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Exploring the Versatility of Composites: An Overview of Their Diverse Applications

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A B S T R A C T

The notable benefits of composites lie in their exceptional stiffness, strength characteristics, and lightweight nature. Fundamental aspects of composites encompass their diverse physical and material properties, alongside considerations in tooling, design, and repair methodologies. Employing composite materials has notably yielded cost efficiencies, heightened operational effectiveness, and enhanced resource utilization. Various sectors have adopted diverse moulding techniques for composite fabrication. Notably, composite materials find extensive utility across sectors such as aerospace, automotive, and manufacturing industries. This analysis underscores the imperative shift towards composite materials from conventional options.

Keywords: Composite material, matrix, fiber, efficiency

1. Introduction

Composite materials are crafted through the fusion of two or more distinct elements to yield a final product boasting superior properties compared to its individual components [1-3]. These materials consist of two integral components: the matrix and the reinforcing phase, often comprising fibers, sheets, or particles. The matrix phase envelops the reinforcing elements, which can encompass a range of materials including metals, non-metals, ceramics, and polymers. Commonly referred to as fiber-reinforced plastics (FRP), composites blend reinforcements and matrices to create versatile materials [4-7]. The advantages of composites are manifold: they are biodegradable, non-toxic, environmentally friendly, user-friendly, cost-effective, non-abrasive, lightweight, and provide a source of income for rural/agricultural communities. They also offer renewable and abundant raw material sources, as well as being free from health hazards such as skin irritations, while exhibiting adequate specific strength and excellent toughness [8-11]. However, certain drawbacks exist, including fiber degradation over prolonged storage periods, moisture absorption, propensity for aggregation during processing, relatively low thermal stability, and diminished resistance to moisture [12-15].

Materials, whether natural or synthetic such as ceramics, glass, metals, meta-materials, and plastics, form the building blocks of composite materials, which represent an advanced category of materials [16-18]. These composites amalgamate materials with disparate physical or chemical properties to generate novel characteristics while retaining the distinct identities of the constituent materials. Their widespread adoption is driven by their superior strength, lighter weight, and cost-effectiveness compared to individual materials, leading to their increasing utilization across engineering and construction applications.

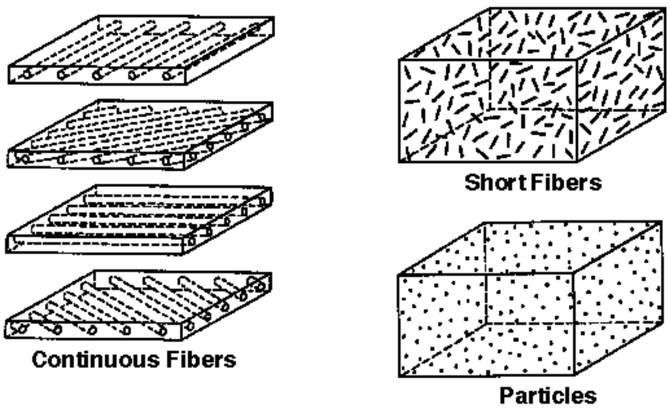

Fig. 1 - Fiber reinforced composites

Composite materials are primarily categorized based on the type of reinforcement and matrix employed. Reinforcement may consist of synthetic or natural fibers, while the matrix can be synthetic resin or plant oil-based resin [19]. The combination of fiber and resin determines whether the composite is non-degradable, partially degradable, or fully degradable. Additionally, classification may consider the geometry of the reinforcement, detailing factors such as fiber size, orientation, and placement directions [20-21]. Further elaboration on this classification is provided in the literature review chapter.

2. Literature Review:

The following are reviews of the composite materials that have been investigated. A helmet was made of an epoxy-based composite material derived from natural fibres. Composites containing natural fibres, such as sisal fibre, are reinforced and have better mechanical qualities than pure matrix materials. The sisal fibre was effectively reinforced with epoxy using a basic wet hand lay-up procedure. They conducted testing on the bending, tensile, and impact strength of the produced helmet [22-25]. A study of composite materials. The composite materials are meant to be flexible, lightweight, corrosion-resistant, and long-lasting [26]. The composite materials maintain their own identities while nevertheless relating their attributes to the product created by their mixing. Composite materials offer a wide range of applications in construction, particularly under compressive pressures [27-29].

