# Benefits of CFRTP Composites in Sports

When and why to consider continuous fiber-reinforced thermoplastic composites in high-performance applications

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RE:BUILD MANUFACTURING

# 1. Introduction

Over the last thirty years, there has been a surge in research on composite materials and their ability and efficacy to replace existing material options across numerous industries. Composite materials, and specifically continuous fiber-reinforced thermoplastic (CFRTP) composites, are an attractive alternative to more traditional materials such as aluminum, steel, thermoset composites, or non-reinforced plastics because of attributes like a high strength-to-weight ratio, high stiffness, greater toughness, and chemical resistance. However, the benefits have been largely unrealized because the manufacturing technologies and processes needed to convert the materials into finished parts have lagged material science, until now. With newly developed automation and digital solutions being brought into the manufacturing process, CFRTP composites are positioned to be a disrupting technology – not only in sporting goods, but in markets such as aerospace, automotive, and medical as well.

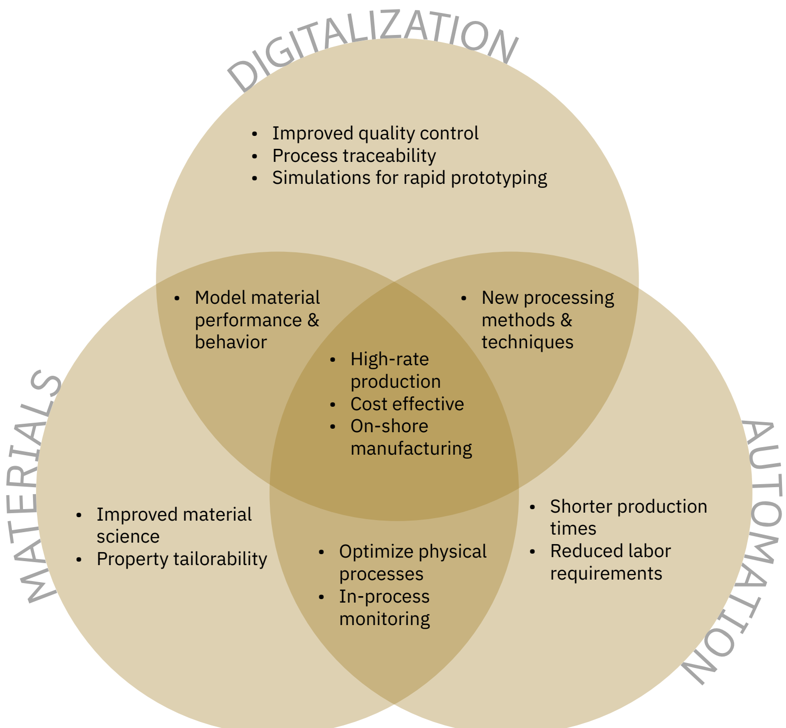


*Figure 1: Advancements in material science, automation technology, and digitalization enable the adoption of CFRTP composites.*

From the beginning, Oribi Composites (Denver, CO) has been focused on making thermoplastic composites more affordable and accessible, and over the years, has developed expertise in the processing technologies required to enable the adoption of thermoplastic composites in a wide range of industries. In 2021, Oribi was acquired by Re:Build Manufacturing (now Re:Build Oribi), bringing renewed investment to the expansion of Oribi's unique processing technologies for a variety of end use products. Oribi's technology has been particularly relevant to markets with rapid innovation cycles, lower barriers to entry, and minimal certification requirements, such as sporting goods & recreation, who tend to be early adopters of new material technologies.

# 2. Material Science in Sports

In high-performance sports and recreation, choosing the right material is critical. Material choice dictates the performance, feel, longevity, and market adoption of any equipment an athlete interacts with, whether that be a bat, helmet, board, or wheel. First, let's consider an athlete's performance from an engineering perspective. Fundamentally, it's the result of how much energy the athlete can generate and how effectively they can transmit that energy into the field of play, whether that's directly through their body (e.g. swimming) or through equipment (e.g. golf, hockey, tennis, running). Performance improves when energy loss, resistance, fatigue, and likelihood of injury are minimized, and energy restitution is maximized, all of which are properties that can be tailored with the right material. For companies seeking to deliver innovative products to the market that are lighter, stronger, and have a higher energy restitution, material selection is vital to designing a great product and doing so within budget. The materials commonly seen in high-performance sports today are metals, plastics, and thermoset composites. While all of these certainly have relevance and proven applications in the sporting goods market, thermoplastic composites have the potential to make another step change in athletic performance, but require affordable and scalable production technologies, as well as dedicated design and prototyping efforts, to support widespread adoption.

