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Advancements in Composite Materials and Their Applications in Engineering and Technology

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Abstract: Composites are designed materials made up of two or more components that have significantly different chemical, physical, and mechanical characteristics. All of these composites' unique characteristics arise from the properties of the materials that make them up, distributed in different proportions and orientations. Composites may be customized to meet a wide range of geometrical, structural, mechanical, chemical, and even aesthetic specifications. These synthetic materials find use in a wide variety of contexts, from the building and bridge industries to the automotive sector and beyond into the aeronautic, naval (e.g., ships and boats), and medical domains. Additional studies are required, as is evident from the importance placed by this study on the specific research topic and preliminary work under its many methodologies. The purpose of this article is to discuss the current state of composites in industry and to look forward to the potential of this material, including its benefits, drawbacks, and uses in manufacturing equipment. Additionally, this study demonstrates the Composite material's Characteristics, Challenges, Opportunities, and Future Demand in the Industrial Environment.

Keywords: Composite materials, Aerospace, Medical devices, High specific strength

I. INTRODUCTION

The high strength to density and stiffness to density ratios of composite materials make them useful in a variety of technical applications, including those dealing with aircraft, vehicles, civil constructions, etc. Composite materials are the principal load-bearing part of any modern construction, but they are also expected to provide a wide range of secondary benefits. In addition to sensing and providing actuation to the system at hand, the composite structure may also control the aforementioned system.

When combined with adaptive and smart materials, traditional composites may improve their qualities and become intelligent. Piezoelectric and electro strictive materials, shape memory alloys, magneto strictive materials, electro- and magnetorheological fluids, fibre optics, etc., are some of the most popular types of smart materials. By bonding or embedding these smart materials into traditional composites, these composites are enhanced in performance and capability and gain new functionality beyond their original (often structural) design.

As the mechanical environment around them undergoes change, smart materials may adapt by modifying their own characteristics in order to keep performing as expected under the new conditions.[1]

Composites are made by combining two or more materials, each of which contributes one or more of the necessary qualities. Matrix materials often consist of polyester, epoxy, or vinyl ester, all of which are thermoset or thermoplastic resins. And carbon, aramid, and glass fibres are the most popular reinforcing agents. Composites may be created using a variety of various additives, core materials, and fillers, and their final products often exhibit unique qualities compared to those of more traditionally used building materials. The key distinction is that anisotropic materials exhibit different behaviour depending on the orientation of the applied force. The ability to tailor composite materials' characteristics to a given project's specifications stands out as one of the material's main benefits. The production of composites allows for lighter and safer alternatives to conventional materials.

Fibre reinforcements are the most popular way to manufacture composites, with carbon being the most frequent reinforcing agent. Many scientists have been studying natural fibres as a means to create environmentally friendly materials for the industrial sector. Materials made from natural fibres like kenaf, abaca, grass, hemp, flax, bamboo, sisal, etc. have been the focus of extensive study into their mechanical and chemical characteristics. [2]

Fig. 1: Classification of composite materials

Composites surpass metals like steel and aluminium in tensile strength by a factor of four to six (depending on the reinforcements). At the time of operations, composites produce less noise and transmit less vibration than metals. Torsional stiffness and impact characteristics are two advantages of composite materials. The fatigue endurance limit of composites is greater (up to 60% of ultimate tensile strength), and they are also impact- and environmentally-resistant and low-maintenance. Composites are fireproof and resistant to corrosion.

Besides having low electrical conductivity and thermal expansion, composites also have easy incorporable incorporated ornamental melamine. When compared to traditional metal components, composites have the ability to reduce the number of moving parts and provide a more streamlined assembly process. The disadvantages of composite materials include their high initial cost, lengthy production time, poor ductility, temperature restrictions, vulnerability to solvent or moisture assault, and susceptibility to concealed defects and damage.

Composite materials' matrix degrades in the environment and is difficult to analyse; many applications need heat curing, which necessitates special equipment and time. Transport and storage in a refrigerator is necessary since the shelf life of the materials is short.

