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TECHNOLOGICAL ADVANCEMENT IN THE FIELD OF MATERIAL SCIENCE-MINI REVIEW

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ABSTRACT

Key words: *Technology, Material Science, Education*

During the last couple of years, significant amount of effort has been made by the researchers in developing materials with applications in the field of structures, aerospace, biomedical science and energy harvesting. Advanced materials such as composites and nanocomposites are emerging as the materials with superior mechanical and thermal properties based on the combination of nanofillers and matrix material. Improvement in the computational techniques also helps researchers in characterizing materials and predicted material properties for various new materials that were earlier not possible with experimental based techniques. Aim of this mini review is to discuss the advantages as well as challenges associated with the development of new materials having applications in diversified field.

1.0 Introduction

Material science has contributed significantly in the advancement of any technology. Current focus of research in the field of materials is to develop materials with higher properties, low weight and must be environment friendly [**1-5**]. Development of lightweight materials such as composites and nanocomposites helps scientist in developing automobiles, airplanes with superior performances [**6-10**]. In addition to lightweight materials, researchers are also focusing on developing materials at nanoscale level, so that atomic configuration of any material can be accounted in improving the overall properties of the material. Advancement in characterizing techniques helps researchers in predicting and estimating the properties of materials at such low scales.

New materials such as carbon nanotubes, graphene, boron nitride nanotube, boron nitride nanosheets, silicon carbide nanotubes and nanocomposites are the current focus of many researchers [**11-15**]. These newly developed materials have exceptionally high mechanical, fracture, thermal or electrical properties [**15-16**]. This mini–review will focus on material for twenty first century and challenges in developing such materials with exceptionally high properties.

2.0 Characterization techniques

Different types of characterizing techniques are available for estimating or predicting the material properties ranging from nanoscale to continuum scale. Despite the cost and time involved in experimental techniques, these are considered as more accurate and practical. There are challenges associated with the experimental characterization of non-conventional materials such as composites, nanocomposites and nanofillers [**15-16**]. These materials are either heterogeneous or their properties cannot be estimated using simple experimental techniques.

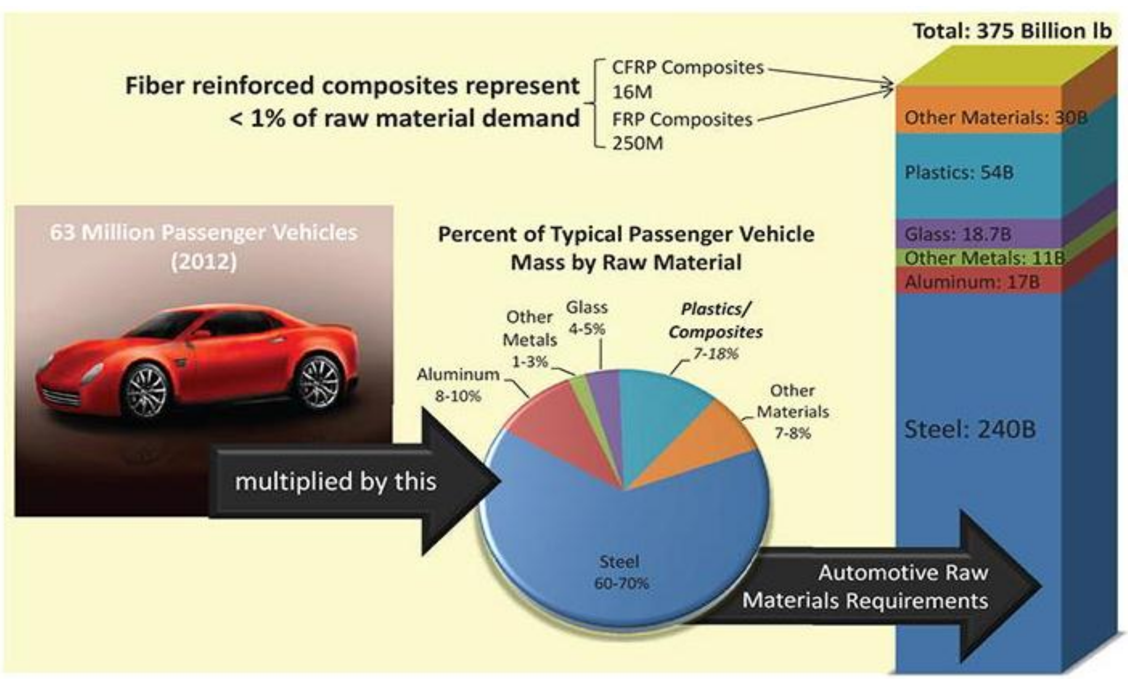
In order to overcome these challenges associated with the experimental techniques, researchers are exploring computer-based techniques for simulating different type of material and their behavior under extreme conditions [**16**]. Significant amount of improvement has been made in the computer based technologies that helps in simulating wide range of materials starting from conventional (steel, aluminum, copper etc.) to unconventional materials (e.g. composites, nanocomposites, graphene, carbon nanotubes etc.) [**17-20**]. Computer based techniques for simulating the material behavior can be further classified under quantum mechanics [**21**], classical mechanics [**22,23**] and continuum based approaches [**24**]. Least computational power is required to model a material at continuum scale, whereas the quantum mechanics based approach are most computational intensive. Despite the computational intensive approach, quantum mechanics based approaches are considered as most accurate among all the available modeling techniques.

