Continuous Fiber Reinforced Thermoplastic Composites

Performance Advantages & Applications

INTRODUCTION

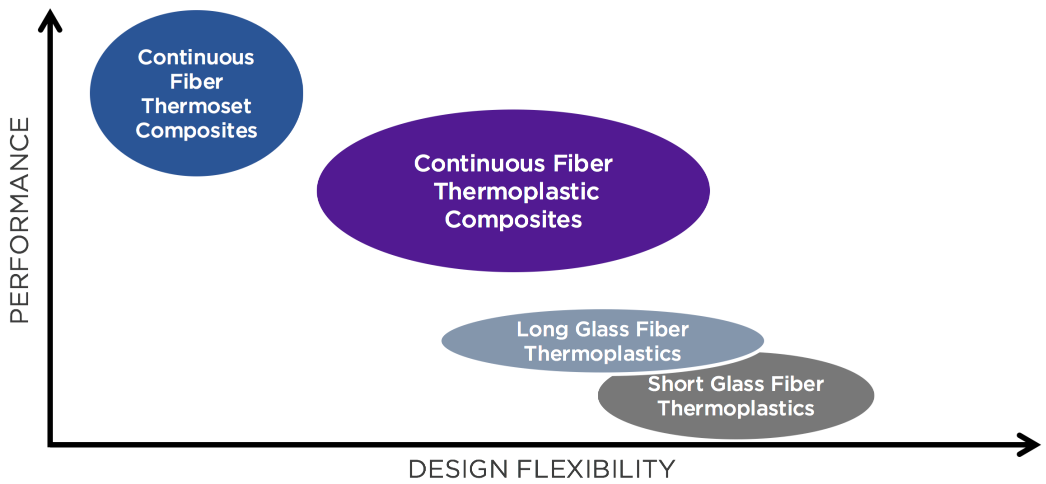
Continuous fiber reinforced thermoplastic (CFRTP) composites, produced in unidirectional tapes and laminate configurations, have the unique ability to add strength and stiffness while reducing manufacturing cycle times and enabling part consolidation of structural components in a wide variety of applications.

In this whitepaper, you will learn:

- What continuous fiber reinforced thermoplastic (CFRTP) composites are and how they differ from other composite materials
- Mechanical characteristics and advantages of CFRTPs
- Secondary forming of CFRTPs and methods for manufacturing complex geometries
- Various applications that benefit from the advantages of CFRTPs

COMPARING COMPOSITES

COMMON COMPOSITE MATERIALS: PERFORMANCE VS. DESIGN FLEXIBILITY

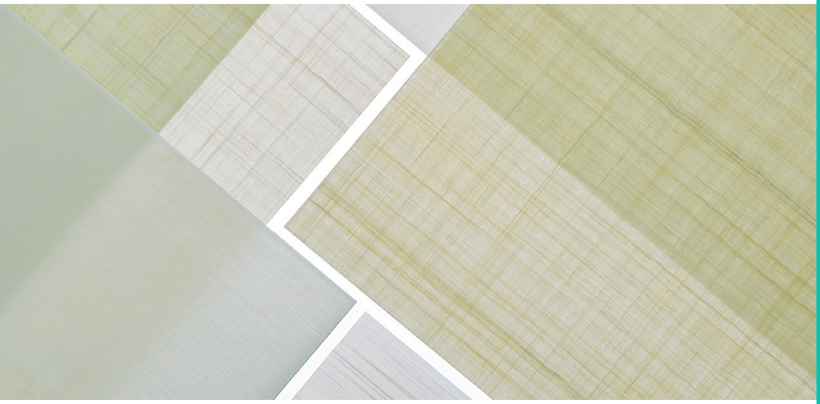


Design engineers know that when high strength-to-weight ratio is required, composites are the material of choice. But choosing which composite material out of the spectrum of reinforcement and matrix combinations—from short to long to continuous fibers, and thermoset to thermoplastic resin formulations—is not so simple. Two characteristics often used to compare the attributes of composite materials are performance and design flexibility. These factors can help determine which material is best suited to a particular application, based on processing and functional requirements.

