FRP Composite Materials: A Comprehensive Review of Properties,manufacturing and Applications

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Abstract - *Fiber Reinforced Polymer (FRP) materials have become increasingly popular in various industries due to their unique properties. FRPs are composed of a polymer matrix reinforced with fibers, and their strength and stiffness can be tailored by selecting different fiber types and orientations. The FRP (Fiber Reinforced Polymer) is an alternative to materials like wood, plastic, metals, etc. The life expectancy of FRP is around 20 to 30 years. It has very good properties, and its strength is equivalent to steel in the longitudinal direction in civil industries and other production industries very rapidly because it is very lightweight and uses in rapid civilizations. However, the challenges exist in the manufacturing and design of FRP structures, including the need for specialized equipment and expertise. This paper provides an overview of FRP materials and their applications, highlighting their advantages and limitations. It is majorly made by the pultrusion process (specially thermosetting polymer) with various reinforced fibers and various resin matrix with different stacking of fiber and different proportions of resin matrix. It has very good properties against the salty water and other harsh environmental industrial applications.*

Key Words: **Fiber Reinforced Polymer (FRP),Polymer Matrix, Pultrusion Process, Strength and Stiffness Tailoring, Longevity and Durability**

1.INTRODUCTION

composite material a materials are made by human being are most sufficient and most accurate work presence in modern era. composite materials are made by creating proper mixture of two or more materials having significant different properties, when it combines and making a new material with good properties of mixed materials. ex, the first composite material made by hum am is mud bricks, it's a combination of mud and bamboo strips, both have special properties, bamboo gives strength and mud gives cohesiveness to bricks. composites materials mainly makes for eliminate the bad properties of materials in particular use, like weight, stiffness, density, thermal conductivity, heat dissipation, elongation, corrosion, chemical effect, environmental effect on material and environment etc.

the most of problems are covered in frp materials ,frp stands for fiber re-inforced polymers/fibre re-inforced plastic.by using the finite element method of square and round and various cross section shape for predicting and the experimenting the behaviour of frp material in various field it has very good proerties in longitudinal direction but it very low or moderate in transverse(lateral) direction.

2. MANUFACTURING

The basic components for making frp material is plastic resin or polymer matrix and different types of fibre, according to requirement the types of components are changed, below figure shows the how reinforced fibre(synthetic fibers) are made from different things.

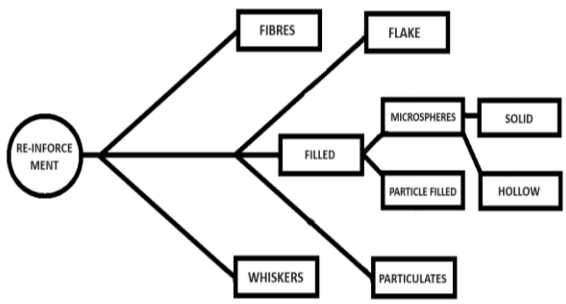

figure 1

Chart-1: different types of fibre particles

2.1.1.HYBRID FIBERS :

Hybrid fibers in composite materials refer to the combination of two or more different types of fibers, typically natural and synthetic fibers, to create a composite with enhanced properties. By blending fibers with distinct characteristics, hybrid composites can achieve a synergistic effect, incorporating the strengths of each fiber type. This results in improved mechanical properties, such as increased strength, stiffness, and impact resistance, compared to using a single fiber type. Hybrid fiber-reinforced composites are gaining attention in various industries due to their ability to tailor properties to specific application requirements, offering a versatile and efficient solution for advanced material design and engineering.

2.1.2.NATURAL FIBERS

Natural fibers are derived from plants, animals, or minerals and offer eco-friendly and sustainable alternatives to synthetic fibers. Common natural fibers include jute, hemp, flax, cotton, and sisal, each with unique properties such as biodegradability, low cost, and high specific strength. Natural fiber composites exhibit good mechanical properties, lightweight characteristics, and reduced environmental impact compared to synthetic counterparts. These fibers are widely used in various industries like automotive, construction, and packaging due to their renewability and biodegradability. Ongoing research focuses on optimizing natural fiber composites for improved performance, making them increasingly popular in the quest for environmentally conscious materials.

2.2.MATRIX

basically matrix is element to strengthen the frp fibre, it is macro and micro component that is differed in chemical composition according to need and mixed with resins and a plied in frp resin.it gives a superior strength to frp material.

