EIGHBOR'S STEEL PIE

- **Understanding Expansive Clay and Its Swell Cycle**
  Understanding Expansive Clay and Its Swell Cycle How Uncompacted Fill Leads to Sudden Settling Groundwater Pressure and Lateral Foundation Movement The Role of Freeze Thaw in Frost Heave Damage Identifying Subsidence Zones With Public Map Data Soil Moisture Fluctuations and Differential Settlement Tree Roots and Their Influence on Soil Stability Effects of Drought on Shrinking Clay Foundations Surface Drainage Patterns That Accelerate Erosion Assessing Bearing Capacity Through Simple Field Tests Topographic Features That Signal Potential Slide Risk Using Rainfall History to Predict Soil Movement
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Understanding surface drainage is crucial when considering its impact on the stability and longevity of building foundations, particularly in areas prone to accelerated erosion. Surface drainage refers to the way water flows over the ground surface after rainfall or irrigation. The soil beneath your home is secretly plotting either stability or chaos depending on its composition and moisture levels **structural engineer consultation Lake County IL** waterproofing. How this water is managed can significantly influence whether it becomes a benign flow or a destructive force.

In regions where surface drainage patterns accelerate erosion, water tends to move quickly over the landscape, picking up speed and carrying away soil particles. This process is exacerbated by certain drainage patterns that channelize water flow. For instance, when water is funneled into narrow paths or directed towards slopes, it gains momentum, leading to more pronounced erosion. Such conditions are often found in areas with poor land planning or natural topography that naturally directs runoff.

The implications for foundations are profound. As soil erodes around a foundation, it loses its supportive structure, leading to potential subsidence or shifting of the building. Over time, this can cause cracks in walls, uneven floors, and even structural failure if not addressed. Furthermore, excessive moisture from poor drainage can weaken foundation materials through processes like freeze-thaw cycles in colder climates or by promoting mold growth which deteriorates materials.

To mitigate these effects, understanding local drainage patterns is essential. Effective strategies include installing proper drainage systems like French drains or swales that redirect water away from foundation areas, maintaining vegetation that slows down runoff, and sometimes reshaping the land to promote more uniform water distribution. Additionally, regular inspection and maintenance of these systems ensure they function as intended over time.

In conclusion, while surface drainage might seem like a straightforward environmental factor, its management requires careful consideration due to its direct impact on foundational integrity. By recognizing how different drainage patterns can accelerate erosion and implementing informed solutions, homeowners and builders can protect structures from the subtle yet powerful forces of water movement across landscapes.

The Swell Cycle: How Expansive Clay Affects Foundations —

When discussing the impact of surface drainage on structural integrity, its crucial to understand how different drainage patterns can not only accelerate erosion but also pose significant threats to building foundations. Common surface drainage patterns that threaten foundations are primarily those that concentrate water flow towards or around the base of structures, leading to potential foundation damage through various mechanisms.

One such pattern is **sheet flow**, where water runs off in a broad, thin layer across the surface. While this might seem less harmful due to its dispersed nature, if the ground slopes towards a building, sheet flow can accumulate at the foundation, leading to soil saturation. Over time, this saturation weakens the soils bearing capacity, causing differential settlement where parts of the foundation sink unevenly.

Another critical pattern involves **channelized flow**, where water is directed into narrow paths or channels due to landscaping features or natural topography. This concentrated flow can erode soil rapidly around a foundation, creating voids or undermining the footing support. For instance, if a downspout directs rainwater into a channel that leads straight to a houses perimeter, it can wash away soil from under the foundation slab or walls.

Swales and ditches, when improperly designed or maintained, can also contribute to foundation issues. Ideally, these should direct water away from buildings. However, if they are too close or if they overflow during heavy rains due to poor design or blockages, they inadvertently channel water towards foundations. This misdirection exacerbates soil erosion around the structure and increases hydrostatic pressure against basement walls.

Lastly, **ponding** occurs when low spots in the landscape hold water after rainfall. If these ponds form near or against a buildings foundation due to poor grading or inadequate drainage systems, they maintain high moisture levels in the soil for extended periods. This prolonged exposure to moisture leads to swelling and shrinking cycles in clay-rich soils (a process known as expansive soil behavior), which can heave and crack foundations.

In conclusion, while effective surface drainage is essential for preventing erosion by dispersing runoff evenly across landscapes, improper management can lead directly to foundational threats. Understanding these common patterns helps homeowners and builders design landscapes that protect rather than endanger structures by ensuring water is directed away from foundations efficiently and safely. Proper grading, strategic placement of downspouts and gutters with extensions, along with regular maintenance of existing drainage systems, are key measures in mitigating these risks.

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Preventive Measures for Foundations on Expansive Soil

Identifying erosion-causing drainage issues around your home is crucial for maintaining the integrity of your property and preventing costly repairs. Surface drainage patterns play a significant role in this process, as they can either manage water flow effectively or exacerbate erosion.

When examining your property, start by observing how water flows during rain. Look for areas where water tends to pool or run off quickly. Poorly managed runoff can lead to soil displacement, which is the first sign of erosion. For instance, if you notice that after a heavy downpour, water rushes down a particular slope near your house, this might indicate a problematic drainage pattern.

One common issue arises when gutters and downspouts are not directing water away from the foundation adequately. If water from these systems is discharged too close to the house or onto non-absorbent surfaces like concrete, it can create concentrated streams that erode the soil rapidly. To mitigate this, ensure that extenders or splash blocks are used to guide water at least 5-10 feet away from your homes foundation.

Another point to consider is the grading of your lawn. Ideally, the ground should slope away from your house at a rate of about 6 inches over the first 10 feet. If you find flat or inward-sloping areas near your foundation, this could be funneling water towards rather than away from your home, leading to erosion. Regrading might be necessary in such cases.

Vegetation also plays a part in managing surface drainage. Sparse vegetation or bare patches allow for higher runoff speeds which can strip topsoil away. Planting ground covers or installing mulch can slow down water flow and promote infiltration into the soil.

