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PROSPECTS AND CHALLENGES OF COMPOSITES IN A DEVELOPING COUNTRY

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ABSTRACT

In spite of the tremendous progress that has been made in the discipline of material science and engineering, there still remain technological challenges, including the development of even more sophisticated and specialized materials such as composite materials. This research is geared towards exposing the prospects and the drawbacks of the development of composite materials. The review of literatures shows the trends of composite materials in the developing countries. The most important advantages of composite over the conventional steel are light weight, corrosion and fatigue resistance, high stiffness and strength. The equipment to adopt this technology is rarely available in some developing countries. A challenge for future growth is the simulation of technology upgrading and dynamism through technology transfer. Most developing countries desire rapid industrialization, export enhancement, self reliance and minimizing the import in order to achieve a robust economy. However, strengthening the link between research institutes and industries will contribute immensely to the development of composites in these countries and also add to the participation in the composites market.

Keywords: composites, developing countries, industrialization, export enhancement, self reliance, robust economy.

INTRODUCTION

The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials. Advancement in the understanding of a material type is often the fore- runner to the stepwise progression of a technology (William, 2001).

Composite is a combinations of materials differing in composition or form on a macro scale. The materials retain their identities in the composite; that is, they do not dissolve or otherwise merge completely into each other although they act in concert. Normally, these materials can be physically identified and exhibit an interface between one another. A composite material usually has characteristics that are not depicted by any of its components in isolation (Al-Mosawi *et al*., 2012). Using this definition, it can be determined that a wide range of engineering materials fall into this category. For example, concrete is a composite because it is a mixture of Portland cement and aggregate. Fiber glass sheet is a composite since it is made of glass fibers embedded in a polymer (Miller, 1998).

Composite materials usually consist of synthetic fibres embedded within a matrix, a material that surrounds and is tightly bound to the fibres. The most widely used type of composite material is polymer matrix composites (PMCs). PMCs consist of fibres made of a ceramic material such as carbon or glass embedded in a plastic matrix. Typically, the fibres make up about 60 per cent of a polymer matrix composite by volume. Polymers composites can be fabricated into different shapes using known polymer melt processing parameters, such as films wires and bulk materials which is dependent on the rheological melt behaviour of the polymer (Tahar *et al*., 1997; Capozzi *et al*., 2004; Gupta *et al*., 2006; Baughman *et al*., 2002; Kota *et al*., 2007; Greco and Maffezzoli, 2003).

Metal matrices or ceramic matrices can be substituted for the plastic matrix to provide more specialized composite systems called Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs), respectively (Kalpakjian and Schmid, 2010; Muhammad *et al*., 2010).

The incorporation of several different types of fibres into a single matrix has led to the development of hybrid bio-composites. The behaviour of hybrid composites is a weighed sum of the individual components in which there is a more favourable balance between the inherent advantages and disadvantages. Also, using a hybrid composite that contains two or more types of fiber, the advantages of one type of fiber could complement with what are lacking in the other. As a consequence, a balance in cost and performance can be achieved through proper material design (Idicula *et al*., 2006). The properties of a hybrid composite mainly depend upon the fiber content, length of individual fibres, orientation, extent of intermingling of fibres, fiber to matrix bonding and arrangement of both the fibres. The strength of the hybrid composite is also dependent on the failure strain of individual fibres. Maximum hybrid results are obtained when the fibres are highly strain compatible (Cristiane *et al*., 2009) Composites differ from common engineering materials in many ways but perhaps the most important are that they are not isotropic, they lack yield, they have low shear modulus, they have infinite variety and possibly the most profound difference is that the material doesn't exist until the component itself is made. All of these differences present challenges to the engineer that may seem daunting. But the appropriate use of composite materials can bring profound benefits to an application and may mean the difference between failure and success.

