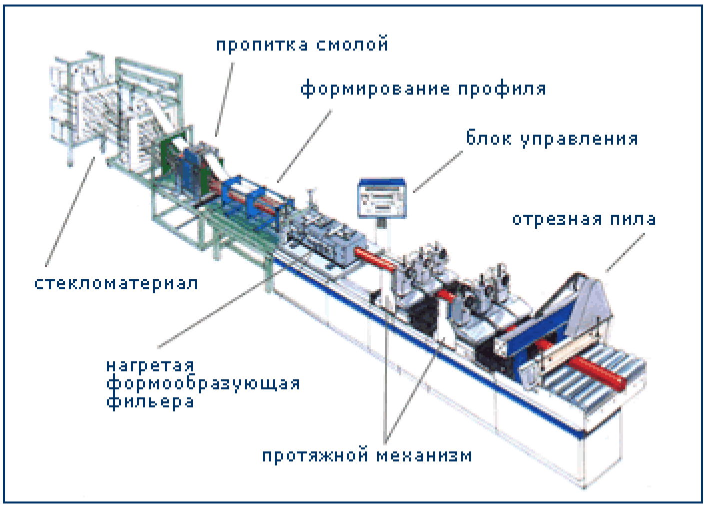
Стеклопластик - это очень перспективный материал, который имеет большую гамму применения в индустриальном строительстве. Полиэфирные стеклопластики обладают теплопроводностью дерева, прочностью и долговечностью стали, биологической стойкостью, влагостойкостью и атмосферостойкостью полимеров, не имея недостатков, присущих термопластам.

До недавнего времени стеклопластик использовался только в самолётостроении, кораблестроении и космической технике. Широкое применение стеклопластиков сдерживалось, в основном, из-за отсутствия промышленной технологии, позволяющей наладить массовый выпуск профилей сложной конфигурации с требуемой точностью размеров. Эта задача успешно решена с созданием пултрузионной технологии.

Пултрузия *представляет собой процесс получения профилей путем вытягивания через нагретую до 130 – 150 градусов формообразующую фильеру стекловолокнистых материалов, пропитанных термореактивной смолой*.



В результате на выходе получается армированный профиль, конфигурация которого повторяет форму фильеры. Этим методом можно получать изделия с любым профилем (стержень, труба, уголок, пластина, швеллер, короб и т.д.). Изготовление профиля таким образом осуществляется с помощью специальной пултрузионной машины.

Основными составляющими пултрузионной машины являются секция подачи стеклоровинга и стекломата, пропиточная секция, секция монтажа фильеры, тянущий агрегат, контрольный узел, который включает в себя блок питания, блок управления нагревательными элементами и систему управления тянущего агрегата, гидромаслостанция, секция пилы.

Пултрузионный армированный стеклопластик – строительный композиционный материал XXI века с уникальным сочетанием свойств дерева, металла, полимера: высокой прочностью, низкой теплопроводностью, устойчивостью к агрессивным средам и резким перепадам температур, био-, влаго-, атмосферостойкостью. Результаты исследований показали, что долговечность конструкций из такого материала значительно превосходит срок службы аналогичных конструкций из других материалов. Стеклопластиковый профиль имеет ряд преимуществ перед традиционными материалами:

- Улучшенные физико-механические свойства
- низкий удельный вес (в 4 резе легче стали)
- неподверженность коррозии, гниению, короблению
- уникальная химостойкость
- трудногорючесть, не выделяет при пожаре сильнодействующего газа-диоксина, в отличии от поливинилхлорида

- низкий тепловой коэффициент линейного расширения
- широкий диапазон рабочих температур
- хорошие электроизоляционные свойства.

Рассмотрим сравнительные характеристики материалов, приведённые в таблице.

Физико-механические характеристики	Стеклопластик	ПВХ	Сталь	Алюминий
Плотность (т/м3)	1,6-2,0	1,4	7,8	2,7
Разрушающее напряжение при сжати (растяжении) МН/м2(МПа)	410-1180	41-48	410-480	80-430
Разрушающее напряжение при изгибе МН/м2(МПа)	690-1240	30-110	400	275
Модуль упругости при растяжении, ГПа	21-41	2,8	210	70
Модуль упругости при изгибе, ГПа	21-41	2,8	210	70
Коэффициент линейного расширения х 10 оС	5-14	57-75	11-14	22-23
Коэффициент теплопроводности, Вт/м2 оС	0,3-0,35	0,3	46	140-190

Пултрузионный стеклопластик находит широкое применение в изготовлении окон, витражей и ограждающих конструкций, облицовки и арматуры электротехнического профиля, арматуры для бетона, элементов крепежных дюбелей, несущих (силовых) конструкций.

Разработана технология производства стеклопластиковых труб и освоено оборудование для их производства. Такие трубы конкурентоспособны со стальными, чугунными, полиэтиленовыми, ПВХ-трубами. При этом стеклопластиковые трубы имеют значительные преимущества:

- Высокая удельная прочность;
- высокая коррозионная стойкость, надежность и долговечность (50-80 лет);
- отсутствие "зарастания" внутренней поверхности;
- отсутствие разрушения при замерзании в них воды;
- минимальные затраты на монтаж и обслуживание, высокая ремонтопригодность.

Трубы пригодны для всех видов трубопроводов: холодного и горячего водоснабжения, канализации, химических трубопроводов, водостоков, мусоропроводов, вентиляции и др.

Проблема долговечности армирования бетона является основной заботой в строительной промышленности. Коррозия стальной арматуры может привести к растрескиванию с отслоением слоя бетона и потере целостности конструкции. Многие армированные бетонные конструкции после выдержке в среде дорожной соли, морской среде и загрязненной атмосфере требуют обширных и дорогостоящих восстановительных работ.

ГУП НИИЖБ Госстроя России считает перспективным применение стеклопластиковой арматуры взамен стальной для железобетона в жилищном строительстве, в поверхностных слоях бетонной конструкции для дорожного строительства, при усилении мостов, ограждений, высотных сооружений и в других конструкциях, подвергаемых в процессе эксплуатации действию блуждающих токов, общей коррозии и динамическим нагрузкам.

По заключению Санкт-Петербургского зонального научно-исследовательского и проектного института жилищно-гражданских зданий, может быть определена следующая область применения стеклопластиковой арматуры:

- Дорожные плиты, бетонные основания под трамвайные пути.
- В качестве гибких связей в многослойных сборных конструкциях наружных стен (трехслойные стеновые панели).
- В качестве сеток косвенного армирования кирпичных стен.
- В конструкциях, работающих в условиях, способствующих ускорению коррозии стальной арматуры и бетона (причалы, элементы фундаментов и т.д.).

КГИОП Санкт-Петербурга считает возможным применение арматуры в качестве пилонов для реставрационных работ.

Традиционными материалами для изготовления оконных и дверных блоков являются древесина, сталь и алюминий. Работа по совершенствованию их конструкций, проводимая в последние годы в мировой строительной промышленности, была направлена на повышение теплотехнических свойств и долговечности, снижение расхода используемых материалов, модернизацию технологии изготовления и индустриализацию монтажа готовых изделий. Стеклопластик - самый перспективный материал для производства оконных и дверных блоков.
В самом деле, стеклопластиковый профиль обладает уникальным набором свойств:

- Имеет теплопроводность дерева, но не гниет и не подвержена деформации, так как не впитывает влагу;
- обладает прочностью металла и имеет вес в четыре раза легче;
- устойчив к коррозии и долговечен, также устойчив к агрессивным средам (химостоек), может окрашиваться;
- окна и двери произведённые из стеклопластика прочнее и долговечнее остальных традиционных систем остекления
  в отличие от ПХВ, не требует дополнительного армирования металлом, не выделяет вредных веществ при горении и может иметь любой цвет по желанию заказчика;
- обладает абсолютной экологичностью и крайне низкой теплопроводностью.

Долговечность стеклопластикового профиля - более 50 лет (по результатам исследований НИИ стройфизики).

Технологическая гибкость изделий позволяет использовать их как в массовом, так и индивидуальном строительстве, а также для реконструкции жилых зданий, особняков и архитектурных памятников

Очень трудно рассказать обо всех возможностях применения стеклопластикового профиля. Можем дать один совет. Там где вы видите профиль из алюминия, ПВХ или дерева, с уверенностью заявляем, что его можно заменить на стеклопластиковый.

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Overview of the FRP Composites Industry - A Historical Perspective

The concept of "composite" building construction has existed since ancient times. Civilizations throughout the world have used basic elements of their surrounding environment in the fabrication of dwellings including mud/straw and wood/clay. "Bricks" were made from mud and straw with the mud acting much like the resin in FRP composite construction and the straw acting as reinforcing to hold the brick together during the drying (and shrinkage) process of the brick. In the "wattle and daub" method of constructing walls, vertical wooden stakes (wattles) were woven with horizontal twigs and branches and then daubed with clay or mud. This is one of the oldest known methods for making a waterproof structure .

While the concept of composites has been in existence for several millennia, the incorporation of FRP composite technology into the industrial world is less than a century old. The true age of plastics emerged just after 1900 with chemists and industrialists taking bold steps to have plastics (vinyl, polystyrene and plexiglass) mimic and outdo nature's own materials. Spurred on by the needs of electronics, defense and eventually space technologies, researchers created materials with properties that seem to defy known principles, like Kevlar stopping bullets. The first known FRP product was a boat hull manufactured in the mid 1930's as part of a manufacturing experiment using a fiberglass fabric and polyester resin laid in a foam mold. From this somewhat inauspicious beginning, FRP composites applications have revolutionized entire industries, including aerospace, marine, electrical, corrosion-resistance and transportation.