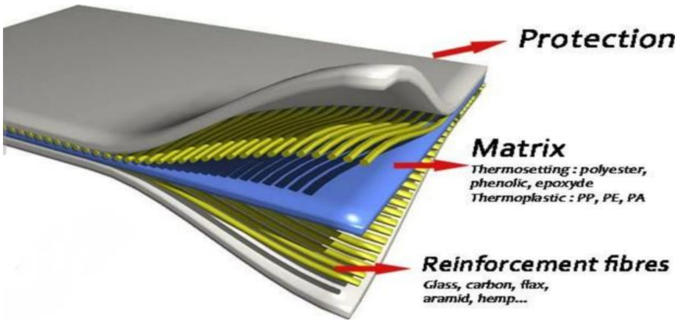

Fig-1: structure of matrix in frp materials

According to various composition matrix decided in four various
types,

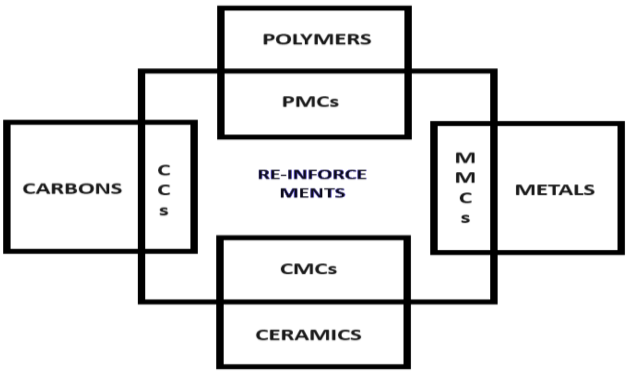

Chart-2 : chart representing different types of matrix's in frp materials

1. PMCs (polymer matrix composites)

2. MMCs (metal matrix composites)

3. CMCs (ceramic matrix composites)

4. C/Cs (carbon/carbon matrix composites)

2.2.1. PMCs (polymer matrix composites)

The pmcs consists a polymer(resin) matrix combined with various fibre

properties :

popular due to light weight

high stiffness

high strength

Ex.thermosets : epoxy resin,phenol formaldehyde resin.

thermoplastics: polystyrene, polyethylene, poly amide, nylon, polypropylene.

2.2.2. MMCs (metal matrix composites)

It basically consist a light weight material like aluminium, magnesium, titanium and copper etc., and it re in-forced with particular type ceramic like ceramic, graphite and silicon.

properties :

low density

high strength and stiffness

high thermal stability and conductivity

2.2.3. CMCs (ceramic matrix composites)

It only consist ceramic fibre with ceramic matrix material.

example : clay, silicon carbide, alumina, porcelain

properties :

high melting point and toughness and strength

corrosion resist stable at high temperature.

2.2.4. C/Cs (carbon/carbon matrix composites)

It insist a graphite matrix with carbon fibre.

properties :

specially mixed with each other to achieve a hard metrial and high thermal resistance.

it is very less brittle in nature compared to other ceramics.

3. PROPERTIES OF FRP MATERIALS

The main properties of frp materials are showed below,

1. tensile strength
2. flexural strength and modulus
3. compressive strength
4. shear strength
5. impact resistance
6. fatigue perfomance
7. environmental durability
8. fire perfomance
9. thermal and electrical stability
10. sea corrosion
11. recylability

3.1. tensile strength

according to research papers and experiments we can say that from (table 1) the strength of frp material are very good(specially CFR and GFRP),the reason for good strength is that the fibre are embedded in with matrix polymer wich gives good strength to fibre,and also from various major factors like fiber type, fiber orientation,matrix material proportion of natural fibres etc.

