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| **Composites: A Vision for the Future**  |

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| Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry.It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even programme management for composites to become competitive with metals.The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years.Increasingly enabled by the introduction of newer polymer resin matrix materials and high performance reinforcement fibres of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume. The increased volume has resulted in an expected reduction in costs.High performance FRP can now be found in such diverse applications as composite armouring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers.For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc.Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity.An examination of the diversity of some of these newer applications and the socio-commercial considerations that underpin their introduction gives an instructive insight into the future of high performance FRP. Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. The design of a structural component using composites involves both material and structural design. Composite properties (e.g. stiffness, thermal expansion etc.) can be varied continuously over a broad range of values under the control of the designer. Careful selection of reinforcement type enables finished product characteristics to be tailored to almost any specific engineering requirement.Whilst the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience & skills of the designer in tapping the optimum potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials. **Why Composites?**Composites are able to meet diverse design requirements with significant weight savings as well as high strength-to-weight ratio as compared to conventional materials. Some advantages of composite materials over conventional one are mentioned below :* Tensile strength of composites is four to six times greater than that of steel or aluminium.
* Improved torsional stiffness and impact properties
* Higher fatigue endurance limit (up to 60% of the ultimate tensile strength).
* 30-45% lighter than aluminium structures designed to the same functional requirements
* Lower embedded energy compared to other structural materials like steel, aluminium etc.
* Composites are less noisy while in operation and provide lower vibration transmission than metals
* Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements
* Long life offers excellent fatigue, impact, environmental resistance and reduced maintenance
* Composites enjoy reduced life cycle cost compared to metals
* Composites exhibit excellent corrosion resistance and fire retardancy
* Improved appearance with smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites
* Composite parts can eliminate joints/fasteners, providing part simplification and integrated design compared to conventional metallic parts

**Composites: The Future Trends** Armed with a wide gamut of advantages, composites have a key role to play in the growing market in India. Composites have made an entry into diverse end-use segments and the developmental efforts for finding newer composites for existing & novel applications is an area of top priority. **Transportation Sector*****Automobiles***Despite the potential benefits of lighter weight and durability resulting from corrosion resistance, advanced composites are not recognized as a material of choice in the near term for automotive applications. Significant changes on a broad spectrum would be required to make advanced composites attractive for widespread commercial use in cars and trucks. The principal barrier is the high cost of the raw & fabricated materials when compared to existing options.However there are opportunities for advanced composites in specific components in the commercial automotive sector. In specialty vehicles of several types, produced in small numbers advanced composite materials have an opportunity to demonstrate their performance benefits, apart from the requirements of the competitive marketplace.The composite industry worldwide is investing in process improvements for the moulding of polymer composites using forms of conventional E-glass in mid-level performance resins, both thermoplastic & thermoset. Automobiles segment of composites accounts for about 50% of the thermoplastic and 24% of the thermoset composite market in the world.Glass-reinforced thermoplastic polymer is a promising material for weight reduction because of the relatively low cost of the fibre, its fast cycle time and its ability to facilitate parts integration. Carbon fibre reinforced polymer is another candidate but will require breakthroughs in cost and manufacturing techniques to be cost effective for high volume production. Pressure for reductions in energy use and lower emissions levels makes advanced composites a favourable option for the automotive sector. The composites usage in this sector is estimated around 3500 TPA by 2005 AD. The likely future business opportunities in automotive sector are mentioned below : * Pultruded Driveshafts
* RTM Panel
* Fiber Glass/Epoxy Springs for Heavy Trucks and Trailers
* Rocker Arm Covers, Suspension Arms, Wheels and Engine Shrouds
* Filament-Wound Fuel Tanks
* Electrical Vehicle Body Components and Assembly Units
* Valve Guides
* Automotive Racing Brakes & Train Brakes
* Clutch Plates

