An Overview of Composites materials and their Machinability in Transport Industries

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Abstract. Many composite materials are increasingly being used in the technology of many fields of study. They find applications in Aerospace, Civil, Electrical, Marine, Medical fields, etc. In this current study, an overview of all these applications were gathered and then consign the study to an interesting application of composite materials in transportation industries where biocomposites are predominantly used as biomaterials. Biocomposite materials are machinable and require machining procedures in many of their applications, this was extensively highlighted in this study. Also some challenges that stem from their machining were mentioned.

1 Introduction

Composite materials are gradually being used in almost every manufacturing process. From the construction of houses to cars, and even aircraft, composites are being used in a bid to get the best qualities in a material. Some of these qualities like light-weight, tensile strength, resistance to heat and corrosion, are important in selecting materials for manufacturing processes. A very good example is the aircraft. Aircraft require minimal weight so as to increase the net action of lift on itself, thus, the materials selected for building the fuselage and other parts require lightweight. However, these materials due to exposure to airflow at high speeds, need high resistance to heat and corrosion. The materials selected must also have great tensile strength, to withstand the actions of pressure and shear-stress distributions due

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to the action of air molecules on the aircraft. In the construction of airplanes as described above, aluminium alloys were used for a long time, and are still used in building aircraft. Pure aluminium metal is set aside in preference of its alloys as it lacks a few of the required characteristics and its alloys are chosen not because they are the best materials for the job**,** but they are the best materials available at the time.

Aircraft fly at varying speeds denoted by the Mach number of the airflow. When flying at higher speeds, the effect of aerodynamic heating is higher and the negative qualities of metals become evident. The metallic structures experienced corrosion and metal fatigue. The treatment of metals to become alloys is among the various methods which were used to counter this hazard as well as reduce the effect of aerodynamic heating. However, more recent developments in the science and engineering of composite materials, have helped in boycotting a few of these methods as composite materials have been designed to have even better resistance to heat and corrosion, than the alloys that were used before them. These composites are now gradually being used to replace the classical design materials that preceded them [2].

Another example is in the civil engineering industry. In the field of construction, engineers are always looking for materials with suitable design qualities like High stiffness, Fatigue resistance, Corrosion resistance etc. Before steel bars were generally used to reinforce concrete, which led to the early depreciation of buildings. With the incorporation of composite materials into many building projects, building strength and durability has far improved with the use of common composites like reinforced concrete that we all know, to translucent concrete which provides an aesthetic view in buildings. GFRP fibreglass rebar is a recent composite material used in construction that has adequately addressed many structural problems including premature depreciation of conventional building materials and other structural failings [3].

Fig 1. Materials used in Airbus A380 construction [1].

CFRP = Carbon Fibre Reinforced Plastic
GLARE = Glass Reinforced aluminium laminates;
AA 2XXX, 6XXX and 7XXX = conventional aluminium alloys
Al-Li = Aluminium-Lithium alloys; LBW = Laser Beam Welding

Fig 2. GFRP Fibreglass Rebar [4].

The website from which this image has been sourced belongs to a company that deals with helping clients get cost-effective energy-saving solutions in several related fields including construction and mining. It also boasts that the GFRP Fibreglass rebar is three (3) times stronger in reinforcement than steel while being ten (10) times lighter. For any civil engineer looking to build a good project with quality materials. The choice is as clear as daylight.

This is the same case across many engineering applications. Composite materials that can provide better design qualities in any form of a project are being selected to replace the preceding non-composites being used. The competition still gets fiercer than that as more and more composites are being developed to outwit the properties of existing composite materials. Perhaps in the nearest future, the use of composite materials would be more common and rampant even in third world/developing countries.

2 Composite Materials

Composite materials are a combination of two distinct materials, which usually have very diverse physical and chemical properties. The materials are combined to enhance the properties of the base material to make it suitable for a purpose. E.g., increasing a material's conductivity or resistance to electricity [5]. Composite materials can be defined as complex materials containing a stronger structural unit (fibres) within a weaker material (matrix). They contain distinct materials with some embedded in the other. Thus, they are different from macroscopically homogeneous materials [6]. Examples of Composite materials include: Fibreglass, Syntactic foams, Plastic coated paper, Papier-Mache, Cement-bonded wood fibre, Pykrete, Carbon Fibre reinforced polymer, Translucent Concrete etc. (Fig 3a-d) [5], [7].