Composite matrix	Density (g/cm^3)	Tensile strength (MPa)	Specific, σ (kN.m/kg)	Young's modulus, E (GPa)	Specific E (×10^3 kN.m/kg)
Polyester	1.221 ± 0.010	122.12 ± 3.20	100.02 ± 2.28	16.84 ± 1.37	13.79 ± 0.69
Polyurethane	0.996 ± 0.016	122.66 ± 4.64	123.11 ± 2.77	18.91 ± 1.53	18.98 ± 0.81
Vinyl Ester	1.087 ± 0.051	112.54 ± 7.21	103.54 ± 4.65	15.27 ± 0.50	14.05 ± 0.64
Polyester-Glass Fiber	2.105 ± 0.009	592.10 ± 14.38	281.26 ± 5.87	51.86 ± 3.41	24.63 ± 2.06

Table-1: table represents the different types of mechanical properties with some materials

at exel composites UK, the researches show the experiment on natural fibre made by thermosetting resin, hemp and wool in proportion of 65-30-5 by weight, with diameter of 4.8 mm with curing temperature of 120-190 degree celcius. by using of polyurethane resin metrix with natural fibre shows 3 to 4 times more flexible compared to other polymer resin metrix,the GFRP has much higher tensile strength and modulus compared to wool/hemp fibre.

3.2. flexural strength and modulus

From experiment its a tendency to bend, and from the graph we observed the polyester has greater strength than other two composites.

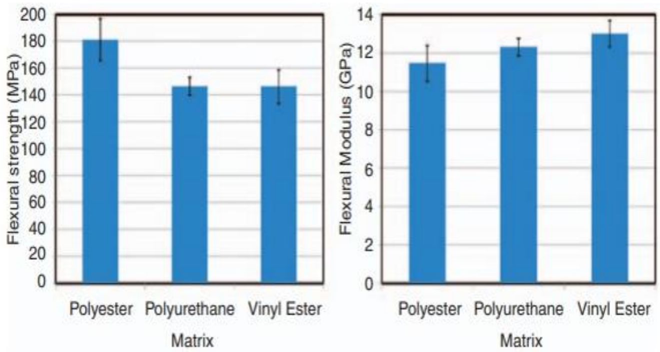

Chart-3 : graph represents the different flexural strength of different materials on hemp or wool fibre matrix structure

From observing the graphs we can say that the flexural strength in polyester is high compared,

To other two, compared polyurethane and vinyl ester has to same strength.

In flexural modulas vinyl ester has highest modulus compared two polyester and polyurethane.

3.3. compressive strength

from the experiment and observing the graph we can say that the vinyl ester are slightly less in tensile and compression both due to lower strength of matrix of poorer bonding between used fibre and matrix.

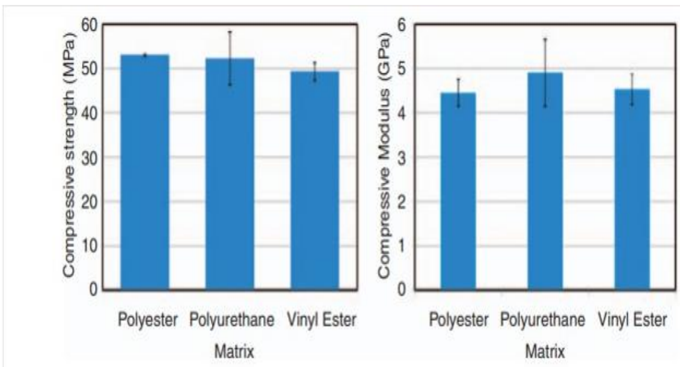

Chart-4 : graph represents the different compression strength of different materials on hemp or wool fibre matrix structure

By observing the graphs we can say that the compressive strength and matrix all material is approx equal to each other.

3.4. shear strength

by analysis if various maded model for experiencing and predicting the behaviour of shear strength and flexural stresses on rc beam using frp material with consideration of stress concentration, fatigue factor. The CFRP and GFRP give very good strength by wrapping frp in shape of u-shape and jacket.

3.5. impact resistance

FRP materials often exhibit good impact resistance, but this property can vary depending on factors such as fiber type, matrix toughness, and laminate layup. Research investigates the impact behavior of FRP composites through impact testing methods like Charpy or Izod tests, assessing energy absorption, damage resistance, and failure modes.

3.6. fatigue perfomance

Understanding the fatigue behavior of FRP materials is critical for assessing their long-term durability under cyclic loading conditions. Research papers may focus on fatigue testing of FRP composites, studying factors like fatigue life, stress concentration effects, and fatigue failure mechanisms.

3.7. environmental durability

the frp material had excellent environmental durability, making them suitable for various applications in challenging environmental conditions like, Corrosion Resistance, UV resistance, chemical resistance, weather etc.