Though not much progress has been made in India towards product development efforts, this area merits attention and holds a lot of promise. The prospects of export of composites currently are low because India does not enjoy any comparative advantage either in raw materials or in processing costs. The other area which holds promise for the coming decade is the use of metal matrix composites for certain auto components. The main advantage of such composite material systems is that their physical, mechanical and thermal properties are tailorable and can drastically surpass those of reinforced metals.MMC can be extruded, forged, investment cast, rolled, machined, and heat treated. Transportation applications represent one of the largest demand segments for MMCs, and include turbine and combustion engine components, disc brakes and brake parts, and drive shaft components.Because of their unique properties, metal matrix composites are also gaining interest in a host of high performance applications across a number of industries. Demand for MMCs is growing in the transportation, electronics, telecommunications and pollution control sectors. It is expected that MMCs may experience a double-digit increase across these industrial markets through 2003.***Marine***With composites exhibiting excellent resistance to the marine environment, their applications have made good inroads in the marine sector worldwide. Complex configurations & the advantages of seamless hulls were the main driving factors in the development of FRP boats.Racing power-boats employ advanced & hybrid composites for a higher performance craft and driver safety. Major structural elements viz. deckhouses, hatch covers, kings posts & bow modules appears to be very well suited for FRP construction.In India, composite applications in marine segment has made some beginning in the last decade in high speed boats, naval vessels, sail boats, fishing boats, high capacity trawlers, barges & other ship components. The consumption of composites by this industry is mainly glass fibre reinforced polyesters. Advanced composites materials on vessels have a potential to reduce fabrication & maintenance cost, enhance styling, reduce outfit weight and increase reliability. The usage of composites is reckoned at about 750-1000 TPA by 2010 in India. Potential ship applications for composite materials are :* Shafting Overwraps,
* Life rails, Handrails,
* Masts, Stacks & Foundations
* Stanchions
* Propellers vanes, Fans & Blowers
* Gear cases
* Valves & Strainers
* Condenser shells

***Bicycles***Composite bicycle frames have been a largely American phenomenon, as a spin-off technology from the aircraft and boating industries. Manufacturing of composites requires greater technical expertise and investment for product development. Carbon composite bike frame is a complex structure with performance characteristics that include lightness, rigidity, durability, shock absorption etc.As composites fabrication offers variation over the length of the tube providing different fiber angles, different plies, different ply thickness, different combinations of materials. So the properties of the end product made from composites can be tailored to specifications. Hybrid fibre (carbon & aramid), carbon/kevlar epoxy materials are ideal composite materials for bicycle components. The composites are finding application in bicycle components such as * Forks
* Handle bars & Connecting bar ends
* Seat posts

India is yet to make a beginning in utilizing the benefits of composites in bicycle sector. In the near future, India can visualize rapid penetration in the bicycle components market as well as finished cycles. This would however need the back-up of design/ processing technology of a high order, to be able to meet the international standards. **Chemical Industry**Supplemented by the advantages of composites of lightweight, mouldability, fire resistance properties, resistance to chemicals has made the material popular in the chemical industry. Composites are extensively used in industrial gratings, structural supports, storage tanks, scrubbers, ducting, piping, exhaust stacks, pumps & blowers, columns, reactors etc. for acidic & alkaline environments.**Some of the potential applications are :*** Composite vessels for liquid natural gas for alternative fuel vehicle
* Racked bottles for fire service, mountain climbing
* Double-wall FRP vessels with an early warning system for leakage detection
* Underground storage tanks
* Casings for electrostatic precipitator
* Drive shafts
* Fan blades (for both axial & centrifugal fans)
* Ducts & Stacks
* Aerial man-lift device…

Internationally, composites applications in chemical industry is a relatively small segment in relation to the total usage of composites. However, in India, this forms the major segment accounting for nearly 28% of total domestic market for composites.With the rapid growth of the chemical industry, this segment is expected to further strengthen with increasing acceptance by the users. The usage of composites in this segment in India is estimated to grow at about 10% p.a. to a level of 11000 TPA by 2005 from the present level of about 5000 TPA.**Electrical & Electronics** Composites equipped with good electric insulation, antimagnetic & spark-free, good adhesion to glue & paint, self-extinguishing qualities are used for the construction of distribution pillars, link boxes, profiles for the separation of current-carrying phases to prevent short circuits etc. The other potential applications of composites in this sector are :* Third rail covers for underground railway
* Structurals for overhead transmission lines for railway
* Power line insulators
* Lightning poles
* Power pole cross arms
* Fibre optic tensile members
* Switchgear frames
* Aerial lift-truck booms