Lastly, keep an eye on any man-made structures like driveways or patios that might interrupt natural drainage paths. These hard surfaces prevent absorption and can redirect water in ways that enhance erosion elsewhere on your property.

By regularly inspecting and addressing these aspects of surface drainage around your home, youre not only protecting against erosion but also ensuring a healthier environment for both your landscaping and structural elements of your home. Remember, prevention through proper observation and maintenance is always less costly than fixing damage after it occurs.

Repair Techniques for Foundations Affected by Clay Swelling

Poor drainage is a critical factor that can significantly weaken foundation structures, and this issue is particularly exacerbated by surface drainage patterns that accelerate erosion. When water is not properly channeled away from a building, it tends to accumulate around the foundation. Over time, this excess moisture can lead to several detrimental effects.

Firstly, water saturation in the soil surrounding the foundation increases its weight and volume, exerting additional pressure on the structure. This phenomenon, known as hydrostatic pressure, can cause the foundation to shift or crack as it struggles against the relentless force of expanding wet soil. In regions where clay soils dominate, this effect is even more pronounced due to clays high expansiveness when wet.

Moreover, poor drainage facilitates erosion around the base of buildings. Erosion removes supportive soil from beneath and around the foundation, leading to an unstable base. Surface drainage patterns that direct water flow towards or around a building instead of away from it exacerbate this process. For instance, if gutters and downspouts are not correctly positioned or maintained, they might inadvertently channel water close to or directly onto the foundation area. Similarly, poorly designed slopes or landscape features can create pathways for water to run towards rather than away from structures.

The weakening of foundations due to poor drainage doesnt just stop at structural integrity; it also affects the longevity of materials used in construction. Concrete foundations are particularly susceptible; prolonged exposure to moisture can lead to degradation through processes like leaching of calcium compounds or freeze-thaw cycles in colder climates, both of which compromise concretes strength.

To mitigate these risks, proper surface drainage design is crucial. Effective solutions include ensuring that land slopes away from buildings at an adequate gradient, installing French drains or swales where necessary to redirect runoff, and maintaining clear and functional drainage systems like gutters and downspouts. Regular inspection and timely repair of any issues with these systems are also vital in preventing long-term damage.

In conclusion, understanding how poor drainage weakens foundation structures highlights the importance of integrating thoughtful surface drainage patterns into property development and maintenance strategies. By managing how water interacts with our built environment through smart design and upkeep practices, we protect not only our homes but also ensure their safety and durability against natural forces like erosion accelerated by improper water management.

Okay, lets talk about how the way water flows around your house – the surface drainage patterns – can be a sneaky culprit behind foundation damage caused by erosion. Think of your foundation as a castle wall. If the land around it is sloped correctly, rainwater will naturally flow *away* from the wall, keeping it nice and dry. But if the drainage is bad, youre basically creating a moat *around* your castle, and thats a recipe for disaster.

One of the first things you might notice is water pooling near your foundation after a rain. This isnt just an aesthetic problem; its a sign that water isnt being directed away properly and is saturating the soil right next to your foundation. Over time, this saturated soil becomes unstable and can start to erode, washing away the support that your foundation relies on.

Look for signs of channels or gullies forming in your yard, especially near downspouts or anywhere water tends to flow. These are like little rivers carving paths through your soil, carrying it away bit by bit. You might also see exposed tree roots near your foundation, which is another indication that the soil around them is being eroded.

Another red flag is discoloration or staining on your foundation walls, particularly near the ground. This can be caused by water repeatedly splashing against the wall, carrying soil particles and minerals that leave behind a visible mark.

These early warning signs are your chance to act before the problem gets serious. Ignoring them could lead to cracks in your foundation, sinking or settling, and ultimately, expensive repairs. So, pay attention to how water moves around your property and address any drainage issues promptly. A little bit of preventative maintenance can save you a whole lot of heartache (and money) down the road.

Foundation repair solutions for erosion-related problems are critical when addressing the impacts of surface drainage patterns that accelerate erosion. Erosion around a homes foundation can lead to serious structural issues, undermining the stability of the building over time. When surface water is not properly managed, it tends to follow natural or man-made drainage patterns that can lead directly towards the foundation, washing away supportive soil and creating voids.

One effective solution begins with understanding and modifying these problematic surface drainage patterns. Homeowners should first assess their property to identify where water accumulates and how it flows during rain events. Often, simple adjustments like regrading the landscape or installing gutters and downspouts can redirect water away from the foundation. For instance, ensuring that the ground slopes away from the house by at least 6 inches over the first 10 feet can significantly reduce erosion risk.

For more severe cases where erosion has already caused damage, more intensive interventions might be necessary. One common approach is to install French drains around the perimeter of the home. These drains collect excess water and channel it away from vulnerable areas, preventing further soil loss. Additionally, retaining walls or riprap (a layer of large stones) can stabilize soil on slopes where runoff has been particularly aggressive.

Another crucial aspect is reinforcing the foundation itself. Techniques like underpinning can provide additional support by extending the foundation down to more stable soil layers or bedrock below. This method not only repairs existing damage but also fortifies against future erosion.

In summary, addressing foundation repair due to erosion involves a multi-faceted approach: altering surface drainage to prevent future issues, implementing drainage solutions like French drains, and sometimes reinforcing or repairing the foundation directly. By tackling both the cause and effect of erosion with these strategies, homeowners can protect their propertys integrity from being compromised by misguided water flow patterns on their land.

Preventing future erosion and protecting your foundation are critical aspects when considering surface drainage patterns that can accelerate erosion. Erosion is a natural process, but when its accelerated by poor drainage, it can become a significant threat to your property. Understanding how water moves across your land is the first step in managing this risk.

Surface drainage patterns dictate where and how quickly water flows away from precipitation or irrigation. When these patterns are not well-managed, water can concentrate in certain areas, leading to soil displacement and undermining the stability of structures like foundations. For instance, if water consistently flows towards your house due to improper grading or lack of diversion structures, it can erode the soil around your foundation, potentially causing cracks or even structural failure over time.

