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TECHNOLOGY FOCUS

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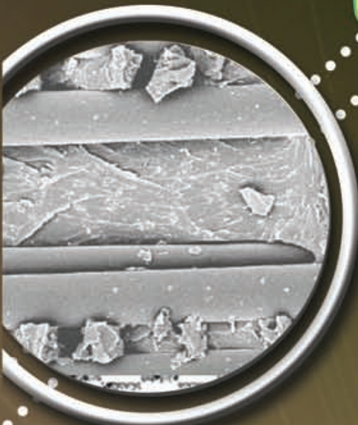
Composite Structures



Technology Focus focuses on the technological developments in the organisation covering the products, processes and technologies. This issue of *Technology Focus* highlights technologies in the area of Composite Materials developed by Research & Development Estt (Engrs), Pune.

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From the Desk of Editor-in-Chief

Dear Readers...

The odyssey of Technology Focus (TF) started from a news bulletin in the year 1992 covering products and technologies of DRDO has now achieved a status of popular S&T magazine. A sense of appreciation for its popularity goes to coordinated efforts of DESIDOC, DRDO laboratories and honest readership. The magazine is punctual and encompasses large readership in India and abroad. The magazine meant to reflect DRDO's technological achievements at various levels in different fields under following categories:

- *Technological breakthrough*
- *Technological developments, including products, and software at their various stages, viz. development trials, in production*
- *Technology available for commercial exploitation both in civil and defence sectors*
- *Facilities established*

It is a goal of TF to provide a platform for presentation of DRDO achievements in proper perspective. In 2018, specialized areas covered were: Aluminium Alloy Technologies for Advanced Defence Systems; Unmanned Ground Vehicles: Present and Future; Warhead for Missiles, Torpedoes and Rockets; Material Development and Characterisation; Parachutes, Aerostats and Beyond; Avalanche Hazard Mitigation in Western and Central Himalaya.

Initiatives were taken in recent time to make the magazine in e-reading form. DESIDOC received much appreciation for its availability on variety of e-reading devices. DESIDOC has also started producing the magazine as audio-visual presentation, video magazines. The video magazine demand coordinated efforts of DESIDOC and respective laboratories for on-location shoots. In a short span of one year, the video magazine has become one of the most popular service among DRDO fraternity.

Improvement is a continual process and success demands continual improvement. We keep requesting our readers for their opinions. A feedback form is included in every issue for your valued inputs and suggestions. DESIDOC requests DRDO laboratories to come forward and use TF as a platform to showcase their achievements. We look forward for your valued contributions in 2019, and beyond. At the end, I, on behalf of Editorial Team, thank all the contributors, DRDO community, and our valued readers and wish them very best wishes for 2019.

Happy Reading..!!

Dr Alka Suri
Director, DESIDOC

From the Desk of Guest Editor

Research and Development Establishment (Engineers), R&DE(E), is a key laboratory of DRDO under the Armament & Combat Engineering (ACE) cluster dealing with Systems Engineering. R&DE(E) has excelled in design and development of combat engineering equipment, ground support for most missile programs and development of shelters and equipment for mountain warfare and other strategic requirements. Research and development on composite materials is a key vertical of the laboratory that focusses on design and development of large composites structures for combat engineering and other applications.

Shri VV Parlikar
Director, R&DE (E)

This issue highlights the work carried out by the Composites Research Centre (CRC). With a charter to replace metallic structures by composites to achieve substantial weight reduction and other collateral advantages, CRC has worked over the past two decades on developing manufacturing and allied technologies for realising large load bearing primary structures in composite materials.

Composites are a macroscopic combination of two or more materials, with a distinct interface between the individual constituents. Structural composites have fibers as the principal load carrying members whereas the surrounding matrix keeps them in desired location and orientation. The matrix, usually a thermoset polymer, also acts as a load transfer medium between the fibers, and protects them from environmental damage due to elevated temperature or humidity. Because of their low density, high strength to weight ratios and high modulus to weight ratios, these polymer matrix composites are markedly superior to metals. They find extensive applications in virtually all sectors of defence engineering; aircraft structures, missiles, ship hulls, military bridging, assault vehicles, etc., to name a few.

CRC has pioneered ab-initio development of two key out-of-autoclave manufacturing processes for cost effective realisation of aircraft grade composites, Vacuum Assisted Resin Transfer Molding (VARTM) and Resin Film Infusion (RFI). The original target was the development of military bridges in carbon fiber composites to replace their heavier steel and aluminum counterparts. However, these processes have found applications in fields other than combat engineering equipment, such as naval and aircraft applications. Several products are currently under development.

CRC has also carried out research in allied areas such as Structural Health Monitoring (SHM), Damage Mitigation, Nano Filler Hybridised Composites and EM applications. This issue summarises work carried out in these areas at CRC, R&DE(E).

Technology Focus is a medium through which we get an opportunity to create awareness of various technologies developed at various establishments of the DRDO. I feel highly privileged to be a Guest Editor for this issue and get an opportunity to highlight work in the area of composites.

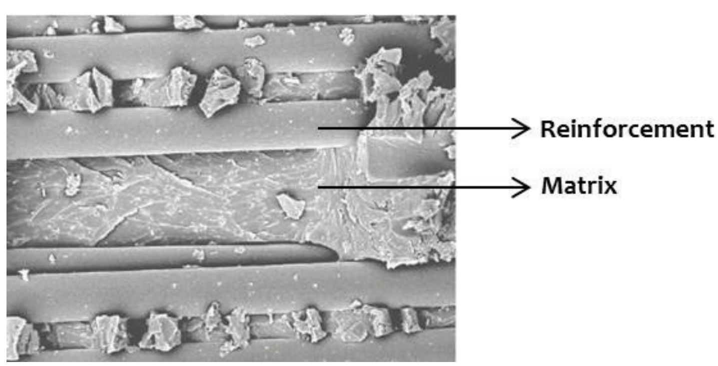
Research and Development Establishment (Engrs), Pune traces its origin to the Inspectorate of Engineer Stores set up at Calcutta during World War II for exercising quality control on stores of indigenous origin and to provide guidance to their manufacturers. This was amalgamated with Chief Inspectorate of Mechanization at Chakala in Pakistan, in 1946.

After partition, this Inspectorate shifted to Ahmednagar and was designated as Technical Development Establishment Vehicles (TDEV). Further, with the expansion of activities of Defence Research and Development Organisation, R&DE (Engrs) was established at Dighi in Pune on 09 February 1962 for design and development of equipment for the Corps of Engineers. R&DE(Engrs), Pune, is a premier systems laboratory of DRDO engaged in the indigenous development of various engineering systems for all the three wings of the Indian defence forces. R&DE (Engrs) has developed and delivered state-of-the-art combat engineering-military bridging, mine-warfare and allied systems, ground support systems and launchers for weapon programs and field-defence and NBC collective-protection systems. The establishment is also working in the areas of robotics, composite products and Micro-Electro-Mechanical-Systems (MEMS).

R&DE(Engrs) was the first DRDO laboratory to obtain ISO 9001:2015 certification. Research and development on composites is a key vertical of the laboratory that focusses on design and realisation of large composites structures for land based, naval and aerospace applications.