### *2.1 Composite Fundamentals*

A composite is two or more materials that have been brought together to create something entirely new, whose physical, chemical, and mechanical properties are an amalgamation of each materials' properties. This broad definition encapsulates a wide range of composites, but when it comes to high-performance applications, there are two types to recognize: continuous fiber-reinforced thermosets and continuous fiber-reinforced thermoplastics (there are also an array of discontinuous fiber composites,  but those are not in scope here). These

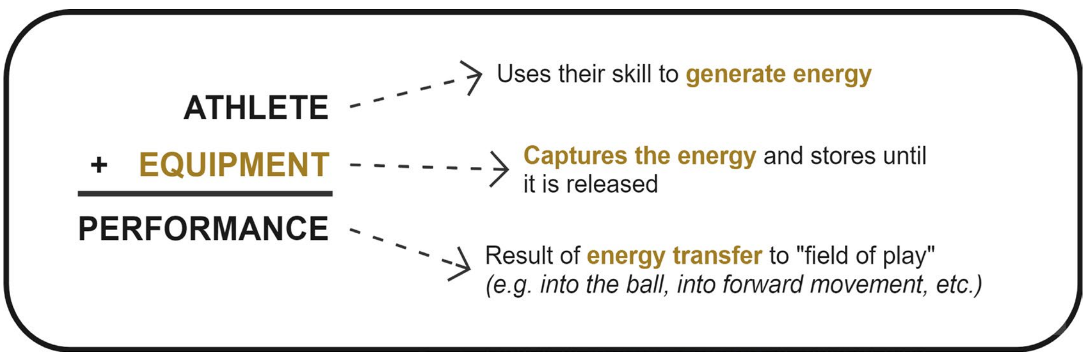


***Figure 2:*** *Equation showing how the athlete works with the equipment to translate the energy they generate into performance gains.*

***Figure 3:*** *Examples of CFRTP composite sports equipment.*

composites consist of a matrix material – the polymer – and a continuous length of fiber – usually glass, carbon, or aramid fiber. The use of fiber-reinforced composites dates back as far as the 1930s, when thermoset composite technologies were first being explored as a metal-alternative. During the 1990s, companies began to experiment with thermoplastics as the composite binder/matrix, signifying another advancement in material science. Both thermoset and thermoplastic composites were seen as capable of solving a wider range of problems, and the expanding knowledge base and available options led to increased adoption of composites in high-performance industries such as aerospace, automotive, and sports.[1] Today, composites are an attractive material choice for many applications due to their high strength-to-weight ratio, corrosion resistance, cost, and potential for high-volume production. So, what is a continuous fiber-reinforced thermoplastic composite? Let's break it down.

**Continuous fibers** are characterized by a very high length-to-diameter ratio, giving them superior mechanical properties over other fiber types (i.e. discontinuous or short fibers). The most common fibers used in sporting goods and other high-performance industries (e.g. aerospace) are glass and carbon, each with its own advantages, which are outlined in Table 1.

- **Glass:** the most common fiber type with great impact resistance at a low cost, but tends to be heavier and less rigid
- **Carbon:** more expensive than glass, but preferred in high-performance applications with excellent strength-to-weight ratio

**Thermoplastics** are a type of polymer that can be reformed or reshaped because the melt temperature ($T_m$) is lower than the degradation temperature. There is a wide range of engineered thermoplastic resins that can be used, which allows for extensive design flexibility at lower costs and faster production times. The final selection is then based on the specific end-use requirements, including considerations for the environment the product will be used in. Thermoplastic resins can be classified based on two properties: crystallinity and processing temperature, illustrated in Figure 4.