The volume of usage of composites in this segment is projected to increase from the present level of 3000 TPA to about 5000 TPA by 2005 in India. **Construction**Construction holds priority for the adaptation of composites in place of conventional materials being used like doors & windows, paneling, furniture, non-structural gratings, long span roof structures, tanks, bridge components and complete bridge systems and other interiors. Components made of composite materials find extensive applications in shuttering supports, special architectural structures imparting aesthetic appearance, large signages etc. with the advantages like corrosion resistance, longer life, low maintenance, ease in workability, fire retardancy etc. **Table – 3.0 : Composite Applications in Building & Construction**

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| **Composite** | **Applications** |
| Coconut/jute/sisal fibre & gypsum plaster | Boards for partitions, ceiling & wall panel |
| Coconut/jute/sisal fibre and glass fibre with gypsum plaster | Solid and perforated building blocks |
| Poplar wood with polymer | Door shutters, doors & window frames |
| Vegetable fibre/red mud & polyester | Flat & corrugated roofing sheets, shutters & tiles |
| Jute fibre polyester/epoxy with red mud | Panels & sheets, wall cladding, partitions & door shutters |
| Bagasse & UF/PF resin | Panels & blocks |
| Coir fibre with fly ash & lime or cement | Bricks & blocks for walling |
| Glass fibre reinforced polyester  | Roofing sheets, partitions, ceilings, sanitary ware, water storage tanks, pipes etc. |
| Glass fibre reinforced PP/nylon | Door hinges |
| Red mud plastic (PVC, polyester) reinforced with sisal fibre | Paneling, roofing, partitions, door panels |
| Acrylic resin and quartz sand composite | Kitchen sinks |

(Source : BMTPC, New Delhi)Usage of composites for damage repairing, seismic retrofitting and upgrading of concrete bridges finds increased adoption as a way to extend the service life of existing structures, they are also being considered as an economic solution for new bridge structures. Composite based 2D & 3D grid-type reinforcement for concrete structures shows considerable potential for use as reinforcement of concrete in tunnels because of its corrosion & chemical resistance, its lightweight and its ease of forming to fit curvatures.Grid-type reinforcement for concrete structures consists of high-performance fibres such as glass, carbon, aramid and hybrids impregnated with resin systems ranging from vinyl esters and other thermosetting resin systems to thermoplastics. The significant systems-level savings were achieved due to the factors of weight.Other critical applications of composites in the civil engineering area are:* Tunnel supports
* Supports for storage containers
* Airport facilities such as runways and aprons
* Roads and bridge structures
* Marine and offshore structures
* Concrete slabs
* Power plant facilities
* Architectural features and structures such as exterior walls, handrails, etc.

The worldwide potential for FRP composite repair systems is estimated as at least US $10 billion per year. The key restricting factors in the application of composites are initial costs due to raw materials and also inefficient moulding processes. With the adoption of advanced technologies & some extent of standardization, these problems could be easily taken care of. A growth rate of 11-13% p.a. in the usage of composites is expected after 2005 AD in this sector. **Offshore Oil and Gas Industry**Steel and concrete are the materials of choice for offshore oil and gas production platforms, with steel dominant in the topside applications. Composites have found their way into limited applications, particularly where corrosion and the need to reduce high maintenance costs have been an issue.As the industry moves to greater water depths, the significance of weight saving has become increasingly important in conjunction with the application of buoyant tension for the leg structures. Composites may find excellent usage in fabrication of the following : * Profiles for oil pollution barriers
* Gratings, ladders and railings on oil-drilling platforms and ships
* Walkway systems Sucker rods

**Consumer & Sports Goods** The optimum design of sports equipment requires the application of a number of disciplines, not only for enhanced performance but also to make the equipment as user-friendly as possible from the standpoint of injury avoidance. In designing sports equipment, the various characteristics of materials must be considered.Among these characteristics are strength, ductility, density, fatigue resistance, toughness, modulus (damping), and cost. To meet the requirements of sports equipment, the materials of choice often consist of a mixture of material types - metals, ceramics, polymers and composite concepts. Following are the general consumer & sports goods where there is lot of potential for composites in the near future :* Canoes and Kayaks
* Vaulting Pole
* Golf & Polo rods
* Archery equipment
* Javelin
* Hand gliders
* Wind surfer boards
* Protective sportswear