Composite Structures

A composite material is a macroscopic combination of two or more materials, with a distinct interface between the individual constituents. They are at times referred to be the result of embedding high-strength, high-stiffness fibers of one material in a surrounding matrix of another material. Structural composites have fibers as the principal load carrying members whereas the surrounding matrix keeps them in desired location and orientation. The matrix, usually a thermoset polymer, also acts as a load transfer medium between the fibers, and protects them from environmental damage due to elevated temperature or humidity. Because of their low density, high strength to weight ratios and high modulus to weight ratios, these polymer matrix composites are markedly superior than metals. In addition, fatigue strength as well as fatigue damage tolerance of many composites is excellent. For these reasons, fiber reinforced polymers have emerged as a major class of materials and are used as primary load bearing structures in several weight-critical components in aerospace, automotive, and other industries. They find extensive applications in virtually all sectors of defence engineering; aircraft structures, missiles, ship hulls, military bridging, assault vehicles, etc., to name a few. Their use is accelerating rapidly with the major impact being felt in aerospace industry, where almost the entire airframe is now made of composites.



Microscopic view of a representative fiber reinforced thermoset-resin matrix composite

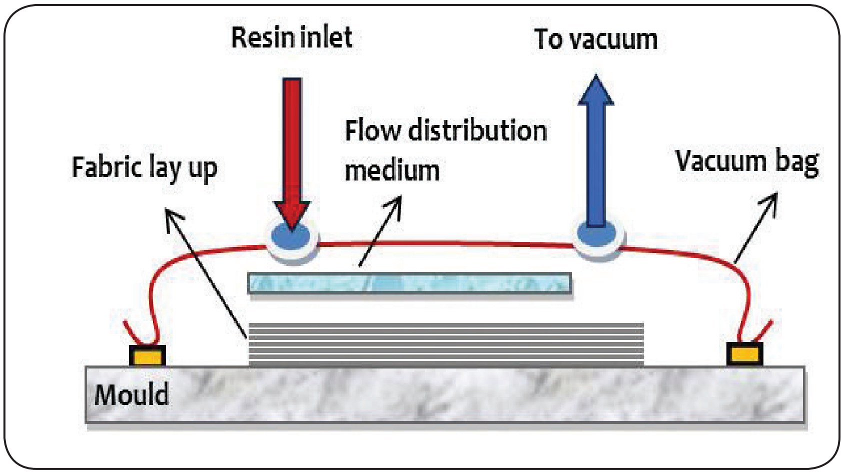
Research and Development Establishment (Engrs) has been working on the design and development of structural composite for over two decades. Cost-effective manufacturing methods have been developed for realising large and thick structures. Using these methods a range of products has been realised. A concise summary of the manufacturing methods, and products realised thereby, is presented here.

Composite Manufacturing Processes

Vacuum Assisted Resin Transfer Moulding

For composite structures that are typically large (few metres in dimensions), thick, and have complex topology, traditional manufacturing methods such as hand lay-up, spray-up, etc., prove to be labor-intensive with limited fiber volume fraction and inconsistent quality. On the other hand, manufacture of such structures using pre-pregs and autoclaves would be extremely expensive and unacceptable for non-aerospace applications. Hence, for high fiber volume fraction (50-60%), uniform resin impregnation and cost-effective manufacturing, Vacuum Assisted Resin Transfer Moulding (VARTM) has become a process of choice. This closed-mold process combines the benefits of high quality, repeatability with the advantages of flexibility and scalability of open-mold hand layup process.

In VARTM process, environmental pressure (e.g. atmospheric pressure) is typically utilised to provide the driving force for the liquid resin to flow through the layup of dry fabric preform. Compaction for the fabric layup is also achieved by application of vacuum, as shown in the schematic. A flexible vacuum bag takes one side of the mold containing preform, other side being a rigid tool. After securing the dry preform against the mold, resin is drawn into the preform. A flow distribution media is used to enhance the resin infusion speed. For a large or complex composite part (with inserts, hybrid fabric systems, co-cured parts, etc.), multiple injection lines and vents could be used to improve the resin infusion. The flow distribution medium layer could also be placed in different patterns to create versatile resin infusion paths that can improve the resin infusion quality for a complex part. Process modeling and subsequent simulation of VARTM enables the designer to virtually infuse the composite structure with different process parameters and test its efficacy based on which the process design can be frozen.



Schematic of VARTM process

Several large, thick and complex composites structures have been realised at R&DE(Engrs), over the last one decade. Features of a few of the latest products realised in VARTM are summarised here.

Carbon/Epoxy Bridge

The laboratory has been playing a major role in the development of India's military bridging systems such as modular class-3 bridge, MLC 70 bridges such as BLT-T72, BLT Kartik, CEASE, SARVATRA, BLT-Arjun, 46 m modular bridge, etc. Indigenous development of bridging equipment that can negotiate all ranges of dry and wet gaps from small span (5-10 m) to large span (15-75 m) have been accomplished successfully. Attempts have been made to replace these metallic bridges with light weight composites.

A 5 m long carbon/epoxy bridge has been successfully realized through VARTM process. The overall length of the bridge is 5 m, which can be used for a gap up to 4 m and overall depth is 0.3 m. It consists of two tread-ways connected by hinges along the centerline of the bridge. Width of the bridge is 4 m during the passing of vehicles and can be folded for transportation. Each tread-way has a deck plate with five integrated I-girders manufactured as monocoque structure without joints. All I-girders are similar in dimensions. The top compression flange of all I-girders is merged into the deck with appropriate ply drops along the width of the bridge. Each tread-way of bridge is also provided with two metallic end caps which are designed to dock an end ramp for traffic to pass over the bridge.


Assembled bridge

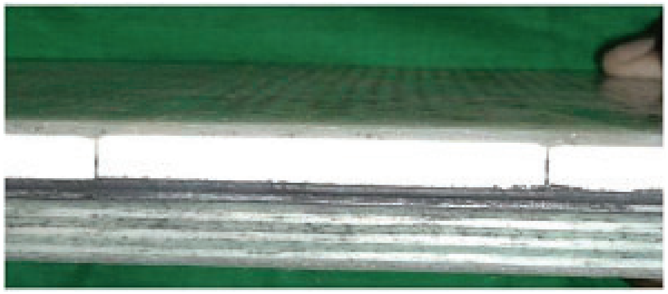

Tank passing on bridge

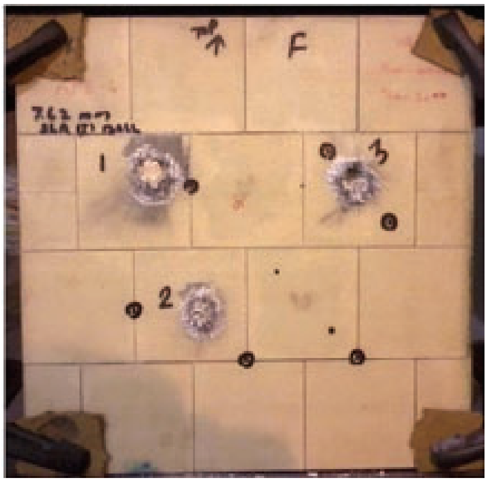
This bridge is designed as per the loading details given in 'Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment'. Finite Element Analysis (FEA) has been carried out using commercial finite element packages. The complete bridge segment is fabricated out of carbon /epoxy composite using VARTM. FBG sensors are embedded inside the bridge at the time of fabrication for process and health monitoring. Weight of the bridge is 1.2 ton as compared with 1.8 ton for an equivalent Aluminum bridge.

Loading of the bridge to design load has been successfully accomplished. Cyclic loading of this bridge has also been carried out at R&DE(Engrs). Total 45000 cycles of load equivalent to MLC-70 tracked loading completed without any failure in the structure. Gun mounted T-72 tank was also passed ten times over the bridge successfully. This light weight CFRP bridge will enable its platform to carry twice the number of bridges as compared to its metallic counterpart, thus providing definitive tactical advantages.