II. APPLICATION OF COMPOSITE MATERIAL

1. In Aerospace- Nearly half of the airframe is constructed from composite materials. Composite parts primarily benefit from being lighter and easier to assemble. Composites are being used extensively in the present helicopter, military fighter, large and small civil transport aircraft, satellites, launch vehicle, & missile development programme. A wide variety of aircraft components, such as the rudder, spoilers, airbrakes, accelerators, LG gates, engines cowlings, propellers, keel beam, primary wings, rear bulkhead, wing ribs, jet turbine fan blades, and aircraft interiors, are made from composites.

2. In Automotive - Lightweight, safer, and more fuel-efficient automobiles are in the works, and composites are being examined. The combination of a high-strength fibre (such as carbon or glass) with a matrix material (such as an epoxy polymer) results in enhanced qualities above those of either component used alone. Vehicle components such as the steering wheel, dashboard, seats, roof, hatch, mats, energy absorbers, instrument cluster, interior and exterior panelling, leaf springs, wheels, engine covers, and many more are all made from composites.

3. In Medical- A composite is a synthetic substance having biological interaction properties used in medical devices. Because of scientific and technological developments in synthetic materials, surgical procedures, and sterilising processes, composites have found several applications throughout the years. Multiple implants and other devices are employed in today's medical practises. Composites are used to replace or restore the function of disturbed or degenerated tissues or organs in order to improve function, facilitate healing, correct abnormalities, and ultimately enhance patients' quality of life. Some examples of such composites include sutures, intraocular lenses, artificial bones and joints, artificial hearts, vascular grafts, pacemakers, heart valves, dental implants, biosensors, etc.

4. In Electrical field- Electronic composites are strong and have a high modulus; high thermal conductivity, reduced temperature expansion, low dielectric constant, as well as high/low electrical conductivity are only few of the useful qualities they provide for electronic applications. In order to achieve high electrical conductivity, electronic composites may use pricey fillers like silver particles. Composites have several uses in the electronics industry, such as interconnections, electrical contacts, lids, interlayer dielectrics, thermal interface materials, connectors, die attach, heat sinks, housings, printed circuit boards, and more.

5. In Sports- Sports equipment made from composite materials is employed because of its portability, durability, strength, light weight, and simplicity of maintenance. Previously, stress absorption was prioritised, thus natural materials like wood were employed. Variation in characteristics and high moisture absorption with different deformations, and the material's anisotropic structure contributed to its poor resistance. The composite material is increasingly employed in sports equipment because to its low weight, high strength, great design flexibility, ease of processing and shaping, and resistance to fatigue, breakage, inferior thermal stability, and vibration. Composites are used in a wide variety of items, including sailboards, planning boats, sailing rackets, badminton paddles, baseball bats, ice hockey sticks, bows, and arrows.

6. In Chemical Industry- The chemical industry has benefited from composites' usage due to the material's fire-resistant qualities, lightweight, moldability, as well as resistance to chemicals. Composites' resistance to alkaline and acidic environments makes them ideal for usage in a wide variety of industrial applications, including gratings, scrubbers, ducts, pipes, vent stacks, pumps & blowers, structural supports, reservoirs, columns, reactors, and many more. Drive shafts, fan blades, ducts, stacks, subterranean storage tanks, composite vessels, etc. are some of the many uses for this versatile material. When compared to the overall use of composites across the world, applications in the chemical sector make up a minor percentage.

7. Other - The use of composites in the construction of factories, buildings, tanks, bridge components, and whole bridge systems has increased in recent years. The strong resilience of composites to salt water makes it possible to go to marine settings with reassurance. Doors,

windows, furniture, buildings, bridges, etc., are all made lighter with the use of composite for residential and commercial use.