3.0 Discussion

As mentioned above materials with exceptional properties are the current focus of research. During the last couple of years' significant development has been made in exploring and developing materials with diversified applications.

3.1 Materials for structural applications

In general, metallic alloys are used for the manufacturing of the major structural components such as pipes and automobiles parts. But, metallic components have some limitations in terms of wear, corrosion and are usually heavy in terms of weight. Due to introduction of advance materials such as composites and nanocomposites, these metallic components are or will be replaced in gradual phase with the light weight advanced materials. It can be inferred from Figure 1 that demand of composites in automobile sector in showing an increasing trend.



Comparison of estimated automotive materials demand during 2012.

Figure 1. Global passenger estimated automotive materials demand during 2012 [25]

Dr Dan Adams research group at The University of Utah is working on developing composites for automobile sector [**26**]. In automobile sector, these advanced materials are being considered to make lighter, safer and more fuel-efficient vehicles. In general, carbon fiber based composites component constitutes only 20% by weight to steel components, but are as good as steel in terms of strength and other mechanical properties. The biggest advantage with these advanced materials is that they are light in weight, do not corrode like steel or aluminum, which ultimately helps in reducing the overall maintenance cost as well as fuel economy of the vehicle.

In addition to automobile sector, structural components in oil and gas industries such as materials for pipe lines are also the focus of current research. In oil and gas sector, the pipelines are the major component used for transporting raw material such as crude oil from one station to another. Due to corrosive environment and chemical content of the material flowing inside these pipes, metallic pipe is more susceptible to corrosion and hydride cracking [**27-28**]. In addition to corrosive nature, sometimes transportation of these pipes to difficult terrains is also a challenge for the industry. In order to overcome some of these challenges, pipes made up of composite materials are proposed for these industrial sectors [**29**]. Composite pipes are light in weight as well as have resistance against corrosive environment.