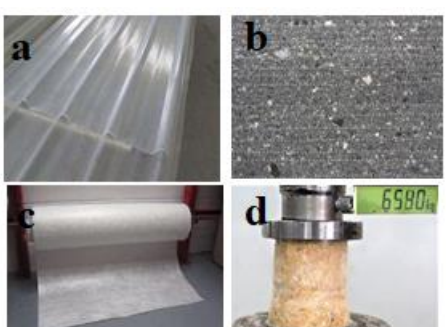

Fig 3. Examples of Composite materials (a) Fibreglass roof sheets (b) Fibreglass (c) Translucent Concrete (d) Pykrete [8]-[10].

2.1 Constituents of Composite materials: Fibers and Matrices:

The concept of composite materials has already been discussed. Now we examine two important terms in our definition: Fibers and Matrices. As already stated, a composite material is formed by embedding reinforcements/fibres in a weaker material (known as a matrix). The composite material then gains better properties than its constituents. The make-up of composite materials is illustrated below.

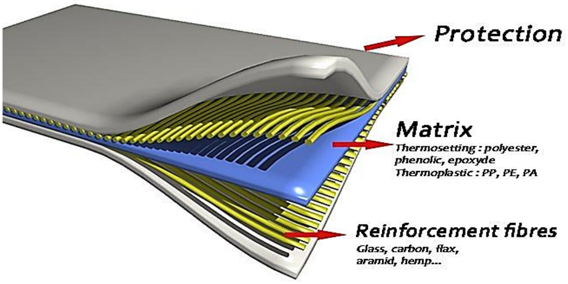

Fig 4. Make-up of Composite materials [11]

Fibres and matrices bond to form composite materials. The bonding which joins fibres and matrices is determined by the manufacturing process of that composite material. Many materials can be fabricated into fibres, examples include: Glass, Carbon, Boron, Silicon Carbide etc. Materials that are used as matrices include: Polymeric matrix (Plastic resins: Thermoplastic and Thermoset). Mineral matrix: Silicon carbide, Carbon etc. Metallic matrix: Aluminum alloys, Titanium alloys, etc. (Fig 4) [6].

2.2 Types of Composite materials

Composite materials are categorized into five (5) distinct types based on the structure or anisotropy of their constituent fibres. These are:

Fibre composites: These composites' fibres reinforce the base material along its length or longitudinal axis. The reinforcement can also occur in 1-D, 2-D or 3-D (one dimension/unidimensional, in two dimensions/bi-dimensional or in three dimensions/tridimensional).

Particle composites: These composites have fibres that reinforce them equally in all dimensions. They are also referred to as isotropic composites.

Flake composites: These composites have fibres that reinforce their base materials in two dimensions (2-D).

Layered/Laminar composites: These composite materials consist of multiple layers of either identical materials or different materials. This makes them able to be reinforced wherever such reinforcements are necessary.

Filled composites: These composites are reinforced by adding outside constituents to the composites in two ways giving rise to two (2) different kinds of filled composite materials. In one, a filler material is added to the composite for reinforcement, while in the other a skeletal 3-D matrix is used to hold the composite material (Fig 5).

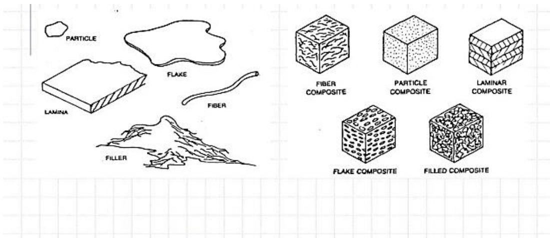

Fig 5. *Types of Composite materials [12]*

2.3 Machinable Composite:

Machinable composites are composite materials. Machinable composites are simply composite materials that can undergo machining processes after manufacturing to be used in various applications. Many composite materials can undergo machining even when subjected to conventional machining procedures. However, due to the anisotropic and non-homogeneous structures of composites, these machining procedures need an effectively designed tool and adequate operating conditions. Without these, the structure of the composite materials could be damaged or the machining tool could be damaged by wear and tear [13].
Example of machinable composites includes MC5000-HT Mica-Silicone composites, Calcium silicate composites, ZYZ zirconium oxide fibre and Epoxy resins etc. [14].