Continuous fiber reinforced thermoset composites combine high molecular weight resins with glass or carbon fibers. These products can operate at high temperatures and have strong mechanical properties. However, design flexibility is limited because as thermosets, finished parts cannot be post formed. Continuous fiber reinforced thermoset materials perform well in applications such as composite springs and archery bow limbs where consistent flexural performance is needed, and electrical transmission and distribution components where lightweight strength and weatherability are critical.

Long and short fiber reinforced thermoplastics provide outstanding design flexibility but offer varying ranges of performance depending on their specific material composition. It is possible to create injection or compression molded plastic parts that would be difficult or impossible to machine using traditional materials such as steel or aluminum. These parts can be molded with assembly features in place to reduce product fabrication and secondary operations. Long and short fiber reinforced thermoplastics are well suited for applications requiring high strength-to-weight ratios as well as complex part geometries, such as automotive components and sporting goods.

Continuous fiber reinforced thermoplastic composites offer a proportional balance of both performance and design flexibility. The continuous fiber reinforcement provides strong and stiff material performance while the thermoplastic resin matrix enables design flexibility through post forming. These materials can be formed into multi-ply laminates to offer off-axis performance, post molded into complex shapes and overmolded with traditional thermoplastics to provide localized reinforcement in specific part locations. Various forming processes and application examples of CFRTP materials will be discussed later in this paper.

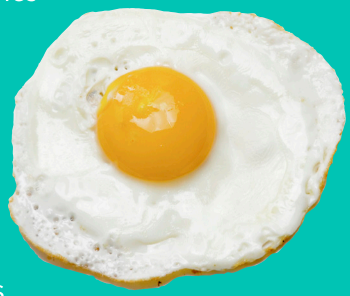


CFRTP STRUCTURE AND PERFORMANCE

Continuous fiber reinforced thermoplastic composites are produced by pulling continuous glass rovings through thermoplastic resin to impregnate the fibers and form a unidirectional tape. This single-ply tape can be layered to form multi-axial laminates by stacking layers of tape in varying directions and applying heat and pressure. The orientation, location, and volume of the fibers contribute to the strength and performance of the laminate structure.

THERMOSETS AND THERMOPLASTICS – WHAT'S THE DIFFERENCE?

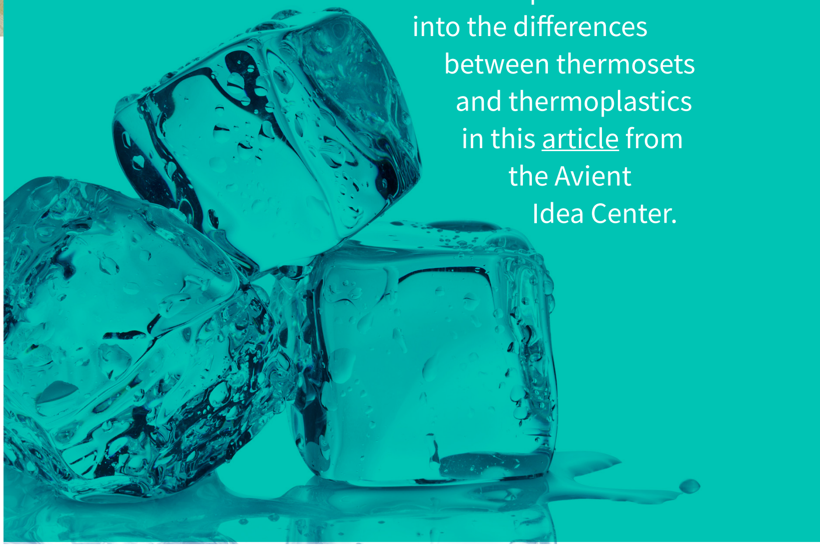
Thermoset resins are liquid polymers that become solid and permanent once cured using heat or another catalyst. Imagine an egg cracked from its shell that begins in liquid form and solidifies as heat is applied. This process is irreversible—it is impossible for the egg, once cooked, to become liquid again. Similarly, thermosets, once cured and formed, cannot be uncured, melted, or reshaped. Common thermosets used in forming composites include polyester, epoxy, vinyl ester and polyurethane.



