magnesium phosphate cement based fire-retardant coating containing glass fiber or glass fiber powder. *Constr. Build. Mater.* **2018**, *162*, 553–560.
31. Report on Carcinogens, 12th ed.; U.S. Department of Health and Human Services, Public Health Service. 2011. Available online: https://www.iaff.org/wp-content/uploads/2019/06/12th-Report-on-Carcinogens-2011.pdf (accessed on 31 March 2024).
32. Bilisik, K. *Functional and Technical Textiles*; Elsevier: Cambridge, UK, 2023; pp. 71–139.
33. Żurowski, W. The Effect of Powder and Emulsion Binders on the Tribological Properties of Particulate Filled Glass Fibre Reinforced Polymer Composites. *Polymers* **2023**, *15*, 245. [CrossRef] [PubMed]
34. Keleștemur, O.; Yildiz, S.; Arici, E.; Gocer, B. Statistical Analysis for Freeze Thaw Resistance of Cement Mortars Containing Marble Dust and Glass Fiber. *Mater. Des.* **2014**, *60*, 548–555.
35. Praven, B.; Balachandra, P.S.; Vinayaka, N.; Srikanth, H.V. Mechanical properties and water absorption behaviour of pineapple leaf fibre reinforced polymer composites. *Adv. Mater. Proces. Technol.* **2020**, *8*, 1–16.
36. Hale, J.M.; Gibson, G.A. Coupon Tests of Fiber Reinforced Plastics at Elevated Temperatures in Offshore Processing Environments. *J. Compos. Mater.* **1998**, *32*, 52.
37. McDonough, W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2022.
38. Schultheisz, R.C.; McDonough, G.W.; Kondagunta, S.; Schutte, L.C.; Macturk, S.K.; McAuliffe, M.; Hunston, L.D. Effect of Moisture on E-Glass/Epoxy Interfacial and Fiber Strengths. In Proceeding of the 13th Symposium on Composite Materials: Testing and Design, Orlando, FL, USA, 20–21 May 1996; pp. 257–286.
39. Mortazavian, V.; Fatemi, A.; Khosrovaneh, A. Effect of Water Absorption on Tensile and Fatigue Behaviors of Two Short Glass Fiber Reinforced Thermoplastics. *SAE Int. J. Mater. Manuf.* **2015**, *8*, 435–443.
40. Rahman, N.A.; Hassan, A.; Yahya, R.; LafiaAraga, R. Impact properties of glass fiber/polypropylene composites: The influence of fiber loading, specimen geometry and test temperature. *Fiber Polym.* **2013**, *14*, 1877–1885. [CrossRef]
41. Jawaid, M.; Alothman, O.Y.; Saba, N.; Paridah, M.; Abdul-Khalil, H. Effect of fiber treatment on dynamic mechanical and thermal properties of epoxy hybrid composites. *Polym. Compos.* **2014**, *36*, 1669–1674. [CrossRef]
42. Cerbu, C.; Curtu, I. Aspects concerning environmental effects on the glass reinforced polymers. In Proceeding of the 9th International Research/Expert Conference, Trends in the Development of Machinery and Associated Technology TMT2005, Antalya, Turkey, 26–30 September 2015; pp. 1451–1454.
43. Hoskin, B.C.; Baker, A.A. (Eds.) *Composite Materials for Aircraft Structure*; AIAA Education Series; AIAA Education: New York, NY, USA, 2016.
44. Ray, B.C. Impact of Environmental and Experimental Parameters on FRP Composites. In Proceedings of the Eighteenth International Symposium on Processing and Fabrication of Advance Materials, Sendai, Japan, 12–14 December 2009.
45. Biswas, S.; Deo, B.; Patnaik, A.; Satapathy, A. Effect of fiber loading and orientation on mechanical and erosion wear behaviors of glass–epoxy composites. *Polym. Compos.* **2011**, *32*, 665–674. [CrossRef]
46. Clyne, T.W.; Hull, D. *An Introduction to Composite Materials*, 3rd ed.; Cambridge University Press: Cambridge, UK, 2019.