Processing and strength study of composite packaging materials. A three-layer composite offers the maximum tensile and flexural strength compared to the four layers. The material produced is only employed for low-load packing; nonetheless, the use of treated jute fiber-reinforced polyester matrix composite was examined and yielded some positive results. Research into the production of composite materials that are totally or partially biodegradable, employing natural textile fibres of new vegetable origin and those recovered from textile waste [30-31]. Natural fibres are used for reinforcing fixings with complicated forms that provide a large surface area. Composite materials are effective choices for mass decline without cost increase [32-35]. Textile waste coming from industrial waste is a process that involves reducing, reusing, recycling, collecting, and so on.

3. Manufacturing processes of composite materials

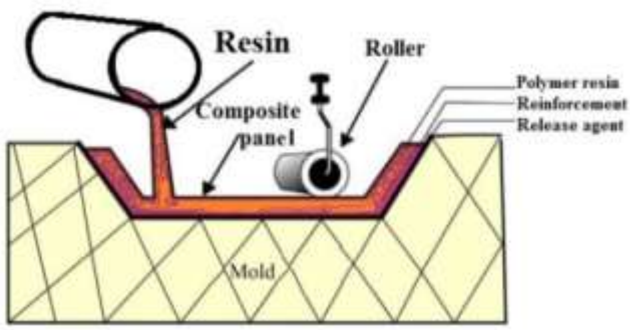

Fig. 2 - Hand lay-up technique

Fibers, whether in woven, knitted, stitched, or bonded fabrics, are positioned within the mold, after which resin is impregnated using rollers, brushes, or a nip-roller type impregnator. This impregnation facilitates the penetration of resin into the fabric. Subsequently, the fabricated laminates are cured under standard atmospheric conditions. A variety of resins, including polyester, epoxy, vinylester, phenolic, can be combined with any fiber material without limitations.

4. Vacuum-assisted resin transfer moulding

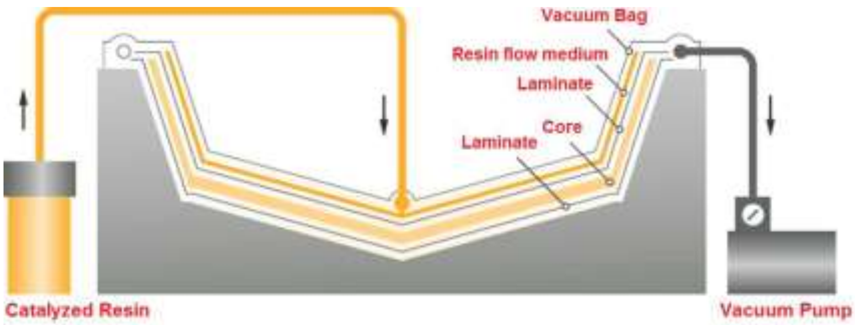

Fig. 3 - Vacuum-assisted resin transfer moulding technique

Vacuum Assisted Resin Transfer Moulding (VARTM) is a closed-mold composite production process. It is a variation of Resin Transfer Moulding (RTM), distinguished by the replacement of the top section of the mold tool with a vacuum pack and the use of vacuum to aid resin flow. The process entails utilizing a vacuum to facilitate the flow of resin into a fiber layup enclosed within a mold tool covered by a vacuum pack. Once impregnation occurs, the composite part is allowed to cure at room temperature, with an optional post-cure sometimes performed.