Thermoplastic resin starts in solid pellet form. The pellets are melted to a liquid state and fibers are pulled through the resin to form a continuous fiber reinforced thermoplastic tape. Just as ice is a solid material when it is frozen, it melts with heat and becomes a liquid. The liquid can be frozen to become solid ice again, and the process can be repeated over and over. Thermoplastics behave similarly in that they can be melted and re-formed through the application of heat.

Thermoplastic polymers commonly used in composite materials include polyethylene (PE), polypropylene (PP), polyethylene terephthalate glycol (PETG), polycarbonate (PC) and nylon (PA).

Take a deeper dive into the differences between thermosets and thermoplastics in this article from the Avient Idea Center.

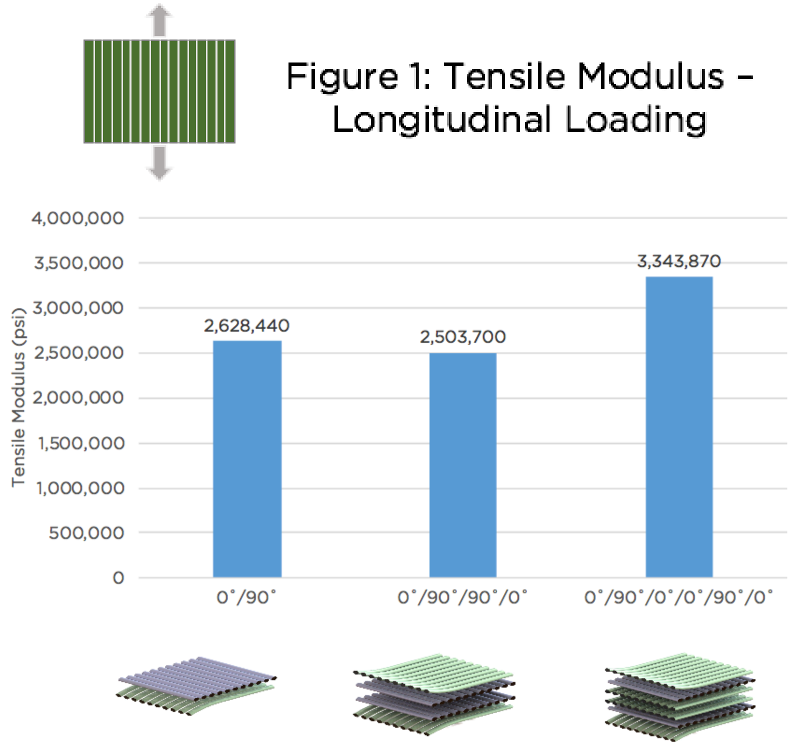


Tensile Modulus

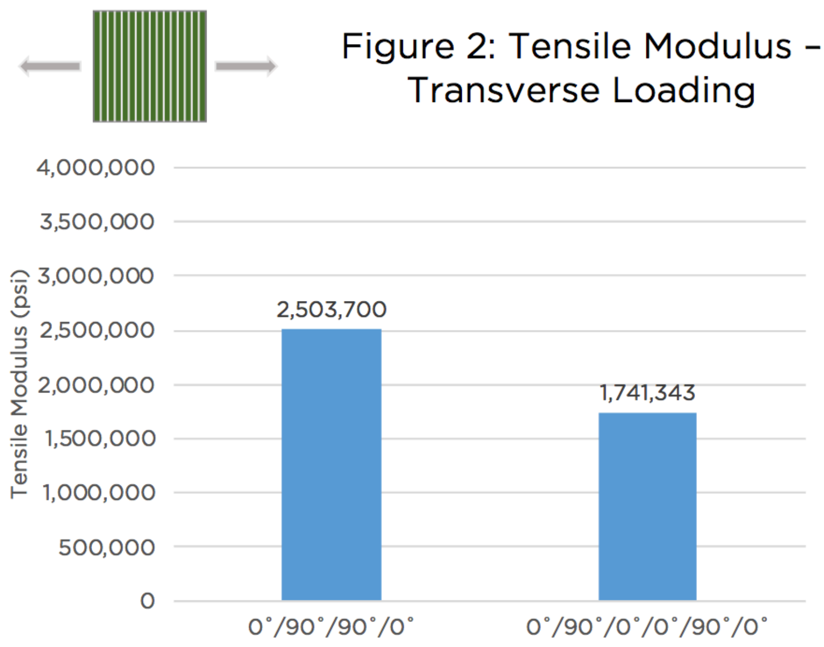
Tensile modulus measures the ratio of stress to strain along an axis and is one way to quantify the strength and stiffness of a composite material. For example, when load or tension is placed on a composite longitudinally (in the direction of the fiber), the fiberglass reinforcement is resistant to the loading. The fibers will pull and eventually fracture but will withstand high loads due to the high tensile modulus of the reinforcement.