A composite material can provide superior and unique mechanical and physical properties because it combines the most desirable properties of its constituents while suppressing their least desirable properties. For example, a glass-fibre reinforced plastic combines the high strength of thin glass fibres with the ductility and chemical resistance of plastic; the brittleness that the glass fibres have when isolated is not a characteristic of the composite. The opportunity to develop superior products for aerospace, automotive, and recreational applications has sustained the interest in advanced composites (Schuh, 2000; Eder *et al*., 2006). Currently composites are being considered on a broader basis for applications that include civil engineering structures such as bridges and freeway pillar reinforcement; and for biomedical products, such as prosthetic devices (Kalpakjian and Schmid, 2010).

Glass-reinforced thermosetting plastics are presently competing with both steel-sheet and zinc die-casting. The use of low-cost composites in the automotive industry has already reached an impressive performance level. Carbon fibers have emerged as the main reinforcement fibre for high-performance composite materials. The development of strong and stiff carbon-fibres for a wide range of industrial applications and their use in lightweight structural parts are among the principal technological achievements of this period. Composites are engineering materials that consist of more than one material type. Fibreglass is a familiar example, in which glass fibres are embedded within a polymeric material. Fibreglass acquires strength from the glass and flexibility from the polymer. Many of the recent material developments have involved composite materials. Fabrication of the composite materials is focused on obtaining materials with improved properties compared to the matrix material. (Włodarczyk-Fligier *et al*., 2008).

Background of study

Humans have been using composite materials for thou- sands of years. For example, they have manufactured bricks out of mud which is thousand-year-old technology. In this modern era, we all depend on composite materials at some aspects of our lives. Fiber glass is one of the first modern composite which was developed in the late 1940s and is still the most common in our daily use. Composite is a term that has different meanings among engineers and manufacturers. In its general form, a composite material can be defined as ‘a composite consists of two or more dissimilar materials which when combined are stronger than the individual (Hossain, 2011).

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks. Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

Typical engineering composite materials

Concrete is the most common artificial composite material of all and typically consists of loose stones (aggregate) held with a matrix of cement. Concrete is a very robust material, much more robust than cement, and will not compress or shatter even under quite a large compressive force. However, concrete cannot survive tensile loading (i.e., if stretched it will quickly break apart). Therefore to give concrete the ability to resist being stretched, steel bars, which can resist high stretching forces, are often added to concrete to form reinforced concrete.

Fibre-reinforced polymers (FRPs) include carbon-fibre reinforced plastic (CFRP), and glass-reinforced plastic (GRP). If classified by matrix then there are thermoplastic composites, short fibre thermoplastics, long fibre thermoplastics or long fibre-reinforced thermoplastics. There are numerous thermoset composites, but advanced systems usually incorporate aramid fibre and carbon fibre in an epoxy resin matrix.

Shape memory polymer composites are high-performance composites, formulated using fibre or fabric reinforcement and shape memory polymer resin as the matrix. Since a shape memory polymer resin is used as the matrix, these composites have the ability to be easily manipulated into various configurations when they are heated above their activation temperatures and will exhibit high strength and stiffness at lower temperatures. They can also be reheated and reshaped repeatedly without losing their material properties. These composites are ideal for applications such as lightweight, rigid, deployable structures; rapid manufacturing; and dynamic reinforcement.

Composites can also use metal fibres reinforcing other metals, as in metal matrix composites (MMC) or ceramic matrix composites (CMC), which includes bone (hydroxyapatite reinforced with collagen fibres), cermet (ceramic and metal) and concrete. Ceramic matrix composites are built primarily for fracture toughness, not for strength. Organic matrix/ceramic aggregate composites include asphalt concrete, mastic asphalt, mastic roller hybrid, dental composite, syntactic foam and mother of pearl. Chobham armour is a special type of composite armour used in military applications.

Additionally, thermoplastic composite materials can be formulated with specific metal powders resulting in materials with a density range from 2 g/cm^3 to 11 g/cm^3 (same density as lead). The most common name for this type of material is "high gravity compound" (HGC), although "lead replacement" is also used. These materials can be used in place of traditional materials such as aluminium, stainless steel, brass, bronze, copper, lead, and even tungsten in weighting, balancing (for example, modifying the centre of gravity of a tennis racquet), vibration damping, and radiation shielding applications. High density composites are an economically viable option when certain materials are deemed hazardous and are banned (such as lead) or when a secondary operation costs (such as machining, finishing, or coating) are a factor.