Indian composites industry is at a nascent stage with respect to this market segment.**Nano-Composites** Nano-composites are a class of materials that has gained much interest recently. The potential of producing these materials with tailored properties at low cost are attractive for applications ranging from drug delivery to corrosion prevention. They will also be more recyclable because there is less additive material in the plastic mix. The aerospace and defence industries will also benefit from new lightweight, high strength nano-composite materials, as will biomedical applications, for example in stronger hip prostheses with extended life expectancy.The nano-composite material is an innovative product having fillers on a nanometer (one-billionth of a meter) scale dispersed in the resin. Owing to the dispersion of extremely tiny fillers, flame retardance and rigidity of the resin improves substantially with the addition of only a small amount of fillers.By optimization of the fabrication process and controlling the nano-sized second phase dispersion, thermal stability & mechanical properties such as adhesion resistance, flexural strength, toughness and hardness can be enhanced - this exhibits the great advantage of nano-dispersion. Nano-composite materials can be used in electronic & automotive parts, industrial equipment and others. **Natural Fibre Composites**The use of natural fibres such as jute, sisal, banana, hemp, ramie, coir etc. as reinforcements in plastics is increasing tremendously. Wood flour and other fibres are primarily used as fillers in thermoplastic decking, building materials, furniture & automotive components.Long agricultural fibres such as flax, kenaf, bast, hemp & jute are used as structural reinforcements in thermoplastic/thermoset composites as a replacement of glass fibre. Natural fibre composites can easily be recycled than glass composites. The usage of natural fibre composites is higher in Europe than North America.North America for such materials alone is expected to grow from US $150 m in 2000 to US $1.4 billion in 2005 - @ 54% growth rate p.a.**Table 1.0: Properties of Select Natural & Glass Fibres**

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| **Property** | **Jute** | **Banana** | **Sisal** | **Pine-apple** | **Coir** | **Cotton** | **Glass** |
| Width or Diameter (mm) | - | 80-250 | 50-200 | 20-80 | 100-450 | 12-20 | 7-8 |
| Density(gms./cc) | 1.3 | 1.35 | 1.45 | 1.44 | 1.15 | 1.52 | 2.5 |
| Volume Resistivity at 100 volts (W cm x 105) | - | 6.5-7 | 0.4-0.5 | 0.7-0.8 | 9-14 | - | 9-10 |
| Micro-Fibrillar Angle (degree) | 8.1 | 11 | 10-22 | 14-18 | 30-49 | 20-23 | - |
| Cellulose/Lignin Content (%) | 61 /12 | 65 /5 | 67 /12 | 81 /12 | 43 /45 | 96/94 | - |
| Elastic Modulus(GN/m2) | - | 8-20 | 9-16 | 34-82 | 4-6 | 27 | 85.5 |
| Tenacity(MN/m2) | 440-533 | 529-754 | 568-640 | 413-1627 | 131-175 | 267-345 | 4585 |
| Elongation (%) | 1-1.2 | 1.0-3.5 | 3-7 | 0.8-1.6 | 15-40 | 3-10 | 5.7 |
| Moisture Absorption after 24 h (%) | 6-9 | - | - | - | 12 | 7-8 | 0.5 |
| Aspect Ratio (L/D) (mm) | 152-365 | - | - | - | - | 500-1300 | 100-140 |

Advantages of Natural fibre composites for automotive components includes weight reduction of 10-30%, excellent acoustical absorption properties, good impact properties with convenience of forming complex shaped parts in a single moulding process. Products such as car underbody coverings, interior door panels, dash & back panels, package trays, truck liners, door trims are being fabricated by natural fibre composites.Natural fibre is a very potential candidate in making of composites, especially for partial replacement of high-cost glass fibres for low load bearing applications. The glass provides strength & stiffness while natural fibre reduces the overall weight. From the point of view of wood substitution, natural fibre composite boards could offer an excellent eco-friendly solution. With ever-depleting forest reserves and premium on wood, a composite based on renewable resources such as jute, coir, sisal etc. is poised to penetrate the market.Any value-added application avenues for these fibres would directly contribute to the economic benefits of their growers. Indigenous wood supply for plywood industry having been stopped virtually and with increasing landed cost of imported plywood veneers in India, the jute-coir composite boards provide very good value for the customers without any compromise in properties.Value-added novel applications of natural fibre composites would not only go a long way in improving the quality of life of people engaged in jute cultivation, but would also ensure international market for cheaper substitution.**Table – 4.0 : Comparative Features of Natural Fibre Composites (NFC) & Other Materials**

