NEWS FOCUS

Composites: Use in saucepan handles, artificial limbs and the AGNI missile

Composites are a mixture of two or more distinct components. One component is called the matrix (continuous phase) such as ceramic, metallic or polymeric, while the other distinct phase is interspersed within this matrix, lending different and improved properties to the material as a whole. For a material to be termed a composite, the following three points are essential:

- The two distinct components have to be present in sufficient proportions.
- The properties of the composite have to be different from those of the individual components that make up the composite.
- The process of making this material is by methods such as mixing; for example, when ceramic particles are well blended into a metal matrix leads to a ceramic–metal composite.

Composites of bricks made from mud with the composite matrix reinforced with straw have been part of early building material. More recent building materials like concrete, also belong to the class of composite materials. Wood and bone are natural composites, but it is the synthetic composites made of fibre reinforced plastics FRPs, or polymer composites that capture attention in the marketplace, such as for leisure and sports goods, or as base material for artificial limbs. Fibre reinforced polymer composite braces offer an alternative with superb strength-to-weight and stiffness-to-weight ratios.

Composites are 'wonder' materials with applications ranging from the humble saucepan handle, artificial limbs, to the Light Combat Aircraft (LCA) and the AGNI missile system. Although India has successfully tested the use of composites in the AGNI missile system, the transfer of such indigenous advanced technology, thus far, for use in the civilian sector is slow. The Indian industry has not shown any interest probably on two counts, ignorance of potential use and lack of know-how on product fabrication with an economic edge, for the consumer market. According to estimates, out of the US $ 50 billion composites market worldwide, the Asian region accounts for about US $ 15 billion with composites for industrial, infrastructure and consumer products taking the lead.

'Nanotechnology' is a thrust area in research in India. Single-walled nanotubes (SWNTs) are described the world over as having amazing potential mechanical properties, high elastic modulus and a fierce resistance to failure. When pulled into fibres they may qualify as the ultimate reinforcement in future composite technology. SWNT-exhibited tensile strength has been found to be an order of magnitude greater than that of conventional carbon fibres that are presently used. However, research is in progress for overcoming problems of non-uniform dispersion, lack of natural orientation and weak interface between the nanotube reinforcement and the matrix of the composite.

SWNTs are for the future, but what exists of demonstrated composite technology and uses? Composite materials are fast changing the aerospace industry. Designers of aircraft have now a choice of affordable composites for manufacture of aircraft parts. The 600-seater passenger jumbo aeroplane from Airbus, the Mach 0.98 Sonic Cruiser from Boeing, light aircraft and seaplanes are making use of composites in aircraft structure such as the entire fuselage, wings and tailfins. These materials lend structures a saving in weight, on providing agility coupled with strength to give an economic advantage.

The 'National Symposium on Strategic Materials and Technologies for Composites', held at Hyderabad during 8–9 August 2003 addressed advances made in the country in the area of composite technology, and delivered this knowledge to industry partners. The Advanced Systems Laboratory (ASL) at the Missile Complex, Hyderabad, a nodal Defence Research and Development Organization (DRDO) laboratory, under the Ministry of Defence, Government of India organized this event. This symposium had participants from research and development areas, as well as industry partners imbibing new advances in composite technology.

The backdrop of India's self-reliance in missile systems, especially the successful flight test of AGNI-I and AGNI-II missile systems is a 'design house approach'. According to Ram Narain Agarwal (Project Director of the AGNI Missile Programme and Director, ASL), this approach comprises of in-house competence synergized with manufacturing, prototyping and production skills of the industry leading to concurrent development and production of cost-effective systems. The AGNI missile system he said, had a unique carbon composite re-entry heat shield with aerospace having 35% of its components made from composite materials, and this would be about 80% within the next three years.

The symposium addressed technology challenges in composites for high speed/high temperature environments for aerospace programmes like AGNI, Satellite Launch Vehicles, aircrafts and reusable systems. The specific areas covered were advanced composites, characterization and processing of composites, epoxy resin systems, advanced resin systems and high-temperature composites.

Box 1.

AGNI-I	AGNI-II
Range: 700 km	Range: 2000 km
Launch weight: 12 t	Launch weight: 17 t
Length: 15 m	Length: 20 m
Single stage solid propulsion	Two-stage solid propulsion
Carbon composite re-entry vehicle	Carbon composite re-entry vehicle
Closed-loop explicit guidance	Closed-loop explicit guidance
Road mobile system	Rail mobile system
Successfully tested on 25 January 2002 and 9 January 2003	Successfully tested on 11 April 1999 and 17 January 2001

Source: ASL, Hyderabad.