To combat this, one should start with a thorough assessment of the existing landscape. Look for signs of current erosion such as rills or gullies, and observe where water tends to pool or run off after rain. Adjusting the grade of your land so that it slopes away from your home can be an effective strategy. This might involve adding soil to create a gentle slope or constructing retaining walls in severe cases.

Implementing physical barriers like swales or French drains can also redirect water flow away from vulnerable areas. Swales are shallow trenches that guide water along a predetermined path, reducing speed and allowing for better absorption into the ground. French drains serve a similar purpose by collecting subsurface water and channeling it away through perforated pipes.

Planting vegetation is another natural method to prevent erosion. Deep-rooted plants like shrubs or grasses stabilize the soil with their root systems while their leaves reduce the impact of raindrops on bare soil. Additionally, mulching around plants helps retain moisture and reduces runoff.

Regular maintenance is key; checking and cleaning out gutters and downspouts ensures they direct water away from your foundation rather than towards it. Also, periodic inspection of any installed drainage systems prevents blockages that could cause overflows.

In essence, protecting your foundation from erosion involves proactive landscaping adjustments tailored to your propertys unique topography. By understanding and manipulating surface drainage patterns effectively, homeowners can safeguard their homes against the insidious creep of erosion while promoting a healthier environment for plant life and soil structure alike. This approach not only preserves the integrity of your home but also contributes positively to local ecosystems by managing water resources more sustainably.

About waterproofing

Waterproofing is the procedure of making a things, person or structure water resistant or waterproof to ensure that it stays reasonably untouched by water or stands up to the ingress of water under specified problems. Such products might be made use of in damp environments or underwater to specified midsts. Waterproof and water resistant usually describe resistance to penetration of water in its liquid state and potentially under pressure, whereas damp evidence describes resistance to moisture or wetness. Permeation of water vapour through a material or structure is reported as a moisture vapor transmission price (MVTR). The hulls of watercrafts and ships were when waterproofed by using tar or pitch. Modern things might be waterproofed by using water-repellent coverings or by securing joints with gaskets or o-rings. Waterproofing is made use of of developing structures (such as basements, decks, or damp areas), boat, canvas, apparel (raincoats or waders), digital gadgets and paper product packaging (such as containers for fluids).
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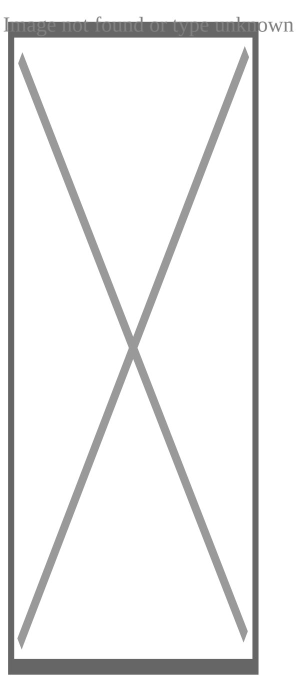
About Carbon-fiber reinforced polymer

"Carbon fiber" redirects here. For fibers of carbon, see **Carbon fibers**.



Tail of a **radio-controlled helicopter**, made of CFRP

Carbon fiber-reinforced polymers (**American English**), **carbon-fibre-reinforced polymers** (**Commonwealth English**), **carbon-fiber-reinforced plastics**, **carbon-fiber reinforced-thermoplastic** (**CFRP**, **CRP**, **CFRTP**), also known as **carbon fiber**, **carbon composite**, or just **carbon**, are extremely strong and light **fiber-reinforced plastics** that contain **carbon fibers**. CFRPs can be expensive to produce, but are commonly used wherever high **strength-to-weight ratio** and **stiffness** (rigidity) are required, such as aerospace, superstructures of ships, automotive, civil engineering, sports equipment, and an increasing number of consumer and technical applications.[1][2][3][4]

The binding **polymer** is often a **thermoset** resin such as **epoxy**, but other thermoset or **thermoplastic** polymers, such as **polyester**, **vinyl ester**, or **nylon**, are sometimes used.[4] The properties of the final CFRP product can be affected by the type of additives introduced to the binding matrix (resin). The most common additive is **silica**, but other additives such as rubber and **carbon nanotubes** can be used.

Carbon fiber is sometimes referred to as *graphite-reinforced polymer* or *graphite fiber-reinforced polymer* (*GFRP* is less common, as it clashes with **glass-(fiber)-reinforced polymer**).

Properties

[**edit**]

CFRP are **composite materials**. In this case the composite consists of two parts: a matrix and a reinforcement. In CFRP the reinforcement is carbon fiber, which provides its strength. The matrix is usually a thermosetting plastic, such as polyester resin, to bind the reinforcements together.[5] Because CFRPs consist of two distinct elements, the material properties depend on these two elements.

Reinforcement gives CFRPs their strength and rigidity, measured by **stress** and **elastic modulus** respectively. Unlike **isotropic** materials like steel and aluminum, CFRPs have directional strength properties. The properties of a CFRP depend on the layouts of the carbon fiber and the proportion of the carbon fibers relative to the polymer.[6] The two different equations governing the net elastic modulus of composite materials using the properties of the carbon fibers and the polymer matrix can also be applied to carbon fiber reinforced plastics.[7] The **rule of mixtures** for the equal **strain** case gives:

$$\displaystyle E_c=V_mE_m+V_fE_f$$

which is valid for composite materials with the fibers oriented **parallel** to the applied load. $\displaystyle E_c$ is the total composite modulus, $\displaystyle V_m$ and $\displaystyle V_f$ are the volume fractions of the matrix and fiber respectively in the composite, and $\displaystyle E_m$ and $\displaystyle E_f$ are the elastic moduli of the matrix and fibers respectively.[7] The other extreme case of the elastic modulus of the composite with the fibers oriented transverse to the applied load can be found using the inverse rule of mixtures for the equal stress case:[7]

$$E_c=\left(\frac{V_m}{E_m}+\frac{V_f}{E_f}\right)^{-1}$$

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The above equations give an upper and lower bound on the Young's modulus for CFRP and there are many other factors that influence the true value.