In contrast, when the loading is perpendicular, or transverse, to the fiber, the matrix of the composite is resisting the load. The resin has a lower tensile modulus than the reinforcement and will fracture at lower loads in this direction.

Figure 1 shows the result of tensile load applied longitudinally to three laminate samples made with Polystrand™ continuous glass fiber reinforced polypropylene in 2-, 4- and 6-ply configurations, illustrated below. The first two samples show similar tensile performance. This is due to the proportion of fibers in the load direction—in both cases 50% of the layers are oriented in the longitudinal direction, resulting in similar tensile modulus. The third column has the highest tensile modulus. The laminate is designed for this load two-thirds of the layers oriented in the 0-degree direction. The greater ratio of fibers placed in the direction of the load increases the tensile modulus of the laminate.



Increasing fibers in the direction of the load improves directional stiffness.

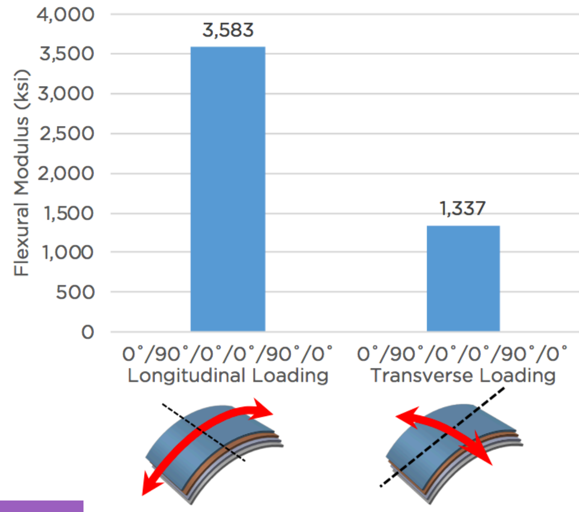


The 4- and 6-ply samples in Figure 2 were loaded in the transverse direction. The 4-ply sample here has similar tensile performance as the 4-ply sample in Figure 1, which is expected because the two samples contain an equal balance of 0- and 90-degree fibers. The 6-ply sample has the lowest tensile modulus because the fiber loading in the transverse direction is much lower.

Flexural Modulus

The flexural modulus indicates a material's resistance to bending. In Figure 3, the 6-ply samples had flexural loads applied in both the longitudinal and transverse directions. The 6-ply sample has the highest flexural modulus when loaded in the longitudinal direction due to the higher ratio of 0-degree layers, as well as the location of the 0-degree fibers outside of the neutral axis. This same laminate configuration loaded in the transverse direction exhibits much lower flexural performance because there are fewer transversely oriented fibers to resist the bending load.