- **Crystallinity** refers to how aligned the polymer chains are with one another (i.e. a higher crystallinity equals greater alignment).[2] Polymer density and hardness increase with greater crystallinity, which makes them less favorable for composite applications. Amorphous (jumbled and random chains, no crystallinity) and semi-

| | Benefits | Hesitancies |
|---|---|---|
| **Glass (GF)** | • Low cost<br>• Impact resistant<br>• Availability | • Weight<br>• Less rigid |
| **Carbon (CF)** | • Strength-to-weight ratio<br>• Dimensional tolerance<br>• Favored in high-performance applications | • Lower impact resistance<br>• Elongation<br>• Cost |

***Table 1:*** *Distinctive characteristics of glass & carbon fibers.*

| | Amorphous | Semi-Crystalline |
|---|---|---|
| **Pros** | Strength, stiffness | Fatigue resistance |
| | Creep resistance | Chemical resistance |
| | Isotropic dimensional stability | Heat deflection below glass transition temperature |
| **Cons** | Chemical resistance | Temperature dependent stiffness |
| | Stress cracking | Opaque |
| | Processing challenges | Noticeable volume contraction |

***Table 2:*** *Pros and cons of amorphous and semi-crystalline polymers.*

crystalline resins are common choices, with amorphous being better for surface quality and finishing options and semi-crystalline being a more reliable choice for any functional component. A few pros and cons are shown in Table 2.

- **Processing temperature** is almost entirely a reflection of the chain morphology of the polymer, with some chains achieving better packing and thus a higher crystallinity than others. How the chains are packed and the degree of crystallization of the polymer influences the processing temperature requirements; higher processing temperatures may be the result of rigid aromatic rings being added into the molecular structure, which restricts the chain movement and improves the thermal stability of the polymer. High-temperature thermoplastics also have better resistance to chemicals, wear, radiation, and burning, and often have superior mechanical performance.[12] It may seem that high-temperature thermoplastics are the obvious choice then, but there's a trade-off between performance and cost; high-temp plastics may cost 1-2 orders of magnitude more per lbs. than commodity plastics.

When selecting a material, understanding the mechanical performance requirements and environmental conditions the product will be used in are important; these considerations should be part of the design process to ensure the product performs as required.

One challenge thermoplastic composite manufacturers are facing with high temperature materials is that the processing temperatures are outside the ranges of what typical off-the-shelf equipment can handle, so they are not able to properly process these materials, or they stretch the current equipment to its limits and have to deal with equipment failures and higher scrap rates. Innovations in processing methods, tooling, and equipment, as well as improvements in the shape and consistency of the resulting components, will lead to performance gains and new opportunities for CFRTP composites, which will become more important as demands for high-performance materials increases.