3.8. fire perfomance

according to fibership research project, This project aims to enable construction of over 50-meter-long ships using FRP materials. The study's first phase tested seven resin systems using cone calorimeter tests, revealing that phenolic resin had the best fire performance. Intumescent coatings improved FRP fire performance, but other issues like mechanical properties and manufacturing processes also influenced product selection. The study ultimately aims to enhance FRP use in shipbuilding and the European shipbuilding industry's competitiveness.

3.9. thermal and electrical stability

Fiber-Reinforced Polymer (FRP) materials have very good thermal stability by making them suitable for applications of various related temperatures.

in Thermal Insulation the frp material sandwich offer thermal insulation benefits, making them a preferred choice for structural engineering applications where temperature control is required. with uses of CFRP and cement type matrix with GFRP.

3.10. sea corrosion

according to research in china, the feasibility of using Fiber Reinforced Polymer (FRP) composites rebar as a replacement for traditional steel bars in marine sand concrete due to its good corrosion resistance. It explores the potential of FRP to improve building durability in alkaline environments like seawater sea sand concrete. The study compares Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) steel bars, frp has life expectancy around 20 to 30 years, in highlighting differences in corrosion resistance and performance in SWSSC(sea water and sea sand concrete). It addresses failure characteristics of FRP composites rebar after corrosion, emphasizing the importance of the resin matrix in maintaining bonding with concrete. Strategies such as finding more corrosion-resistant resin matrices or adding layers at the fiber-matrix interface are proposed to enhance the performance of FRP composites rebars.

3.11. recyclability

The recyclability of frp materials is an important aspect for sustainable waste management and environmental conservation. Here the recyclability of frp materials can recycled by mechanically, thermally, chemically, composite-to-composite(convert frp waste in another form of frp used again) and circular economy initiatives(using frp in loop).

4.METHODS OF MAKING OF FRP COMPOSITE

the frp materials are made by eight methods,

1. hand lay-up

2. spray moulding

3. wet compression moulding

4. resin transfer moulding

5. filament winding

6. injection moulding process

7. electrospinning process

8. pultrusion process

4.1. hand lay-up

the hand lay-up method is very easy and traditional method for making frp material part,this process is very cheap and it doesn't required any highly skilled worker.the easy parts are made easily.

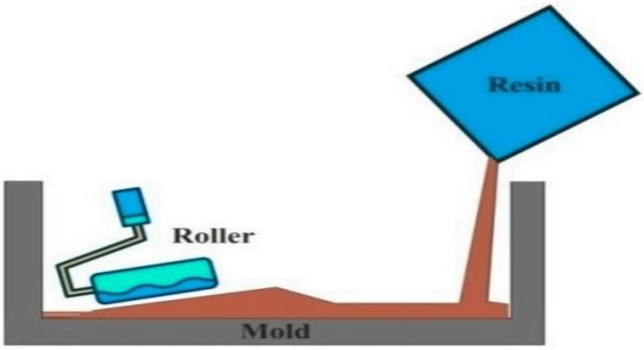

Fig-2: figure of hand lay-up process

ex.Wind-turbine blades, boats, architectural shapes, secondary structure in aerospace, Composites, automobile parts, Dashboard and deck.

4.2. spray moulding

in spray moulding process the fibre are thrown by spray gun in form of small fibre and simultaneously mixed with resin.this mixture sprayed on part die and leave for drying,it is more speedy than hand lay up method, it takes time for drying of mixture.

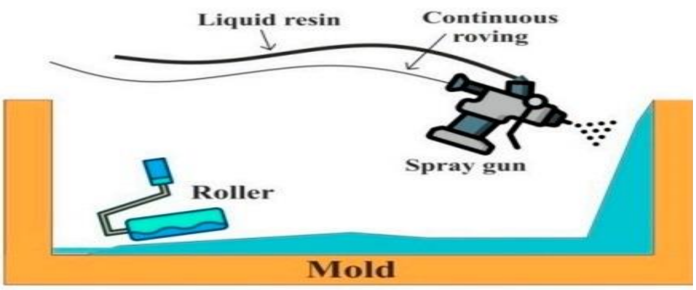

Fig-3: figure of spray moulding process

ex.caravan bodies,truck fairings,bathtubs,shower trays,small dinghies,Vent hoods,boats,shower unit.

4.3. wet compression moulding

in this method the fibre is coated by resin on both side by hopper and catted by required dimension and arranged mutltidirectionally then put in die and pressed with heating,after some time mould is taken out from die.this method is very useful in large and precise part manufacturing.