The fracture toughness of carbon fiber reinforced plastics is governed by multiple mechanisms:

- Debonding between the carbon fiber and polymer matrix.
- Fiber pull-out.
- Delamination between the CFRP sheets.[8]

Typical epoxy-based CFRPs exhibit virtually no plasticity, with less than 0.5% strain to failure. Although CFRPs with epoxy have high strength and elastic modulus, the brittle fracture mechanics presents unique challenges to engineers in failure detection since failure occurs catastrophically.[8] As such, recent efforts to toughen CFRPs include modifying the existing epoxy material and finding alternative polymer matrix. One such material with high promise is **PEEK**, which exhibits an order of magnitude greater toughness with similar elastic modulus and tensile strength.[8] However, PEEK is much more difficult to process and more expensive.[8]

Despite their high initial strength-to-weight ratios, a design limitation of CFRPs are their lack of a definable **fatigue limit**. This means, theoretically, that stress cycle failure cannot be ruled out. While steel and many other structural metals and alloys do have estimable fatigue or endurance limits, the complex failure modes of composites mean that the fatigue failure properties of CFRPs are difficult to predict and design against; however emerging research has shed light on the effects of low velocity impacts on composites.[9] Low velocity impacts can make carbon fiber polymers susceptible to damage.[9][10][11] As a result, when using CFRPs for critical cyclic-loading applications, engineers may need to design in considerable strength safety margins to provide suitable component reliability over its service life.

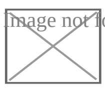
Environmental effects such as temperature and **humidity** can have profound effects on the polymer-based composites, including most CFRPs. While CFRPs demonstrate excellent corrosion resistance, the effect of moisture at wide ranges of temperatures can lead to degradation of the mechanical properties of CFRPs, particularly at the matrix-fiber interface.[12] While the carbon fibers themselves are not affected by the moisture diffusing into the material, the moisture plasticizes the polymer matrix.[8] This leads to significant changes in properties that are dominantly influenced by the matrix in CFRPs such as compressive, interlaminar shear, and impact properties.[13] The epoxy matrix used for engine fan blades is designed to be impervious against jet fuel, lubrication, and rain water, and external paint on the composites parts is applied to minimize damage from ultraviolet light.[8][14]

Carbon fibers can cause **galvanic corrosion** when CFRP parts are attached to aluminum or mild steel but not to stainless steel or titanium.[15]

CFRPs are very hard to machine, and cause significant tool wear. The tool wear in CFRP machining is dependent on the fiber orientation and machining condition of the cutting process. To reduce tool wear various types of coated tools are used in machining CFRP and CFRP-metal stack.[1]

Manufacturing

[**edit**]



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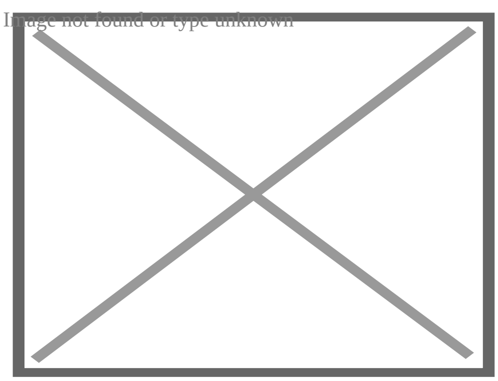


Carbon fiber reinforced polymer

The primary element of CFRPs is a **carbon filament**; this is produced from a precursor **polymer** such as **polyacrylonitrile** (PAN), **rayon**, or petroleum **pitch**. For synthetic polymers such as PAN or rayon, the precursor is first **spun** into filament yarns, using chemical and mechanical processes to initially align the polymer chains in a way to enhance the final physical properties of the completed carbon fiber. Precursor compositions and mechanical processes used during spinning filament yarns may vary among manufacturers. After drawing or spinning, the polymer filament yarns are then heated to drive off non-carbon atoms (**carbonization**), producing the final carbon fiber. The carbon fibers filament yarns may be further treated to improve handling qualities, then wound onto **bobbins**.[16] From these fibers, a unidirectional sheet is created. These sheets are layered onto each other in a quasi-isotropic layup, e.g. 0°, +60°, or ?60° relative to each other.

From the elementary fiber, a bidirectional woven sheet can be created, i.e. a **twill** with a 2/2 weave. The process by which most CFRPs are made varies, depending on the piece being created, the finish (outside gloss) required, and how many of the piece will be produced. In addition, the choice of matrix can have a profound effect on the properties of the finished composite.**[17]**

Many CFRP parts are created with a single layer of carbon fabric that is backed with fiberglass.**[18]** A tool called a chopper gun is used to quickly create these composite parts. Once a thin shell is created out of carbon fiber, the chopper gun cuts rolls of fiberglass into short lengths and sprays resin at the same time, so that the fiberglass and resin are mixed on the spot.**[19]** The resin is either external mix, wherein the hardener and resin are sprayed separately, or internal mixed, which requires cleaning after every use. Manufacturing methods may include the following:

Molding

[**edit**]

One method of producing CFRP parts is by layering sheets of carbon fiber cloth into a **mold** in the shape of the final product. The alignment and weave of the cloth fibers is chosen to optimize the strength and stiffness properties of the resulting material. The mold is then filled with **epoxy** and is heated or air-cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas are manufactured by draping cloth over a mold, with epoxy either pre-impregnated into the fibers (also known as ***pre-preg***) or "painted" over it. High-performance parts using single molds are often vacuum-bagged and/or **autoclave**-cured, because even small air bubbles in the material will reduce strength. An alternative to the autoclave method is to use internal pressure via inflatable air bladders or **EPS foam** inside the non-cured laid-up carbon fiber.