Figure 3: Flexural Modulus – Longitudinal & Transverse Loading



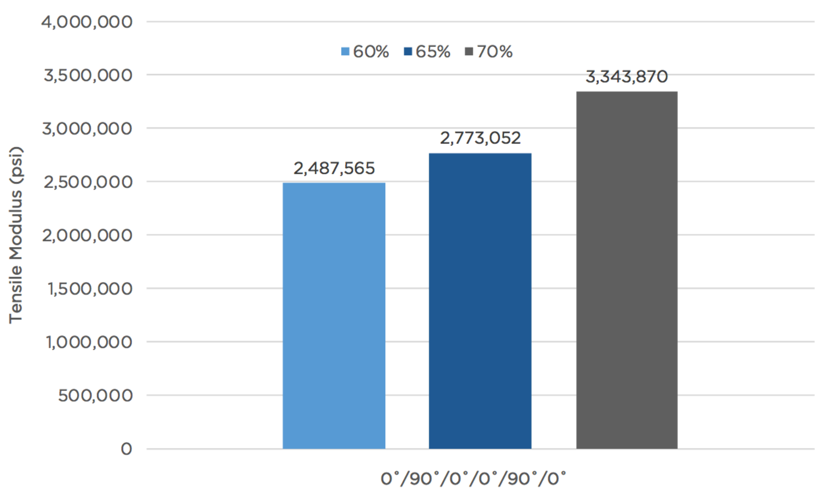
By combining unidirectional composite tapes into multi-axial, multi-layered laminates at specified fiber volumes, CFRTP materials can be designed to provide customized mechanical properties to meet specific performance targets.

Fiber Volume

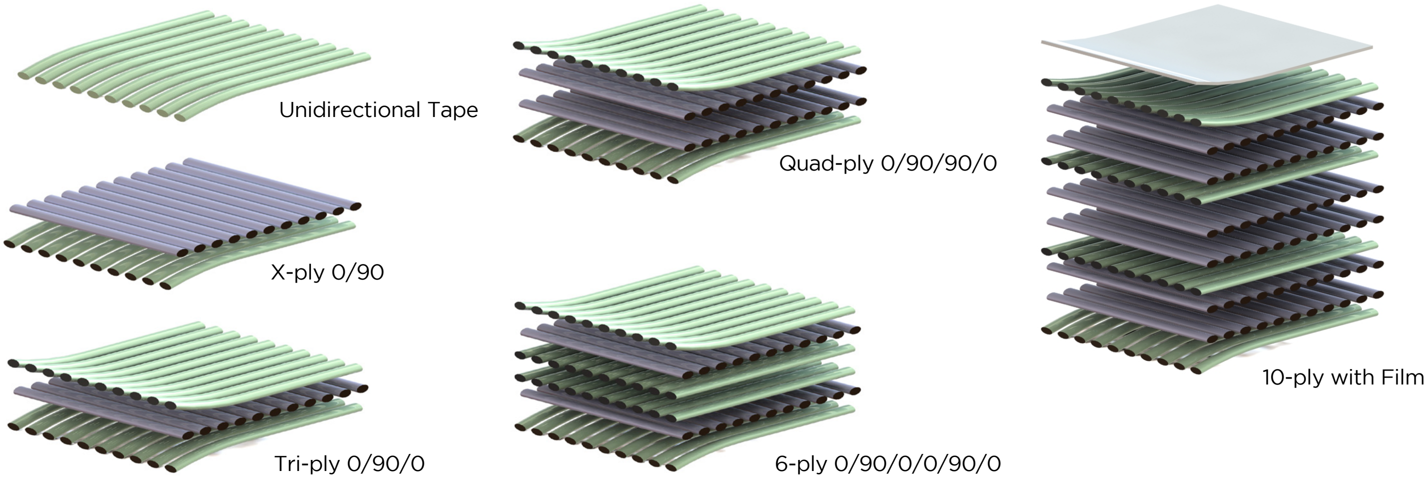
Fiber volume is the ratio of fiber to resin in a composite structure. Increasing the fiber volume of a composite increases its mechanical performance as illustrated in Figure 4. In general, the more fiber in the structure, the higher the performance. CFRTP composite materials can be produced with fiber volume percentages ranging from 58% to 80% to achieve specific performance requirements depending on the intended application.

Fiber orientation, fiber location and fiber volume are three key variables in composite laminate design that affect the performance of the finished composite. By combining unidirectional composite tapes into multi-axial, multi-layered laminates at specified fiber volumes, CFRTP materials can be designed to provide customized mechanical properties to meet specific performance targets.

Figure 4: Effect of Fiber Volume on Tensile Modulus



A 10% increase in fiber volume improved laminate stiffness by 25%.