5. Compression moulding

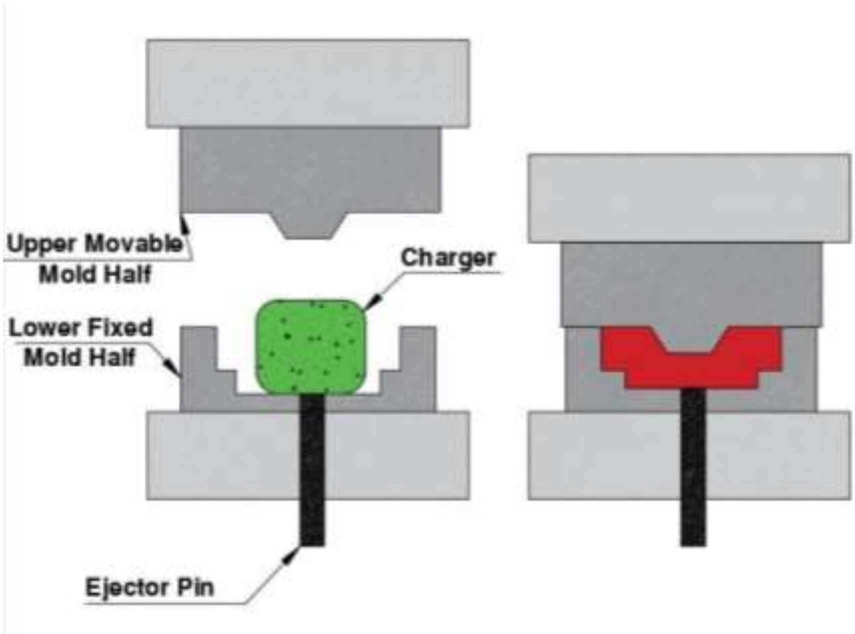

Fig. 4 - Compression Moulding technique

Compression moulding is a closed-mold composite production process that employs matched metal molds along with external force. In this method, a pre-constructed composite layup is placed into the open mold cavity, the mold is closed, and compression force is applied. This force is maintained on the mold throughout the curing cycle, typically occurring in an oven. The combination of pressure and heat results in a composite part with minimal void content and a high fiber volume fraction, achieving near-net shape completion of the component. Compression moulding often produces composite parts with the optimal mechanical properties achievable from the specific combination of constituent materials.

6. Classification of composite materials

Composite materials are widely divided as synthetic fiber-reinforced polymer composites, bio composites, and natural fiber-reinforced polymer composites. Fiber-reinforced composites have been used in engineering and other industrial applications because they can give qualities that are equivalent to or better than traditional pure polymer materials [36-38].

Furthermore, fiber-reinforced resin-matrix composite materials with high strength-to-weight and stiffness-to-weight ratios are becoming increasingly popular in weight-sensitive applications such as aeroplanes and other space vehicles, as well as the automotive, marine, and construction sectors [39-41]. Bio-composites are widely employed in the interior and external body elements of vehicles. Carbon, glass, aramide, Kevlar, boron, and other synthetic fibres are employed as reinforcing materials [42-45].

7. Bio-composites or natural fibres composites

The bio-composites include natural fiber-reinforced polymer matrices derived from both non-renewable and renewable resources. Bio-composites are either partially or entirely biodegradable.[46-49] Natural fibres combined with non-biodegradable synthetic polymers yield partially biodegradable composites. In the case of entirely biodegradable composites, natural fibres or bio-fibres are combined with biodegradable polymers such as poly lactic acid (PLA), poly vinyl alcohol, plant-based oil resins, etc. Bio-fibres reinforced with biopolymers are known as 'green composites' [50]. Natural fibres for reinforcing include wood and non-wood fibres such as jute, flax, hemp, banana, sisal, pineapple, sugarcane, oil palm, and others.