Vacuum bagging

[**edit**]

For simple pieces of which relatively few copies are needed (one or two per day), a **vacuum bag** can be used. A fiberglass, carbon fiber, or aluminum mold is polished and waxed, and has a **release agent** applied before the fabric and resin are applied, and the vacuum is pulled and set aside to allow the piece to cure (harden). There are three ways to apply the resin to the fabric in a vacuum mold.

The first method is manual and called a wet layup, where the two-part resin is mixed and applied before being laid in the mold and placed in the bag. The other one is done by infusion, where the dry fabric and mold are placed inside the bag while the vacuum pulls the resin through a small tube into the bag, then through a tube with holes or something similar to evenly spread the resin throughout the fabric. Wire loom works perfectly for a tube that requires holes inside the bag. Both of these methods of applying resin require hand work to spread the resin evenly for a glossy finish with very small pin-holes.

A third method of constructing composite materials is known as a dry layup. Here, the carbon fiber material is already impregnated with resin (pre-preg) and is applied to the mold in a similar fashion to adhesive film. The assembly is then placed in a vacuum to cure. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup. Also, because larger amounts of resin are more difficult to bleed out with wet layup methods, pre-preg parts generally have fewer pinholes. Pinhole elimination with minimal resin amounts generally require the use of **autoclave** pressures to purge the residual gases out.

Compression molding

[**edit**]

A quicker method uses a **compression mold**, also commonly known as carbon fiber forging. This is a two (male and female), or multi-piece mold, usually made out of aluminum or steel and more recently 3D printed plastic. The mold components are pressed together with the fabric and resin loaded into the inner cavity that ultimately becomes the desired component. The benefit is the speed of the entire process. Some car manufacturers, such as BMW, claimed to be able to cycle a new part every 80 seconds. However, this technique has a very high initial cost since the molds require CNC machining of very high precision.

Filament winding

[**edit**]

For difficult or convoluted shapes, a **filament winder** can be used to make CFRP parts by winding filaments around a mandrel or a core.

Cutting

[edit]

Carbon fiber-reinforced **pre-pregs** and dry carbon fiber textiles require precise cutting methods to maintain material integrity and reduce defects such as fiber pull-out, **delamination** and fraying of the cutting edge. **CNC digital cutting systems** equipped with drag and oscillating are often used to cut carbon fiber pre-pregs, and rotating knives are commonly used to process carbon fiber fabrics. **Ultrasonic** cutting is another method to cut CFRP pre-pregs and is particularly effective in reducing delamination by minimizing **mechanical stress** during the cutting process. **Waterjet cutting** can be the preferred method for thicker and multilayered polymer **composites**.**[20]**

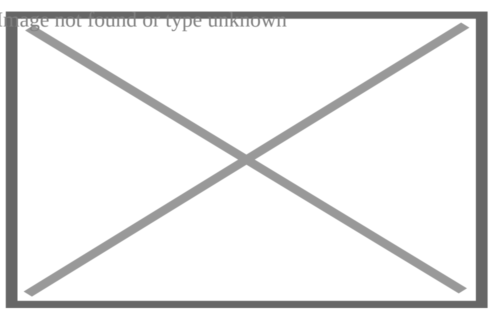
Applications

[edit]

Applications for CFRPs include the following:

Aerospace engineering

[edit]



An **Airbus A350** with carbon fiber themed **livery**. Composite materials are used extensively throughout the A350.

The **Airbus A350 XWB** is 53% CFRP**[21]** including wing spars and fuselage components, overtaking the **Boeing 787 Dreamliner**, for the aircraft with the highest weight ratio for CFRP at 50%.**[22]** It was one of the first commercial aircraft to have wing spars made from composites. The **Airbus A380** was one of the first commercial airliners to have a central wing-box made of CFRP and the first with a smoothly contoured wing cross-section instead of partitioning it span-wise into sections. This flowing, continuous cross section optimises aerodynamic efficiency.[*citation needed*] Moreover, the trailing edge, along with the rear bulkhead, **empennage**, and un-pressurised fuselage are made of CFRP.[23]

However, delays have pushed order delivery dates back because of manufacturing problems. Many aircraft that use CFRPs have experienced delays with delivery dates due to the relatively new processes used to make CFRP components, whereas metallic structures are better understood. A recurrent problem is the monitoring of structural ageing, for which new methods are required, due to the unusual multi-material and anisotropic[24][25][26] nature of CFRPs.[27]

In 1968 a *Hyfil* carbon-fiber fan assembly was in service on the **Rolls-Royce Conways** of the **Vickers VC10s** operated by **BOAC**.[28]

Specialist aircraft designers and manufacturers **Scaled Composites** have made extensive use of CFRPs throughout their design range, including the first private crewed spacecraft **Spaceship One**. CFRPs are widely used in **micro air vehicles** (MAVs) because of their high strength-to-weight ratio.

Airbus then moved to adopt CFRTP, because it can be reshaped and reprocessed after forming, can be manufactured faster, has higher impact resistance, is recyclable and remoldable, and has lower processing costs.[29]

Automotive engineering

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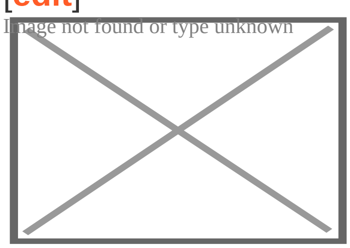
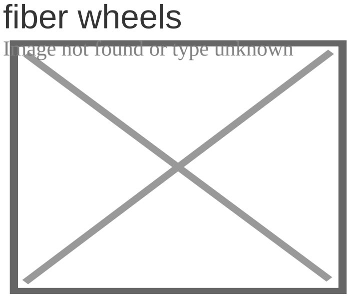
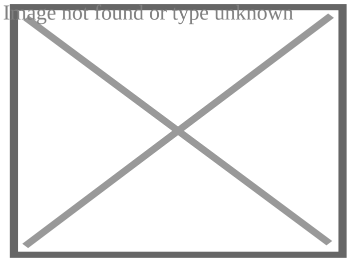