Examples of Polystrand™ CFRTP composite laminate configurations

FORMING METHODS

The design flexibility of thermoplastic resins enables the use of high-volume thermal forming manufacturing processes such as compression molding and vacuum forming with CFRTP materials. They can be used alone or in conjunction with other materials such as thermoplastics, wood, and metal, and with techniques such as overmolding, coextrusion, and thermal lamination to incorporate CFRTP tapes and laminates into hybrid, multi-material structures. These processes minimize weight and maximize design efficiency by providing localized reinforcement, applying the composite materials in targeted areas to achieve structural performance requirements at accelerated production rates.

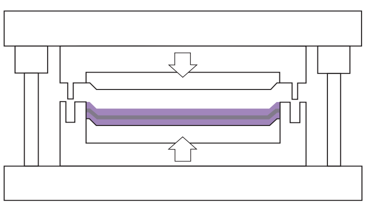


Diagram: matched metal compression molding

Matched Metal Compression Molding

Matched metal compression molding is a common method for producing components with CFRTP laminates. Fast cycle times are achieved with this process, and the process can be automated. A video demonstration of compression molding using Avient's Polystrand CFRTP material can be viewed here.

Vacuum Bagging

A lower pressure method than compression molding, vacuum bagging uses vacuum pressure to compress the material into a final shape. Vacuum bagging enables fast cycle times, with simpler equipment requirements compared to other methods.

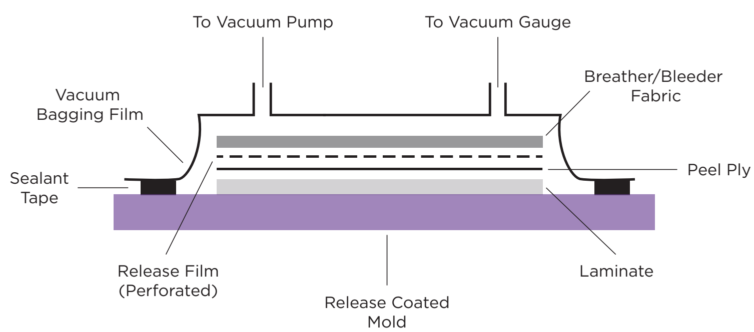


Diagram: Vacuum bagging process

Thermal Lamination

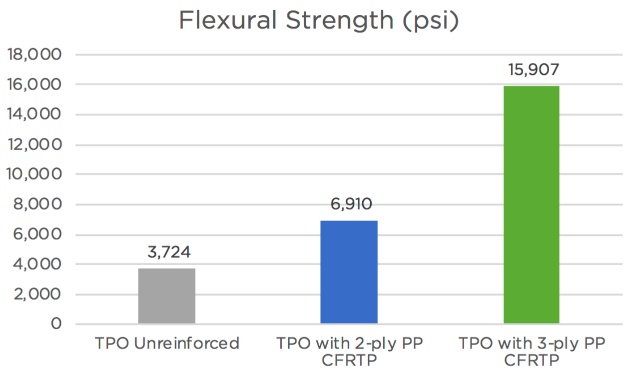
The adhesive properties of thermoplastics enable the construction of sandwich panels and reinforcement of materials such as wood and metal through thermal lamination without requiring the use of additional adhesives. By eliminating secondary processes, thermal lamination facilitates fast throughput in manufacturing for an economical end product.

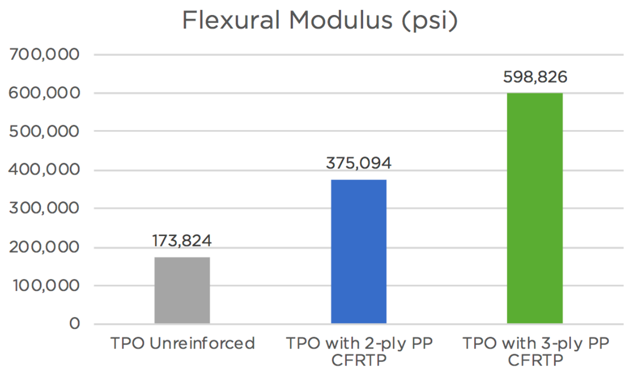
Co-molding Hybrid Structures

CFRTP can also be molded on or into thermoplastic structures via hybrid compression and injection overmolding to create locally-reinforced, molded components in a one-shot process. Incorporating CFRTP reinforcement in molded thermoplastic components combines the design flexibility and fast cycle times of traditional molding with the strength, stiffness, and lightweighting benefits that composites offer, all with the use of standard processing equipment.