47. Alfred, C. *Introduction to Composite Materials*; Michigan State University: East Lansing, MI, USA, 2020.
48. Rajak, D.K.; Durgesh, D.; Pruncu, C.I. Recent progress of reinforcement materials: A comprehensive overview of composite materials. *J. Mater. Res. Technol.* **2019**, *8*, 6354–6374. [CrossRef]
49. Dilfi, A.; Balan, A.; Hong, B.; Xian, G.; Thomas, S. Effect of surface modification of jute fibre on the mechanical properties and durability of jute fibre-reinforced epoxy composites. *Polym. Compos.* **2018**, *39*, E2519–E2528. [CrossRef]
50. Sayeed, M.M.A.; Rawal, A.; Onal, L.; Karaduman, Y. Mechanical properties of surface modified jute fibre/polypropylene nonwoven composites. *Polym. Compos.* **2014**, *35*, 1044–1050. [CrossRef]
51. Asmatulu, E.; Twomey, J.; Overcash, M. Recycling of fiber-reinforced composites and direct structural composite recycling concept. *J. Compos. Mater.* **2013**, *48*, 593–608. [CrossRef]
52. Modesti, M.; Lorenzetti, A.; Bon, D.; Besco, S. Thermal behaviour of compatibilised polypropylene nanocomposite: Effect of processing conditions. *Polym. Degrad. Stab.* **2006**, *91*, 672–680. [CrossRef]
53. Surface Modelling for Composite Materials—SIAG GD. Available online: http://www.ifi.uio.no/siag/problems/grandine/ (accessed on 31 March 2024).
54. Praveena, B.A.; Balachandra, P.S.; Vinayaka, N.; Srikanth, H.V.; Shiv, P.S.Y.; Avinash, L. Mechanical properties and water absorption behaviour of pineapple leaf fibre reinforced polymer composites. *Adv. Mater. Process. Technol.* **2022**, *8*, 1336–1351.
55. Araújo, J.R.; Waldman, W.R.; De Paoli, M.A. Thermal properties of high density polyethylene composites with natural fibres: Coupling agent effect. *Polym. Degrad. Stab.* **2008**, *93*, 1770–1775. [CrossRef]
56. Queiroz, H.F.M.; Banea, M.D.; Cavalcanti, D.K.K. Adhesively bonded joints of jute, glass and hybrid jute/glass fibre-reinforced polymer composites for automotive industry. *Appl. Adhes. Sci.* **2021**, *9*, 2.
57. Loganathan, S.; Valapa, R.B.; Mishra, R.K.; Pugazhenthi, G.; Thomas, S. Chapter 4-Thermogravimetric Analysis for Characterization of Nanomaterials. In *Micro and Nano Technologies*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 67–108.

58. Ramakrishnan, S.; Krishnamurthy, K.; Rajeshkumar, G.; Asim, M. Dynamic Mechanical Properties and Free Vibration Characteristics of Surface Modified Jute Fibre/Nano-Clay Reinforced Epoxy Composites. *J. Polym. Environ.* **2021**, *29*, 1076–1088. [CrossRef]
59. Roy, R.; Sarkar, B.K.; Bose, N.R. Effects of moisture on the mechanical properties of glass fibre reinforced vinylester resin composites. *Bull. Mater. Sci.* **2001**, *24*, 87–94. [CrossRef]
60. Piñero-Hernanz, R.; Dodds, C.; Hyde, J.; García-Serna, J.; Poliakoff, M.; Lester, E.; Cocero, M.J.; Kingman, S.; Pickering, S.; Hoong Wong, K. Chemical recycling of carbon fibre reinforced composites in near critical and supercritical water. *Compos. Part A Appl. Sci. Manuf.* **2008**, *39*, 454–461. [CrossRef]
61. Piñero-Hernanz, R.R.; Dodds, C.; Hyde, J.; García-Serna, J.; Poliakoff, M.; Lester, E.; Cocero, M.J.; Kingman, S.; Pickering, S. Chemical recycling of carbon fibre composites using alcohols under subcritical and supercritical conditions. *J. Supercrit. Fluids* **2008**, *46*, 83–92. [CrossRef]
62. Pimenta, S.; Pinho, S.T. Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook. *Waste Manag.* **2011**, *31*, 378–392.