Citroën SM that won 1971 **Rally of Morocco** with carbon fiber wheels



1996 McLaren F1 – first carbon fiber body shell



McLaren MP4 (MP4/1), first carbon fiber F1 car

CFRPs are extensively used in high-end automobile racing.[30] The high cost of carbon fiber is mitigated by the material's unsurpassed strength-to-weight ratio, and low weight is essential for high-performance automobile racing. Race-car manufacturers have also developed methods to give carbon fiber pieces strength in a certain direction, making it strong in a load-bearing direction, but weak in directions where little or no load would be placed on the member. Conversely, manufacturers developed omnidirectional carbon fiber weaves that apply strength in all directions. This type of carbon fiber assembly is most widely used in the "safety cell" **monocoque** chassis assembly of high-performance race-cars. The first carbon fiber monocoque chassis was introduced in **Formula One** by **McLaren** in the 1981 season. It was designed by **John Barnard** and was widely copied in the following seasons by other F1 teams due to the extra rigidity provided to the chassis of the cars.[31]

Many **supercars** over the past few decades have incorporated CFRPs extensively in their manufacture, using it for their monocoque chassis as well as other components.[32] As far back as 1971, the **Citroën SM** offered optional lightweight carbon fiber wheels.[33][34]

Use of the material has been more readily adopted by low-volume manufacturers who used it primarily for creating body-panels for some of their high-end cars due to its increased strength and decreased weight compared with the **glass-reinforced polymer** they used for the majority of their products.

Civil engineering

[edit]
Further information: **Structural applications of FRP**

CFRPs have become a notable material in **structural engineering** applications. Studied in an academic context as to their potential benefits in construction, CFRPs have also proved themselves cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron, and timber structures. Their use in industry can be either for **retrofitting** to strengthen an existing structure or as an alternative reinforcing (or prestressing) material instead of steel from the outset of a project.

Retrofitting has become the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures (such as bridges, beams, ceilings, columns and walls) that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed the cost of strengthening using CFRP.[35]

Applied to reinforced concrete structures for flexure, the use of CFRPs typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only moderately increases **stiffness** (as little as 10%). This is because the material used in such applications is typically very strong (e.g., 3 GPa ultimate **tensile strength**, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa elastic modulus, a little less than steel, is typical). As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness.

CFRPs can also be used to enhance **shear strength** of reinforced concrete by wrapping fabrics or fibers around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the **ductility** of the section, greatly increasing the resistance to collapse under dynamic loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economic than alternative methods.

If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the CFRP wrap enhances the **compressive strength** of the concrete. However, although large increases are achieved in the ultimate collapse load, the concrete will crack at only slightly enhanced load, meaning that this application is only occasionally used. Specialist ultra-high modulus CFRP (with tensile modulus of 420 GPa or more) is one of the few practical methods of strengthening **cast iron** beams. In typical use, it is bonded to the tensile flange of the section, both increasing the stiffness of the section and lowering the **neutral axis**, thus greatly reducing the maximum tensile stress in the cast iron.

In the United States, **prestressed concrete** cylinder pipes (PCCP) account for a vast majority of water transmission mains. Due to their large diameters, failures of PCCP are usually catastrophic and affect large populations. Approximately 19,000 miles (31,000 km) of PCCP were installed between 1940 and 2006. **Corrosion** in the form of hydrogen embrittlement has been blamed for the gradual deterioration of the prestressing wires in many PCCP lines. Over the past decade, CFRPs have been used to internally line PCCP, resulting in a fully structural strengthening system. Inside a PCCP line, the CFRP liner acts as a barrier that controls the level of strain experienced by the steel cylinder in the host pipe. The composite liner enables the steel cylinder to perform within its elastic range, to ensure the pipeline's long-term performance is maintained. CFRP liner designs are based on strain compatibility between the liner and host pipe.[36]

CFRPs are more costly materials than commonly used their counterparts in the construction industry, **glass fiber-reinforced polymers** (GFRPs) and **aramid** fiber-reinforced polymers (AFRPs), though CFRPs are, in general, regarded as having superior properties. Much research continues to be done on using CFRPs both for retrofitting and as an alternative to steel as reinforcing or prestressing materials. Cost remains an issue and long-term **durability** questions still remain. Some are concerned about the **brittle** nature of CFRPs, in contrast to the ductility of steel. Though design codes have been drawn up by institutions such as the **American Concrete Institute**, there remains some hesitation among the engineering community about implementing these alternative materials. In part, this is due to a lack of standardization and the proprietary nature of the fiber and resin combinations on the market.

Carbon-fiber microelectrodes

[**edit**]

Carbon fibers are used for fabrication of carbon-fiber **microelectrodes**. In this application typically a single carbon fiber with diameter of 5–7 ?m is sealed in a glass capillary.[37] At the tip the capillary is either sealed with epoxy and polished to make carbon-fiber disk microelectrode or the fiber is cut to a length of 75–150 ?m to make carbon-fiber cylinder electrode. Carbon-fiber microelectrodes are used either in **amperometry** or **fast-scan cyclic voltammetry** for detection of biochemical signalling.

Sports goods

[**edit**]

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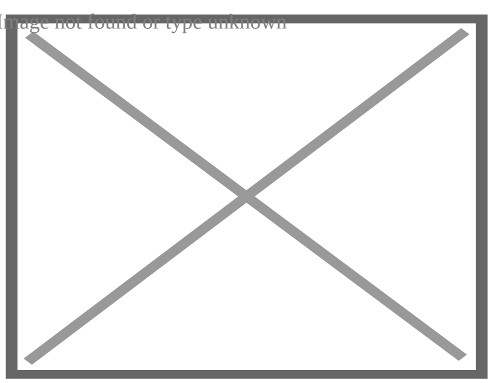

A carbon-fiber and **Kevlar** canoe (Placid Boatworks Rapidfire at the **Adirondack Canoe Classic**)

CFRPs are now widely used in sports equipment such as in squash, tennis, and badminton racquets, **sport kite** spars, high-quality arrow shafts, hockey sticks, fishing rods, **surfboards**, high end swim fins, and rowing **shells**. Amputee athletes such as **Jonnie Peacock** use carbon fiber blades for running. It is used as a shank plate in some **basketball** sneakers to keep the foot stable, usually running the length of the shoe just above the sole and left exposed in some areas, usually in the arch.