Composite Armoured Hull

The laboratory has developed a composites armoured hull for Infantry Combat Vehicle (ICV) through VARTM process. The hull has co-cured, monocoque lower and upper composite halves that are joined together by bolting. Glacis plate for the hull is retained same as that of the metallic ICV. The side armour is, however, integrated with the composites structure. This Composites Integral Armour (CIA) has a sandwich construction with ceramic tiles sandwiched between structural composites layer at the back and a cover layer at front. A thin elastomer layer separates the stiff ceramic layer from the structural composites layer. This multi-layered and multi-functional configuration provides ballistic protection against 14.5 AP threats. Armor panel successfully tested against multiple bullet hits is shown.


Cross section of composite integral armor


Tested armor panel after multiple hits

Composite armoured hull for Infantry Combat Vehicle

Design of hull structure and armour is based on simulations supported by experimental validations. The hull has been designed for normal running as well as extreme mobility conditions such as para-dropping, obstacle hit, sideways fall, etc. It is also analysed for gun fire loads. A full scale section of the hull was fabricated and tested to verify the analysis methodology and validate the joints. Armour configuration was finalised through simulations and conducting ballistic impact testing on armour panels.

The hull conforms to ICV Abhay Mk-II geometry and all critical features have been maintained to enable seamless interfacing of all integrands. It matches the structural and ballistic performance of metallic Abhay hull at 40 per cent less weight. The structure is in process of integration of all internal systems to demonstrate a running ICV with composites hull.

Composite Underground Shelter

A 2.8 m diameter and 7.5 m long capsule shaped shelter has been developed to house and to protect eight persons for ten days under Nuclear Biological Chemical (NBC) environment. The shelter is equipped with all essential life support systems including air filtration system, NBC detection system, light, toilet, water tank, septic system, decontamination shower, food storage, and communication systems. The shelter would be buried 2.5 m underground and communication to the ground will be through a 1 m diameter entranceway. The shelter is in two halves which have sandwich construction with E-glass/epoxy walls and Poly Vinyl Chloride (PVC) foam core and is fabricated through VARTM process as two single pieces without joints.

The structure has several openings for connecting the piping from outside using metallic flanges. The

Composite underground shelter

entrance way has a hatch dome which contains the door for entrance and exit. These hatch dome and door are designed for fire resistance, bullet and log impact etc. Apart from the pressure of 2.5 m soil cover, the shelter and entrance way are designed to withstand the ground shock of 20 g intensity and exponentially decaying surface overpressure of 40 psi. It is also designed to withstand an earthquake of intensity 8.5 on the Richter scale. The self-contained lightweight shelter can be installed in less than two days even below the water table without concrete and may be dug up and transported to another location on a 3T truck. The shelter will not have radar, thermal and metallic signatures and will not collect any electromagnetic pulse. The life span of composite underground shelter will be over 50 years and will be operational in all weather and in severe NBC environments.

SONAR Dome for P15A Class Ships

SONAR dome is a protective cover to SONAR array in warships. It is fitted in the bow (front) of the ship and is always submerged when the ship sails. The dome is required to have acoustic transparency; at the same, it must be structurally rigid to withstand slamming loads. Earlier, domes were manufactured using titanium. Because of superior properties of composites, composite domes have replaced metallic domes, of late. R&DE (E) has designed and developed the first indigenous Glass Fiber Reinforced Plastic (GFRP) Dome for P15 class of ships of the Indian Navy. Under guidance of R&DE (Engrs), M/s Kineco, Goa, has manufactured this dome by VARTM process. The dome is 10.5 m in length, 3.1 m in width at the bulbous section and its height is 3 m. The acoustic window is the front portion of the dome, about 6 m in length. This region has a sandwich construction with a glass/epoxy-rubber-glass/epoxy configuration. Apart from the complex shape, there are significant thickness variations from 16 mm composite to 60 mm thick composite. The entire dome is manufactured as a co-cured monocoque structure without joints. A baffle wall, which is bonded with acoustic tiles, developed by Naval Materials Research Laboratory (NMRL), is fitted at the end of acoustic window to absorb radiated noise.

An impervious coating developed by NMRL was applied on inner surface of the dome wall to protect water ingress into the GFRP material. Naval Physical and Oceanographic (NPOL), Kochi tested the dome for acoustic transparency and recommended for

GFRP SONAR dome; as manufactured and as fitted on INS Kolkata

Composite hood mounted on wagon Communication equipment housed within the hood (Inset)

fitment to the warship. The dome was handed over to Indian Navy in October 2016 and is fitted on to INS Kolkata, in May 2017. A second sonar dome was also realised and is now fitted on to INS Chennai.

Radome Hood for Agni Missile System

The communication coach of Agni missile system consists of various types of communication equipment and satellite tracking antennae. This coach is a wagon similar to the wagons manufactured by Indian Railways with some modifications on the base platform. Canopy of the coach is designed such that it provides radar transparency to all installed communication systems. The composite radome hood was realised in four segments designed as per radio transmissibility requirement of the antennae. All segments are provided with water tight joints. Doors are provided at the end to facilitate maintenance of equipment placed inside.

The radome hood was realised in E-glass/epoxy by the VARTM process. GFRP based mould was used for fabrication of all hood segments. Mould consists of integrated heating system for post curing of segments. Eight sets of hood, each consisting four segments were fabricated and installed on eight wagons of Agni missile system.

Resin Film Infusion

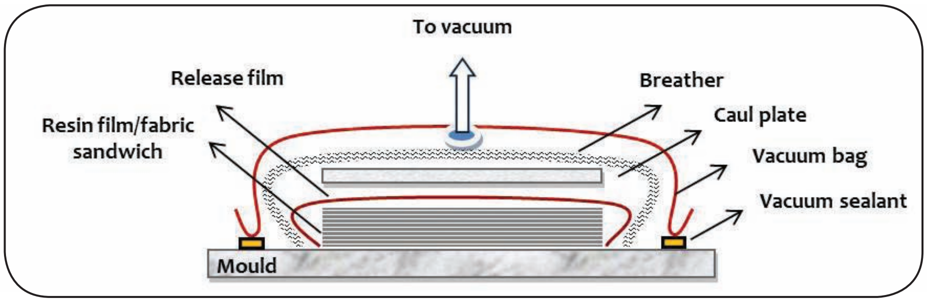
Autoclave curing using prepregs has been the gold standard for aerospace composites manufacturing. This technology has been by and large limited to aerospace applications primarily due to high cost. Resin Film Infusion (RFI), has been developed at R&DE (E) as a cost-effective alternative for autoclave based processes for manufacturing of structural composites.

In the RFI process, polymer resin, for example epoxy, is cast in film form and sandwiched between two reinforcement layers. These layers are cut to shape, laid on the tool, and vacuum bagged. The rest is a standard vacuum bagging process at ambient pressure and elevated temperature thus doing away with the necessity of an autoclave. When heated resin becomes fluid, it flows and wets out the fibers of the reinforcements. Latent curing agents premixed in the resin, act at an elevated temperature and cured parts are made.

Advantages of the RFI process are:

◊ Large and thick structures can be manufactured without necessity of an autoclave

◊ Products manufactured through RFI process have excellent structural properties with near-zero void content



Schematic of RFI process

◊ The resin film needs to be stored at -18 °C, similar to prepregs used in autoclave processing. However, since sandwiching can be done on demand, only the resin films need to be stored at lower temperatures. Thus, exceeding shelf life results in the loss of only resin films

◊ The resin film exhibits a light tack at room temperature which allows adhesion to curved surfaces. Extra adhesives, which may introduce defects in a finished laminate, are not required for support before infusion

CFRP wings of smart anti-airfield weapon

◊ Prepregs are not as drapable as dry fabrics and more prone to creasing in complex areas of moulding. RFI offers added advantage of excellent drapability

◊ Since resin-hardener mixing and its film casting are carried out under strict control, reproducibility and quality of fabricated parts are not reliant on operators

◊ To achieve better properties, resins can be modified using nano fillers resulting in hybrid composites. Structural composites modified with nanofillers can be realised only through resin film infusion. Since the process involves a local flow of molten resin, uniform distribution of the filler particles is ensured which otherwise is impractical in conventional liquid composite moulding techniques

◊ Repeated debulking for thick composites lay-up is not required

◊ This process has special significance for large structures as there is no possibility of an incomplete infusion

Following are a few recent products realised, or under development by resin film infusion process.