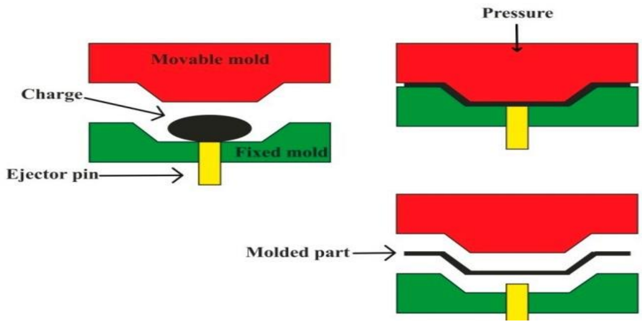

Fig-4: figure of wet compression moulding process

Ex.prototypes, small-scale parts, and components with complex geometries in industries such as automotive, aerospace, and construction.

4.4. resin transfer moulding

this process is very similar to injection moulding process,in this process the die is split in two part and closed tighthly one resin injection unit is inserted in die and die filled with resin and fibre mixture, for easily removal of mould the ejector pin and vent are given in die.it is very productive in mass production.

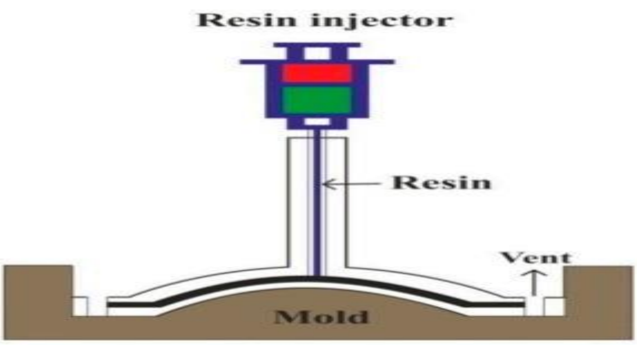

Fig-5: figure of resin transfer moulding process

ex.bath and Shower enclosures,cabinets,aircraft parts,automotive.

4.5. filament winding

this process is very similar to pultrusion process,in this process the resin rovings are continuous pulled by roller and dipped in resin bath then through nip rollers in turns in circular shape in guide and turned on die outside,the guide is moving and wind the filament over the die.

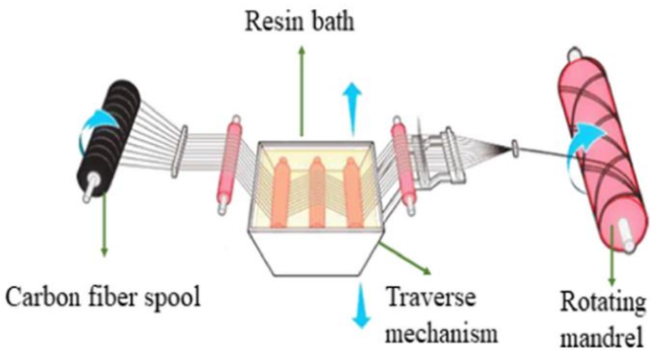

Fig-6: figure of filament winding process

ex.Pipe lines,tubing, pressure,vessels,tanks,gas cylinders,fire-fighters,breathing tanks,tube light poles, aircraft fuselages, wing sections,randomness,helicopter rotor shafts.

4.6.injection moulding process

It is very useful and very fast process for making frp material components,it is basically based on die shape.in this process,the ready made fibre and resin mixture pallets are stored in hopper and when it heated and melted,it goes through nozzle with help of rotating screw or pressure ram.

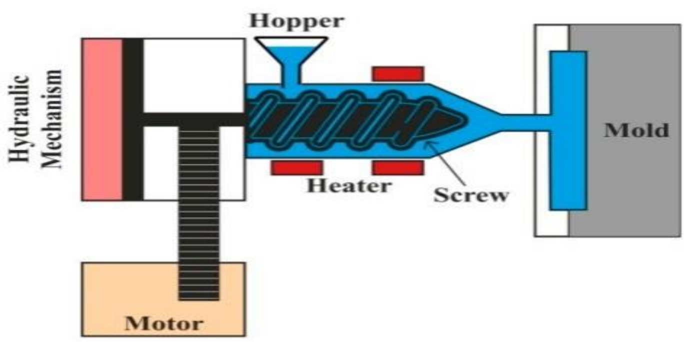

Fig-7: figure of injection moulding process

Ex. Die based parts,medical,automobile,mechanical parts etc.