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| **Properties** | **NFC** | **MDF** | **Particle Board** |
| Density (gms/cc) | 1.72 – 1.76 | 0.5 – 0.9 | 0.5 – 0.9 |
| Moisture content % | 0.2 – 0.38 | 5 – 8 | 5 – 15 |
| Modulus of rupture N/mm2 | 85 - 95 | 12.5 – 15 | 12.5 – 15 |
| Tensile strength N/mm2 | 22 – 24 | 0.6 – 0.7 | 0.4 – 0.45 |
| Flexural strength N/mm2 | 78.48 – 101 | - | - |
| Water absorption % 2 hrs.24 hrs. | 0.15 – 0.41.1 – 1.5 | 6 – 1010 – 12 | 6 – 1017 –20 |
| Fire retardancy | Self extinguishing | - | - |

(Source : BMTPC, New Delhi)Bamboo is one of the fastest renewable plants with a maturity cycle of 3-4 years, thus making it a highly attractive resource compared to forest hardwoods. Bamboo offers good potential for processing it into composites as a substitute of solid wood for structural uses. Bamboo composite based flooring tiles, boards (for partitions, cupboards, racks, door & window panels) and blocks (for door & window frames, rails & styles etc.) could be a cost-effective wood substitute.Bamboo laminates are made from bamboo strips (slivers) milled out from the bamboo wall core. These slivers are than subjected to an anti-fungal treatment. After drying, these strips are passed through the glue applicator for surface & edge gluing with the thermoset resin.The slivers are arranged systematically and subjected to a hydraulic hot press. The pressed panels/tiles are then put through trimming, sanding & grooving machines to give a pre-finish shape before surface coating (Polyurethane coating & UV curing).While phenolic & melamine based resin systems are used traditionally for bamboo laminates, polyurethane based new resin system could be explored for major advantages viz. reduced energy requirement and no phenolic emissions as desired in the international market. The natural fibres are currently extracted from plants, animals can also provide a source of fibres. Research is underway to develop composites reinforced with fibres made from poultry feathers. Tests of these revealed that they are roughly equal in strength to nylon fibres.The length of feather fibre fibrillation is of the order of 10 times the fibre diameter. This provides additional strength and toughness to the composites. Feather fibres can reduce weight of composite by 50% & increase tensile strength by 20%.Plant fibres containing natural sugar tend to caramelize at temperature above 150 0C thus limiting their processing with high temperature polymers such as nylon & PPS. Whereas the thermal degradation of poultry fibres begins after 235 0C thus widening their usage. US companies are testing feather fibres as a replacement of glass fibre in moulded automotive components. The advantages of the feather fibres over glass include lower abrasion, easier recycling and reduced health risks from inhalation.Fibres are not the only agriculture products that can be used in composites. A polyol, called soyOyl has been developed from soyabean oil. Properties of the SoyOyl based polyurethane are similar to petrochemical systems, finding application in spray-on bedliners for farm delivery trucks, moulded seats for tractors & trucks, office furniture and structural foam. The use of natural fibre in composites is on the rise. Initially these products were chosen for their environmental benefits. However, these materials offer both processing & structural benefits. As the quality & uniformity of natural materials continues to improve, they will appear they ever-increasing number of products. **Manufacturing Technology**The tailorability of composites for specific applications has been one of its greatest attractions and simultaneously one of its most perplexing challenges. The wide choice of material combinations, processing methods present bewildering problems of selection.The development of composites is a complex process and requires the simultaneous consideration of various parameters such as component geometry, production volume, reinforcement & matrix types, tooling requirements, process and market economics. The myriad choices available make it imperative that the functions of economics, design and manufacturing be integrated during the development process. The fabrication of composite structures and products is evolving from labour intensive hand lay-up to automated manufacturing methods. Innovations such as automated laying of reinforcement in contoured tools with close conformance have reduced hand labour by about 69%.Developments in automated integration of the pre-form fabrication & moulding make already available technologies more desirable from the standpoint of economics and productivity. Improvements in process models and controls would result in newer methods of monitoring cure conditions, optimizing process cycles and predicting micro-structural changes based on processing conditions.A major new breakthrough in composites manufacturing technology is not likely to occur in the foreseeable future. Most likely, there will be incremental improvements to existing manufacturing technologies. For composites to become competitive with metals, cost reduction has to occur besides durability, maintainability and reliability. Some of the manufacturing technology developments expected to occur in the foreseeable future are described below.**Filament Winding** Improvements in automation, speed, variable thickness, pad-up insertion, consistent quality, flexibility in fiber orientation, control of resin and void content and shapes other than cylinders are expected in near future. A combination of robotic and traditional filament winding (7 to 10-axis windings) system is being developed to wind complex multi-axes shapes, such as T and elbow shapes.**Resin Transfer Moulding**This technique has to be improved for handling large & complex designs with varying skin thickness ranging from less than 1/4" to more than 1". Further, there also exists scope for developing a new cost-effective resin system specifically for RTM application. **Pultrusion**For pultrusion to become an acceptable & popular composite manufacturing technology, it must be possible to pultrude complex multi-element cross sections, such as J-stiffened panels and constant airfoil sections. It is expected that a new technique for making tapered sections with variable thickness and even variable shapes will be available within this decade. **Table 2.0 : Physical & Chemical Properties of Pultruded Profiles Vs. Other Structural Materials**