Wings for SAAW

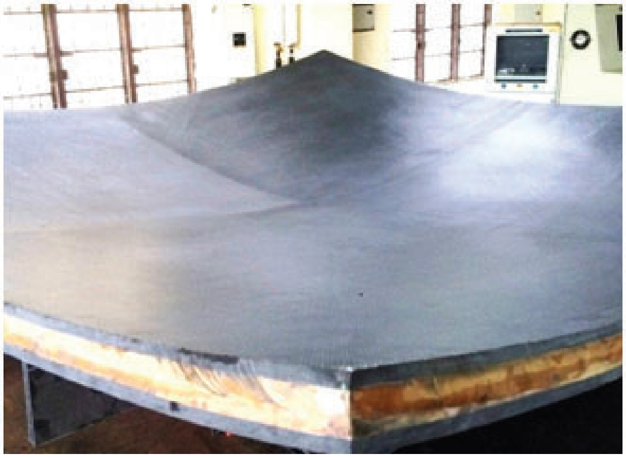
SAAW is a square cross-sectional, 125 kg class smart anti airfield weapon, having a length of 1.8 m, and is meant to destroy the adversaries' targets such as airstrips, hangers, and other installations using warhead being droped from the aircraft. To ensure the safety of parent aircraft carrying the store, it is required to be released from the far-off distance from the target.

Moreover, the store being an unpropelled one, it needs to cover a downrange (distance of target from aircraft at release) of up to 100 km after drop from aircraft at around 10-11 km altitude. This is achieved by incorporating a camber airfoil wing. The wing assembly is required to provide necessary lift to the store and ensure that store glides towards its intended target like a glider. Moreover, as the store is a light weight system and majority of the weight belongs to the warhead in order to increase its kill–power (more than 70 % of total weight), it is imperative for other systems be light weight. The weight of the wing has been reduced by more than 45 per cent (from 3.3 kg per metallic wing to 1.75 kg per composite wing) by converting it into a composite wing instead of existing solid metallic wing to realise a light weight smart weapon.

SAAW wing has been realised by the RFI process. The total wing weight of 1.645 kg is achieved with a contour tolerance of 0.4 mm and high surface finish of ~ 1 μ Ra value. Structural and vibration testing of the wings are in progress.

125 mm FSAPD hybrid Sabot

Scaled down CFRP wing of Rustom-II (1 m long)



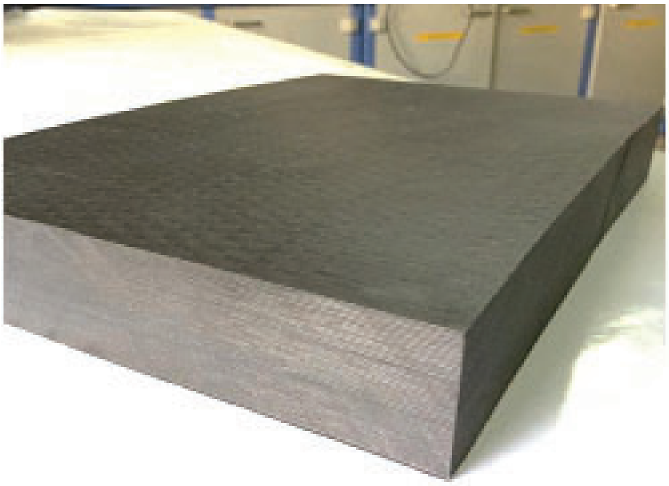
Curved CFRP sandwich structure realised through RFI

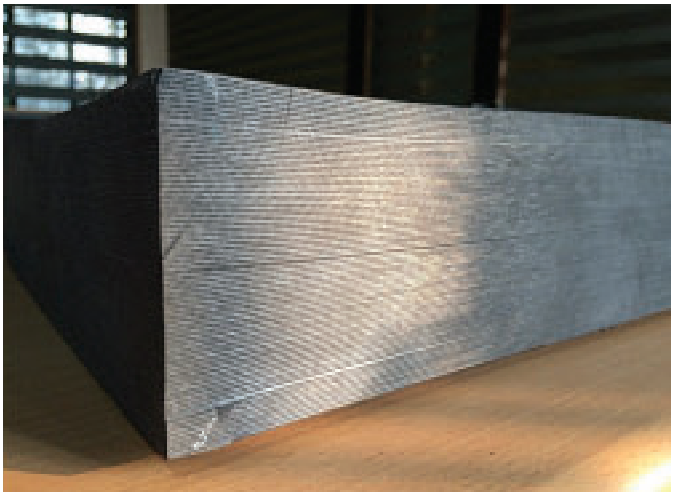
Closer view of the cross-section

RFI has also been used to realise a 125 mm Fin Stabilised Armor Piercing Discarding Sabot (FSAPDS) in carbon/epoxy composite and the same has been successfully tested. Products such as wings of Unmanned Aerial Vehicle (UAV) Rustom-II, Radome for AWACS, etc., are also under process of manufacturing through RFI.

RFI also offers possibility to manufacture structures with practically no thickness limitation. Shown in photograph is a 2 m × 2 m curved sandwich structure realised through this process. Each of the 10 mm thick face sheets are carbon/epoxy and the 30 mm thick core is dockblock rubber. This is a representative configuration of a SONAR dome, which was tested at NPOL, Kochi and proved to be acoustically transparent.

Composite structures as thick as 78 mm have also been realised through this process. Shown in the photograph, are representative structures realised with carbon fabric of unidirectional architecture (top: 46 mm and bottom: 78 mm). They have fiber volume content as high as 57 per cent and near zero void fractions. This forms part of a strategic weapon system.





Thick composites realised through resin film infusion

Allied Technologies

Shape Memory Alloys in Hybrid Composites

Resistance of composites against impact loading is poor in through-the-thickness direction. They dissipate very little strain energy (such as plastic yielding in ductile metals) during impact loading. There are various methods for improving impact damage resistance of composites such as toughening of matrix, through thickness reinforcement by stitching, 3D weaving, braiding, etc. One promising method is to hybridise composites with Shape Memory Alloys (SMAs). SMAs are capable of absorbing impact energy through superelastic deformation thereby mitigating effect of impact on composite structures.

Hybridising composites with SMA results in improvement of their fracture toughness properties. Fracture toughening mechanisms uses energy dissipation properties of the super-elastic or Stress Induced Martensite (SIM) phase transformations of SMA material embedded in composites to dissipate energy. The dissipation mechanisms required for damage mitigation using pseudoelastic SMA are passive and do not require any external activation mechanism. Part of the energy required for generation of damage in composites is absorbed by SMA during SIM transformation thereby reducing the damages. Passive damage suppression using pseudoelastic SMA is effective and easy to implement in engineering composites structures.