2.4 Bio-composites:

Bio-composites are simply composite materials that are formed from naturally derived fibres and matrices. These composite materials can be obtained naturally or can be synthesised artificially using their constituent fibres and matrices. Bio-composites just like composite materials, find increasing applications in many engineering sectors including the automotive and aerospace industries as well as medical-related fields, where they form the bedrock of biomaterials used for biomedical applications such as bone tissue engineering [15]. Examples of bio-composites include Natural Fibre Polypropylene (NFPP) and Poly-bioactive glass [16], [17].

2.5 Applications of composites:

2.5.1 Aerospace applications:

Composites have found numerous applications in the aerospace industry, particularly in the design of many important aircraft components such as the wings and turbines of the aircraft engine. Composites possess many properties that make them suitable for implementation in manufacturing aircraft parts. These properties include: Lightweight, High strength to weight ratio, Fatigue resistance, Resistance to Corrosion, High resistance to heat etc. A good example is the Boeing 787 "Dreamliner", where almost the whole fuselage is constructed using Carbon laminate composite (Fig 6).

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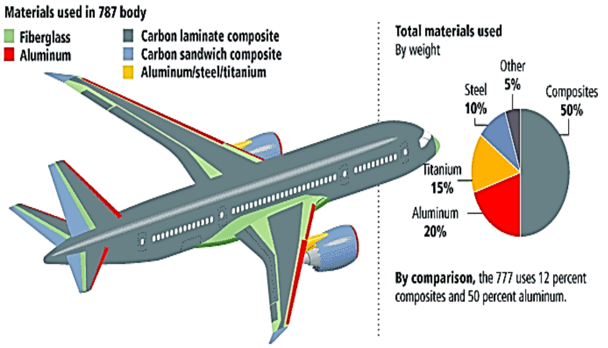

Fig 6. Boeing 787 "Dreamliner" composites proportion [20].

This composite is also used in the construction of its upper and lower wing skins. Carbon sandwich composite is also used in the construction of the rudder and elevators on the vertical fins and horizontal stabilizer respectively. The airliner boasts that the composites in the Dreamliner occupy 80% by volume and yet still amount to 50% by weight [15], [17].

2.5.2 Automotive Construction

For the same reasons as the aerospace industry, composites are being utilized in the production of automobiles. The composites demonstrate qualities that make them suitable for the construction of both exterior and interior automobile parts.
For instance, the high strength to weight ratio of composites helps in reducing the overall weight of vehicles. According to the Oak Ridge National Laboratory (ORNL), this characteristic will help reduce the fuel consumption of vehicles, thereby improving private expenses on fuel by reducing the weight of vehicle parts by 60% [20].
Another instance is the research conducted by Ahmed Mohamed Elmarakbi and Wiyao Leleng Azoti from the Faculty of Applied Sciences of the University of Sunderland and the University of Strasbourg on the use of Graphene Related Material (GRM) composites for automotive (Fig 7).

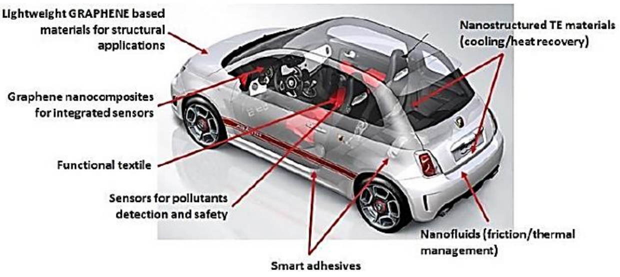

Fig 7. Graphene Related Materials applications in Automobile Construction [21].

2.5.3 Civil infrastructure

We have already described briefly in the Introductory aspect of this work, the breakthrough that composite materials provided to the construction of civil infrastructure, where we cited the use of GFRP Fibreglass rebar as a stronger material for reinforcement than steel. Another use of composite materials in the construction of civil infrastructure is aesthetics. In building projects designed for personal convenience, recreation or even tourism, aesthetics becomes an important consideration. In this regard, the use of composites still stands out as some composites are designed to exhibit aesthetic properties without losing the design properties that make them suitable for construction. An example is the composite Translucent Concrete. With this composite, the building structure becomes translucent allowing a certain degree of light from behind the concrete to pass through. Figures behind the concrete then appear as shadows [19].