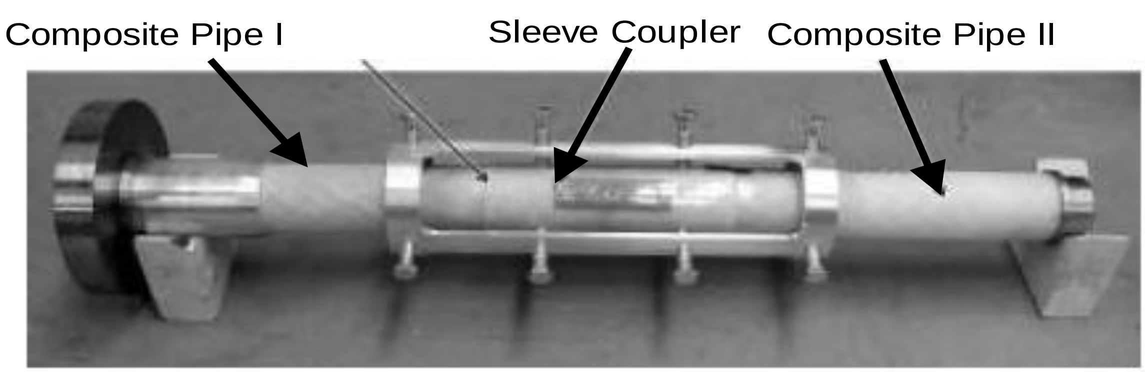


Figure 2. Experimental setup to join composite pipes

Despite having advantage in employing these materials for replacing metallic components in several structural applications, there are some limitations that are still associated with composites. First of all, conventional manufacturing techniques cannot be employed with composite materials, and hence more specific manufacturing techniques are required with composite materials and some of them are even time consuming. Due to challenges associated with the manufacturing techniques size of the structural component is having some limitations in terms of dimensions. Joining of composite parts is still a topic of research as commonly used mechanical bolts, flanges cannot be used for these materials [**30**]. In Figure. 2 two composite pipe sections are shown with a metallic fixture and composite sleeve to join two sections. Cost of composite parts is relatively higher as compared to metallic components, but in long term that higher cost can be compensated with lower maintenance cost.

3.2 Materials for aerospace

Due to higher cost and typical manufacturing techniques, application of composites as well as nanocomposites is still limited for structural components, but in aerospace industrial with no restrictions in terms of cost, these advanced materials are continuously replacing metallic counter parts. In aerospace sector, the biggest limitation is weight of the aero plane that needs to be as low as possible without compromising the overall strength and safety of the aero plane.

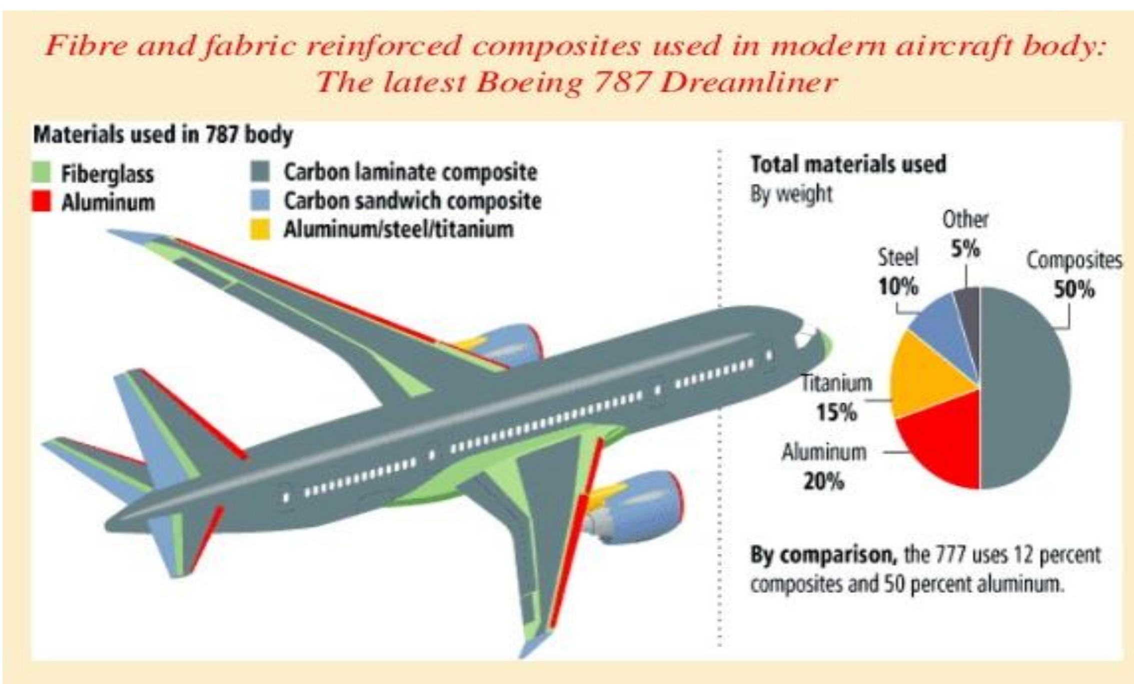


Figure 3. Composition of materials used in structural units of Boeing 787 Dreamliner [31]

Composites and nanocomposites are emerging as potential candidates for replacing metallic components in aero planes. The low weight, high specific strength of composites helps in achieving lower fuel cost as well as more space for passengers with the same material volume. Recently, BOEING (787 or Dreamliner) as well as AIRBUS (320) has launched new series of aero planes with bigger size and more space for accommodating passengers. In these recently introduced models of passenger planes (AIRBUS-320 and BOEING 787) the use of composite material was significantly increased, and overall 40% by weight composites has replaced the metallic material. It can be seen in Figure 3 that significant amount of composite materials has been employed in BOING 787. The increase use of composites in these aero planes has help in accommodating higher number of passengers, reduced cost of flight with increased fuel economy.