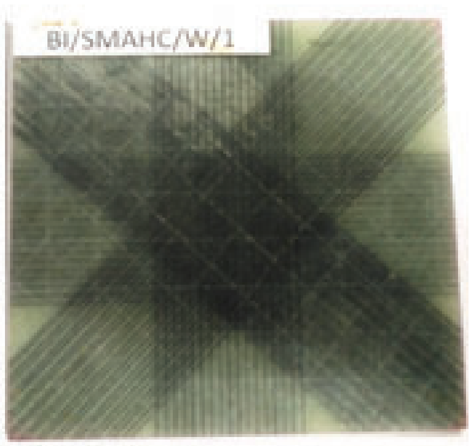
Preliminary investigations on SMA hybrid composites revealed that their residual compressive strength after low velocity impact considerably improved in comparison to pristine composites. High strain rate characterisation of SMA also depicts energy absorbing capability. This can be utilised for designing composite armours with enhanced post impact strengths.

Hybrid Composites

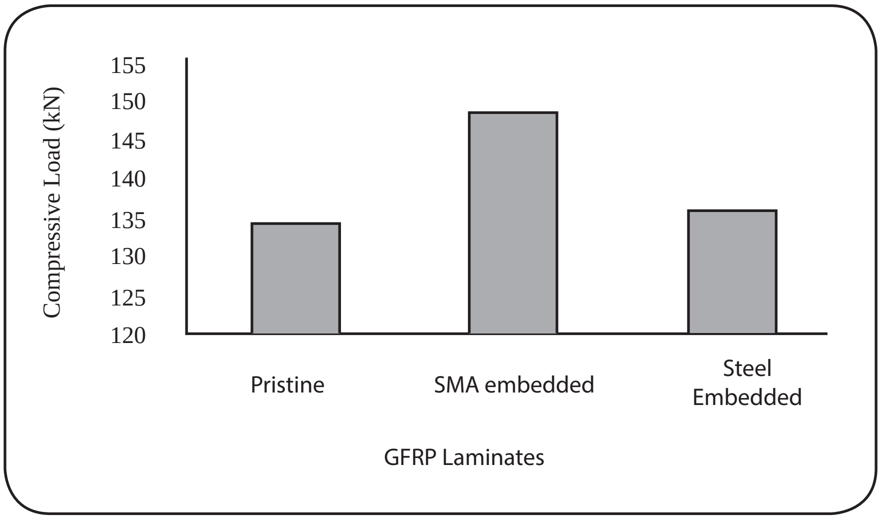
The laboratory has been working on structural composites hybridised with nanofillers for over five years. The concept of hybridising structural composites with nanomaterials can benefit from the macro scale reinforcement provided by traditional fibres and from the complimentary reinforcement on the nanoscale offered by nanomaterials.

Methods have been optimised to disperse nanomaterials such as Carbon Nanotubes (CNTs), Carbon Nano fibers (CNFs), Graphene, Nanoclay, Nanosilica, etc. in epoxy to generate composites reinforced with Glass/Carbon fabric for load bearing/structural applications. Loading fractions of nanofillers for an efficient reinforcement, yet retaining the ideal processing parameters has been optimised and can be scaled up for large structures through the RFI process. An increase in glass transition temperature (Tg) of epoxy has also been observed with fillers such as carbon nanofibers.

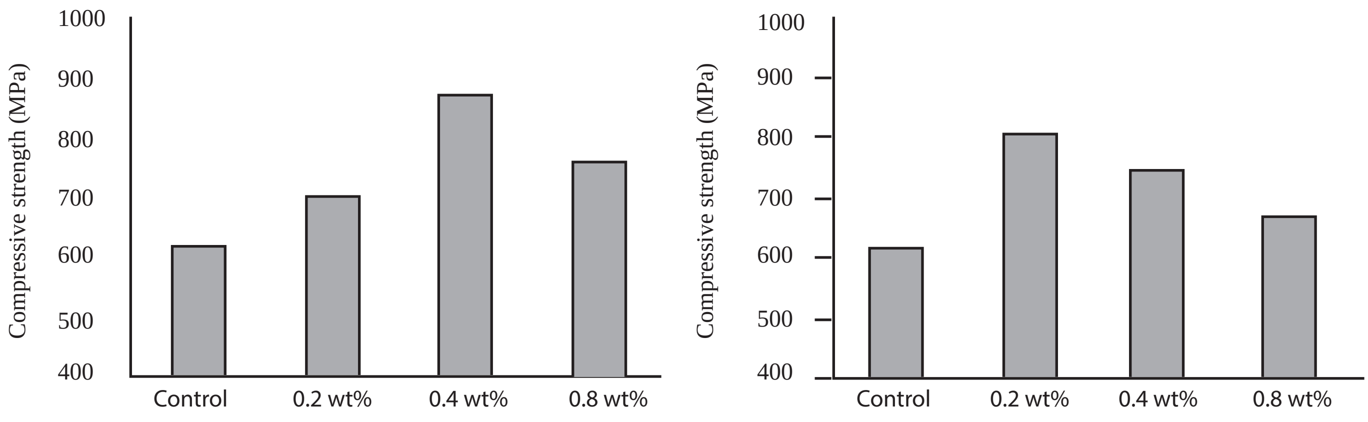
With amine functionalised carbon nanofibers, at loading fractions as low as 0.4 wt per cent, an improvement of 40 per cent in compressive strength of unidirectional E-glass/epoxy composites have been achieved. A less expensive nanofiller, nanosilica at a lower concentration of 0.2 wt per cent has also resulted 30 per cent increase in compressive strength of glass fibre reinforced epoxy.



SMA wire embedded GFRP Composite

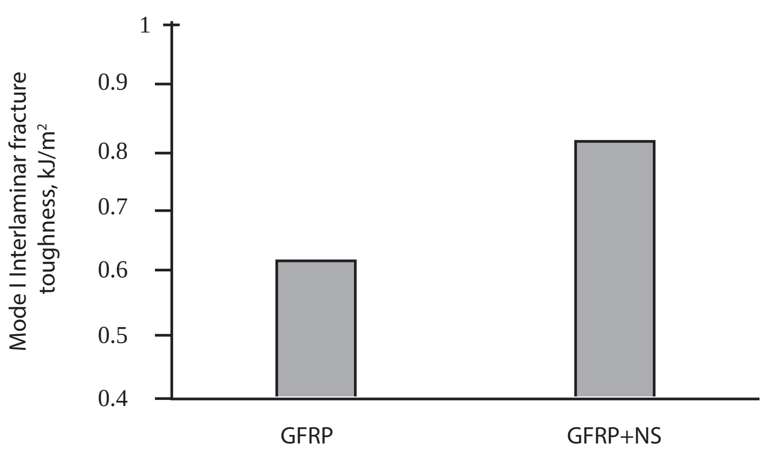


Effect of SMA on compressive properties of GFRP laminates in comparison to pristine and steel embedded laminates



Effects of various loading fractions of carbon nanofibers (a) and nanosilica (b) on compressive strength of glass/epoxy composites

Glass transition temperature of epoxy remained unaffected with nanosilica while the toughness of the matrix improved to a substantial amount. This is reflected in a 30 pe rcent improvement in mode I Interlaminar Fracture Toughness (GIc) of continuous unidirectional glass/epoxy composites, containing nanosilica.



Effect of 0.2 wt percent of nano-silica on GIc of glass/epoxy composites

Polymer Nanofibers through Electrospinning

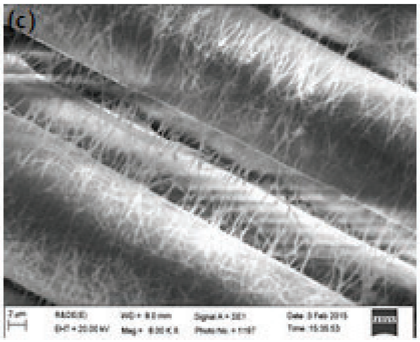
One-dimensional nanomaterials such as polymer nanofibers have spurred considerable research attention owing to their inimitable characteristics and wide range of applications. Electrospinning is a simple and cost-effective technique to synthesise such nanofibers. In this process, a viscous polymer solution is injected from a syringe, needle of which is connected to very high positive potential.