Fiber-reinforced polymer (FRP) composite materials date back to the early 1940's in the defense industry, particularly for use in aerospace and naval applications. The U.S. Air Force and Navy capitalized on FRP composites high strength-to-weight ratio capability and inherent resistance to weather and the corrosive effects of salt air and sea. By 1945, over seven million pounds of fiberglass were being shipped, primarily for military applications. Soon the benefits of FRP composites, especially its corrosion resistance capabilities, were communicated to the public sector. Fiberglass pipe, for instance, was first introduced in 1948 for what has become one of its widest areas of use within the corrosion market, the oil industry. FRP composites proved to be a worthy alternative to other traditional materials even in the high-pressure, large diameter situations of chemical processing. Besides superior corrosion resistance, FRP pipe offered both durability and strength thus eliminating the need for interior linings, exterior coatings, and/or cathodic protection. Since the early 1950's, FRP composites have been (and still are) used extensively for equipment in the chemical processing, pulp and paper, power, waste treatment, metals refining and other manufacturing industries. Myriads of products and FRP installations help build a baseline of proven performance in the field in such products as chemical plant scrubbers, hoppers, hoods, ducts, fans, stacks, piping, pumps and pump bases, valve bodies and above-ground as well as underground tanks for chemicals or gasoline.

The decades after the 40's brought new, and often times, revolutionary applications for FRP composites. The same technology that produced the reinforced plastic hoops required for the Manhattan nuclear project in World War II, spawned the development of high performance composite materials for solid rocket motor cases and tanks in 60's and 70's. In fact, fiberglass wall tanks were used on the Skylab orbiting laboratory to provide oxygen for the astronauts. In 1953, the 1st production Chevrolet Corvette with fiberglass body panels rolled off the assembly line. Now, high-performance racecars are the proving ground for technology transfer to passenger vehicles. In the 1960's, the British and U.S. Navies were simultaneously developing minesweeper ships as FRP composites are not only superior to other materials in a harsh marine environment, they are also non-magnetic in nature. It was also noticed at that time that one of the features of FRP is the ability of the materials to reduce the radar signature of the structure, such as a ship or an aircraft. High performance composites materials have been demonstrated in advanced technology aircraft such as the F-117 Stealth Fighter and B-2 Bomber. Currently, FRP composites are being used for space applications and are involved in several NASA test initiatives.

The marine market was the largest consumer of composite materials in the 1960's. In the 1970's, the automotive market surpassed marine as the number one market; a position it retains. Composites have also impacted the electrical transmission market with products such as pole line hardware, cross-arms, and insulators.

While the majority of the historical and durability data of FRP composite installations come from the aerospace, marine and corrosion resistance industries, FRP composites have been used as a construction material for several decades. FRP composite products were first demonstrated to reinforce concrete structures in the mid 1950's. In the 1980's, resurgence in interest arose when new developments were launched to apply FRP reinforcing bars in concrete that required special performance requirements such as non-magnetic properties or in areas that were subjected to severe chemical attack.

Composites have evolved since the 1950's in architectural applications starting with semi-permanent structures and continuing with restoration of historic buildings and structural applications. Typical products developed were domes, shrouds, translucent sheet panels, and exterior building panels.

During the late 1970's and early 1980's, many applications of composite reinforcing products were demonstrated in Europe and Asia. In 1986, the world's first highway bridge using composites reinforcing tendons was built in Germany. The first all composites bridge deck was demonstrated in

China. The first all composites pedestrian bridge was installed in 1992 in Aberfeldy, Scotland. In the U.S., the first FRP reinforced concrete bridge deck was built in 1996 at McKinleyville, WV followed by the first all-composite vehicular bridge deck in Russell, KS. Numerous composite pedestrian bridges have been installed in U.S. state and national parks in remote locations not accessible by heavy construction equipment, or for spanning over roadways and railways.

For the 21st century, composite fabricators and suppliers are actively developing products for the civil infrastructure, considered to be the largest potential market for FRP composites. Concrete repair and reinforcement, bridge deck repair and new installation, composite-hybrid technology (the marriage of composites with concrete, wood and steel), marine piling and pier upgrade programs are just some of the areas that are currently being explored.

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Definition of FRP Composites

Definition of FRP Composites

Not all plastics are composites. In fact, the majority of plastics today are pure plastic, like toys and soda bottles. When additional strength is needed, many types of plastics can be reinforced (usually with reinforcing fibers). This combination of plastic and reinforcement can produce some of the strongest materials for their weight that technology has ever developed...and the most versatile.

Therefore, the definition of a fiber-reinforced polymer (FRP) composite is:
A combination of

- a polymer (plastic) matrix (either a thermoplastic or thermoset resin, such as polyester, isopolyester, vinyl ester, epoxy, phenolic)
- a reinforcing agent such as glass, carbon, aramid or other reinforcing material

such that there is a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions. FRP composite may also contain:

- fillers
- additives
- core materials

that modify and enhance the final product. The constituent elements in a composite retain their identities (they do not dissolve or merge completely into each other) while acting in concert to provide a host of benefits ideal for structural applications including:

- **High Strength and Stiffness Retention** - composites can be designed to provide a wide range of mechanical properties including tensile, flexural, impact and compressive strengths. And, unlike traditional materials, composites can have their strengths oriented to meet specific design requirements of an application.

- **Light Weight/Parts Consolidation** - FRP composites deliver more strength per unit of weight than most metals. In fact, FRP composites are generally 1/5th the weight of steel. The composite can also be shaped into one complex part, often times replacing assemblies of several parts and fasteners. The combination of these two benefits makes FRP composites a powerful material system- structures can be partially or completely pre-fabricated at the manufacturer's facility, delivered on-site and installed in hours.
- **Creep (Permanent Deflection Under Long Term Loading)** - The addition of the reinforcement to the polymer matrix increases the creep resistance of the properly designed FRP part. Creep will not be a significant issue if the loads on the structure are kept below appropriate working stress levels.
- **Resistance to Environmental Factors** - Composites display excellent resistance to the corrosive effects of:

    - Freeze-thaw: because composites are not attacked by galvanic corrosion and have low water absorption, they resist the destructive expansion of freezing water.
    - Weathering and Ultra-Violet Light: FRP composite structures designed for weather exposure are normally fabricated with a surface layer containing a pigmented gel coat or have an ultraviolet (UV) inhibitor included as an additive to the composite matrix. Both methods provide protection to the underlying material by screening out UV rays and minimizing water absorption along the fiber/resin interface.
    - Chemicals and Temperature: Composites do not rust or corrode and can be formulated to provide long-term resistance to nearly every chemical and temperature environment. Of particular benefit, is composites ability to successfully withstand the normally destructive effects of de-icing salts and/or saltwater spray of the ocean.
- **Fire Performance of Composites** - FRP composites can burn under certain conditions. Composites can be designed to meet the most stringent fire regulations by the use of special resins and additives. Properly designed and formulated composites can offer fire performance approaching that of most metals.

COMPOSITES BASICS: MATERIALS (PART 1)

Introduction

Fiber Reinforced Polymer (FRP) composites is defined as a polymer (plastic) matrix, either thermoset or thermoplastic, that is reinforced (combined) with a fiber or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or aluminum. FRP composites are anisotropic (properties only apparent in the direction of the applied load) whereas steel or aluminum is isotropic (uniform properties in all directions, independent of applied load). Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. Composites are similar to reinforced concrete where the rebar is embedded in an isotropic matrix called concrete.

Many terms have been used to define FRP composites. Modifiers have been used to identify a specific fiber such as Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), and Aramid Fiber Reinforced Polymer (AFRP). Another familiar term used is Fiber Reinforced Plastics. In addition, other acronyms were developed over the years and its use depended on geographical location or market use. For example, Fiber Reinforced Composites (FRC), Glass Reinforced Plastics (GRP), and Polymer Matrix Composites (PMC) can be found in many references. Although different, each of aforementioned terms mean the same thing; FRP composites.

Benefits

FRP composites have many benefits to their selection and use. The selection of the materials depends on the performance and intended use of the product. The composites designer can tailor the performance of the end product with proper selection of materials. It is important for the end-user to understand the application environment, load performance and durability requirements of the product and convey this information to the composites industry professional. A summary of composite material benefits include:

- Light weight
- High strength-to-weight ratio
- Directional strength
- Corrosion resistance
- Weather resistance
- Dimensional stability
    - low thermal conductivity
    - low coefficient of thermal expansion
- Radar transparency
- Non-magnetic
- High impact strength
- High dielectric strength (insulator)

- Low maintenance
- Long term durability
- Part consolidation
- Small to large part geometry possible
- Tailored surface finish

Composition

Composites are composed of resins, reinforcements, fillers, and additives. Each of these constituent materials or ingredients play an important role in the processing and final performance of the end product. The resin or polymer is the "glue" that holds the composite together and influences the physical properties of the end product. The reinforcement provides the mechanical strength. The fillers and additives are used as process or performance aids to impart special properties to the end product.