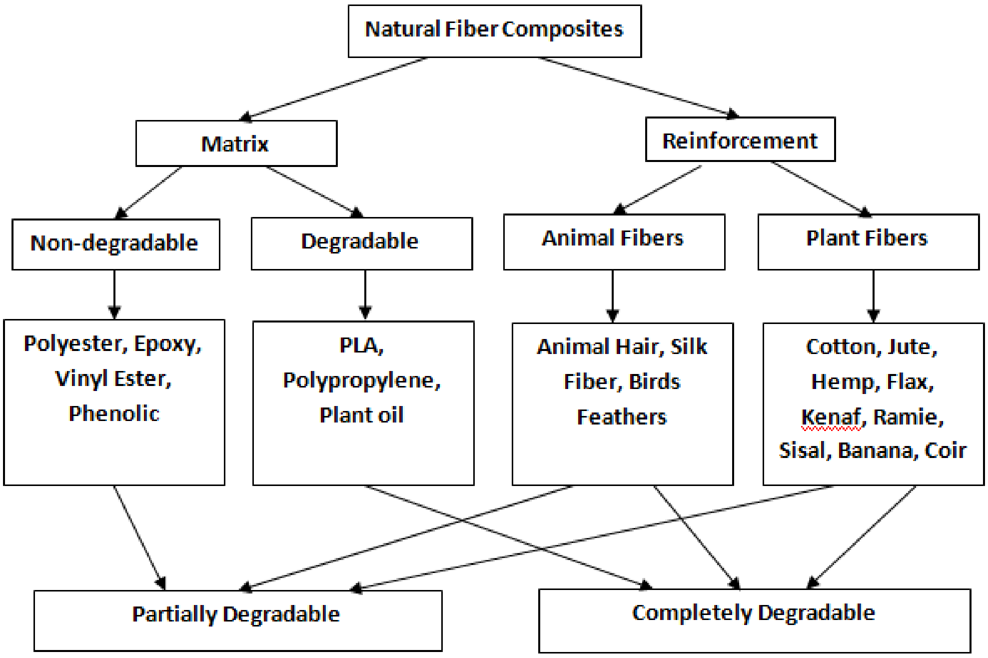

Fig. 5 - Constituents used in natural fibers composites

A composite material, known as a "Composition of Materials," comprises a reinforcing phase such as fibers, particles, or sheets embedded within the matrix phase. The reinforcing material serves as the primary load-bearing component, while the matrix phase maintains the reinforcing material in position and transfers loads between them. Additionally, it shields the reinforcing materials from damage during composite processing. The matrix phase, being ductile compared to the reinforcing phase, contributes to the composite's toughness. The amalgamation of these phases results in a new material with superior properties compared to the individual components. Composite materials are dependable, exhibit enhanced mechanical properties per unit weight, and modern manufacturing techniques enable the fabrication of large and complex-shaped components [51-53].

Composite materials are categorized as synthetic fiber-reinforced polymer composites and natural fiber-reinforced or bio composites. Fiber-reinforced composites have found widespread use in engineering and various industrial applications due to their comparable or superior properties compared to conventional materials [54-55]. Moreover, fiber-reinforced resin-matrix composite materials, renowned for their high strength and stiffness, are increasingly utilized in weight-sensitive applications such as aircraft, space vehicles, automotive, marine, and construction industries [56-58]. Bio composites have seen extensive usage in manufacturing automobile body parts [59-63]. Synthetic fibers used for reinforcement include carbon, glass, aramid, Kevlar, boron, among others.

8. Conclusion

Composite materials offer boundless design possibilities, with careful consideration of matrix, fiber, and performance selections being crucial in the design process. They boast attractive mechanical and physical properties, which are increasingly being leveraged in the automotive and aerospace industries worldwide on a large scale. Composite materials have now become ubiquitous in our everyday lives. The selection of appropriate raw materials and manufacturing techniques is pivotal in creating high-quality composite materials. Composite structures can be engineered with specific properties to meet the requirements of end-users. Continuous advancements in new fibers, polymers, and processing techniques across all classes of composites are continually being developed. The application of composites indicates an optimal balance between minimum structural weight and manufacturing cost. Numerous investigations have been conducted and are ongoing to develop new composite materials to replace conventional materials, while polymers with higher temperature ranges are also readily available.

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