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| **Physical & Chemical Properties** | **Pultruded** **FRP** | **Rigid** **PVC** | **Mild** **Steel** | **Stainless** **Steel** | **Wood** |
| Specific Gravity | 1.8 | 1.38 | 7.8 | 7.92 | 0.52 |
| Thermal Conductivity(Kcal/hr/m2/° C) | 24.4 | 6.4 | 1220 | 732.00 | 0.4 |
| Coeff. of Linear Expansion(cm/cm° C) x 10-6 | 5.2 | 37 | 8 | 10 | 1.7 |
| Safe Working Temp.(° C) | 130 | 55 | 600 | 600 | 160 |
| Flame Resistance | Good\* | Poor | Excellent | Excellent | Poor |
| Corrosion Resistance : |
| a. Acidic | Excellent | Good  | Poor | Excellent | Poor |
| b. Alkaline | Good | Fair | Good  | Excellent | Poor |
| c. Solvents | Fair | Poor | Good | Excellent | Fair |
| d. Coastal Environment | Excellent | Good | Poor | Excellent  | Fair |
| e. Outdoor Exposure | Excellent | Poor | Fair | Excellent | Fair |
| f. Effluent Water | Excellent | Good | Poor | Excellent | Fair |
| g. Steam | Good | Poor | Fair | Excellent | Fair |