3.3 Materials for desalination

Pure drinking water is one of the basic necessity for the survival of human kind. Increasing population, depleting source of fresh water and uncertainty associated with the monsoon rain has put pressure on the researchers to search for technologies that can help in desalinating or purifying the sea water. Reverse osmosis is commonly used for the purification of water, which has certain drawbacks such as slow production rate with higher power consumption.

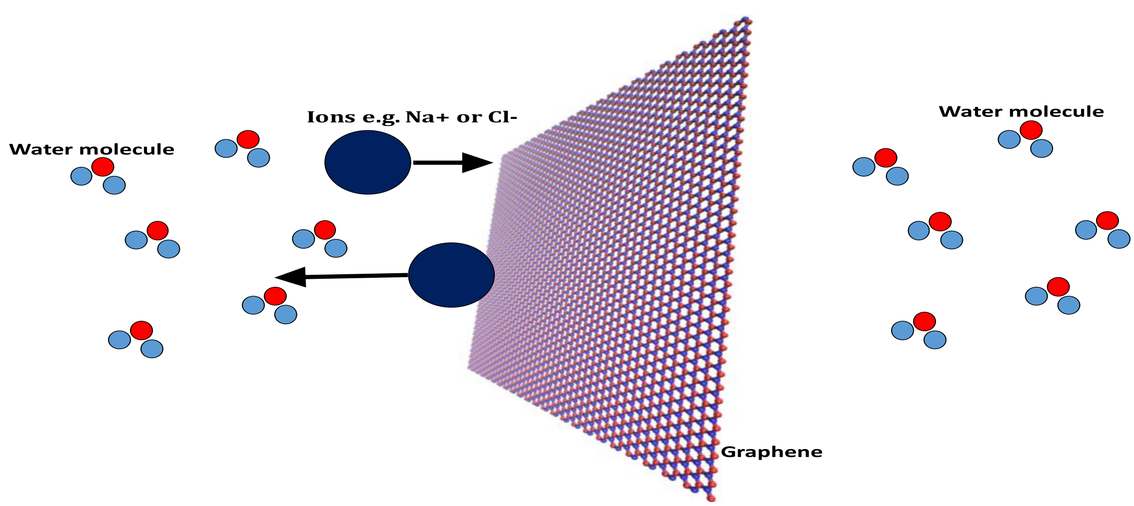


Figure 4. Schematic of graphene as nanomembrane for desalination purpose.

The presence of toxic contaminants in the water are increasing exponentially with industrialisation and deforestation, and it eventually mitigates the efficiency of conventional water purification systems. Membrane separation technology has played a key role in food processing, DNA sequencing, pharmaceutical industries and water treatment [32]. Majority of membranes used in ion separation techniques are made up of polymeric materials such as cellulose, polyamide and polysulfide [33]. Despite the wide range of polymeric membranes, these membranes have poor tolerance to oxidants, strong acidic/ alkaline regents and high

temperature operations [33]. In order to improve the membrane separation technology, researchers are focusing more on nanomaterial's such as graphene, carbon nanotube (CNT) and boron nitride (h-BN) nanosheets. These nanomaterial's have enough potential to replace polymeric membranes in ion separation techniques. It can be seen in Figure 4 that graphene sheet can be successfully used for the desalination purpose, which restricts the bigger Na+ and Cl- ions to pass through the graphene sheet, but water molecule easily passes through.

4.0 Conclusion and future prospects

Increasing population and depleting resources has put pressure on the researchers to explore new technologies. Advanced materials are replacing the conventional materials to improve the technology in structural units, automobile sector and in biomedical science. Introduction of advance material helps in improving the fuel efficiency and life span of automobiles and aero planes. These materials are also responsible for improving the quality and wear resistance of pipes used in oil and gas sector.

Bio-degradable materials for structural units is requirement for the future technologies, so that, pollution from the non-degradable materials can be mitigated. Green composite such as cellulose based structural material is the focus of researchers for future applications.

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