Scientists from the following institutions made their presentations:

- Advanced Systems Laboratory, Hyderabad
- Aeronautical Development Agency, Bangalore
- Defence Materials and Stores Research and Development Organization, Kanpur
- Defence Metallurgical Research Laboratory, Hyderabad
- Indian Institute of Chemical Technology, Hyderabad
- Indian Institute of Technology, Delhi
- Madras Institute of Technology, Chennai
- National Aerospace Laboratories, Bangalore
- National Physical Laboratory, Delhi
- Naval Materials Research Laboratory, Anand Nagar, District Thane, Maharashtra
- Sardar Patel University, Vallabh Vidyanagar, Gujarat
- Vikram Sarabhai Space Centre, Thiruvananthapuram

The following is a brief technical summary culled from the symposium. Composites are widely used in aerospace applications due to advantages such as high specific strength and modulus. Components for aerospace applications include rocket motor casings, nozzles, radomes, fuselage, wings, control surfaces, canisters, pressure vessels and the like. As these are strategic and patentable areas of research, information is hard to come by. Hence for indigenous applications, India continues its endeavour to master composites, in the area of both processing and equipment.

Radome

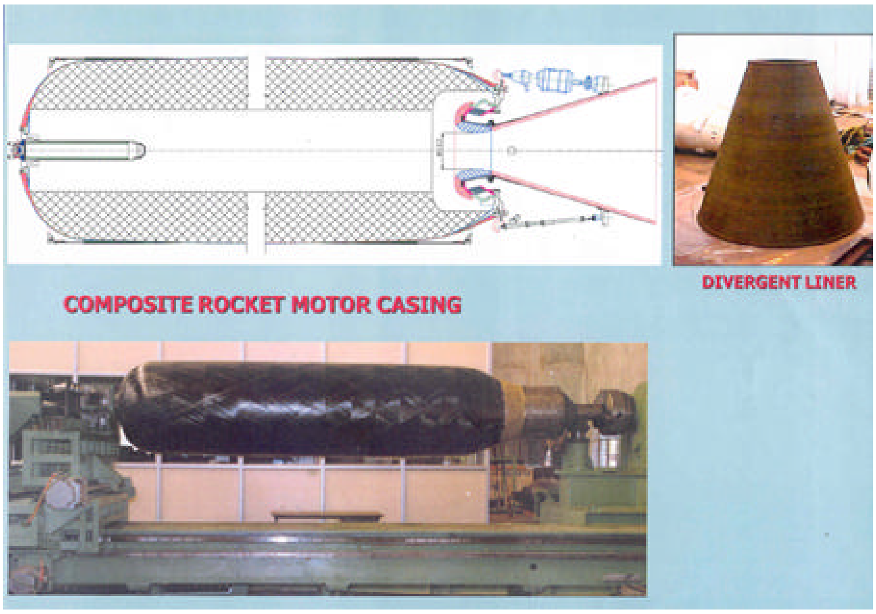
Radomes or radar domes are casings for antenna, protecting these from the outside environment. Radomes have to meet a combination of aerodynamic, electromagnetic and structural needs and are used in several ground, maritime, aircraft and missile electronic systems. For optimum radome performance, fabricating a radome having the right wall thickness and dielectric properties that are determined by the even resin to reinforcement ratio throughout the radome are important. Materials used in radomes include thermoplastics such as polyether ether ketones (PEEK), which are fashioned using injection moulding. For improved thermal stability, reinforcements such as quartz, S-glass (silica–alumina–magnesia), E-glass (alumina–borosilicate), Kevlar (aramid fibre) are used. Other types of reinforcements are epoxy, polyester, polymide and cyanate ester resins. For high-temperature applications aluminium-oxide ceramics and slip-cast-fused silica (silicon oxide) are used. Radome materials generally need to withstand about Mach 8 velocities.

Indian technology based on glass–polymer composite radomes, Kevlar contour

a

b

a, AGNI-I. ***b***, AGNI-II (Photocredit: ASL, Hyderabad).



Light combat aircraft of DRDO (Photocredit: ASL, Hyderabad).