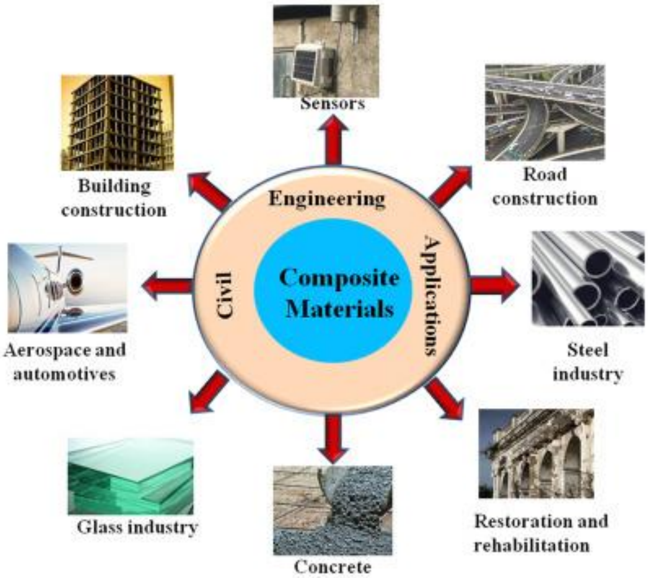

Fig. 2: Applications in construction

III. ADVANCEMENTS

a) Ceromers
b) Smart composites
c) Oemocers
d) Giomers
e) Single crystal modified composites
f) Nanocomposites

CEROMERS: Ivoclar used the word ceromer to characterise their composite Tetric Ceram; the acronym stands for "Ceramic Optimized Polymer." These resins may be classified as either microfilled hybrid resins or universal composite resins. They comprise of paste of "Barium glass, ytterbium trifluoride, spheroidal mixed oxide, and silicon dioxide (57 vol (Bis-GMA & urethane dimethacrylate)".

SMART COMPOSITES: Smart Composites are active dental polymers that incorporate bioactive amorphous calcium phosphate (ACP) filler capable of reacting to ambient pH variations by releasing calcium and phosphate ions and therefore becoming adaptive to the surroundings. Intelligent composites is another term for them. In 1998, a new kind of composite called Ariston pHc was launched. As a composite material, Ariston gives out ions. As the pH in the region immediately around the restorative materials decreases, active plaque releases functional ions such fluoride, hydroxyl, and calcium ions.

ORMOCER: The ORMOCER is a brand-new material for use in dental restoration treatment. In 1994, Dr. Herbert Wolters of the Fraunhofer Institute for Silicate Research introduced this category of material. Organically Modified Ceramic, or ORMOCER for short, is a brand-new substance that has emerged as an ideal and cutting-edge substitute for amalgam, composite, and compomers for all filling indications in the front and posterior regions of the mouth.

NANO COMPOSITES: Products with nano-sized fillers set them apart from conventional composites. Among them is Filtek's Supreme XT, which first appeared on the marketplace that year, 2003. It has been claimed that Supreme makes use of cutting-edge nanofiller technology, being composed of nanomer and nanocluster filler particles. Manufacturers of universal composites and reinforced microfills make claims similar to those made about Supreme, namely that it combines the strength of a hybrid with the polish of a microfill.

IV. LITERATURE REVIEW

(Parveez et al., 2022) [3] Composites, one such cutting-edge material, have seen steady growth thanks to recent developments in aviation materials and their production technology. The aircraft industry has benefited from the development of a wide variety of advanced materials, including ceramic and polymer composites, as well as alloys of aluminium, magnesium, and titanium. Mechanical characteristics, fretting wear, stress corrosion cracking, and corrosion are still concerns with these materials. Therefore, many efforts have been made to create aircraft materials that are both corrosion-resistant and mechanically better. The performance and total cost of ownership (TCO) may both benefit from the use of such materials. This article provides an overview of recent progress made in the field of composites for use in aviation. Then, it goes deep into the research done on composite materials designed for aeroplane frames, before moving on to the different production methods and finally, the aviation industry uses for these materials. Afterwards, it reviews the research done to this far, together with the difficulties scientists have encountered, and then predicts the future directions of aeroplane materials.