The mechanical properties and composition of FRP composites can be tailored for their intended use. The type and quantity of materials selected in addition to the manufacturing process to fabricate the product, will affect the mechanical properties and performance. Important considerations for the design of composite products include:

- Type of fiber reinforcement
- Percentage of fiber or fiber volume
- Orientation of fiber (0^o, 90^o, +/- 45^oor a combination of these)
- Type of resin
- Cost of product
- Volume of production (to help determine the best manufacturing method)
- Manufacturing process
- Service conditions

Go to next section: Resins

Composites Basics: Composites Manufacturing

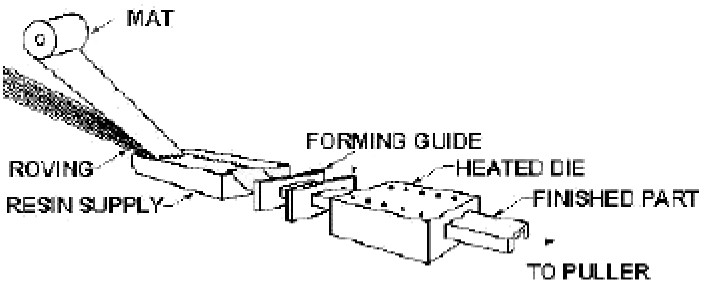
Introduction

In this section, those manufacturing processes typically used to make products found in construction/civil infrastructure market are covered. Unique to the composites industry is the ability to create a product from many different manufacturing processes. There are a wide variety of processes available to the composites manufacturer to produce cost efficient products. Each of the fabrication processes has characteristics that define the type of products to be produced. This is advantageous because this expertise allows the manufacturer to provide the best solution for the customer. In order to select the most efficient manufacturing process, the manufacturing team considers several factors such as:

- User needs
- Performance requirements
- Size of the product
- Surface complexity
- Appearance
- Production rate
- Total production volume
- Economic targets/limitations
- Labor
- Materials
- Tooling/assembly
- Equipment

Pultrusion

Pultrusion is a continuous molding process that combines fiber reinforcements and thermosetting resin. The pultrusion process is used in the fabrication of composite parts that have a constant cross-section profile. Typical examples include various rods and bar section, ladder side rails, tool handles, and electrical cable tray components and now bridge beams and decks. Most pultruded laminates are formed using rovings aligned down the major axis of the part. Various continuous strand mats, fabrics (braided, woven and knitted), and texturized or bulked rovings are used to obtain strength in the cross axis or transverse direction.

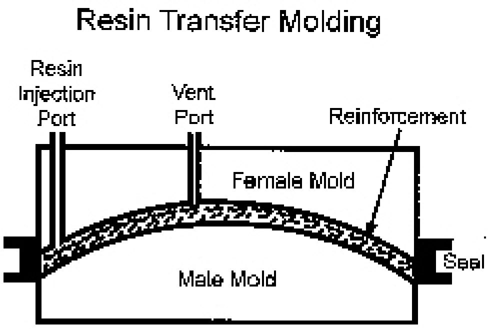


The process is normally continuous and highly automated. Reinforcement materials, such as roving, mat or fabrics, positioned in a specific location using preforming shapers or guides to form the profile. The reinforcements are drawn through a resin bath or wet-out where the material is thoroughly coated or impregnated with a liquid thermosetting resin. The resin-saturated reinforcements enter a heated metal pultrusion die. The dimensions and shape of the die will define the finished part being fabricated. Inside the metal die, heat is transferred initiated by precise temperature control to the reinforcements and liquid resin. The heat energy activates the curing or polymerization of the thermoset resin changing it from a liquid to a solid. The solid laminate emerges from the pultrusion die to the exact shape of the die cavity. The laminate solidifies when cooled and it is continuously pulled through the pultrusion machine and cut to the desired length. The process is driven by a system of caterpillar or tandem pullers located between the die exit and the cut-off mechanism.

The initial capital investment for pultrusion is generally higher than open mold or hand layup processes. The primary expense for pultrusion manufacturers is the material handling guides and die fabrication costs. The net result is a low-cost process for high volume. The process provides flexibility in the design of pultruded profiles. Currently, profiles up to 72 inches wide and 21 inches high are possible. Pultrusion can manufacture both simple and complex profiles, eliminating the need for extensive post-production assembly of components. Since the process is continuous, length variations are limited to shipping capabilities. This process allows for optimized fiber architectures with uniform color eliminating the need for many painting requirements.

Resin Transfer Molding (RTM)

Resin Transfer Molding or RTM as it is commonly referred to is a “Closed Mold Process” in which reinforcement material is placed between two matching mold surfaces – one being male and one being female. The matching mold set is then closed and clamped and a low-viscosity thermoset resin is injected under moderate pressures (50 – 100 psi typical) into the mold cavity through a port or series of ports within the mold. The resin is injected to fill all voids within the mold set and thus penetrates and wets out all surfaces of the reinforcing materials. The reinforcements may include a variety of fiber types, in various forms such as continuous fibers, mat or woven type construction as well as a hybrid of more that one fiber type. Vacuum is sometimes used to enhance the resin flow and reduce void formation. The part is typically cured with heat. In some applications, the exothermic reaction of the resin may be sufficient for proper cure.



RTM as a process, is multi-compatible with a variety of resin systems including polyester, vinyl ester, epoxy, phenolic, modified acrylic and hybrid resins such as polyester and urethane. Typically, it requires a resin viscosity of 200 to 600 centerpoise to penetrate all surfaces of the mold cavity. Advantages of the RTM process include:

- As a closed mold process, emissions are lower than open mold processes such as spray up or hand lay up
- The mold surface can produce a high quality finish (like those on an automobile)
- This process can produce parts faster – as much as 5 –20 times faster than open molding techniques.
- RTM produces tighter dimensional tolerances to within ± .005inch.
- Complex mold shapes can be achieved. Cabling and other fittings can be incorporated into the mold designs.

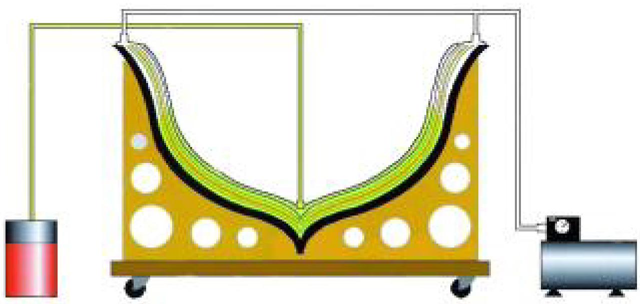
Disadvantages of the RTM process are:

- High production volumes required to offset high tooling costs compared to open molding techniques.
- Reinforcement materials are limited due to the flow and resin saturation of the fibers.
- Size of the part is limited by the mold.

Vacuum Assisted Resin Transfer Molding (VARTM)

In the traditional RTM process, a matched set of molds or "closed mold" is used. The fiber reinforcements are usually preformed off line to enhance the production cycle time of the molds to perform at a respectable production rate. Resin is injected at high pressures and the process is sometimes assisted with vacuum.

However, Vacuum Assisted Resin Transfer Molding (VARTM) is different for many reasons. First, the fabrication of parts can be accomplished on a single open mold. Second, the process uses the injection of resin in combination with a vacuum and captured under a bag to thoroughly impregnate the fiber reinforcement. In the late 1980's, Bill Seemann invented and patented a variation to the VARTM process called SCRIMP^{TM}, which is Seemann Composite Resin Infusion Molding Process. This process has been used in many new and large applications ranging from turbine blades and boats to rail cars and bridge decks. Unique to this process is the manufacturing method that allows the efficient processing of VARTM to produce large structural shapes that are virtually void-free. This process has been used to make both thin and very thick laminates. In addition, complex shapes with unique fiber architectures allow the fabrication of large parts that have a high structural performance.



Parts using VARTM are made by placing dry fiber reinforcing fabrics into a mold, applying a vacuum bag to the open surface and pulling a vacuum while at the same time infusing a resin to saturate the fibers until the part is fully cured. This process allows for easy visual monitoring of the resin to ensure complete coverage to produce good parts without defects.

<u>Hand Layup - Open Molding Process</u>

Lamination technology is based on the joining or bonding of two or more laminae to form a laminate. The materials can vary in type and mechanical properties in addition to property specific orientation particularly pertaining to wood and composites.

Laminate Materials

There are an infinite number of laminate types that can be developed. These materials can be categorized into three basic areas, core materials, high strength and stiffness skins and outer protective layers. Core materials typically serve the function of connecting and spacing of the skins to develop stiffness and strength in a sandwich arrangement. The key property of core materials is shear strength to insure shear conductivity between the skins, thus the ability to sustain loads and bending. Core materials are normally wood, honeycomb and structural foams. The outer structural layer or skins traditionally are either metal or composite, either in combination with a core material or a multitude of high strength and stiffness layers. Composite materials offer the widest range of high strength skins with the ability to change fiber type (fiberglass, carbon and aramid) in addition to the fiber volume and orientation. Composites are well suited for large deflection applications where high strain capability and fatigue is required. Typically they are more corrosion and environmentally resistant than metals. Composite materials in a lamina form are applied in the form of precured, prepreg or "B" stage and wet layup configurations. The final group of laminae is made up of thermoplastic and thermoset materials, which act as a covering to the laminate structure. In some applications a plastic film or coating is incorporated into the laminate structure to protect the structure from impact and environmental effects.

Hand lay up is the oldest and simplest method used for producing reinforced plastic laminates. Capital investment for hand lay up processes is relatively low. The most expensive piece of equipment typically is a spray gun for resin and gel coat application. Some fabricators pour or brush the resin into the molds so that a spray gun is not required for this step. There is virtually no limit to the size of the part that can be made. The molds can be made of wood, sheet metal, plaster, and FRP composites.

In a particular hand lay up process (otherwise known as wet lay up), high solubility resin is sprayed, poured, or brushed into a mold. The reinforcement is then wet out with resin. The reinforcement is placed in the mold. Depending upon the thickness or density of the reinforcement, it may receive additional resin to improve wet out and allow better drapeability into the mold surface. The reinforcement is then rolled, brushed, or applied using a squeegee to remove entrapped air and to compact it against the mold surface.