2.5.4 Electrical Industry:

Composites also find applications in the electrical industry. Their main applications occur in electrical insulation and shielding processes as well as the production of semiconductors (some composites can become semiconductors at certain temperatures). The properties of composites that make them desirable for electrical applications include: Heat resistance., Low electrical conductivity (Insulation), Moisture resistance, High Dielectric strength., Electromagnetic Interference, Low Thermal expansion coefficient, High Thermal conductivity.
These qualities make them suitable for the production of Printed Circuit Boards (PCBs), electrical insulation, Electromagnetic shielding, production of semiconductor derived components (Transistors, Integrated Circuits, Diodes etc.), production of Lightning harvesters, etc. Some semiconductors are used as base materials to develop composites that have better properties. An example is Graphene-Semiconductor composites which exhibit a better overall photocatalytic performance than their base semiconductors (Fig 8) [19], [20].

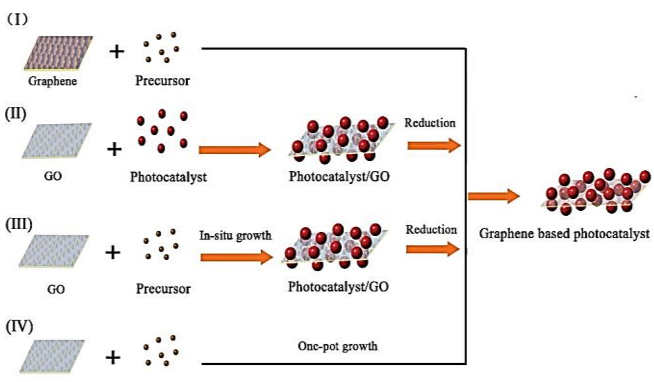

Fig 8. Fabrication process for Graphene-based Photocatalytic Composites[20].

2.5.5 Medicals applications

a. Composite applications
Fibre-reinforced polymer composite materials (also known as FRPs) are used in the field of medical sciences because of the suitable properties they possess for producing medical components like prosthetics, filling tooth cavities and are useful in many fields of medical research. Examples of these suitable properties are Lightweight, Fatigue resistance, High-stiffness characteristics, High specific properties, Flexibility, Bio-compatibility, etc.
External medical mechanisms such as artificial limbs utilize these properties of composites in their manufacturing. Because of the use of composites, these components become lighter and more effective while remaining eco-friendly and not posing any hazards to human health [15].

b. Biocomposite applications

Biocomposites (special composites formed by polymer matrices and natural fibres) find many biomedical applications. One of these applications is drug delivery: where a Biocomposite is used to send medicine to precisely targeted places in the human body. A biomaterial (or biocomposite) used for this is Conducting Polymer nanomaterials (CP nanomaterials) [18].

Another important application is bone tissue engineering. The concept is to introduce a tissue engineering construct to encourage the repair of damaged bone tissues. The engineering construct requires a scaffold that has certain requirements to be met to work appropriately. They include: Biocompatibility, Open porosity, Biodegradability, Adequate Mechanical properties, Good surface chemistry.

Biocomposites have been developed to meet these requirements. Some biomaterials used for preparing this scaffold include Extracellular matrix (ECM), Demineralised bone matrix (DBM), etc. (Fig 9a-c) [17].

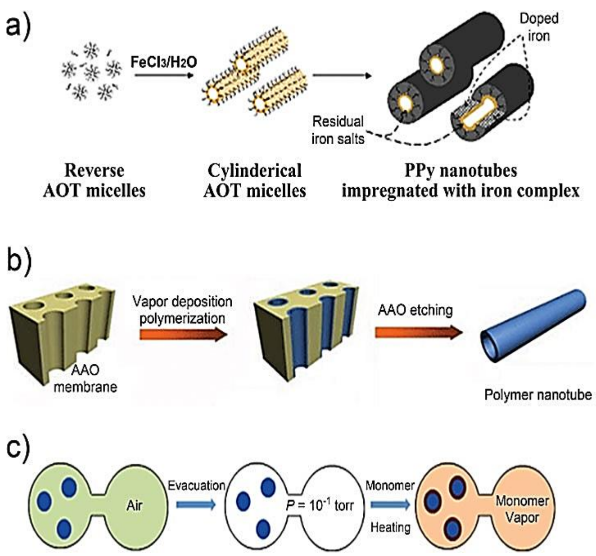

Fig 9. Synthesis procedures for Conducting Polymer nanomaterials [20].

