COMPOSITE MATERIALS: FROM STRUCTURAL TO MULTIFUNCTIONAL

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1. Introduction

Advanced composites have come a long way since their emergence in the 1960's. They are now found in a variety of applications such as aerospace, marine, automotive, renewable energy, offshore, civil infrastructure, etc. The initial emphasis in their development was to save weight. However, their wider applications over the years have called for improvements in other attributes, such as damage tolerance, low observable, and low cost. Now composites are at the throe of being able to provide multifunctional functions. By multifunctional we mean structural plus any other functions that are not possible with "traditional" composites.

2. Structural Composites

As a result of research and development over half a century, structural composites are being used in large load bearing structures. Boeing 787, where half of its structure is made of composites, is a crowning example of such usage. Other examples include composite buses, rail cars, and truck trailers. In the renewable energy area, 2-MW wind turbine blades are being deployed while 5-MW blades are under development. Composite pipes are used widely as petroleum pipelines and on board ships as they have superior chemical resistance. They are also making inroad as waterworks and sewer lines. It is interesting to note that the use of structural composites has increased substantially as predicted by Ashby [1].

3. Multifunctional Composites

The recent advancement in nanotechnology has opened a new avenue for another revolution in composites technology. Functional nano-structures that have become possible via the nanotechnology are ideally suited for integration into structural composites to render them functional as well, Fig. 1.

Another approach is to combine different functional components at a micro scale. Whatever scale the functional integration is carried out, the key is to ensure that the structural integrity is not degraded.

3.1 Structural Health Monitoring

Various types of approaches have been proposed to monitor structural health of composite structures. These approaches involve sensors of one type or another, such as acoustic, optical, electrical, etc. These sensors are embedded in the composite, becoming an integral part of the structure.

Unfortunately, these sensors are discrete, and difficult to deploy over a large area. One solution to solve this problem is to monitor the resistivity of the composite itself using an addressable conducting network. The network is laid on the surfaces of the laminate in such a way that the through-thickness resistance can be measured at any point of choice. This allows any damage affecting the through-thickness resistance to be detected spatially.

3.2 Self-Healing

In general, self-healing involves one of the two approaches: the parasitic introduction of a healing agent into the composite or the use of a healable polymer as the matrix resin. The former may be in the form of microcapsules or hollow tubes containing the healing agent. A damage in the composite would break microcapsules/tubes letting the healing agent spill out. Upon contact with the separately deployed curing agent or a catalyst, the healing agent will cure, repairing the damage.
An example of the second approach is a thermally remendable polymer used as the matrix. This polymer heals itself via the retro Diels-Alder reaction upon heating.

3.3 Energy Harvesting and Storage

A thin-film solar cell and a thin-film battery may be integrated into a composite laminate to form an energy harvesting and storage composite. Such integration subjects the functional devices to the same deformation as the composite laminate itself. Unfortunately, there is little data available on the performance of functional devices under mechanical loading. For think-film amorphous Si solar cells and thin-film lithium metal batteries, the maximum tensile strain that can be applied in fatigue is rather small. There is thus a need for flexible solar cells and batteries to render energy harvesting and storage composites a reality.

3.4 Electromagnetic Composites

Conducting nanostructures such as carbon nanotubes and nickel nanostrands can be integrated into a composite to improve electrical conductivity. Also, load-carrying electro-magnetic composites can be made by incorporating dielectric and magnetic nanoparticles into composite laminates. One can design stealth composites by optimizing these nanoparticles for the frequency range of interest.

3.5 Other Multifunctional Composites

Many other multifunctional composites are possible with the introduction of appropriate functional nanoparticles into structural composites. A good quality nanocomposite requires good dispersion of nanoparticles and good interfacial bonding, which are quite often difficult to achieve. Further research is needed to improve nanocomposite processing and to explore performances of these multifunctional composites.

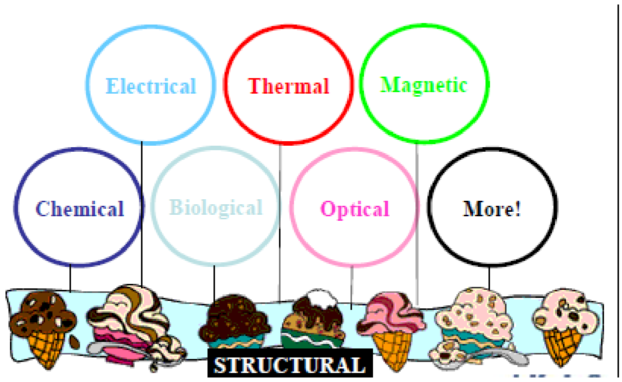

Fig. 1. Sugar cone for ice cream as a multifunctional structure.

References

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