Electrospinning occurs when the electric forces at the surface of the solution overcome its surface tension and ejects an electrically charged jet. Because of the interaction between the jet and external electric field and charge repulsion inside the jet, the charged jet gets unstable to stretch it thinner. Axial tension of the fiber provided by electrostatic forces leads to high elongation ratios, and solvent evaporation results in solid fibers.

In an attempt toward large scale production of nanofibers, nylon 6/6 nanofibers with a diameter as low as 80-100 nm have been grafted to reinforcement fabrics using a customised electrospinning machine This unit, with a dozen syringes can produce nanofibers that are collected as a thin interconnected web of nonwoven filaments with random orientation, over the reinforcement fabric that conveys slowly over a grounded target.

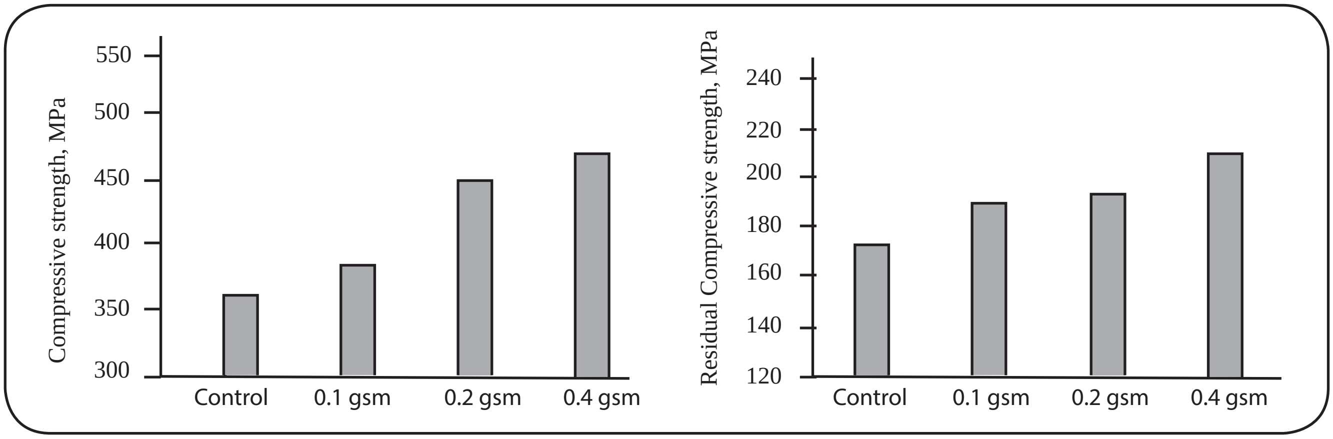
RFI has been successfully implemented to realise composites with interleaved electrospun nanofibers. Nylon 6/6 nanofibers at low areal densities in continuous bidirectional E-glass/epoxy laminae are found to have improved the compressive strength of composites by over 30 per cent. Residual compressive

(a) Customised electrospinning machine



(b) Closer view of the spinning unit,
(c) Micrograph of nylon Nanofibers deposited over glass fabric

strength of composites after a low velocity impact has also improved by nearly 20 per cent. Interleaving nylon 6/6 nanofibers of diameters as low as 80 nm-100 nm can be an effective method to reinforce regions that have localised stress concentrations and are prone to damages such as delamination, without affecting the processing of composites and with no weight penalty for the final product. Enormous improvements in mechanical properties of structural composites hybridised with low weight fractions of nanofillers/nanofibers pave the way for lighter, yet stronger/tougher composites. As nano-filler modification results in no change in processing of composites, nor any cost implications, hybrid composites offer straightforward solutions to several limitations of laminated composites. Environmental characterisation is nearing completion and subsequently the technology will be adopted in realising primary load bearing structural products.

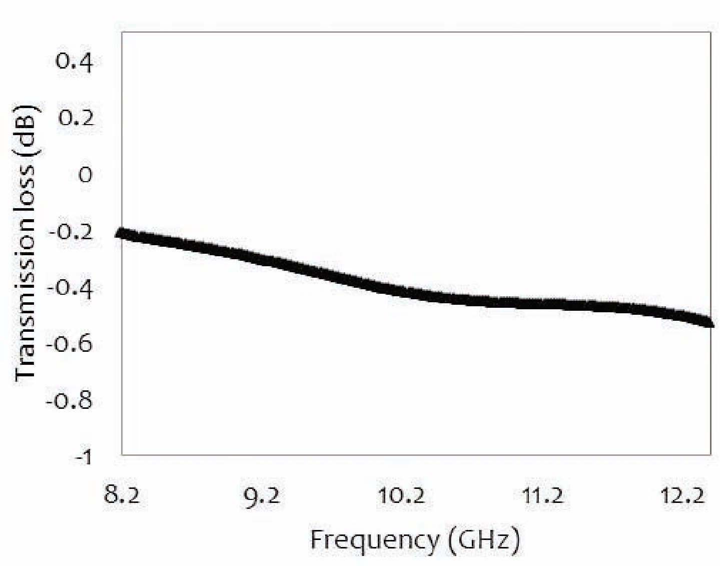


Effect of Nylon 6/6 nanofibers at varying areal densities on the compressive strength (left) and residual compressive strength after low velocity impact (right) of GFRP composites

High Temperature Composites

High temperature resistant light-weight composites are in huge demand for various defence applications. Cyanate esters are a class of advanced thermoset resin systems widely used in such applications because of high service temperature (Tg=200 to 400 °C). They also possess excellent dimensional tolerances, ease of processability, reduced micro cracks while exposed to thermal cycling, etc. The low dielectric constant enables cyanate esters as a choice of radar transparent materials for high temperature RADOME applications as well. The laboratory has carried out research in the development of composites products that can withstand more than 230 °C operating temperature using cyanate ester resins and their blends through RFI process.

Highly tough engineering thermoplastics, e.g. polyether imide, miscible with and possessing similar processing temperatures of cyanate esters are blended with the latter and resulted in excellent damage tolerant high temperature composites. They exhibit better mechanical properties in comparison to composites realised with epoxy resin, through RFI process (Table 1). These blends are also proved to be radar transparent. Transmission loss data in X-band, of 1 mm thick GFRP laminates realised with Cyanate ester-PEI blend as matrix is also shown.



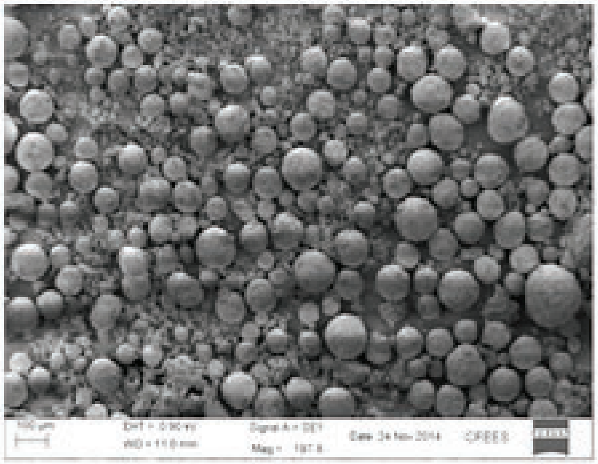
Transmission loss data of 1 mm thick GFRP laminates realised with Cyanate Ester-PEI blend as matrix in X-band

Self-healing Composites

Durability of structural composites, for instance, in an event of impact is a matter of concern. Lack of plastic deformation in these materials results in energy absorption by the formation of defects and damages. Microcracking, for example, is one of the fatal deteriorations, propagation and coalescence of which would bring about catastrophic failure of structures. Solution is an inherently damage tolerant design philosophy, but can be expensive, time-consuming and inefficient. There are also conventional methods to repair damages. Nevertheless, typical structural repairs often result in damaging practices, where material is ground away or holes are drilled to secure patches, which can act as new sites for damage.