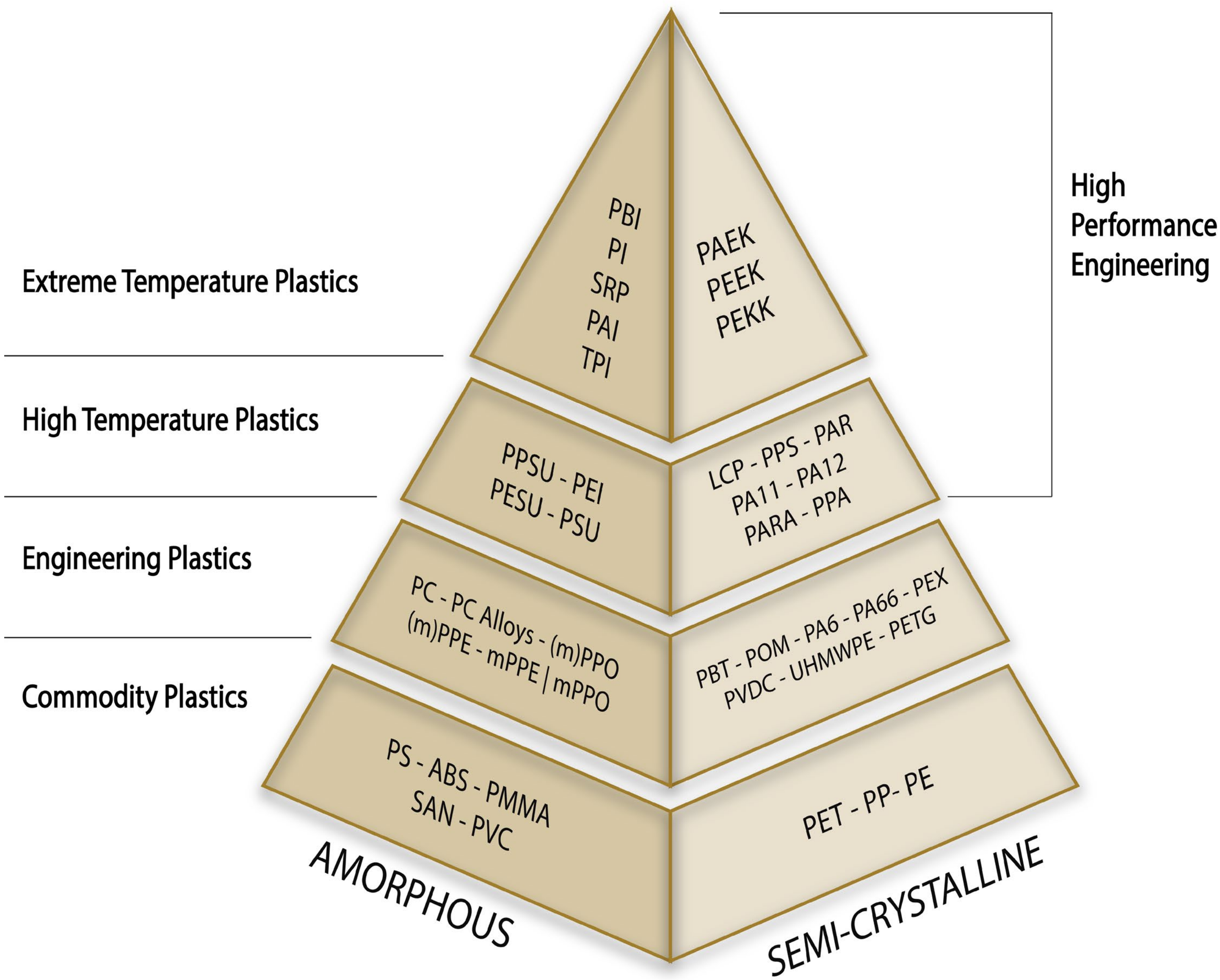


***Figure 4:*** *Different classes of thermoplastics broken down by crystallinity and plastic grade/processing temperature.*

***Figure 5:*** *Examples of composite fabrics.*

## *2.2 Mechanical Performance of Composites*

When it comes to the mechanical properties of the composite, the strength and stiffness is determined by the fiber type and orientation, with the matrix being responsible for transferring the load to the fiber, holding it all together, and the shape and surface quality of the component. By adding a continuous fiber to a thermoplastic polymer, you can tune the properties in a way that is not possible with traditional materials. You can further dictate component properties via the material format that is used in the design, the two most common being fabrics and tapes. While both are made of the same input materials (fiber and resin), fabrics are created by weaving these materials into a cloth and tapes are produced by aligning the fiber and resin into a linear, continuous strip of material, typically 6-12” wide. Fabrics offer better drapability, superior cosmetics, and isotropic stiffness in two directions (which is dependent on the weave type and angle); tapes, on the other hand, provide greater control over ply orientation, thickness, and the mechanical properties of the final product and are better suited for higher automation such as slitting and tape layup. For high-performance applications, Re:Build Oribi usually recommends using unidirectional (UD) tapes because they can meet tighter tolerances and the layup can be tailored to achieve specific performance requirements in different areas of the component.

***Figure 6:*** *Unidirectional (UD) composite tape.*

## 3. What Are My Options?

Designing with traditional materials is comfortable – you know what to expect, there is an established supply chain that has worked through the learning curve of applying these materials to each application, and there's a lot of research and literature available to aid in design and production. However, there is not a "super material" that meets every need perfectly, every time; in fact, this points to the very nature of composite materials – the combinations of fiber type, resin, and layup are nearly endless. Designing with composites is unique because you can mix and match different materials to achieve the desired properties, and advances in material science and processing methods will continue to open this technology up to broader markets and applications. For a high-level overview of how thermoset and thermoplastic composites compare to metals, ceramics, and polymers, see Table 3.