Chopped strand mat is the lowest cost form of reinforcement used in wet lay up. It also provides equal reinforcing strength in all directions due to the random orientation of the fibers that form the mat. Woven roving is especially suitable for thick laminates requiring greater strength. Woven fabric and braid can also provide a low cost reinforcement. Once the reinforcement is thoroughly wet out with resin, it can be easily formed into complex shapes.

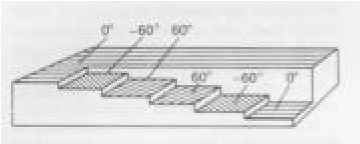
Surface Preparation and Bonding

A key component to a successful lamination is the bonding process of the layers. There are three basic components, which make up the bonding process. First is the surface preparation of the laminae, which improves the substrate's ability to accept and adhere to an adhesive. Surface preparation varies depending on material type. Composites use sanding and grinding, surface texturing, or solvent cleaning. The second component is the adhesive itself, including epoxies, urethanes, phenolics, polyesters, solvents, acrylics and others. Each adhesive has its attributes depending on substrate type, in use requirements and process constraints. As a general rule, a maximum bond is achieved for a given substrate type when the material itself fails during an ultimate strength test. The maximum lap shear strength of an adhesive is achieved when the adhesive exhibits a cohesive failure in the bond line. The third component of lamination is the process by which the materials are bonded together. This involves a host of parameters primarily time, heat pressure, mixture, moisture and catalysts (initiators). It is important that the three basic components of bonding are properly employed to achieve a successful lamination.

Laminate Construction

There are three types of laminated construction. These include sandwich lamination consisting of at least two high stiffness and strength outer layers connected by a core, all laminated construction consisting of relatively high stiffness and strength layers and a third type consisting of a structural member that is reinforced on the tensile or compression or both sides of a flexural beam.

Sandwich lamination constructions are found in many applications from satellite structures to snow skis. Although both applications may utilize a sandwich approach, satellite applications generally require stiffness, strength and extreme lightweight, while the snow ski requires the laminated beam or composite structure to withstand large deflections and dynamic performance requirements. In addition the ski structure is integrated with thermoplastic surfaces and metal components. Typically metal and composite materials are applied to these sandwich structures. Even complex shapes can be achieved by using composite prepregs and wet lay-ups.



All laminate constructions utilize relatively high strength/stiffness materials. An array of laminate configurations is possible. In aerospace applications, multiple plys are orientated in various directions and to provide customized structural strength and stiffness. These same principles, although less complex are used in automotive, industrial and recreational products in the form of structural members, springs, archery limbs and bicycles.

Multiply Construction

The third type of laminated construction is utilized most often in construction and infrastructure applications. To date, reinforcements have been integrated into Glue-Laminated wood beams (Glu-Lams) and infrastructure components for fabricating columns, beams and walls. In many of these applications, a reinforcement, most typically a composite, is used via lamination to the tensile side of a beam or as a wrap on a column. Precured, prepreg or wet layup composite materials have all been utilized in these applications. These types of reinforcements improve the strength of laminated wood beams and or reduce the use of E-Rated lumber with less costly new growth wood. Lamination in bridges and buildings provide a lower cost simplified method to revitalize existing structures, increase load-carrying capability and increase resistance to seismic events.

In the automotive industry composites are being combined with metals for performance, weight reduction and cost advantages. The construction industry is applying composites to wood laminated beams and I-Joists.

The possibilities and advantages of laminated materials are significant and provide solutions to product requirements generally not achievable by using a single material. The advantages in structural performance, reduced weight and oriented structural properties are just some the advantages of this approach. In many cases, the result is a simplified and less costly solution to many engineering structural problems.

Compression Molding

Compression molding is the most common method of molding thermosetting materials such as SMC (sheet molding compound) and BMC (bulk molding compound). This molding technique involves compressing materials containing a temperature-activated catalyst in a heated matched metal die using a vertical press.

The molding process begins with the delivery of high viscosity uncured composite material to the mold. Mold temperatures typically are in the range of 350° - 400° F. As the mold closes, composite viscosity is reduced under the heat and pressure approximating 1000 psi. The resin and the isotropically distributed reinforcements flow to fill the mold cavity.

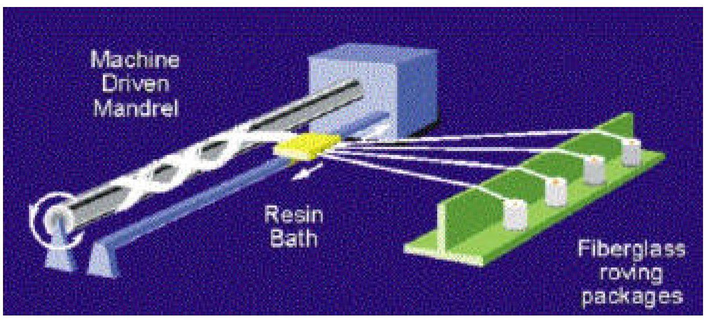
While the mold remains closed, the thermoset material undergoes a chemical change (cure) that permanently hardens it into the shape of the mold cavity. Mold closure times vary from 30 seconds up to several minutes depending on part design and material formulation.

When the mold opens, parts are ready for finishing operations such as deflashing, painting, bonding, and installation of inserts for fasteners. By varying the formulation of the thermoset material and the reinforcements, parts can be molded to meet applications ranging from automotive class 'A' exterior body panels to structural members such as automobile bumper beams.

Filament Winding

The filament winding process is used in the fabrication of tubular composite parts. Typical examples are composite pipe, electrical conduit, and composite tanks. Fiberglass roving strands are impregnated with a liquid thermosetting resin and wrapped onto a rotating mandrel in a specific pattern. When the winding operation is completed, the resin is cured or polymerized and the composite part is removed from the mandrel.

Capital investment is relatively higher compared to open mold processes. The primary expense for an existing filament winder would be the cost of the winding mandrel for a specific application.



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Glossary of Terms

A

Abrasion
The wearing away of materials by friction. Particles become detached by a combined cutting, shearing and tearing action.

Absorbed Moisture
Moisture that has entered a solid by absorption and has physical properties not substantially different from ordinary water at the same temperature and pressure.

Accelerated Test
A test procedure in which conditions are increased in magnitude to reduce the time required to obtain a result. To reproduce in a short time the deteriorating effect obtained under normal service conditions.

Accelerator
A material that acts synergistically with the prompter to speed up the chemical reaction between the catalyst and the resin.

Acoustic Emission
A measure of integrity of a material, as determined by sound emission when a material is under stress. Ideally, emissions can be correlated with defects and/or incipient failure.

Additive
A constituent component that may be added to the composite matrix to modify its properties and in general, enhance its performance. Additives include catalysts, colorants, flame retardants and other ingredients that expand and improve the capabilities of the matrix.

Adhesive
The method of joining two substrates using either paste, liquid or film.

Admixture
The addition and uniform dispersion of components before cure.

AFRP
Aramid fiber reinforced polymer.

Aging
The effect on materials of exposure to an environment for an interval of time. The process of exposing materials to an environment for an interval of time.

Air Void
Air entrapment within and between the plies of reinforcement or within a bondline or encapsulated area; localized, non-interconnected, spherical in shape.

Alkalinity
The condition of having or containing hydroxyl (OH^-) ions; containing alkaline substances.

Ambient
The surrounding area; encompassing on all sides. In composites, refers to environmental conditions such as temperature, humidity, pressure, etc.

Anisotropic
Not exhibiting the same physical properties in all directions.

Antioxidant
A substance that when added in small quantities to the resin, prevents its oxidative degradation and contributes to the maintenance of its properties.

Aramid
Used as a high-strength, high-modulus (stiffness) fiber. It is a type of highly oriented organic material derived from polyamide, but incorporating aromatic ring structure.

Arc Resistance
The length of time (in seconds) that an arc may cross a surface without rendering it conductive.

Aspect Ratio
Ratio of length to diameter. For a composite, it refers to the specific ratio of the fiber or filler in the composite matrix.

B

B-Stage
Intermediate stage in the polymerization reaction of thermosets, following which material will soften with heat and is plastic and fusible. The resin of an uncured prepreg or premix is usually in B-stage.

Barcol Hardness
A hardness value obtained by measuring the resistance to penetration of a sharp steel point under a spring load. Measured on a scale of 0-100, the hardness value is used to measure the degree of cure of plastic.

Bearing Strength
The maximum bearing stress that can be sustained. Also, the bearing stress at that point on the stress-strain curve where the tangent is equal to the bearing stress divided by n% of the bearing hole diameter

Bearing Stress
The applied load in pounds sustained by a specimen divided by the bearing area.

Bias Fabric
Warp and fill fibers at an angle to the length of the fabric.

Bidirectional Laminate
A reinforced plastic laminate with the fibers oriented in two directions in its plane. A cross laminate.

Binder
Chemical treatment applied to the random arrangement of glass fibers to give integrity to mats. Specific binders are utilized to promote chemical compatibility with the various laminating resins used.

Bond
The adhesion and grip of a material to other surfaces against which it is placed.

Bond Area
The nominal area of interface between two elements across which adhesion develops or may develop

Bond Strength
The measurement of the stress needed to separate two bonded surfaces calculated using the load/bond area.

Bond Stress
The force per unit area necessary to rupture a bond

Braid-Braiding
The weaving of fibers into a tubular shape to be used as a reinforcement instead of a flat reinforcement.

C

C-Stage
The final stage in the reaction of certain thermosetting resins in which the material is practically insoluble and infusible.

Carbon
An element common to all organic substances. Graphite is one of the forms under which carbon occurs in nature (as is diamond)

Carbon-Carbon
A composite that consists of a carbon matrix and a carbon reinforcement

Carbon Fiber
Fiber produced by the prolysis of organic precursor fibers such as rayon, polyachrylonitrile (PAN) and pitch in an inert environment

Casting
The process of pouring the resin and fillers (and possibly fibers) into a mold.