Table 1. Mechanical Properties of GFRP Composites with Cyanate Ester-polyetherimide Blend as Matrix in Comparison to that with Epoxy

Property	GFRP with Cyanate Ester/PEI	GFRP with Epoxy
Compressive strength, MPa	361 ±22	279 ±16
Tensile strength, MPa	327 ±16	337 ±5
Tensile modulus, GPa	16 ±0.1	18 ±0.2
Interlaminar shear strength, MPa	38 ±1	44 ±3
In-plane shear strength, MPa	157 ±2	113 ±2
In-plane shear modulus, GPa	7.7 ±0.03	5.6 ±0.01
Mode I interlaminar fracture toughness, KJ/m^2	0.824 ±0.01	0.620 ±0.01
Compression after impact, MPa	344.29 ±19	174.01 ±21



Micrograph of microcapsules containing self-healing agent

A bio-inspired approach to self-healing of structural composites offers many exciting possibilities. In an engineering context, the concept of self-healing is where mechanical, thermal or chemically induced damage is repaired by the materials already housed within the structure, analogous to the healing process of living organisms. The strategy involves housing of reservoirs containing a healing agent, in the composite. In the event of a crack formation and its propagation, the reservoirs would break and the healing agent would flow out into the crack. Reactions of the healing agent with a catalyst that flows from another set of reservoirs in the similar way will ensure crosslinking and subsequent crack healing.

Extensive research has been carried out to formulate an epoxy based self-healing agent and a formulated hardener. This formulation has low viscosity, is independent of resin-hardener stoichiometry, has excellent bonding with the host matrix, and is thermally stable for composite manufacturing conditions. The healing agent and hardener were encapsulated in polyurethane microcapsules at CSIR-NCL. Experiments with these healing agent reservoirs are in progress.

Thermoplastic Composites

Manufacturing of continuous fiber reinforced composites with thermoplastics as matrix has been a challenge. Because of the high viscosity, molten thermoplastics cannot be infused through the stack of fabric using any conventional composites molding techniques. If the viscosity is to be retained for processing, it has to be controlled with temperature. A prolonged holding of high temperature would thermally degrade the polymer by the time infusion completes. To resolve these issues a methodology has been devised to infuse a pre-catalysed monomer and subsequently polymerise it after infusion. A commercially available low viscosity acrylic monomer (Elium 150 from Arkema) has been chosen, which will undergo polymerisation with a peroxide catalyst to result in composites that have mechanical properties comparable to that of epoxy. Composites have been realised through a simple Vacuum Assisted Resin Transfer Molding (VARTM) process. A summary of mechanical properties of thermoplastic composites with a multi-compatible E-glass fabric as reinforcement is presented in Table 2. These composites also show excellent toughness. Data of epoxy (Araldite LY1564-Aradur 3486 from Huntsman Advanced Materials) composites with the same reinforcement is also presented in the Table for comparison. Laminates have comparable fiber volume and void fractions. In the events of fracture, thermoplastic composites can be repaired with ease, which otherwise is impossible with thermoset composites. They also offer a scope for recycling.

Table 2. Comparison of mechanical properties of thermoplastic and epoxy composites fabricated through VARTM process

Property	**GFRP with Thermoplastic Matrix**	**GFRP with Epoxy**
Compressive strength, MPa	263.6 ± 17.7	230.9 ± 24.3
Tensile strength, MPa	511.7 ± 12.9	409.2 ± 18.5
Interlaminar shear strength, MPa	54.32 ± 1.8	32.76 ± 1.7
In plane shear strength, MPa	84.08 ± 0.1	60.73 ± 1.1
In-plane shear modulus, GPa	10.92 ± 0.8	9.36 ± 0.5
Compression after impact, MPa	381.0 ± 29.1	157.4 ± 11.7

Structural Health Monitoring of Composites

Damages which a composite structure in service encounters are severe than its metallic counterparts. Moreover it is required to continuously monitor the health of mission critical structures. Therefore Structural Health Monitoring (SHM) is an apt tool for online and offline health monitoring of composite structures. SHM consists of deployment of sensors, collection of data and its processing and an algorithm for damage detection and localisation. The key aspect of SHM is development of low footprint sensors and robust algorithms.

Composites research centre has explored three techniques, viz., strain based, vibration based and ultrasound based SHM of composites. Laboratory level experiments conducted on detection of delaminations/disbonds using these techniques have given encouraging results.

Subsequently strain based SHM has been implemented on the 5 m CFRP bridge using Fiber Bragg Grating (FBG) sensors in the framework of Artificial Neural Network (ANN). Based on the experience gained, efforts are being made to implement hybrid SHM, where more than one scheme shall be combined, on Rustom II wings.

Way Ahead

The uniqueness of composites, especially with regard to its pervasiveness into virtually all sectors of defence engineering, explains why its impacts will exceed those of all conventional materials. Composites Research Centre of R&DE(Engrs) is set for continued expansion of the range of composite products and technologies.

With functional features incorporated in structures, such as acoustic transparency, sonar domes for future ships and submarines are under development. Composite radomes for aircrafts and AWACS applications, stealthy components for subsonic and supersonic aircrafts are also under development. Airframes for manned and unmanned aircrafts will be realised through resin film infusion process. Hulls for corvette class ships and Mine Counter Measure Vessels (MCMV) are some of the future products that can be developed for naval applications. Hulls for Main Battle Tanks (MBT) are also envisaged in the future.

The centre also focuses on development of cutting edge technologies in the area of composites.

With the initial experimental results obtained from composite specimens containing nano fillers depicting enhancement of mechanical properties, attempts will be made to incorporate these fillers in large structures, where there is a demand for improved properties. Attempts will be made to incorporate SHM, self-healing, damage mitigation and multifunctionality in composites to make them smart structures.

Embedment of nano-sensors in composites is another key area of research. These sensors shall be explored for monitoring of strain, radiation, and moisture.

In large, thick and complex composite structures, composite-metal joints are inevitable. In general, bolted joints are used. However, transmission of heavy forces results in development of bearing stresses. Therefore, development of hybrid joints, which do not undergo bearing, is underway at the centre.

Development of armor using Functionally Graded Materials (FGMs) and shear thickening fluids, composite repair strategies, 3D printing of structural composites, etc. are a few other technologies that are planned to be tackled in roadmap over the next decade.

Feedback for Technology Focus

We have been receiving a tremendous appreciation & good words on the contents, quality, and presentation of Technology Focus and we intend to continue with our efforts. The editorial team requests your support to further improving it. The feedback form as below would be one of the resource that would provide us your level of satisfaction and newer aspects you would want to incorporate in the Technology Focus.

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Celebrating 26 Years of Publishing


Technology Focus
BULLETIN OF DEFENCE RESEARCH & DEVELOPMENT ORGANISATION
December 1992
LAKSHYA–A PILOTLESS TARGET AIRCRAFT
Lakshya at its launch pad
LAKSHYA, an unmanned remote-control air vehicle, has been designed and developed by DRDO as a live practice target for air and ground missiles and long range artillery guns. This pilotless target aircraft has demonstrated its capability to fly at altitudes ranging from 300 to 9,000 m at a variable speed with a flight endurance exceeding 40 min.