Additionally, the implementation of digital tools utilized by thermoplastic composite manufacturers (including Re:Build Oribi) will further support the transition from traditional materials to CFRTP composites and aid in the design for manufacturing (DFM) process. On the design side, digitalization includes utilizing software like finite element analysis (FEA), simulation tools (e.g. AniForm), 3D scanning platforms (e.g. Creaform), and digital twins. On the manufacturing side, this can include integrating sensors into the equipment to monitor part quality and machine health. Digital tools reduce total development costs by enabling teams to determine the optimal material and processing parameters without extensive physical prototyping and destructive testing, while also accelerating all stages of the process – from R&D through production.

| | Metals | Ceramics | Polymers | Thermoset Composites | Thermoplastic Composites |
|---|---|---|---|---|---|
| Toughness / Impact Resistance | ✓ | ✗ | ✓ | ✗ | ✓ |
| Vibration Damping | ✗ | ✗ | ✓ | ✓ | ✓ |
| High-Temp Stability | ✓ | ✓ | ✗ | ✗ | ✗ |
| Lightweight | ✗ | ✗ | ✓ | ✓ | ✓ |
| Cost | ✓ | ✗ | ✓ | ✗ | ✓ |
| Recyclability | ✓ | ✗ | ✓ | ✗ | ✓ |
| Flexibility | ✗ | ✗ | ✓ | ✗ | ✓ |
| Corrosion Resistance | ✗ | ✓ | ✓ | ✓ | ✓ |

***Table 3:*** *High-level overview of benefits and drawbacks of different material types.*

### *3.1 Thermoplastic vs. Thermoset*

CFRTP composites have often been overlooked in favor of thermoset composites or non-composite materials due to the challenging processing conditions required – high temperature and high pressure – and prohibitive tooling and equipment costs needed to produce components. However, in the last decade, improvements in material chemistry, processing technologies (e.g. automation), and digitalization have made thermoplastic composites a more viable and desirable option (Table 4). When compared to traditional thermoset composites, CFRTP composites outperform in areas like:

1. High-rate production capability
2. Toughness gain & vibration damping
3. Sustainability

#### *3.1.1 High-rate production capability*

The material processing requirements that were previously a major impediment for thermoplastic composite adoption (stamping at high pressure and high temperature) are now advantageous and enable automated solutions for high-rate production of CFRTP components at a lower cost. Thermoset composite materials are tacky and require a chemical cure, lending to a very manual process from start to finish that is difficult to automate. CFRTP composites, on the other hand, are dry (no liquid resin), easier to handle, and are commonly formed through a high-pressure, high temperature stamping process (Figure 7), which provides a faster cycle time and therefore a cost-competitive alternative to traditional thermoset composites that are manufactured in low-labor countries; subsequently, thermoplastic composites enable onshore manufacturing of advanced components. CFRTP composite manufacturing is also an out-of-autoclave process, which requires lower CAPEX spend. Being able to automate the production of thermoplastic composite components

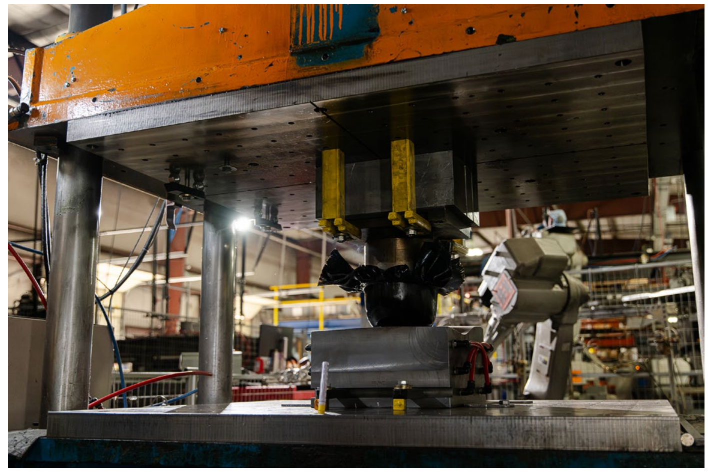

***Figure 7:*** *A CFRTP helmet being produced via stamp forming at Re:Build Oribi in Denver, CO.*

presents possibilities to address overarching supply chain challenges related to composite manufacturing, which for thermoplastic composites is largely located overseas. Bringing these supply chains closer to home and establishing local manufacturing capabilities is another way we can make CFRTP composites a cost-competitive alternative that meets (or exceeds) performance requirements for many applications.