Catalyst
A substance that initiates a chemical reaction and enables it to proceed under milder conditions than otherwise required and which does not, itself, alter or enter into the reaction. Also called an initiator.

Catenary
The property of or creating or maintaining equal tension in parallel fibers.

CFRP
Carbon fiber reinforced plastic (includes graphite fiber reinforced plastic).

Chopped Strand Mat
A fiberglass reinforcement that utilizes continuous rovings that are cut into short strands, arranged in a random pattern and held together with a binder.

Coefficient of Thermal Expansion (CTE)
The change in length (or volume) per unit length (or volume) produced by one degree Celsius rise in temperature.

Cohesion
The propensity of a single substance to adhere to itself. The internal attraction of molecular particles toward each other. The force holding a single substance together.

Composite
A combination of one or more materials differing in form or composition on a macroscale. The constituents retain their identities; i.e. they do not dissolve or merge completely into one another, although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another (see FRP Composite).

Compound
An admixture of a polymer with other ingredients such as reinforcements, fillers, and additives. A thermoset compound normally consists of the necessary ingredients for the finished product.

Compression Molding
A composite manufacturing technique whereby thermoset composite materials are compressed between matched die molds using hydraulic pressure and heated until the materials are cured to its final form

Compressive Strength
The ability of a material or structure to resist a crushing or buckling force. The maximum compressive load sustained by the material or structure divided by the original cross-sectional area of the material or structure.

Continuous Roving
Parallel filaments coated with sizing, drawn together into single or multiple strands and wound into a cylindrical package.

Core
The central member, usually foam or honeycomb, of a sandwich construction to which the faces of the sandwich are attached or bonded. The central member of a plywood assembly. A channel in a mold for circulation of heat transfer media. A device on which prepreg is wound.

Corrosion Resistance
The ability of a material to withstand contact with ambient natural factors or those of a particular artificially created atmosphere, without degradation or change in properties.

Coupling Agent
Part of a surface treatment or finish which is designed to provide a stronger bonding link between the fiber surface and the laminating resin.

Crazing
The development of ultrafine cracks; the pattern of cracks that extend on or under the surface of a resin or plastic material.

Creel
A device for holding the required number of roving balls (spools) or supply packages of reinforcement in desired position for unwinding onto the next processing step, that is, weaving, braiding, or filament winding.

Creep
The change in dimension of a material under sustained load over a period of time, not including the material's initial elastic deformation. The time-dependent part of strain resulting from an applied load.

Crimp
Waviness of a fiber, a measure of the difference between the length of the unstraightened and straightened fibers.

Cure
To irreversibly change the properties of a thermosetting resin by chemical reaction, that is, condensation, ring closure, or addition. Cure may be accomplished by addition of curing (cross-linking) agents, with or without heat and pressure.

Curing Agent

D E

Debonding
The separation of bonded surfaces, usually unplanned.

Deformation
A change in dimension or shape due to stress.

Delamination
A separation of the layers of a material in laminate, either local or covering a wide area. Can occur in the cure or during the life of a product.

Dieletric
The ability of a material of resist the flow of electricity. Non-conductive.

Dieletric Strength
The property of an insulating material that enables it to withstand electric stress. The average potential per unit thickness at which failure of the dielectric material occurs. The higher the dielectric strength, the greater insulating properties of the material.

Dimensional Stability
Ability of a part to retain the precise shape to which it was molded, cast, or otherwise fabricated.

Ductility
The ability of a part to undergo large, permanent deformation without rupture. The ability of a material to deform plastically before fracturing.

Durability
The ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service. Also, the capability of a structure or its components to maintain serviceability over a designed period of time in a specified environment.

E-Glass
A family of glasses with a calcium alumina borosilicate composition and a maximum alkali content of 2.0% A general-purpose fiber that is most often used in reinforced plastics, and is suitable for electrical laminates because of its high resistivity.

Elasticity
The ability of a material to recover to its original size and shape after the removal of a force causing deformation.

Elongation
The increase in length of a material

Elongation at Break
Elongation recorded at the moment of rupture of the specimen, often expressed as a percentage of the original length.

End
A strand of roving consisting of a given number of filaments gathered together. The group of filaments is considered and end or strand before twisting, a yarn after twisting.

Epoxy
A polymerizable thermoset polymer containing one or more epoxide groups and curable by reaction with amines. alcohols, phenols carboxylic acids, acid anhydrides, and mercaptans.

Exotherm (Exothermic)
A compound in the formation of which heat is liberated, and in the reduction of which to its original components, heat is absorbed. For composite terminology, it applies to the heat released during the curing of the composite.

Extenders
An inert material added to provide economical extension of resins without lessening of properties.

F

Fabric
Arrangement of fibers held together in two dimensions. A fabric may be woven, nonwoven, or stitched.

Fabric, nonwoven
Material formed from fibers or yams without interlacing. This can be stitched. knit or bonded.

Fabric, woven
Material constructed of interlaced yams, fibers, or filaments.

Fatigue
The lessening or failure of mechanical properties after repeated applications of stress.

Fatigue Life
The number of cycles of deformation required to bring about failure of the test specimen under a given set of oscillating conditions (stresses and strains).

Fatigue Strength
The maximum cyclical stress a material can withstand for a given number of cycles before failure occurs. Also the residual strength after being subjected to fatigue.

Fiber
General term for a filamentary material. The single unit of substance that is broken into parts fit to form threads to be woven; a filament. Any material whose length is at least 100 times its diameter, typically 0.10 to 0.13 mm.

Fiber Architecture
The design of the reinforcement; the arrangement of the fibers to achieve specific results. Examples include braiding, fabrics (stitched and woven), rovings, mats, etc.

Fiber Content
The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of the composite.

Fiber Direction
The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

Fiberglass Reinforcement
Major material used to reinforce plastic. Available as a mat, roving, fabric, etc.

Fiber Pattern
Visible fibers on the surface of laminates or molding. The thread size and weave of glass cloth.

Fiber-Reinforced Plastic (FRP)
A general term for a composite that is reinforced with cloth, mat, strands, or any other fiber form.

Filament
Smallest unit of a fibrous material. A fiber made by spinning or drawing into one long continuous entity.

Filament Winding
A process for fabricating a composite structure in which continuous reinforcements (filament, wire, yarn, tape, or other), either previously impregnated with a matrix material or impregnated during the winding, are placed over a rotating and removable form or mandrel in a prescribed way to meet certain stress conditions. Generally the shape is a surface of revolution and may or may not include end closures. When the required number of layers is applied, the wound form is cured and the mandrel removed.

Filler
An inorganic addition to the composite matrix that may impart a variety of performance improvements such as shrinkage control, surface smoothness, water resistance and cost reduction or is added to lower cost or density. Sometimes the term is used specifically to mean particulate additives.

Finish
A mixture of materials that is applied to fibers that improve the bonding characteristics of the resin to the fiber.

Fire Retardants
Certain chemicals that are used to reduce the tendency of a resin to burn.

Flexural Modulus
The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.

Flexural Strength
The property of a material or a structural member that indicates its ability to resist failure in bending. A unit of resistance to the maximum load before failure by bending.

Fracture
The separation of a body. Defined both as a rupture of the surface without complete separation of the laminate or as a complete separation of a body because of external or internal forces.

FRP
Fiber reinforced polymer (plastic).

FRP Composite
A polymer matrix, either thermoset or thermoplastic, reinforced with a fiber or other material with a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions (see composites).

G

H

Gel Coat
A quick setting resin applied to the surface of a mold and gelled before lay-up. The gel coat becomes an integral part of the finished laminate, and is usually used to improve surface appearance and performance.

GFRP
Glass fiber reinforced plastic.

Glass Fiber
Fiber drawn from an inorganic product of fusion that has cooled without crystallizing.

Glass Fiber, types
Alkali resistant (AR-glass)
General Purpose (E-glass)
High Strength (S-glass)

Glass-Transition Temperature
The midpoint of the temperature range over which an amorphous material changes from (or to) a brittle, vitreaous state to (or from) a plastic state.

Graphite Fiber
Fiber containing more than 99 percent elemental carbon made from a precursor by oxidation.

Grid
Large cross-sectional area construction in two or three axial directions made up using continuous filaments.

Hand Lay-Up
Fabrication method in which reinforcement layers, pre-impregnated or coated afterwards, are placed in a mold by hand, then cured to the formed shape.

Hardener
Substance added to thermoset resin to cause curing reaction.

Heat Deflection Temperature
The temperature at which a plastic material has an arbitrary deflection when subjected to an arbitrary load and test condition; an indication of the glass transition temperature.

Honeycomb
Manufactured product of resin-impregnated sheet material formed into hexagonal-shaped cells. Used as a core material in sandwich construction.

Hoop Stress
The circumferential stress in a material or cylindrical form subjected to internal or external pressure.

Hybrid
A composite laminate consisting of laminae of two or more composite material systems. A combination of two or more different fibers, such as carbon and glass or carbon and aramid, into a structure.

I-L

Impact Strength
The ability of a material to withstand shock loading.

Impregnate
In reinforced plastics, to saturate the reinforcement with a resin. A process of filling the interstices of a porous body with polymer compound.

Inhibitor
A substance that retards a chemical reaction. Also used in certain types of monomers and resins to prolong storage life.

Initiator
Peroxides used as sources of free radicals. They are used in free-radical polymerizations, for curing thermosetting resins, as cross-linking agents for elastomers and poly-ethylene, and for polymer modification.