Figures 5 and 6 illustrate the advantages that can be gained by incorporating CFRTP materials with traditional thermoplastics. In this case, unreinforced thermoplastic olefin was molded with a 2-ply and a 3-ply CFRTP laminate. Comparisons reveal significant improvements in flexural strength and flexural modulus vs. the unreinforced material: up to **327% increase in flexural strength and 245% increase in flexural modulus with the 3-ply reinforcement.**

Figure 5 & 6: Flexural Properties of TPO with CFRTP Reinforcement



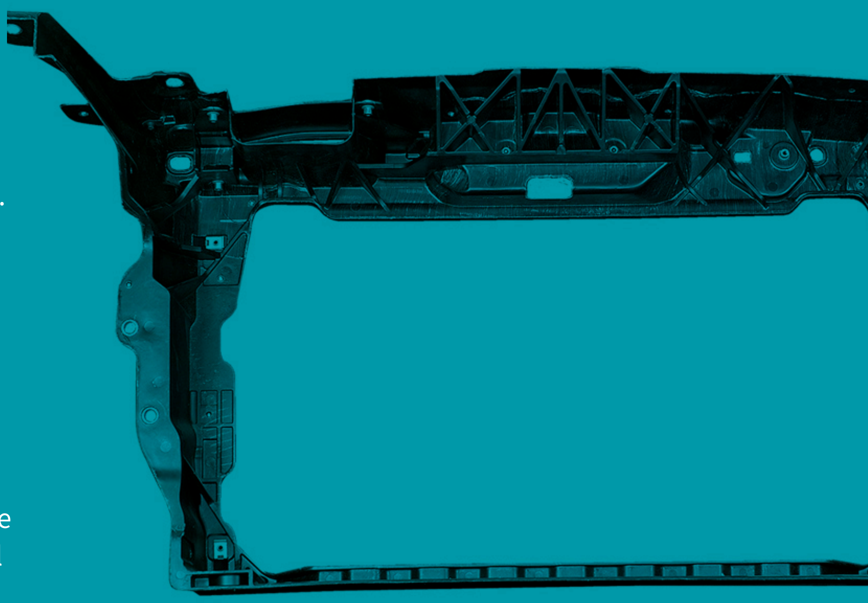


CASE STUDY: AUTOMOTIVE FRONT END MODULE

CHALLENGE: A market-leading tier 1 supplier needed to improve the strength of the front end module to prevent the vehicle hood latch from opening in a crash. The existing solution—reinforcing the latch area with a steel plate—added vehicle weight and involved additional manufacturing processes, increasing time and cost.

SOLUTION: Polystrand continuous fiber reinforced thermoplastic 6-ply laminate sheet was integrated into the direct long fiber thermoplastic (DLFT) manufacturing process and applied via compression molding.

IMPACT: The CFRTP reinforcement improved strength and performance in the high-stress latch area and resolved crash test issues. By replacing the metal plate and integrating the Polystrand material into the molded part, the supplier saved 8 pounds of overall vehicle weight.



APPLICATIONS FOR CFRTP

Continuous fiber reinforced thermoplastic composites are well suited for applications where strength, stiffness, impact resistance or corrosion resistance are required. Some examples include:

AUTOMOTIVE
Underbody shields, underhood enclosures, interior components, storage areas

BUILDING & CONSTRUCTION
Reinforcement of wood products & plywood, window lineals, ceiling tiles, pipe reinforcement

MARINE
Panels for decking, bulkheads, cabinets, doors, transoms & stringers, hull reinforcement