Controversially, in 2006, cricket bats with a thin carbon-fiber layer on the back were introduced and used in competitive matches by high-profile players including **Ricky Ponting** and **Michael Hussey**. The carbon fiber was claimed to merely increase the durability of the bats, but it was banned from all first-class matches by the **ICC** in 2007.**[38]**

A CFRP **bicycle frame** weighs less than one of steel, aluminum, or **titanium** having the same strength. The type and orientation of the carbon-fiber weave can be designed to maximize stiffness in required directions. Frames can be tuned to address different riding styles: sprint events require stiffer frames while endurance events may require more flexible frames for rider comfort over longer periods.**[39]** The variety of shapes it can be built into has further increased stiffness and also allowed **aerodynamic** tube sections. CFRP **forks** including suspension fork crowns and steerers, **handlebars**, **seatposts**, and **crank arms** are becoming more common on medium as well as higher-priced bicycles. CFRP **rims** remain expensive but their stability compared to aluminium reduces the need to re-true a wheel and the reduced mass reduces the **moment of inertia** of the wheel. CFRP spokes are rare and most carbon wheelsets retain traditional stainless steel spokes. CFRPs also appear increasingly in other components such as derailleur parts, brake and shifter levers and bodies, cassette sprocket carriers, suspension linkages, disc brake rotors, pedals, shoe soles, and saddle rails. Although strong and light, impact, over-torquing, or improper installation of CFRP components has resulted in cracking and failures, which may be difficult or impossible to repair.**[40][41]**

Other applications

[**edit**]

Dunlop "Max-Grip" carbon fiber guitar picks. Sizes 1mm and Jazz III.

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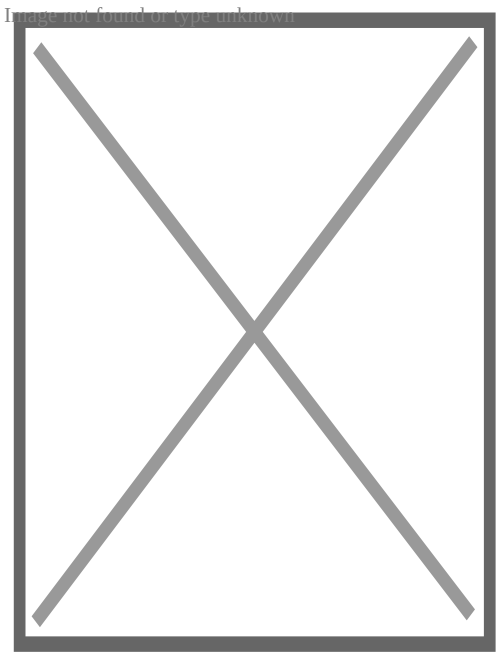
Dunlop "Max-Grip" carbon fiber guitar picks. Sizes 1mm and Jazz III.

The fire resistance of polymers and thermo-set composites is significantly improved if a thin layer of carbon fibers is moulded near the surface because a dense, compact layer of carbon fibers efficiently reflects heat.**[42]**



Strandberg Boden Plini **neck-thru** & **bolt on** versions that both utilize carbon fiber reinforcement strips to maintain rigidity.

CFRPs are being used in an increasing number of high-end products that require stiffness and low weight, these include:

- Musical instruments, including violin bows; guitar picks, guitar necks (fitted with carbon fiber rods), **pickguards**/scratchplates; drum shells; bagpipe chanters; piano actions; and entire musical instruments such as carbon fiber cellos, violas, and violins, acoustic guitars and ukuleles; also, audio components such as turntables and loudspeakers.
- Firearms use it to replace certain metal, wood, and fiberglass components but many of the internal parts are still limited to metal alloys as current reinforced plastics are unsuitable.
- High-performance drone bodies and other radio-controlled vehicle and aircraft components such as helicopter rotor blades.
- Lightweight poles such as: tripod legs, tent poles, fishing rods, billiards cues, walking sticks, and high-reach poles such as for window cleaning.
- Dentistry, **carbon fiber posts** are used in restoring root canal treated teeth.
- Railed train **bogies** for passenger service. This reduces the weight by up to 50% compared to metal bogies, which contributes to energy savings.**[43]**
- Laptop shells and other high performance cases.
- Carbon woven fabrics.**[44][45]**

- Archery: carbon fiber arrows and bolts, **stock** (for crossbows) and **riser** (for vertical bows), and rail.
- As a filament for the 3D fused deposition modeling printing process,**[46]** carbon fiber-reinforced plastic (polyamide-carbon filament) is used for the production of sturdy but lightweight tools and parts due to its high strength and tear length.**[47]**
- District heating pipe rehabilitation, using a **CIPP** method.

Disposal and recycling

[**edit**]

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The key aspect of recycling fiber-reinforced polymers is preserving their mechanical properties while successfully recovering both the **thermoplastic** matrix and the reinforcing fibers. CFRPs have a long service lifetime when protected from the sun. When it is time to decommission CFRPs, they cannot be melted down in air like many metals. When free of vinyl (PVC or **polyvinyl chloride**) and other halogenated polymers, CFRPs recycling processes can be categorized into four main approaches: mechanical, **thermal**, chemical, and biological. Each method offers distinct advantages in terms of material or **energy recovery**, contributing to **sustainability** efforts in composite waste management.