Interface
The common boundary surface between two substances. In a composite laminate, it is the contact area between the resin and the reinforcement. On fibers, it is the contact area between the sizing or finish.

Interlaminar
Term to describe an event that occurs between two or more adjacent laminae.

Interlaminar Shear
Shearing force that produces a relative displacement between two laminae along their interface.

Isophthalic acid
A raw material that is added to polyester resins to increase their ability to withstand severe environmental/chemical factors and increase its heat deflection temperature.

Isopolyester
Resins that have been re-formulated with isophthalic acid and glycols of various types to enhace water, heat and corrosion resistance of the composite part.

Isotropic
Having uniform properties in like degree in all directions

Kevlar
See Aramid

Laminate
Two or more layers of fiber bound together in a resin matrix usually through pressure and heat.

Lay-Up
The reinforcing material placed in position in the mold. The process of placing the reinforcing material in position in the mold.

Live Load
Any load that is not permanently applied to the structure.

Low Profile
Resins specifically formulated to achieve a zero or low shrinkage factor during molding/curing.

M-O

Mandrel
The core tool around which resin-impregnated paper, fabric, or fiber is wound to form pipes, tubes, or structural shell shapes.

Mat
A fibrous material for reinforced plastic consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or swirled filaments loosely held together with a binder.

Matrix
The essentially homogeneous resin or polymer material in which the fiber system of a composite is imbedded. Both thermoplastic and thermoset resins may be used, as well as metals, ceramics, and glasses.

Mean Stress
The average of the maximum and minimum stress in one cycle of fluctuating loading (as in a fatigue test); tensile stress is considered positive and compressive strength, negative.

Mechanical Properties
The properties of a material such as compressive and tensile strengths and modulus that are associated with elastic and inelastic reaction when force is applied. The relationship between stress and strain.

Microcracking
The cracks formed when exerted stress exceeds the strength of the matrix.

Mil
The unit of measurement for the diameter of glass strands
(1 mil = 0.001 inch)

Modulus
The ratio of stress to strain. A high modulus indicates a stiff material.

Modulus of Elasticity
The ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of the material.

Mold
The cavity on which composite materials are placed in order to fabricate the final part.

Monomer
A single molecule that can react with like or unlike molecules to form a polymer. The smallest repeating structure of a polymer.

Nondestructive Evaluation (NDE)
A process or procedure, such as ultrasonic or radiographic inspection, for determining the quality or characteristics of a material, part, or assembly, without permanently altering the subject or its properties.

Nomex
See Aramid

Nonwoven Roving (Fabric)
A textile structure produced by loosely compressed fibers (rovings) with or without a scrim cloth carrier.

Open Molding
The general term used to describe composites manufacture whereby resin and reinforcement are placed on an open mold. See also hand lay up and spray-up.

Orthotropic
A material that has six different sets of moduli and Poisson's ratios.

Outgassing
The release of solvents and moisture from composite parts under a vacuum.

Oxidation
Combining or increasing the proportion of oxygen.

P

Pan
A carbon fiber made from polyacrylonitrile (pan) fiber.

Part Consolidation
The process of replacing assemblies of several parts and fasteners by designing and fabricating a single part.

Peel Ply
A layer of open-weave material, usually fiberglass, applied directly to the surface of a prepreg lay-up.

Permeability
The passage or diffusion rate of a gas, vapor, liquid or solid through a barrier without physically or chemically affecting it.

Phenolic
A thermosetting resin produced by the condensation of an aromatic alcohol particularly based on phenol (carbolic acid) and formaldehyde.

Pit
A small crater in the surface of plastic, usually of a width approximately the same as its depth.

Pitch
Carbon fiber made from a residual petroleum product.

Plain Weave
A weaving pattern in which the warp and fill fibers alternate; that is, the repeat pattern is warp/fill/warp/fill, and so on.

Plastic
A material that contains as a essential ingredient and organic polymer of large molecular weight, hardeners, fillers, reinforcements, and so forth; is solid in its finished state; and at some stage in its manufacture of its processing into finished articles, can be shaped by flow.

Plastic Deformation
Changes in dimensions of an object under load that is not recovered when the load is removed as opposed to elastic deformation.

Ply
In general, fabrics or felts consisting of one or more layers (laminates, and so forth). The layers that make up a stack.

Poisson's Ratio
The ratio of the change in lateral width per unit width to change in axial length per unit length caused by the axial stretching or stressing of a material. The ratio of transverse strain to the corresponding axial strain below the proportional limit.

Polyester
Resin produced by the polycondensation of dihydroxy derivatives and dibasic organic acids or anhydrides yielding resins that can be compounded with vinyl.

Polymer
A high molecular weight organic compound, natural or synthetic, containing repeating units.

Polymerization
A chemical reaction in which the molecules of monomers are linked together to form large molecules whose molecular weight is a multiple of that of the original substances. When two or more monomers are involves, the process is called copolymerization.

Porosity
The ratio, usually expressed as a percentage of the volume of voids in a material, to the total volume of a material, including the voids.

Post Cure
Additional elevated temperature cure, usually without pressure, to improve final properties and/or complete the cure or to decrease the percentage of volatiles in the molding.

Pot Life
The length of time that a catalized thermosetting resin retains a viscosity low enough to be used in processing.

Precursor
For carbon or graphite fiber, the rayon, PAN or pitch fibers from which carbon and graphite fibers are derived.

Preform
A preshaped fibrous reinforcement formed by distribution of chopped fibers or cloth by air, water flotation, or vacuum over the surface of a perforated screen to the approximate contour and thickness desired in the finished part.

Preform Binder
A resin applied to the chopped strands of a preform, usually during its formation, and cured so that the preform will retain its shape and can be handled.

Premix
A molding compound prepared prior to and apart from the molding operations and containing all components required for molding.

Prepreg
Either ready-to-mold material in sheet form or ready-to-wind material in roving form, which may be cloth, mat, unidirectional fiber, or paper impregnated with resin and stored for use. Also semi-hardened construction made by soaking strands or roving with resin.

Promoter
A chemical that reduces the activation energy required for a given initiator.

Pultrusion
A continuous process for manufacturing composites that have a cross-sectional shape. The process consists of pulling a fiber - reinforcing material through a resin impregnation bath and through a shaping die, where the resin is subsequently cured.

Pyrolysis
The transformation (or decomposition) of a compound by the action of heat. In respect to organic precursor fiber materials such as pan and pitch, the action of heat chemically changes them

Q R S

Quality Assurance
Actions taken by an owner or his representative to provide assurance that what is being done and what is being provided are in accordance with the applicable standards of good practice for the work.

Reinforcement
Strong materials bonded to or into a matrix to improve mechanical properties. Materials, ranging from short fibers through complex textile forms, that is combined with a resin to provide the composite with enhanced mechanical properties.

Release Agent
A substance used to prevent the unwanted bonding of the composite material to the mold/tooling. Assists in the removal of the part from the mold.

Repair Systems
To replace or correct deteriorated, damaged, or faulty materials, components or elements of a structure. The materials and techniques used for repair.

Resin
A natural or synthetic viscous liquid, solid or semisolid, organic material of indefinite and often high molecular weight having a tendency to flow under stress, usually has a softening or melting range, and usually fractures conchoidally. Polymeric material that is rigid or semi-rigid at room temperature, usually with a melting-point or glass transition temperature above room temperature.

Resin Content
The amount of resin in a laminate expressed as either a percentage of total weight or total volume.

Resin Transfer Molding (RTM)
A process whereby catalyzed resin is transferred or injected into a closed mold in which the fiberglass reinforcement has been placed.

Rheology
The study of the flow of materials, particularly plastic flow of solids. The science of treating the deformation and flow of matter.

Rockwell Hardness
A value derived from the increase in depth of an impression as the load on an indenter is increased from a fixed minimum value to a higher value and then returned to the minimum value.

Roving
A number of yarns, strands, tows, or ends collected into a parallel bundle with little or no twist.

S-Glass
A magnesium alumina silicate composition that is especially designed to provide very high tensile strength glass filaments.

Sandwich Panel
Panels composed of a lightweight core material, such as honeycomb, balsa,

Shear
An action or stress resulting from applied forces that causes or tends to cause two contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact.

Shear Reinforcement
Reinforcement designed to resist shear or diagonal tension stresses.

Shear Strength
The maximum shearing force a flexural member can support at a specific location as controlled by the combined effects of shear forces and bending moment.

Sheet Molding Compound (SMC)
A composite of fibers, a liquid thermosetting resin and other filler/additives that have been compounded together and processed into sheet form to facilitate handling in the molding operation.

Shrinkage
Decrease in either length or volume; a volume decrease caused by curing, drying and/or chemical changes.

Sizing
Surface treatment or coating applied to filaments to improve the filament-to-resin bond and to impart processing and durability attributes.

Solvent
A liquid in which another substance may be dissolved.

Spray-up
Technique in which a spray gun is used as an applicator tool. In reinforced plastics, for example, fibrous glass and resin can be simultaneously deposited in a mold.

Stiffness
A measure of modulus or a material's ability to resist bending. The relationship of load and deformation.

Stiffness
A measure of modulus. The relationship of load and deformation.

Storage Life
The period of time during which a liquid resin, packages adhesive or prepreg can be stored under specified temperature conditions and remain suitable for use. Also called shelf life.

Strain
Deformation per unit length due to stress.

Strand
Bundle of filaments, normally untwisted or an assembly of continuous filaments, bonded with sizing and used as a unit.

Stress
The internal force per unit area that resists a change in size or shape of a body as expressed in force per unit area.

Stress Crack

T-V

Tensile Reinforcement
Reinforcement designed to carry tensile stresses. Can be internal reinforcement of the product or external reinforcement such as a composite repair material placed on an existing structure.