As we can see from the above, there are a lot of applications of composite materials in many engineering jobs, some of which play an important role in the operation of high-end medical equipment and technology both directly and indirectly. As the use of composite materials finds more applications in medical fields, one particular use stands out as very crucial. The use of biomaterials or bio-composites. These components have been found to provide a lot of helpful solutions in the field of Biomedical Engineering, including drug delivery, bone-tissue engineering and cancer treatment among others. However, because of the structural design of bio-composites, the difficulties in machining these composites for large scale manufacturing have hindered their implementation. In this study, we will investigate Bio-composites, the conventional machining processes they undergo and good machining procedures that can help solve the challenges in machining them effectively [21].

3 Overview of Machining of Biocomposites

The machining of biocomposites is not a far fetched concept. It simply means the application of machining procedures to biocomposites to meet assembly or dimensional requirements. Composite fabrications generally produced composites designed to a near neat shape. Nevertheless, these composites cannot be joined or welded together to produce the required final shape or tolerance without difficulty despite the precise configurations of their manufacturing design. Hence the need for composites to undergo machining process even after manufacturing [20], [21].
In our study on research data on the machining of biocomposites, the focus of the research works available to us were those on Natural Fibre Reinforced Composite materials (NFRCs) or Natural Fibre Reinforced Polymer materials (NFRPs). These composite materials can be subjected to various machining procedures including Drilling, Milling, Turning etc. Some of these procedures are described below:

3.1 Drilling of NFRCs:

Drilling of components produced from NFRCs is still a very essential machining procedure in shaping these components for assembly. Drill cutting tools or (drill bit) is used in creating holes through the material. Drilling operations are characterised by the combined cut and jut of the material being drilled on the edges of the cutting tool in the centre of a drill. The drill bit is applied to the workpiece (i.e., the composite component) and rotated at very high speeds. This process causes the cutting tool to exert a very strong force on the workpiece, the force begins extruding material so that a hole gradually appears on the material being drilled [11].
There are various geometries of cutting tools used for drilling. Some of them include brad, spur, twist, slot, dagger, step, core, and straight flute drill bits (Fig 10). These cutting tools also have distinct angles or orientations for cutting and are made of various materials such as solid carbide, coated and uncoated cemented carbides, and high-speed steel (HSS). Another material polycrystalline diamond is used in the drilling of NFRCs [15].

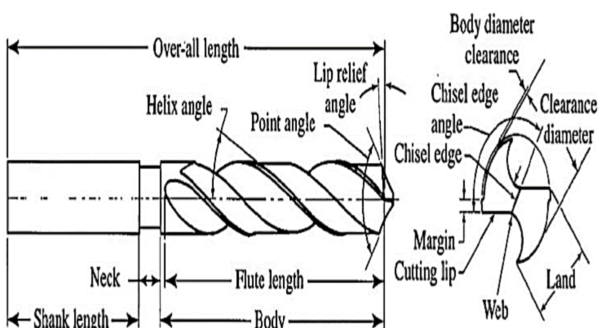

Fig 10: Double Flute Drill bit [12]

3.2 Milling of NFRCs:

Milling is a unanimous form of machining or material processing. It is a capable of modifying components to yield various kinds of surface features by simply removing excess material. Milling is conventionally used as a final machining process in many machining projects or as a means to yield high-quality defined surfaces. The milling of NFRCs is no different than usual. In many component production operations from composites, milling is used to adjust the materials shape qualities as a form of surface finishing before the component is used in assembly (Fig 11) [21].