4.7Electrospinning process

In this process the continuous fibre are thrown in nozzle of diameter nanometer or micrometer and it thrown by spinneret by electric forces and it is collected on collector.

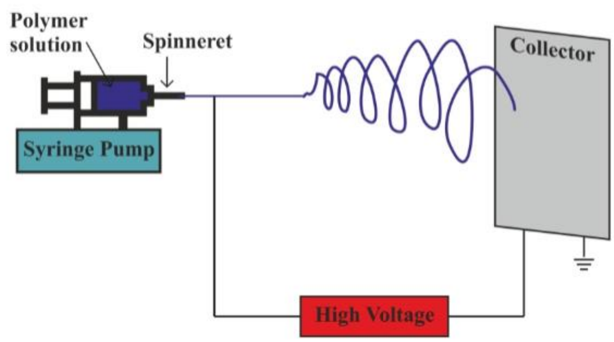

Fig-8: figure of electro spinning process

Ex. biomedical applications (wound healing,tissue engineering scaffolds,drug delivery), bio sensors,enzyme immobilization,cosmetics,etc.

4.8. pultrusion process

in this area this process is widely used in mass production of continuous production, in this process the fibre are continuous are coming out from rovings and goes into impregnation bath after goes into pre-former, here the resin are close together and taking shape according to die, after the fibre and resin mixture goes into temperature control die and and takes final shape of die, during this whole process the resin are pulled by two caterpillar haul off system that's for that reason this process is called pultrusion process after the ready shape are cutted required dimension.

This process is very effective,this can produce rebars of various cross sections.

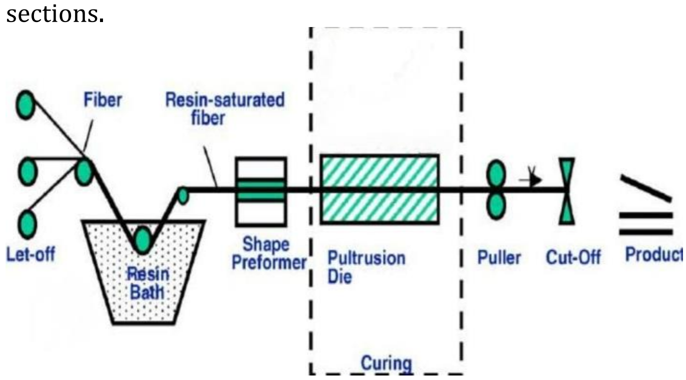

Fig-9: figure of pultrusion process

ex.Bar and rod,pipe,tubing,ladder rails and rungs and supports of many kinds,Beams and girders used in roof structures,bridges,frameworks.

5.FUTURE AND INCOMING DEMAND OF FRP

the future of frp materials are used in modular construction with efficient structural design and rapid assembly due to easy uses of frp material to create innovative design of buildings,it's life expectancy around 50 to 60 years approx.the ability of FRP composites to offer a combination of strength, durability, corrosion resistance, and design flexibility makes them a compelling choice for replacing conventional materials in various industries and applications. As research and new technology is continue to advance in the field of composite materials, the use of FRP composites is can be a sustainable and innovative solution for modern engineering challenges.

6. CONCLUSION

In conclusion, Fiber Reinforced Polymer (FRP) materials offer a promising solution for modern engineering challenges. With a combination of strength, durability, and design flexibility, FRP composites are increasingly replacing conventional materials in various industries. Their properties, including excellent environmental durability and fire performance, make them ideal for applications in challenging conditions. As research and technology advance, FRPs role in modular construction and innovative structural design is expected to grow, with a lifespan of around 50 to 60 years. Acknowledging the collective efforts of researchers and industry peers, FRP continues to evolve as a sustainable and innovative material choice.

7. Acknowledgement

The paper on FRP materials acknowledges the contributions of various researchers, including Li, Shen, Dong, and Peng etc., whose studies provided insights into FRP properties. These references enriched understanding of FRP mechanical properties, manufacturing, and applications. The paper also appreciates the guidance from mentors and peers, underscoring collective efforts that shaped its content.This acknowledgment recognizes the broader academic and industrial community for advancing knowledge on FRP materials and their applications, emphasizing collaboration and shared expertise.

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