63. Pickering, S.J. Recycling technologies for thermoset composite materials—Current status. *Compos. Part A Appl. Sci. Manuf.* **2006**, *37*, 1206–1215. [CrossRef]
64. Palmer, J.; Ghita, O.R.; Savage, L.; Evans, K.E. Successful closed-loop recycling of thermoset composites. *Compos. Part A Appl. Sci. Manuf.* **2009**, *40*, 490–498. [CrossRef]
65. Debiasi, M.; Bouremel, Y.; Khoo, H.H.; Luo, S.C.; Tan, E.Z. Shape Change of the Upper Surface of an Airfoil by Macro Fibre Composite Actuators. In Proceedings of the 29th AIAA Applied Aerodynamics Conference, Honolulu, HI, USA, 27–30 June 2011. AIAA Paper 2011-3809.
66. Debiasi, M.; Bouremel, Y.; Khoo, H.H.; Luo, S.C. Deformation of the Upper Surface of an Airfoil by Macro Fibre Composite Actuators. In Proceedings of the 30th AIAA Applied Aerodynamics Conference, New Orleans, LA, USA, 25–28 June 2012. AIAA Paper 2012-3206.
67. Jacobs, E.N.; Pinkerton, R.M. *Tests of the N.A.C.A. Airfoils in the Variable Density*; National Advisory Committee for Aeronautics Technical Note No. 401; National Advisory Committee for Aeronautics: Washington, DC, USA, 1931.
68. Mastascusa, E.J. Exploring Electrical Engineering Operational Amplifier The Unity Gain Buffer. In *Amplifier Basic EE Lesson*; Electrical Engineering Department, Bucknell University: Lewisburg, PA, USA, 2008.
69. Soutis, C. Fibre reinforced composites in aircraft construction. *Prog. Aerosp. Sci.* **2005**, *41*, 143–151. [CrossRef]
70. Uzawa, K.; Nishiwaki, K.; Niitsu, M.; Kamita, T.; Kimura, G. Low cost fabrication of HOPE-X all-composite prototype structure. *Adv. Compos. Mater.* **2005**, *14*, 289–304. [CrossRef]
71. Kotwani, K. Design and Development of Fully Composite Mini Unmanned Aerial Vehicle (Mini-UAV). 2003. Available online: https://ro.scribd.com/document/466899744/Design-and-Development-of-Fully-Composite-Mini-Unmanned-Aerial (accessed on 31 March 2024).
72. De Oliveira, T.L.; de Carvalho, J. Design and numerical evaluation of quadrotor drone frame suitable for fabrication using fused filament fabrication with consumer-grade ABS. *J. Braz. Soc. Mech. Sci. Eng.* **2021**, *43*, 436. [CrossRef]
73. Guy, J.P.; Schumann, J.M.; Andreadis, K.M. Rapid Mapping of Small-Scale River-Floodplain Environments Using UAV SfM Supports Classical Theory. *Remote Sens.* **2019**, *11*, 982. [CrossRef]
74. Zhu, L.; Li, N.; Childs, P.R.N. Light weighting in aerospace component and system design. *Propuls. Power Res.* **2018**, *7*, 103–119. [CrossRef]
75. Skawinski, I.; Goetzendorf-Grabowsk, T. FDM 3D printing method utility assessment in small RC aircraft design. *Aircr.Eng. Aerosp. Tec.* **2018**, *91*, 865–872. [CrossRef]
76. Chanzy, Q.; Keane, A.J. Analysis and experimental validation of morphing UAV wings. *Aeronaut. J. -New Series* **2017**, *122*, 390–408. [CrossRef]
77. Mishra, A.K.; Bhuvana, S.; Agnihotri, P. Design and Development of Solar Powered UAV for long endurance. *Multidiscip. Int. J.* **2022**, *8*, 31–39.