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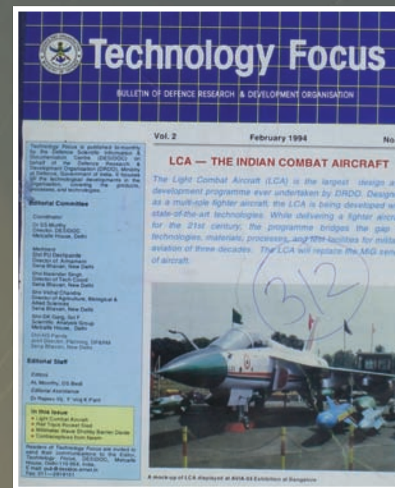
Vol. 1 February 1993
TRISHUL
The Trishul Weapons System, developed around the indigen Surface-to-Air Missile (SAM) popularly known as Trishul—nam after the three-pronged weapon of Lord Shiva—can eng low-flying enemy targets within 6-8 s after detection. In a mod version, the SAM can be deployed to provide defence aga sea-skimmer anti-ship missiles.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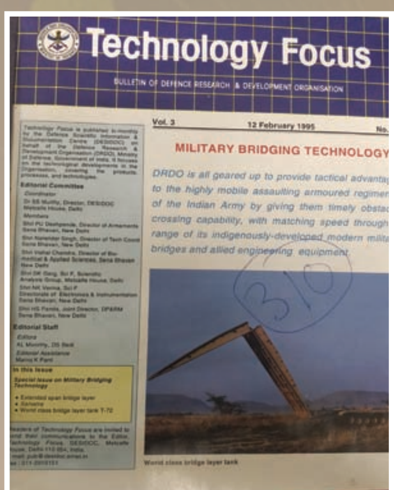
Vol. 2 February 1994
LCA — THE INDIAN COMBAT AIRCRAFT
The Light Combat Aircraft (LCA) is the largest design an development programme ever undertaken by DRDO. Designe as a multi-role fighter aircraft, the LCA is being developed wi state-of-the-art technologies. While delivering a lighter aircr for the 21st century, the programme bridges the gap technologies, materials, processes, and test facilities for milita aviation of three decades. The LCA will replace the MiG seri of aircraft.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Vol. 3 12 February 1995
MILITARY BRIDGING TECHNOLOGY
DRDO is all geared up to provide tactical advantag to the highly mobile assaulting armoured regimen of the Indian Army by giving them timely obstac crossing capability, with matching speed through range of its indigenously-developed modern milit bridges and allied engineering equipment.
World class bridge layer tank


Technology Focus
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Vol. 4 April 1996
AUTOMOBILE TEST INSTRUMENTS
DRDO has developed a number of specia purpose instrumentation systems for use in the technical evaluation and proving of vehicles t help the users in both military and civil sector to achieve international standards in the qualit of automobile systems. These instruments a in use at a specially established nation facility, the National Proving Ground.
Hydraulically-operated Articulation Test Rig


Vol. 5 No. 1 February 1997 ISSN : 0971-4413
TECHNOLOGY FOCUS
Bulletin of Defence Research & Development Organisation
DEFENCE TECHNOLOGY SPIN-OFFS FOR HEALTH CARE
Under the aegis of newly formed Society fo Biomedical Technology, an interministerial initiative t utilise Defence technology spin-off for medicare DRDO has developed a number of biomedica products. These equipment, diagnostics and medica devices have ushered in a new era in th indigenisation of medical technology in our countr with a view to provide appropriate and affordabl health care for the common man.


Vol. 6 No. 6 December 1998 ISSN : 0971-4413
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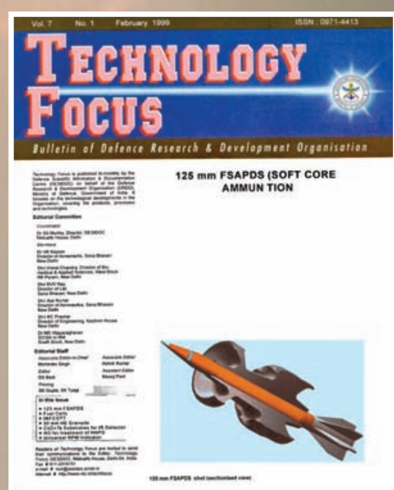
Vol. 7 No. 1 February 1999 ISSN : 0971-4413
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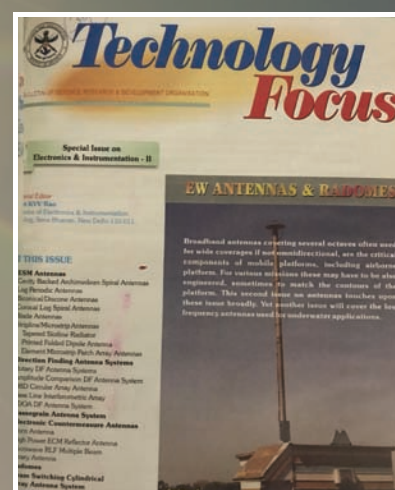
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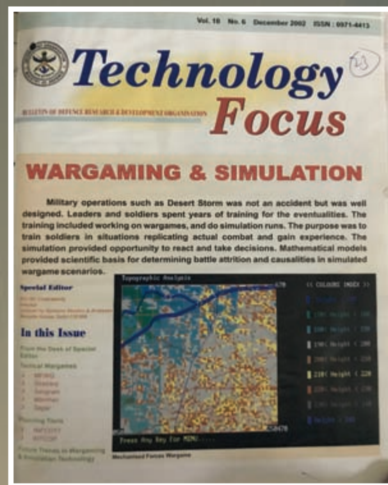

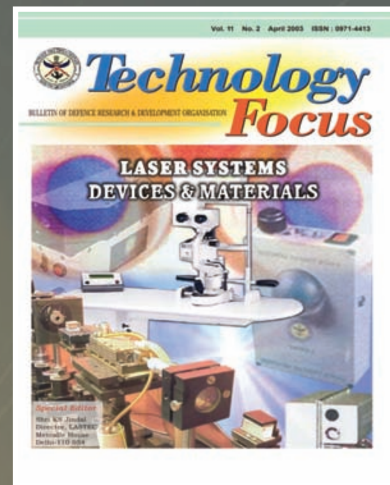

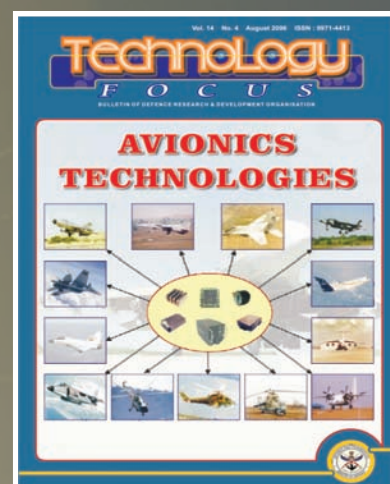

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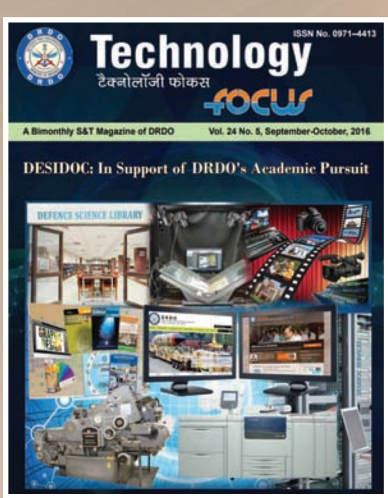

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