\* Excellent with special additives **Continuous Sandwich Panel**Presently this method is limited to making flat constant sandwich panels. Future improvements will improve quality and speed of fabrication for fabricating complex shapes and variable thickness. **3-D Weaving**The advantages of 3-D weaving to obtain a 3-D fabric are widely known, but the cost has been prohibitively high. A few automated and semi-automated systems have been created or are under development to reduce cost. Although 3-D weaving is still in its infancy, it has the potential to replace expensive titanium fittings, hinges, engine blades, etc. In addition to reduced costs of weaving, improvements in curing also warrants attention.**Forming, Stamping, Injection Moulding, Rolling**These manufacturing methods have great potential for high volume production, especially when combined with the use of thermoplastics. Application is limited to small to medium size parts. Sports goods & industrial products will benefit from this group of technologies.**Repair Technology**Repair technology is gaining more attention. Composites are showing a better service record than are metals, mainly due to their better fatigue & corrosion resistance properties. But at the same time composites are more prone to impact damages, which increases the importance of repair. Currently available repair technology needs to be improvised to meet the stringent demands.**Recycling of Composites Waste**Ecological awareness has resulted in a renewed interest in natural materials and issues such as recyclability & environmental safety are becoming increasingly important for the introduction of new composite materials and products.These environmental issues have recently generated considerable interest in the development of composite materials based on renewable resources such as natural fibres as low-energy & low-cost alternatives for glass fibres. Efforts are also underway to develop matrix systems based on natural resources for the development of true bio-composites. Internationally, FRP recycling technologies have been developed separately focusing on either resin or glass fibre. Recycling technology for thermoset composites have had some success in applications such as vacuum assisted resin transfer moulding, centrifugal casting, pultrusion and reaction injection moulding on a limited basis. Out of the composite waste, resin could be utilized as fuel and glass fibre partly as a raw material for producing the cement.The following recycling solutions are being evaluated to suit specific processes and markets :* Milling of scrap to powder : Used as filler for polyester resin systems for SMC & injection moulding. However, the fillers lose much of their reinforcement properties.
* Milling of scrap to form granules : In an open mould, these granules could be sprayed similar to a gun roving application together with resin system directly on a laminate
* Milling of scrap and chemical processing : By depolymerization of the resin, reinforcement materials could be recovered. Fibres & some of the depolymerized resin components could be reused.
* Packing of scrap in a sandwiched structure : Used as flat textile sheets as veil, mat and fabrics. The sandwich structure is held together by sewing, mechanical or adhesive bonding. Pyrolysis or incineration

So far, there is no technology source available in India for recycling the composite waste in an economical mode. Considerable efforts are being diverted across the world to recycle & reuse the composite waste, which is the need of the hour. **Future Business Opportunites**Strong developmental activities focusing primarily on products & processes need to be pursued in India. Towards such an objective, a multi-agency approach involving the industry, Government, academia, research laboratory, certification/standardization and user agencies would be required for a quantum jump in composite technology in the country. Thus, the key thrust areas may be summarized as hereunder : * Short & long term R&D
* Application development
* Fabrication & testing support
* Availability & pricing of raw materials
* Manpower training
* Technical support services for materials & process selection, process optimization & design, product quality improvement etc.
* Standardization

Adoptation of automated technologies (such as RTM, pultrusion) along with proper technical/training support would help achieving the improved quality & quantity of composite products. The biggest advantage of composite processing is that unlike with metals, it is not capital intensive and a smaller volume production can be justified. "The future is in composites" is the realization of many decades of high-technology progress toward different materials and parts assembled and combined as monolithic units that would provide a combination of versatility, strength and other properties beyond the possibilities of conventional materials like metal, wood or concrete.Assessing the importance of composites as an advanced performance material the Advanced Composites Mission programme was launched by the Department of Science & Technology (DST), Govt. of India. The Mission-mode activities are being implemented by the Technology Information, Forecasting & Assessment Council (TIFAC), an autonomous organization under DST. The Advanced Composites Mission aims to improve upon the laboratory-industry linkages towards application development & commercialization. The Mission has been successful in launching **26 projects** across the country in active collaboration with the industry and national laboratories.The Mission has been catalytic in bridging the knowledge gaps and bringing together the industries & the users. Such an objective oriented, demand driven and time bound programme on composite technology with the involvement of stake holders would go a long way in developing innovative composite applications meeting international quality and wider acceptance thus contributing to the growth of knowledge-based business in India. An efficient mechanism such as the **Advanced Composites Mission** can help in synergising the users & industry thus reaching the products to the market with a shorter gestation period.In India, the indigenous achievements are very scattered compared to the large geographical area. There is an urgent need to launch very directed, concerted & planned efforts for developing & demonstrating novel composite products. This would call for an improved awareness, technology adaptation, technology sourcing & subsequent transfer etc. all at one place. While the national centres of excellence in India possess very rich expertise in composite technology, the knowledge flow to the industry has not come up to the desired level. It is high time to bring the technology sourcing avenues and industries together on one platform for technology development, transfer & subsequent commercialization.This calls for '**Composites Technology Park**' promoting such activities. This could generate a significant boost to the usage of composites while simultaneously evolving specialized products towards commercialization.  |