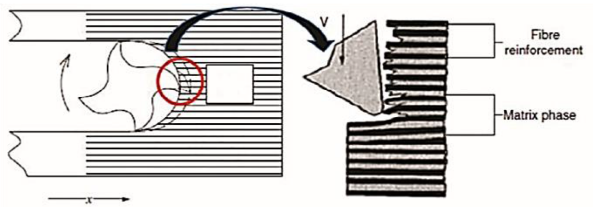

Fig 11. Milling of NFRCs [12]

3.3 Turning of NFRC

Turning is another important machining process in the production of NFRCs. It involves the elimination of undesirable materials from the surface of a component to attain a specified design and dimension for any form of application, by applying a cutting tool to a single point. In turning operations, the workpiece is set to rotate around an axis without translating, while the cutting tool is gradually moved to make contact with the workpiece at a single point. The turning operation is useful in resizing workpiece shapes to circular sections or reducing the diameter of a circular cross-section. It is equally important in the machining processes of NFRCs It also depends on different constraints for example feed rate, cutting speed and depth, as well as the cutting tool material and geometry (Fig 12) [22].

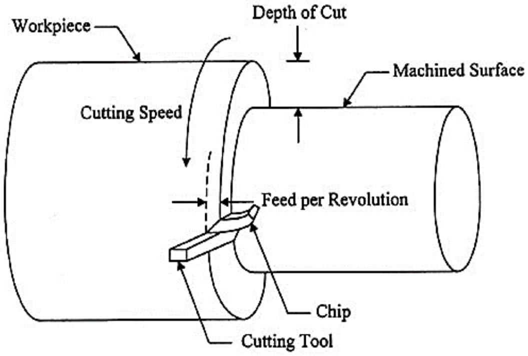

Fig 12. Turning operation [12]

3.4 Challenges of Machining NFRCs

There are various concerns that the machining of NFRCs presents. These challenges will be itemized and briefly discussed.

1. Surface roughness:

This refers to the surface quality of a machined surface. Due to the anisotropy and inhomogeneity of Natural Fibre Reinforced Composites (NRFCs), the fibres when machined are not effectively sheared causing some fibres to be detached or torn-off. Other factors such as very high thrust force cause transverse deformation among fibre cross-sections. All these cause the machined surface to have a low surface quality and a high surface roughness.

2. Wear of cutting tool:

Tool wear is another defect of NFRC machining. When the composites being machined are induced to have high shearing energy, not only does the surface of the composite exhibit surface roughness but, the tool itself would have to exert a similar amount of energy to overcome the composites shearing energy. This exertion of energy can lead to friction and heating which cause the tool to wear off.

3. Delamination:

Delamination is an inter-fibre failure phenomenon that is caused by the action of external forces on a composite structure leading to the separation of different layers of fibre reinforcement as depicted in Fig 13. It also is an important cause of surface roughness. The external forces applied are usually due to the effect of machining operations on composite structures. Delamination caused by drilling can be reduced by achieving enhanced drilling precision. This can be obtained by reducing the thrust force and torque by adequately selecting input constraints. These can be done, for instance, by using a lesser feed rate and a greater cutting speed [23].

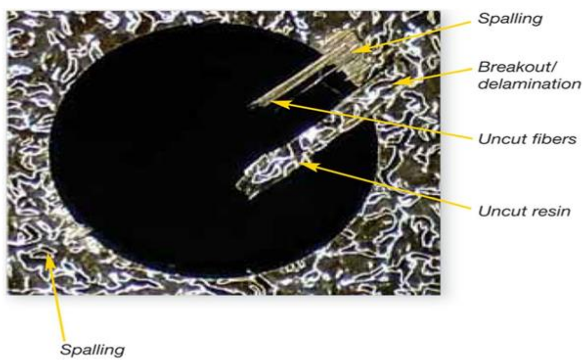

Fig 13. Delamination in Fibre-reinforced polymers [23].

4 Conclusion

In this study, the machinability of composite materials used in transport industries has been reviewed. The challenges in machining biocomposites were highlighted and several applications of composite materials were discussed in this review. Machining processes of the following composites were discussed in this review such as Carbon Fibre Reinforced Plastic (CFRP), Glass Reinforced aluminium laminates (GLARE) as well as Natural Fibre Reinforced Composite (NFRCs) and Natural Fibre Reinforced Polymer (NFRPs).

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