78. Dagur, R.; Singh, D.; Bhateja, S.; Rastogi, V. Mechanical and material designing of lightweight high endurance multirotor system. *Mater. Today Proc.* **2020**, *21*, 1624–1631. [CrossRef]
79. Girolamo, C.; Tata, M.E. Shape Memory Alloys for Aerospace, Recent Developments, and New Application: A Short Review. *Materials* **2020**, *13*, 1856. [CrossRef] [PubMed]
80. Niemand, J.; Mathew, S.J.; Gonzalez, F. Design and Testing of Recycled 3D Printed Foldable Unmanned Aerial Vehicle for Remote Sensing. In Proceedings of the International Conference on Unmanned Aircraft Systems: ICUAS, Athens, Greece, 1–4 September 2020; pp. 892–901.
81. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. *Circular Economy: Measuring Innovation in the Product Chain*; PBL Netherlands Environmental Assessment Agency: The Hague, The Netherlands, 2017.
82. Geiger, R.; De Sousa, A.R.; Hannan, Y.A. Advanced Composite Drone Manufacturing. In Proceedings of the 8th Annual World Congress of Advanced Materials, Osaka, Japan, 22–24 July 2019.
83. Hoa, S.; Abdali, M.; Jasmin, A.; Radeschi, D.; Prats, V.; Faour, H.; Kobaissi, B. Development of a New Flexible Wing Concept for Unmanned Aerial Vehicle Using Corrugated Core Made by 4D Printingof Composites. *Compos. Struct.* **2022**, *290*, 115444. [CrossRef]

84. Lancea, C.; Chicos, L.A.; Zaharia, S.M.; Pop, M.A.; Pascariu, I.S.; Buican, G.R.; Stamate, V.M. Simulation, Fabrication and Testing of UAV Composite Landing Gear. *Appl. Sci.* **2022**, *12*, 8598. [CrossRef]
85. Nawaz, H.; Ali, H.M.; Massan, S. Applications of Unmanned Aerial Vehicles: A Review. *3C Tecnol.* **2019**, *2019*, 85–105. [CrossRef]
86. Nguyen, D.H.D.P.; Nguyen, D.D. *Drone Application in Smart Cities: The General Overview of Security Vulnerabilities and Countermeasures for Data Communication*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 185–210.
87. Piljek, P.; Krznar, N.; Krznar, M.; Kotarski, D. Framework for Design and Additive Manufacturingof Specialised Multirotor UAV Parts. In *Trends and Opportunities of Rapid Prototyping Technologies*; Intech Open: London, UK, 2022; pp. 1–16.
88. Ramadhoni, B.F.; Rizkyta, A.G.; Bintoro, A.; Nugroho, A. Effect of Glass Fibres and Aramid Fibre on Mechanical Properties of Composite Based Unmanned Aerial Vehicle (UAV) Skin. In Proceedings of the iMEC-APCOMS 2019, Putrajaya, Malaysia, 21–22 August 2019; Lecture Notes in Mechanical Engineering. Springer: Berlin/Heidelberg, Germany, 2020; pp. 435–440.
89. Singhal, G.; Bansod, B.; Mathew, L. Unmanned Aerial Vehicle Classification, Applications and Challenges: A Review. *Preprints* **2018**, 2018110601. [CrossRef]
90. Dantec, D. Analysis of the Cost of Recycling Compliance for the Automobile Industry. MSc Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2005; p. 73.
91. Plastics Recycling in the Strategies of Well-Known Automotive Brands. Available online: https://knaufautomotive.com/recycled-plastics-in-the-automotive-industry/ (accessed on 2 May 2024).
92. Shuaib, N.A.; Mativenga, P.T. Energy demand in mechanical recycling of glass fibre reinforced thermoset plastic composites. *J. Clean. Prod.* **2016**, *120*, 198–206. [CrossRef]
93. Gonçalves, R.M.; Martinho, A.; Oliveira, J.P. Recycling of Reinforced Glass Fibers Waste: Current Status. *Materials* **2022**, *15*, 1596. [CrossRef]
94. Townsend, A.; Jiya, I.N.; Martinson, C.; Bessarabov, D.; Gouws, R.A. Comprehensive Review of Energy Sources for Unmanned Aerial Vehicles, their Shortfalls and Opportunities for Improvements. *Heliyon* **2020**, *6*, e05285. [CrossRef]