(Razaq et al., 2022) [4] Materials based on graphene have garnered a lot of interest because of their potential to usher in a new age of flexible and bending electronics. Graphene's remarkable electrical, mechanical, and optical characteristics, as well as the simplicity of functionalizing its derivatives, have made it a promising material for the development of bendable electronics. The latest developments in the production and uses of graphene-based composites are reviewed in depth in this study. "Graphene, graphene oxide (GO), as well as reduced graphene oxide (rGO)," along with conducting polymers, metal matrices, carbon-carbon matrices, & natural fibres, are emerging as a potential to be used in energy-harvesting systems, clean-energy storage devices, portable and wearable electronics, and other applications due to their superior mechanical strength, conductivity, and extraordinary thermal stability. The challenges and constraints that are now limiting graphene's growth are also highlighted. This study compiles a wealth of information that may be used to propel developments in graphene-based composites.

(Khan et al., 2021) [5] In order to achieve polymer-filler interaction, the appropriate biopolymers with specific additives must be chosen. Biopolymer composites may have their chemical composition, rate of breakdown, and mechanical properties tailored to a variety of applications. Interfacial interactions between the biopolymer and the nanofiller have a major impact on the mechanical characteristics of biopolymer composites. Biopolymeric composites are discussed in this study for their varied and potentially useful applications in controlled medication release, tissue engineering, and wound healing. To fully analyse regular biomaterials with improved biomedical engineering features, the biomedical sector and regenerative medicines need biopolymeric composite materials with advanced and multifunctional qualities. Multiple references to published research on topics such as tissue engineering, medication transport, and wound dressing have been made. This research is necessary because a review of these findings is necessary for future growth and analysis.

(Egbo, 2021) [6] Composites are designed materials made up of two or more components that have significantly different chemical, physical, and mechanical characteristics. All of these composites' unique characteristics arise from the properties of the materials that make them up, distributed in different proportions and orientations. Composites may be tailored to meet a wide range of geometrical, structural, mechanical, chemical, and even aesthetic specifications. These synthetic materials find use in a wide variety of contexts, from the building and bridge industries to the automotive sector and beyond into the aeronautic, naval (e.g., ships and boats), and medical domains. This paper's primary goal is to introduce readers to composite materials and to examine their present and prospective applications in the realm of medicine.

(Ali & Andriyana, 2020) [7] In the aerospace industry, aboard spacecraft, and in the construction of heavy machinery, composite materials are increasingly utilised. Recent developments in the area of "multifunctional composite materials" have shown an increase in the application of composite materials. Despite extensive destructive and non-destructive testing, metals continue to undergo refinement, invention, and replacement, demonstrating their resilience and longevity. The purpose of this research was to examine recent developments in the field of multifunctional composites. Nanomaterial-based MFCMs are the primary focus of the reviewed literature. The structural functions place a focus on the mechanical attributes of the material, such as its resistance to fractures, strengths, thermal stability, dampening, stiffness, as well as tensile strength. Some examples of these non-structural properties are biodegradability, thermal conductivity, electrical conductivity, and EMI shielding. The research found that "multifunctional nanoparticle-based composite materials and structures" could be used for a variety of purposes, including the development of lightweight but strong aircraft wings, the development of electric self-driving vehicle components and structures, and the development of biomedical composite materials for drug delivery.

(Syriac et al., 2020) [8] PTCs, or piezoelectric thermoset composites, are a kind of material that can convert mechanical energy into electrical energy. PTCs feature high stiffness, elastic modulus, and strain coefficients in addition to the previously mentioned strengths, processing ease, temperature and pressure requirements, and infinite storage space. This paper highlights recent developments and methodologies in PTCs, as well as some of the ways in which they have been put to use. Methods for assessing the linked piezoelectric responses are also discussed, including analytical, finite element, and experimental approaches. "Strain detection, vibration control, actuation, energy harvesting, structural health monitoring, and biological applications" are also discussed in this study. Although research into PTCs and their applications is only getting started, this review will help researchers come up with fresh ideas for future interface studies and modelling developments. These summaries also open up new avenues for study into the rapidly developing fields of relevance to PTCs' prospective applications. Additional studies are required, as is evident from the importance placed by this study on the specific research topic and preliminary work under its many methodologies.