Process	Matrix recovery	Fiber recovery	Degradation of Mechanical Properties	Advantages/Drawbacks
Mechanical	X	X	X	+No use of hazardous chemical substances +No gas emissions +Low-cost energy needed +Big volumes can be recycled -Poor bonding between fiber/matrix -Fibers can damage the equipment
Chemical		X		+Long clean fibers +Retention of mechanical properties +Sometimes there is high recovery of the matrix -Expensive equipment -Possible use of hazardous solvent

Thermal	X	X	+Fiber length retention +No use of hazardous chemical substances +better mechanical properties than mechanical approach +Matrix used to produce energy -Recovered fiber properties highly influenced by process parameters -some processes have no recovery of matrix material

Mechanical Recycling

[edit]

The mechanical process primarily involves grinding, which breaks down composite materials into pulverulent charges and fibrous reinforcements. This method is focused on both the thermoplastic and filler material recovery; however, this process shortens the fibers dramatically. Just as with downcycled paper, the shortened fibers cause the recycled material to be weaker than the original material. There are still many industrial applications that do not need the strength of full-length carbon fiber reinforcement. For example, chopped reclaimed carbon fiber can be used in consumer electronics, such as laptops. It provides excellent reinforcement of the polymers used even if it lacks the strength-to-weight ratio of an aerospace component.[48]

Electro fragmentation

[edit]

This method consists in shredding CFRP by pulsed electrical discharges. Initially developed to extract crystals and precious stones from mining rocks, it is now expected to be developed for composites. The material is placed in a vessel containing water and two electrodes. The high voltage electrical pulse generated between the electrodes (50-200 kV) fragments the material into smaller pieces.[49] The inconvenient of this technique is that the energy consumed is 2.6 times the one of a mechanical route making it not economically competitive in terms of energy saving and needs further investigation.

Thermal Recycling

[**edit**]

Thermal processes include several techniques such as **incineration**, **thermolysis**, **pyrolysis**, **gasification**, fluidized bed processing, and **cement plant** utilization. This processes imply the recovery of the fibers by the removal of the **resin** by volatilizing it, leading to by-products such as gases, liquids or inorganic matter.**[50]**

Oxidation in fluidized bed

[**edit**]

This technique consists in exposing the composite to a hot and **oxygen-rich** flow, in which it is combusted (450–550 °C, 840–1,020 °F) . The working temperature is selected in function of the matrix to be **decomposed**, to limit damages of the fibers. After a shredding step to 6-20 mm size, the composite is introduced into a bed of **silica sand**, on a metallic mesh, in which the resin will be decomposed into oxidized molecules and fiber filaments. These components will be carried up with the air stream while heavier particles will sink in the bed. This last point is a great advantage for contaminated end-of-life products, with painted surfaces, **foam cores** or metal insert. A **cyclone** enables the recovery of fibers of length ranging between 5 and 10 mm and with very little contamination . The matrix is fully oxidized in a second burner operating at approximatively 1,000 °C (1,850 °F) leading to **energy recovery** and a clean flue gas.**[51]**

Chemical Recycling

[**edit**]

The chemical recycling of CFRPs involves using a reactive **solvent** at relatively low temperatures (below 350°C) to break down the resin while leaving the fibers intact for reuse. The solvent degrades the composite matrix into smaller molecular fragments (**oligomer**), and depending on the chosen solvent system, various processing parameters such as temperature, pressure, and **catalysts** can be adjusted to optimize the process. The solvent, often combined with **co-solvents** or catalysts, penetrates the composite and **breaks specific chemical bonds**, resulting in recovered **monomers** from the resin and clean, long fibers with preserved mechanical properties. The required temperature and pressure depend on the type of resin, with **epoxy resins** generally needing higher temperatures than polyester resins. Among the different reactive mediums studied, water is the most commonly used due to its environmental benefits. When combined with **alkaline** catalysts, it effectively degrades many resins, while **acidic** catalysts are used for more resistant polymers. Other solvents, such as **ethanol**, **acetone**, and their mixtures, have also been explored for this process.

Despite its advantages, this method has some limitations. It requires specialized equipment capable of handling **corrosive** solvents, hazardous chemicals, and high temperatures or pressures, especially when operating under **supercritical** conditions. While extensively researched at the laboratory scale, industrial adoption remains limited, with the technology currently reaching a **Technology Readiness Level** (TRL) of 4 for carbon fiber recycling.[52]

Dissolution Process

[**edit**]

The dissolution process is a method used to recover both the polymer matrix and fibers from thermoplastic composites without breaking **chemical bonds**. Unlike **solvolysis**, which involves the **chemical degradation** of the polymer, dissolution simply dissolves the polymer chains into a solvent, allowing for material recovery in its original form. An energy analysis of the process indicated that dissolution followed by **evaporation** was more energy-efficient than **precipitation**. Additionally, avoiding precipitation helped minimize polymer loss, improving overall material recovery efficiency. This method offers a promising approach for sustainable recycling of thermoplastic composites.[53]

Biological Recycling

[**edit**]

The biological process, though still under development, focuses on **biodegradation** and **composting**. This method holds promise for bio-based and agro-composites, aiming to create an environmentally friendly end-of-life solution for these materials. As research advances, biological recycling may offer an effective means of reducing plastic composite waste in a sustainable manner.[54]

Carbon nanotube reinforced polymer (CNRP)

[**edit**]

In 2009, **Zyvex Technologies** introduced carbon nanotube-reinforced epoxy and carbon **pre-pregs**.[55] **Carbon nanotube** reinforced polymer (CNRP) is several times stronger and tougher than typical CFRPs and is used in the **Lockheed Martin F-35 Lightning II** as a structural material for aircraft.[56] CNRP still uses carbon fiber as the primary reinforcement,[57] but the binding matrix is a carbon nanotube-filled epoxy.[58]

See also

[**edit**]

- **Carbon fibers** – Material fibers about 5–10 ?m in diameter composed of carbon
- **Composite repair** – Composite repair patch preparation and application
- **Mechanics of Oscar Pistorius's running blades** – Blades used by South African Paralympic runner Oscar Pistorius
- **Reinforced carbon–carbon** – Graphite-based composite material
- **Forged carbon fiber**
- **Carbon-ceramic**
- **Carbotanium**

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