SECURITY & DEFENSE
Ballistic-resistant panels and body armor, vehicle armor

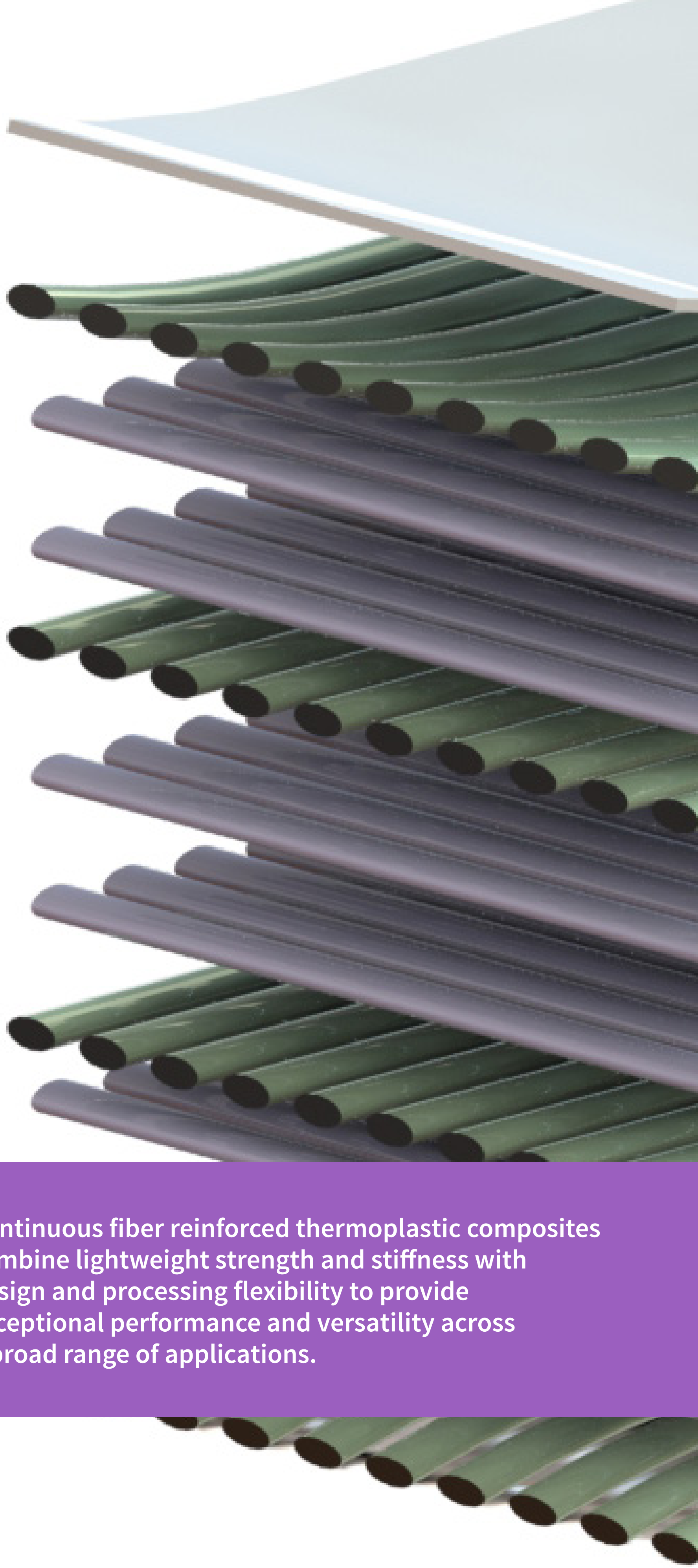
TRANSPORTATION
Truck floors, liners and aerodynamic components, railcar panels, air cargo containers

CONSUMER
Sporting goods and protective equipment, furniture, electronics

CONCLUSION

Continuous fiber reinforced thermoplastic composites offer a balance of performance characteristics together with design and processing flexibility that is unmatched by other composite materials. In unidirectional tape or multi-axial laminate form, CFRTPs give design engineers customizable options to incorporate lightweight strength and stiffness into demanding applications ranging from air cargo containers to snowboard bindings to automotive hatch covers.

For more information on Polystrand continuous fiber reinforced thermoplastic composites, or help with your next project, please call **1.844.4AVIENT** or visit **www.avient.com**.



Continuous fiber reinforced thermoplastic composites combine lightweight strength and stiffness with design and processing flexibility to provide exceptional performance and versatility across a broad range of applications.