Box 2. Advanced Systems Laboratory (ASL), Hyderabad

Set up in 2001, ASL is spearheading the development of long-range missile systems in the country with two major programmes AGNI-I and AGNI-II inducted and the AGNI-III under development. ASL is also responsible for development of solid propulsion systems, aerospace mechanisms and composite products for all missile and aerospace programmes of DRDO, Government of India. The front-end technologies being developed include ultra high temperature composites, high performance composite rocket motor casings, radome for missiles and aircrafts, all-carbon re-entry vehicle structure, carbon composite canister technology, thrust vectoring through flex nozzles for large rocket motors, solid propulsion, control systems, system integration and explicit energy management guidance systems.

woven socks with epoxies and low-loss polyester resin systems have been developed and flights tested in surface-to-surface and surface-to-air missile systems and the LCA. India has also developed and patented integrated design software technology for constant thickness and variable thickness radomes, as well as a radome of 2 m length and 900 m diameter for the LCA, made from Kevlar and low-loss polyester. India is developing hypersonic radome systems, from mainly ceramic fibre-reinforced ceramic matrix composites that has fracture toughness for withstanding temperatures as high as 1600°C.

Rocket motor casing

Composites are ideal candidates for making rocket motor casings (RMCs) which are essentially cylindrical pressure vessels comprising two tapered-end domes, and end-fittings termed as polar bosses and skirts. Polar bosses have features for connecting the igniter and the nozzle of the missile to the casing, and the skirts for transfer of loads to interfacing systems. The RMC generally has different sizes for the two end-openings due to varied interfacing parts. This presents a challenge for filament-winding technology that has to be non-geodesic in nature, which successfully nets the fibres in tension. The optimum composite RMC needs to have high specific strength, light weight and needs to withstand higher internal pressure. The composites generally used include carbon and aramid fibres. Advanced carbon fibre composite RMCs for large rocket motors, such as for the AGNI class systems have been fabricated with indigenous technology.

For Indian Space Research Organization's (ISRO's) Satellite Launch Vehicles, a 2 m diameter aramid fibre epoxy composite motor casing for solid propellants, having a length of 2 m and an internal volume of about 5000 l, has been successfully used for an upper stage motor.

Smart composites

Examples of smart composites include piezo fibre composites, shape memory alloys, bio-composites, magnetostrictive particulate composites that have applications in aerospace, civil engineering, automotive and leisure goods. The National Programme on Smart Materials addresses the research and development of smart materials and devices.

Multiple Independently Targetted Re-entry Vehicle (MIRV)

Reusable missions and MIRVs are future systems that would gain from carbon nanotubes, nanocarbon reinforced ceramics, smart structures and advanced materials. India has developed propulsion and re-entry systems of aerospace vehicles that need to operate in high temperature regimes such as 3000–5000°C and meet the aero thermal environment of re-entry. Scientists have successfully flight-tested the unique all-carbon composite re-entry heat shield with multi-directional carbon–carbon re-entry nose tip and control surfaces in the AGNI missile systems. The carbon–carbon composite brake discs developed for the LCA have undergone flight tests.

Characterization facilities for composite materials

Although working designs have been made for systems used in India's missile and space programmes, there is still a need for lighter systems to be built comparable to current international systems. For this to happen, it is necessary to have detailed information on the material properties over various operative conditions. Materials characterization is key to successful fabrication and lower rejection rates. There is a need to establish more facilities for material characterization such as for high temperature composite materials.

High performance composite fabrication technologies

Cost is an important factor when a larger percentage of systems are built from advanced composites. Composites have till now used autoclave moulding process. However with the advent of Resin Transfer Moulding (RTM) technology and its variants, it is becoming increasingly clear that a shift in this direction is inevitable for cutting the cost of production methods. RTM is a process by which the reinforcement is kept in a cavity and the resin system is injected, wet out and cured achieving fibre volume fractions of between 20 and 40%. Variants of RTM include vacuum-assisted RTM, Seeman's composite resin infusion manufacturing process, Double chamber vacuum RTM, Fast remotely actuated channelling process and solvent-assisted RTM. These newer variants provide between 57 and 60% fibre volume fraction. It is time for India to make use of these cost-effective newer technologies.

India's integrated facility for carbon fibres and prepegs (IFCAP)

With the large volume of carbon fibres required for various applications and the increased costs of importing the material, and even facing denial of this raw material in some cases, India is finally taking some action on a need that had been felt for some time now. The process of setting up and pre-production testing of a carbon fibre manufacturing unit that would be housed in the National Aerospace Laboratories, Bangalore is in progress. Detractors of this project feel that the output of about 10 t is insufficient to meet even a small fraction of the country's requirements, as only a pilot-plant scale is envisaged, whereas those associated with this significant project cite that this is just the beginning of achieving target requirements of users.