Tensile Strength
Maximum unit stress that a material is capable of resisting under axial tensile loading; based on the cross-sectional area of the specimen before loading.

Textile
Fabric, usually woven.

Thermal Conductivity
The property of a particular body or assembly to transfer heat.

Thermal Contraction
Contraction caused by the decrease in temperature.

Thermal Expansion
Expansion caused by by an increase in temperature.

Thermoplastic
Resin that is not cross linked. Thermoplastic resin generally can be remelted and recycled.

Thermoset
Resin that is formed by cross linking polymer chains. A thermoset cannot be melted and recycled because the polymer chains form a three dimensional network.

Thixotropic (thixotropy)
Concerning materials that are gel-lie at rest but fluid when agitated.

Tool (Tooling)
The mold onto which the composite material is placed to in order to fabricate the composite part. The mold itself may or may not be made of composite materials, it may be one or two sided and may be open or closed.

Tow
An untwisted bundle of continuous filaments. Commonly used in referring to man-made fibers, particularly carbon and graphite, but also glass and aramid. A tow designated as 140K has 140,000 filaments.

Tracer
A fiber, tow or yarn added to a prepreg for verifying fiber alignment and, in the case of woven materials, for distinguishing warp fibers. It is often time a particular color in order to distinguish it from the other reinforcement.

Twist
The spiral turns about its axis per unit of length in a yarn or other textile strand.

Unidirectional Laminate
A reinforced plastic laminate in which substantially all of the fibers are oriented in the same direction.

V-RTM (VARTM)
Acronym for vacuum resin transfer molding; a vacuum process to combine resin and reinforcement in an open mold.

Vacuum Bag Molding
A process in which a sheet of flexible transparent material plus bleeder cloth and release film are placed over the lay-up on the mold and sealed at the edges. A vacuum is applied between the sheet and the lay-up.

Veil
An ultrathin mat similar to a surface mat, often composed of organic fibers as well as glass fibers.

Vent
A small hole or shallow channel in a mold that allows air or gas to exit as the molding material enters.

Vinyl Esters
A class of thermosetting resins containing ester of acrylic and/or methacrylic acids, many of which have been made from epoxy resin.

Viscosity
The property of a body of material to resist a change to its shape: internal friction.

Voids
Pockets of entrapped gas that were cured into a laminate. Void content should be less than 1% in a properly cured composite.

W-Z

Warp
The yarn running lengthwise in a woven fabric. A group of yarns in long lengths and approximately parallel.

Weave
The specific pattern which a fabric is formed from interlacing yarns.

Wet Lay-Up
A method of making a reinforced product by applying the resin system as a liquid when the reinforcement is put in place.

Wet-Out
The condition of an impregnated roving or yarn in which substantially all voids between the sized strands and filaments are filled with resin.

Wetting Agent
A substance capable of lowering the surface tension of liquids facilitating the wetting of solids surfaces and permitting the penetration of liquids into the capillaries.

Woven Fabric
A material constructed by interlacing yarns, fibers or filaments to form specific fabric patterns.

Woven Roving
A heavy glass fiber fabric made by weaving roving.

Yarn
An assemblage of twisted filaments, fibers, or strands, either natural or manufactured, to form a continuous length that is suitable for use in weaving or interweaving into textile materials.

Yield Point
The point at which permanent deformation of a stressed specimen begins to take place.

Yield Strength
The stress at the yield point. The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain.

Young's Modulus
The ratio of normal stress to corresponding strain for tensile or compressive stresses less than the proportional limit of the material.

Zero Bleed
A procedure that prohibits the loss of resin during the cure of a laminate.

Glossary References

The Market Development Alliance would like to gratefully acknowledge the following publications that were used in the compilation of the Glossary of Terms.

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- *Introduction to Composites, 4th Edition*, Composites Institute of the Society of the Plastics Industry, Washington, D.C., 1998.
- *Source Book 2000*, High Performance Composites, Ray Publishing, Wheat Ridge, CO, 2000.
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Codes & Standards

Committees

A number of committee activities from professional organizations are addressing the recommended use and specification of FRP composites. Many organizations have published codes, standards, test methods and specifications for FRP composites and their products for the respective products. For example in the FRP pipe market, design standards, test methods, and recommended practices were published by the American Petroleum Institute (API), American Society of Mechanical Engineers (ASME), American Water Works Association (AWWA), Underwriter Laboratories (UL), and others. In the corrosion resistant structural equipment market, ASME published an industry standard called RTP-1. In RTP-1, the document provides purchasers of corrosion-resistant composite equipment with guidelines for the specification of high-quality, cost-effective and high-performance equipment. The American Society of Testing and Materials (ASTM) published recognized industry test methods for FRP composites used in all markets.

Organization	Committee
American Concrete Institute (ACI)	▪ 440 – Composites for Concrete ▪ 440C – State-of-the-art-Report ▪ 440D – Research ▪ 410E – Professional Educations ▪ 440F – Repair ▪ 440G – Student Education ▪ 400H – Reinforced Concrete (rebar) ▪ 440I – Prestressed Concrete (tendons) ▪ 440J – Structural Stay-in-Place Formwork ▪ 440K – Material Characterization

	▪ 400L - Durability
American Society of Civil Engineers (ASCE)	Structural Composites and Plastics
American Society of Testing and Materials (ASTM)	▪ ASTM D20.18.01 – FRP Materials for Concrete ▪ ASTM D20.18.02 – Pultruded Profiles ▪ ASTM D30.30.01 – Composites for Civil Engineering
AASHTO Bridge Subcommittee	T-21 - FRP Composites
International Federation of Structural Concrete (FIB)	Task group on FRP
Canadian Society of Civil Engineers (CSCE)	ACMBS – Advanced Composite Materials for Bridges and Structures
Japan Society of Civil Engineers	Research Committee on Concrete Structures with Externally Bonded Continuous Fiber Reinforcing materials
Transportation Research Board	A2C07 – FRP Composites

For almost twenty years, the American Society of Civil Engineers (ASCE) has operated a technical committee called Structural Composites and Plastics (SCAP) to address the design and implementation of composites. This committee published a design manual in the early 1980's and is currently working to update this manual to address the many FRP composite products developed over the years.

The American Concrete Institute, and its Committee 440 with ten different subcommittees, address FRP composites in concrete in such topics as state-of-the-art, research, professional and student education, repair, rebar, prestressing, and stay-in-place structural formwork. These highly active committees are focused to produce guidance documents for the engineer. In particular, ACI 440F is developing a document titled "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures". This landmark publication, reviews the state-of-the-art, provides guidelines for application and selection, design recommendations, and construction techniques for the use of FRP materials to repair, strengthen, or upgrade concrete structures. The ACI 440H committee is developing a similar document of FRP rebar titled "Guide for the Design and Construction of Concrete Reinforced with FRP Bars". The proposed guideline reviews knowledge based on research and field applications of FRP bars worldwide.

Several ASTM committees are currently working on consensus test methods for the use of rebars, repair materials, and pultruded structural profiles. In ASTM D20.18.01 (FRP Materials for Concrete) committee, industry experts are addressing materials and products to develop standard test methods for FRP rebar and repair materials. In ASTM D20.18.02 is a committee focused on the development of test methods for FRP pultruded profiles and shapes. The ASTM D30.30.01 (Composites for Civil Engineering) committee addresses FRP composites products used construction.

The American Association of State Highway and Transportation Officials (AASHTO) Bridge Committee established a subcommittee in 1997 called "T-21 Composites". This committee has an ongoing effort to develop design guidelines for of the use of composites in bridge applications including FRP reinforced concrete, concrete repair, and vehicular bridge deck panels.

Organizations

The Civil Engineering Research Foundation (CERF), the research arm of the American Society of Civil Engineers is actively engaged with technology transfer of new cutting edge technologies. One of CERF's programs, Highway Innovation Technology Evaluation Center (HITEC), coordinates product evaluations between the end-user community and industry to produce highway products that meet the needs of the end-user with the program results being shared with all State DOT bridge departments. HITEC has provided the civil engineering community with several product evaluation programs that address the use of composites. One program in particular, FRP Composite Bridge Decks, has developed an evaluation plan for several composites bridge manufacturers for testing, design, and performance of bridge deck panels manufactured with FRP materials.

The Intelligent Sensing for Innovative Structures (ISIS) of the Canadian Network of Centers of Excellence was established to advance civil engineering to a world leadership position through the development and application of FRP composites and an integrated intelligent fiber optic sensing technology to benefit all Canadians through innovative and intelligent infrastructure. ISIS Canada, through its universities, has coordinated a team of professionals dedicated to advancing technology by building better roads, buildings, and bridges. ISIS has many research projects and field evaluations under study that demonstrate successful implementation of FRP composites with validated design and testing as well as techniques to document the in-field service of new products and systems. ISIS Canada is credited with building the first smart sensing FRP composite bridge and continues to make advancements in the areas of concrete repair, bridge construction with FRP rebars and tendons, and roadways.

Several professional societies from around the world have published design codes for FRP Rebar. In Canada, the civil engineers have documented design procedures in the Canadian Highway Bridge Design Code for the use of FRP rebars. The Japan Society of Civil Engineers has published a code that provides design recommendations for the use of FRP rebars and tendons.