A sandwich-structured composite is a special class of composite material that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density. Wood is a naturally occurring composite comprising cellulose fibres in a lignin and hemicellulose matrix. Engineered wood includes a wide variety of different products such as wood fibre board, plywood, oriented strand board, wood plastic composite (recycled wood fibre in polyethylene matrix), Pykrete (sawdust in ice matrix), Plastic-impregnated or laminated paper or textiles, Arborite, Formica (plastic) and Micarta. Other engineered laminate composites, such as Mallite, use a central core of end grain balsa wood, bonded to surface skins of light alloy or GRP. These generate low-weight, high rigidity materials.

Areas of application of composites

The application of composites cuts across all phases in human's life. Fiber-reinforced composite materials have gained popularity (despite their generally high cost) in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames, swimming pool panels and racing car bodies (Smallman, 1999). Other uses include fishing rods, storage tanks, and baseball bats. The new Boeing 787 structure including the wings and fuselage is composed largely of composites. Composite materials are also becoming more common in the realm of orthopaedic surgery.

Carbon composite is a key material in today's launch vehicles and heat shields for the re-entry phase of spacecraft. It is widely used in solar panel substrates, antenna reflectors and yokes of spacecraft. It is also used in payload adapters, inter-stage structures and heat shields of launch vehicles. Furthermore disk brake systems of airplanes and racing cars are using carbon/carbon material, and the composite material with carbon fibers and silicon carbide matrix has been introduced in luxury vehicles and sports cars.

In 2006, a fiber-reinforced composite pool panel was introduced for in-ground swimming pools, residential as well as commercial, as a non-corrosive alternative to galvanized steel. In 2007, an all-composite military Humvee was introduced by TPI Composites Inc and Armor Holdings Inc, the first all-composite military vehicle. By using composites the vehicle is lighter, allowing higher payloads. In 2008, carbon fiber and DuPont Kevlar (five times stronger than steel) were combined with enhanced thermoset resins to make military transit cases by ECS Composites creating 30-percent lighter cases with high strength.

Pipes and fittings for various purpose like transportation of potable water, fire-fighting, irrigation, seawater, desalinated water, chemical and industrial waste, and sewage are now manufactured in glass reinforced plastics.

Advantages of composites

Light weight - Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, where less weight means better fuel efficiency (more miles to the gallon). People who design airplanes are greatly concerned with weight, since reducing a craft's weight reduces the amount of fuel it needs and increases the speeds it can reach. Some modern airplanes are built with more composites than metal including the new Boeing 787, Dreamliner. Due to the lower weight and an aerodynamic shape, fuel consumption is significantly reduced, has a positive effect on costs and the environment. An example of cost-reduction can be found in composite bridges. Although manufacturing of such a bridge is more expensive than of a traditional bridge out of steel and concrete, the lower weight saves a lot of money on the costs of the foundation and on transport costs. In addition, the higher resistance against corrosion requires less maintenance whereas in general the lifetime is much longer. All benefits mentioned lead to a significant long term cost reduction. Significant reduction in production time is achieved compared to the welding of a similar metal pressure vessel. Secondly, the weight of the wound vessel is significantly reduced compared to a steel one.

High strength - Composites can be designed to be far stronger than aluminum or steel. Metals are equally strong in all directions. But composites can be engineered and designed to be strong in a specific direction.

Strength related to weight - Strength-to-weight ratio is a material's strength in relation to how much it weighs. Some materials are very strong and heavy, such as steel. Other materials can be strong and light, such as bamboo poles. Composite materials can be designed to be both strong and light. This property is why composites are used to build airplanes-which need a very high strength material at the lowest possible weight. A composite can be made to resist bending in one direction, for example. When something is built with metal, and greater strength is needed in one direction, the material usually must be made thicker, which adds weight. Composites can be strong without being heavy. Composites have the highest strength-to-weight ratios in structures today.