(Marwaha et al., 2020) [9] One of the major achievements of current biomaterials research is the development of composite restorative materials, which may mimic the look and function of human tissue. Composite materials are used in at least 50% of all posterior direct restorations.

Unfortunately, these restorations are subject to high demands in terms of mechanical characteristics, positioning, and in-situ need. There has been a lot of work done in recent years to improve the restoration performance of these materials by experimenting with different initiation systems, monomers, fillers, and coupling agents, and polymerization techniques. Furthermore, we take a look back at the fundamentals of the polymerization process and discuss some of the newer methods used to boost the effectiveness of composite restorations.

(Lavanya et al., 2019) [10] Composite resins have been the dental industry's go-to for aesthetically pleasing restorations. These substitutes were developed as an improvement over the previously used amalgam fillings. Mercury amalgam fillings are hazardous and unsightly. Unfortunately, the mechanical characteristics of earlier composites aren't sufficient to survive the masticatory forces. To boost their physical and mechanical qualities, composite resins have been filled with a wide variety of filler particles. The compressive strength, abrasion resistance, application simplicity, and transparency of filled composite resins are all exceptional. Too far, several different types of composites have been produced, each tailored to a certain filler's size and form. This article provides a survey of many composites that use cutting-edge technology to tailor their qualities.

(Yıldızhan et al., 2018) [11] The potential of bio-composite materials to replace traditional materials in production has grown their popularity in recent years. Natural fibres or resins are used to create bio- composites instead of man-made ones like carbon, glass, or resins . Jute, sisal, hemp, flax, bamboo, hair, wool, silk, etc. are all examples of bio-based fibres. Plants are also used to create natural rubber, polyester, and other natural matrix materials. Being renewable and sustainable, as well as having disposal benefits and the ability to compost bio-composites beyond their expiry date have drawn the attention of many scientists. Moreover, bio-composites' versatile mechanical qualities allow them to be used in a wide range of goods. In this paper, the recent advancements, chemical and mechanical properties, and real-world applications of bio-composites are discussed.

(Žlebek et al., 2017) [12] The development of civilisation and national infrastructure are inextricably linked to the availability of various materials. Engineers may use composites in a wide variety of situations because of its high strength-to-weight ratio, cheap cost, and simple manufacture. Using composites instead of metals has reduced weight and cost in several situations. Motor engine cascades, leaf springs, curved fairing and fillets, welded metal component replacements, tubes, cylinders, medical and electrical gadgets, sports equipment, etc. For its high specific strength, low weight, and high stiffness, composites account for around half of an airplane's airframe in the aerospace industry. The purpose of this article is to discuss the current state of composites in industry and to look forward to the potential of this material, including its benefits, drawbacks, and uses in manufacturing equipment.

V. CONCLUSION

Composites have several potential applications in numerous fields, including the automobile, aircraft, wind energy, electrical, sports, home, civil construction, medicinal chemistry, and others. When it comes to compressive stresses, composite materials show considerable promise as a viable solution. Composite materials are appealing due to their low weight, low density, and corrosion resistance as well as their inexpensive cost and relatively high compressive strength. As a result of their favourable mechanical, electrical, and chemical qualities, composites have found widespread use in a wide range of fields. Composite material is widely used in the automotive and aerospace industries for the production of a variety of components owing to its desirable qualities. Numerous household items, including furniture, windows, doors, mats, civil construction, etc., are made from composite materials. Composites may improve the functionality of products in the maritime, chemical, and sporting sectors. From this overview, we learn that composite materials provide many benefits and may be used in many different sectors; they also allow us to improve our standard of living.

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