Standards Development

Several global activities are taking place to implement FRP composites materials and products into respective design codes and guidelines. The following summarizes this activity:

Code/Standard	Reference
Canadian Building Code	Design and Construction of Building Components with Fiber Reinforced Plastics
Canadian Highway Bridge Design Code (CHBDC)	Fiber Reinforced Structures (section of code)
International Conference of Building Officials (ICBO)	AC 125: Acceptance Criteria for Concrete and Unreinforced Masonry Strengthening Using Fiber-Reinforced Composite Systems
Japan Society of Civil Engineers (JSCE) Standard Specification for Design and Construction of Concrete Structures	Recommendation for Design and Construction for Reinforced Concrete Structures Using Continuous Fiber Reinforcing Materials

In April 1997, The International Conference of Building Officials (ICBO) published AC125 "Acceptance Criteria for Concrete and Unreinforced Masonry Strengthening Using Fiber-Reinforced Composite Systems". ICBO has also published individual company product evaluation reports on FRP systems used to strengthen concrete and masonry structural elements such as columns, beams, slabs, and connections of wall to slab.

Technology Transfer

Many academic institutions in the North America, as well as around the world are actively engaged in research involving FRP applications for civil infrastructure. Several universities have distinguished themselves as centers of excellence in specific fields of expertise. Universities and State Departments of Transportation often collaborate on the evaluation and implementation of FRP composites that best meet the needs of the State.

Organization	Activity
American Society of Civil Engineers	*Journal of Composites for Construction*
Federal Highway Administration (FHWA)	TEA-21 Innovative Bridge Research and Construction Program (IBRC)
Intelligent Sensing for Innovative Structures (ISIS) of the Canadian Network of Centers of Excellence	• Industry research and collaboration • *FRP International* (global newsletter)
Market Development Alliance of the FRP Composites Industry	Project Teams and Programs geared towards development of FRP composites for construction applications

The Fed Federal Highway Administration (FHWA) through the TEA-21 Innovative Bridge Research and Construction Program (IBRC) has provided new construction materials the opportunity to meet the goals of reducing maintenance and life-cycle costs of bridge structures. Funds are provided for the Federal share of the cost for repair, rehabilitation, replacement, and new construction of bridges using innovative materials. Each year since the first solicitation in 1998, FRP composites led other innovative construction materials for funding to demonstrate the unique benefits being sought by FHWA to build a better and long-lasting infrastructure.

Many societies, trade associations, academic institutions and organizations worldwide host periodic conferences, trade shows, and seminars in forums that educate as well as transfer state-of-the-art technology to end-users. Some of the conferences are listed below:

- ACMBS Advanced Composites Materials for Bridges and Structures (Canada)
- ASCE Construction and Materials Congress
- PORTS, every three years (2001, 2004)
- Structures Congress
- American Composites Manufacturer's Association (formerly Composites Fabricators Association -CFA) annual conference and exposition, early fall
- FRPRCS Fiber-Reinforced Polymers for Reinforced Concrete Structures (International)
- IBC International Bridge Conference, annual, June
- ICCI International Conference on Composites for Infrastructure
- SAMPE Society for the Advancement of Material and Process Engineering, annual conference and exposition, late spring/early summer.

Why Use FRP Composites?

FRP composites are no longer considered "space-age" materials utilized only for stealth bombers and space shuttles. This versatile material system has become a part of everyday life as composites are now routinely used in automobiles, boats, golf clubs, high-performance bicycles, computer housings, bulletproof vests, prosthetics and thousands of products too numerous to mention here. FRP composites are also providing practical solutions to the civil engineer or owner faced with the challenges of restoring structural integrity, increasing load bearing capabilities, and/or enhancing the strength and stiffness of aging structures. The advantage of composites is that a variety of resin/fiber systems can yield a possible solution most types of situations. Depending on the product and application, the use of FRP products for civil infrastructure/construction applications deliver the following benefits:

- Product and system design can be optimized for specific loads
- Reduced structure dead load can increase load ratings
- Increased structure service life
- Reduced maintenance costs due to resistance from deicing salts and other corrosive agents
- Engineered system packaging reduces field installation time
- Faster construction reducing traffic delays
- Reliability of pre-engineered systems
- Enhanced durability and fatigue characteristics as proven in related applications from other industries
- Products and systems enables value engineering that result in innovative and efficient installations

A myriad of FRP products are available for either the repair or outright replacement of existing structures. Most that have been extensively demonstrated and used around the world. Examples of FRP composite products include:

- New structural shapes applied to beams for bridge decks
- Vehicular and pedestrian bridge systems
- FRP rebars and tendons for concrete reinforcement
- Piling products and systems for marine waterfront structures
- FRP composite systems for repair and strengthening, and seismic retrofit for beams, columns, slabs and walls
- FRP dowel bars for concrete highway pavements

The FRP composite products or engineered systems featured in the Product Locator section of this site are often dramatically different in approach, they each offer the civil engineer consistent performance for longer periods of time than conventional construction materials.

the source for information on FRP composites for the built environment, the MDA is frequently approached to provide "Composites Basics" tutorials at seminars and conventions. We are often asked similar questions at these venues which are included below:

- How do I specify composites?
- How do I install composites?
- What maintenance is required for composites?
- Can composites be used with other materials so that a structure can be repaired rather than replaced?

How do I specify composites?

Simple. You use descriptive specifications and drawings the same as you use to specify any structural engineering project, but with a few additional requirements. Because FRP composites are a relatively new material of construction, the codes and standards for the design and construction of FRP structures has not fully matured. A professional engineer experienced in the design and fabrication of FRP products is a reliable source. Descriptive specifications should be expanded to include details pertaining to composite materials, fabrication methods, and shipping requirements. It is also recommended to contact engage the services of an FRP product manufacturer or FRP engineering consultant. The MDA membership is a cross-section of experts in composites materials and fabrication. For that reason, if you have a question(s) concerning a specific installation, ASK AN EXPERT who will respond to your inquiry.

How do I install composites?

Typically, composites are easier to install than traditional materials because of their lighter weight. Manufacturers of composites provide installation guides to facilitate a proper installation and may offer workers training on proper installation procedures.

What maintenance is required for composites?

FRP is not necessarily maintenance-free, but it is the closest economical alternative when used properly. For instance, painting can be eliminated for composites that have pigment incorporated in the resin or gel coat out layer and even if the topcoat is damaged, the composite does not experience rusting or other forms of galvanic corrosion because of its inherent resistance to environmental factors.

Can composites by used with other materials so that a structure can be repaired rather than replaced?

The answer is yes, with some strong words of advice. As the need to balance budgets often supersedes the outright replacement of structures, a new opportunity emerges for composites - where composites are joined with traditional materials to form hybrids, or "super composites." The combination of materials is powerful, but there are also some considerations:

- Elastic Modulus: The stiffness, or elastic modulus of the hybrid combination is critical to the general behavior of the structure. Traditional materials maintain the same stiffness within a normal environmental service temperature range. Plastics can act differently, depending on the choice of resin. If consideration is not given to the polymer's glass transition temperature, the fiber/matrix interfacial bond may be weakened, resulting in a disbond failure.
- Coefficient of Thermal Expansion: CTE is the change in length (or volume) per unit length (or volume) produced by one degree Celsius rise in temperature. If the substrate and the repair material (FRP composite) are not thermally compatible, failure will occur with a disbond or delamination. Consideration of the resin's CTE must be considered. In most repair situations, the resin matrix requires a low modulus and relatively high elongation at break.
- Moisture: In general, FRP composites are impermeable to moisture. If however, the substrate contains moisture, the polymer will not allow it to "out gas" or pass through and a disbond can occur at the interface between the composite and the substrate. Therefore it is important to properly prepare the substrate (i.e. sandblast, air dry, etc.) prior to applying the composite material.

Ask An Expert

If you have a question regarding **the specification or application of FRP composites to a specific civil engineering installation**, please complete the following form and MDA will utilize its network of industry contacts to provide a timely response.

A FRIENDLY NOTE TO VISITORS

The CGI website has been developed with the objective of providing information about FRP composites, or otherwise linking, civil engineering end-users (designers, engineers, constructors, owners, etc.) with MDA's members. Our "Ask an Expert" desk is set up to perform this function. We regret that we cannot respond to inquiries about inventions, regulatory affairs, business financing and investment, partnership opportunities or miscellaneous inquiries other than those that are directly involved in putting potential customers in touch with our members who might supply them a product or service.

Please note that all entries with an arrow must be completed prior to submitting the form.

оформленный архитекторами студии leroy Street. Заказчику требовалась гостеприимная атмосфера, в которой, однако, будет задан энергичный ритм, способствующий активной ротации клиентов в краткие часы обеденного перерыва. Теплота и "личностность" сочетаются с прохладным лаконизмом: оказывается, холодные цвета ассоциируются с чистотой и возбуждают аппетит. Ограниченный бюджет требовал недорогих, легко доступных материалов и простых, но эффектных решений. Чтобы привлечь внимание к тому, как свежие салатные ингредиенты нарезаются у вас на глазах, архитекторы выдвинули часть фасада на тротуар и усадили повара в образовавшуюся стеклянную будку. Светильник, сконструированный специально для Chop-t из металлических "ломтей", пересекает весь потолок по диагонали и, кажется, готовится вырваться за пределы фасада - туда, где сейчас светится вывеска. Интерьер облицован полупрозрачными панелями рифленого фиброгласа, которым обычно покрывают крыши. Фиброглас обрамляют специально акцентированные деревянные рейки и равномерно расположенные шурупы. Клен и фиброглас использованы также для изготовления скамей, столов и т. д. Ресторан функционирует уже некоторое время и гордится неиссякающими очередями у дверей.

Американская компания "Шеврон" открыла в Атырау автозаправочную станцию, которая соответствует всем мировым стандартам по охране окружающей среды, противопожарной и технической безопасности.

Три подземные емкости из фиброгласа с двойными стенками исключают возможность утечки нефтепродуктов, а также внутренней и внешней коррозии.