Corrosion resistance - Composites resist damage from the weather and from harsh chemicals that can eat away at other materials. Composites are good choices where chemicals are handled or stored. Outdoors, they stand up to severe weather and wide changes in temperature.

High-impact strength - Composites can be made to absorb impacts-the sudden force of a bullet, for instance, or the blast from an explosion. Because of this property, composites are used in bulletproof vests and panels, and to shield airplanes, buildings, and military vehicles from explosions.

Design flexibility - Composites can be moulded into complicated shapes more easily than most other materials. This gives designers the freedom to create almost any shape or form. Most recreational boats today, for example, are built from fibreglass composites because these materials can easily be moulded into complex shapes, which improve boat design while lowering costs. The surface of composites can also be moulded to mimic any surface finish or texture, from smooth to pebbly.

Part consolidation - A single piece made of composite materials can replace an entire assembly of metal parts. Reducing the number of parts in a machine or a structure saves time and cuts down on the maintenance needed over the life of the item.

Dimensional stability - Composites retain their shape and size when they are hot or cool, wet or dry. Wood, on the other hand, swells and shrinks as the humidity changes. Composites can be a better choice in situations demanding tight fits that do not vary. They are used in aircraft wings, for example, so that the wing shape and size do not change as the plane gains or loses altitude.

Nonconductive - Composites are nonconductive, meaning they do not conduct electricity. This property makes them suitable for such items as electrical utility poles and the circuit boards in electronics. If electrical conductivity is needed, it is possible to make some composites conductive.

Nonmagnetic - Composites contain no metals; therefore, they are not magnetic. They can be used around sensitive electronic equipment. The lack of magnetic interference allows large magnets used in MRI (magnetic resonance imaging) equipment to perform better. Composites are used in both the equipment housing and Table. In addition, the construction of the room uses composites rebar to reinforced the concrete walls and floors in the hospital.

Durable - Structures made of composites have a long life and need little maintenance. We do not know how long composites last, because we have not come to the end of the life of many original composites. Many composites have been in service for half a century.

Prospects of composites in developing countries

Composites present immense opportunities to play increasing role as an alternate material to replace timber, steel, aluminium and concrete in buildings. Their benefits of corrosion resistance and low weight have proven attractive in many low stress applications. The use of high performance FRP in primary structural applications, however, has been slower to gain acceptance although there is much development activity. They are being used for the manufacture of prefabricated, portable and modular buildings as well as for exterior cladding panels, which can simulate masonry or stone. In interior applications, composites are used in the manufacture of shower enclosures and trays, baths, sinks, troughs and spas. Cast composite products are widely used for the production of vanity units, bench tops and basins.

Composite material properties can be converted into important financial and performance benefits during offshore operations. Studies have shown that the use of composite products can reduce offshore capital requirements, decrease maintenance costs, and enable operations that otherwise are not feasible both technically and financially. Drilling operations constitute approximately 25-40% of the total project cost; so, extended reach drilling capability is very important in offshore operations. Offshore oil and gas reservoirs are often accessed through horizontal drilling. There are other advanced composites that are currently being used in oil field production applications (Fowler *et al*., 1998).

Natural fibre composites (NFC) as building materials

Natural fibres, as a substitute for glass fibres in composite components, have gained interest in the last decade, especially in the housing sector. Fibres like jute, sisal, coconut fibre (coir), ramie, banana, flax, hemp etc. are cheap and have better stiffness per unit weight and also have a lower impact on the environment. Structural applications are rare since existing production techniques are not applicable for such NFC products and non-availability of semi-finished materials with adequate quality. The moderate mechanical properties of natural fibres prevent them from being used in high-performance applications (e.g. where carbon reinforced composites would be utilized), but for many reasons they can compete with glass fibres.