Carbon fibres of three main grades with standard modulus, intermediate modulus and high modulus are manufactured by the heating of different grades of poly acrylonitrile fibres (SAF or precursor fibres) depending upon the desired grade. The IFCAP programme would cater to all these requirements as well as incorporate design and fabrication of customized equipment for the processes involved in making carbon fibres, such as spinning lines specific to SAF fibres than those, for example, used in textile acrylic fibres.

The IFCAP programme would also transform carbon fibres into unidirectional prepegs based on epoxy resins on a pilot plant scale. The products include high strength PAN fibres as precursors to carbon fibres and also as a replacement of cables, asbestos and the like.

Fibre-reinforced composites

High performance composites offer combination of low density, high specific strength, with ease of fabrication to complex shapes. These epoxy resins have excellent mechanical properties and processing characteristics, although, PMR (polymerization of monomeric reactants) composites could have limitations such as batch reproducibility, micro-cracks during thermal cycling, and toxicity of chemicals used in PMR.

Bismaleimide and polyimide resin composites have possible uses in reusable launch vehicles that require lightweight materials for high temperature applications, such as to operate at temperature of about 500°C. Requirements are thermal stability, flame resistance and low dielectric constant. Other uses are ductwork for jet engine applications, fan blades, automotive engine and exhaust system components, self-lubricating bearing for high-temperature use, heat-resistant panels, fire barriers and lightweight fire-safe objects. Polyimide composites have been used in radomes, missile fins, jet-engine nozzle flaps, gear cases and heat shields. Their high specific strength and low density make them better candidates over traditional aerospace materials such as titanium by reducing component weight, reduced vehicle weight, reduced fuel consumption, increase in payload and performance.

Kota Harinarayana, University of Hyderabad, said that the LCA had gone supersonic with an indigenously designed aircraft and with several components such as central fuselage, duct skins, fin and rudder, wings, landing gear, forward and rear fuselage, radome all made from carbon composites amounting to 45%. This had reduced weight, cost, part cost and assembly costs.

K. V. Raghavan, Indian Institute of Chemical Technology (IICT), Hyderabad said that what is needed is to nurture Indian industry to invest its time and funds in materials and component manufacture in the area of carbon composites. IICT had contributed to the strategic sector by making a special resin for radome and space applications, where a strong interface between chemistry and engineering was needed. Madhavan Nair, Indian Space Research Organization said that his organization had recognized the role of carbon composites in space applications with several components having been made from these advanced materials, and they have been successfully proven in satellite launch vehicle flights. He pointed out that the science behind the making of a composite nozzle liner, where inputs came from R&D and are manufactured by industry, could also be made use of in artificial dentures and prosthetic articles. The Reinforced Plastics Center at Thiruvananthpuram is now in the process of making next-generation composites for use in recoverable missions where materials environment, thermal management, control systems and carbon composite nose tips for the re-entry phase were important.

So, where do we go from here?

V. K. Aatre, Scientific Advisor to Raksha Mantri and the Secretary to Defence R&D summed up how India needs to develop any technology. He pointed out that for generating wealth for the country there needed to be a thread of continuity between technology and the product. He said, ‘if technology does not build wealth, that technology is not worth following’, emphasizing that we needed to build on our own R&D, which he termed to be presently a limitation. For spawning new technologies, the technology had to be generated in academic institutions. DRDO could then make use of this for building systems and industry has to participate both in the strategic and civilian sectors using the generated technology.

Since most of Indian industry did not have in-house R&D, he implored industry partners to latch onto composite technology that was funded by the government. He stated that just making the Jaipur foot from composite technology was insufficient for building up wealth for the country; more products needed to be researched on and manufactured. To rectify the situation and augment industry to look forward to seeding of technology, an open house had been started by DRDO, wherein all DRDO technology was available to industry, with no charges in the initial phase, and as the ventures made profit they could pay back.

The bottomline appears to be that Indians are slow in converting to products the fruits of R&D. High technology developed in government-funded institutions for specific systems was confined to those applications that they were originally designed for, with little being done to diversify and unearth novel uses that could be of direct benefit to the common man and society. Industry was not converting or investing enough in searching for the strengths of a new technology for other applications and this was topped with venture capital funding still being in its infancy. India needs to take a bold step forward through public–private partnership in evolving ways and means to take precious indigenous advanced technologies and retrofit it for consumer markets and needs. Only then would there be synergy between all players of wealth generation.

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