Advantages and disadvantages determine the choice of their consideration. Lower specific weight of NFCs results in higher specific strength and stiffness compared to glass fibre and is a benefit especially in parts designed for bending stiffness. Many components are now produced in natural composites, mainly based on polyester or polypropylene and fibres like flax, jute, sisal, banana or ramie. Until now however, the introduction in this industry is led by motives of price and marketing (‘processing renewable resources’) rather than technical demands.

It can be moulded into sheets, boards, gratings, pallets, frames, sections and many other shapes. They can be used as a substitute for wood, metal or masonry for partitions, false ceilings, facades, barricades, fences, railings, flooring, roofing, wall tiles etc.

Challenges of composites

Today, a major challenge relating to automotive composite design is the unavailability of simulation tools and a general lack of composite material characterisation. Another issue is the computational time required to model composite structures and components. Current composite material models within commercial design software require very long solution times. These times are usually too long for the first phase of vehicle development, in which many different options have to be analysed over a period of just a few months. For composites to be properly evaluated at these early stages, the automotive industry needs a factor of ten reductions in solution times. The commercial software developers have not yet solved this problem, so some of the more advanced research and design centres are developing in-house methodologies, which usually remain confidential (Ciaraldi *et al*., 1992).

Manufacturing is an issue for composites in the automotive sector when one considers the high production volumes required. One reason why composites are not widely used in mass production automotive applications is the cost of the raw materials, but the main reason is the lack of suitable manufacturing processes. Currently, the choice of manufacturing process depends strongly upon the required rate of production. A typical truck application might have a volume of between 5,000 and 20,000 parts per year, whilst for cars it might be 80,000 - 500,000 parts per year, or even more. Other aspects that have to be considered are tooling costs, scrap production and cycle time.

Composites can fail on the microscopic or macroscopic scale. Compression failures can occur at both the macro scale or at each individual reinforcing fibre in compression buckling. Tension failures can be net section failures of the part or degradation of the composite at a microscopic scale where one or more of the layers in the composite fail in tension of the matrix or failure of the bond between the matrix and fibres. Some composites are brittle and have little reserve strength beyond the initial onset of failure while others may have large deformations and have reserve energy absorbing capacity past the onset of damage. The variations in fibres and matrices that are available and the mixtures that can be made with blends leave a very broad range of properties that can be designed into a composite structure.

Tools for composite production are much cheaper than tools for sheet metal forming. This is because composite processes are one-shot operations (i.e. one mould), whilst sheet metal forming requires five - six separate tools per component line. These savings in tool costs are very influential at low production volumes, but this competitiveness is lost at higher volumes where part costs dominate. The flaws that are present in natural fibres present a further challenge. These include areas where the fibre has a growth defect, thinning due to an increased inner hole dimension, and “kink bands” where the fibre direction is briefly translated sideways, leading to local strain concentrations when placed under load. Commonly, with present approaches to the manufacture of bast fibre composites, a strain of less than 0.5% is achievable. The techniques for addressing these issues are still under development, and include new approaches to tailoring the fibre interface. A second approach is to process the materials so that the reinforcement dimension is under the level of these flaws. The development of nanocellulose is being driven by the wood industry worldwide due to the excellent stiffness properties of cellulose (estimated at 130 GPa), and may provide an entirely new class of composite in the future. Major challenges associated with dispersion and pre-treatment of the nanocellulose in its polymer and ensuring adhesion may be well rewarded with a flexibly manufactured material with good environmental characteristics.

CONCLUSIONS

Most developing countries desire rapid industrialization, export enhancement, self-reliance and minimizing the import in order to strengthen the economy. Hence, there is the need to look more inwards to exploit the available resources to enhance the desired technological advancement. This can only be achieved by giving more attention to Research and Development. The development of locally available material as reinforcement fibres in composite producing is gradually gaining prominence in the developing nations in form of research in several research institutes and the institutions of learning. It is however good to note that, more there is emphasis on research and training, the more there are discoveries of new and more advanced engineering materials, the more ground is covered in technological development.

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