#### *3.1.2 Toughness gain & vibration damping*

CFRTP composites demonstrate comparable mechanical performance to thermoset composites and are proven to outperform them in toughness and vibration damping. Because thermoplastic composites rely on a matrix with some level of elasticity, they are more flexible and better at managing impact energy, whereas thermosets tend to fracture and fail under high impact. In a case study on Mountain Bike Frame Innovation Using Thermoplastic Composites, Revved Industries (Denver, CO) and Toray Advanced Composites (Morgan Hill, CA) replace an aluminum bike frame with a nylon 6/carbon fiber (PA6/CF) composite to achieve a "fracture toughness that is on the order of three times that of a toughened epoxy matrix, and an inherent dampening effect that is 5 times better than epoxy." [3] In mountain biking, uneven terrain is a given, so the higher fracture toughness helps increase the life span of the frame and reduce the likelihood of frame failure, as does designing the frame to efficiently manage stress through custom layups of UD tape.

In a more general sense, increased toughness is advantageous in sports because the equipment can withstand more impact before failure, helping to improve the athlete's confidence in the equipment and enabling them to be more focused on the game. Vibration is a unique property because in many sports, the vibration felt from the equipment interacting with the environment (e.g. skis on the snow) or an object (e.g. ball or puck) provides feedback that the athlete subconsciously uses to inform their behavior. If vibration is eliminated or significantly reduced, the athlete loses this "feel" and may find it harder to control the equipment and their performance. Determining the optimal vibration level is very athlete- and sport-dependent, which makes it difficult to quantify and turn into design metrics. Regardless of what sport and which athlete, the key takeaway is that it's important to find the balance between vibration damping and feel and control when designing for performance, and CFRTP composites can help do that.

### *3.1.3 Sustainability*

One key difference between thermosets and thermoplastics is the secondary bonding between

## *Case Study:*

## WHEELS

A more recent example of CFRTP composites breaking into sports is in wheel applications, specifically in cycling (Figure 8). At the 2024 Paris-Roubaix race, known colloquially as the Hell of the North, Italian cyclist Elisa Balsamo (Team Lidl-Trek) finished second using a thermoplastic carbon wheel frame from Trek's in-house component brand Bontrager.[7] The CFRTP composite wheel was advantageous for this race specifically because of the extensive sections of cobblestone roads that are part of the course. The cobbles can lead to race-ending wheel failure, demanding that the frame be able to repeatedly withstand the forces/impact from the uneven terrain. Athletes that have ridden on these wheels report a highly favorable ride quality, which is a key metric that qualifies the balance between the vibration damping and the stiffness and control the athlete feels. Bontrager states that this is a "smoother, faster, and overall more durable wheel all while being friendlier on the planet,"[8] and it'll be interesting to follow whether this wheel continues to have the same athlete endorsement when competing on smoother roads.


***Figure 8:*** *Bike used by Balsamo in the 2024 Paris-Roubaix.*[17]

Beyond cycling, there is growing interest in adopting thermoplastic composites for other circular-shaped products such as electric vehicle wheels, ATV wheels, and golf cart wheels.

polymer chains, which impacts the materials' processability, mechanical, thermal, and chemical properties, and what happens at end-of-life. For thermosets, chemical bonds are formed between chains to create a crosslinked or networked structure that is irreversible; the melting temperature ($T_m$) is greater than the degradation temperature so the thermoset will break down before it melts. Thermoplastics have weaker bonds (e.g. Van der Waals forces), that organize in a linear or branched fashion and allow for greater impact resistance and flexibility (Figure 9). The $T_m$ of thermoplastics is less than the degradation temperature, giving CFRTP composites an inherent ability to be re-melted, or recycled, that thermoset composites lack.

In theory, when a CFRTP composite bat breaks, for example, the material can be ground down, reheated, and the resulting material (now a mixture of discontinuous fiber and resin) can be re-purposed and reformed into a new component. While the ability of CFRTP materials to do this is interesting and provides a nice opportunity for re-purposing versus landfilling the components, the infrastructure to enable this is not yet well defined. In addition, because the material is now a discontinuous fiber/resin mixture, the mechanical performance compared to the original unidirectional fiber and resin combination is substantially reduced unless the fiber length is kept above 0.5". Typically, the recycled material is more appropriate for use in lower performance applications, or in applications that do not need the performance benefit of continuous fiber. Research is being done to resolve these issues so that the benefit can be more fully realized; Toray Advanced Components is exploring the use of the recycled CFRTP material as a flow layer of discontinuous fiber in combination with virgin CFRTP to add complex geometries, vary material thickness, and provide reinforcement to components while improving the performance-to-cost ratio.[9]

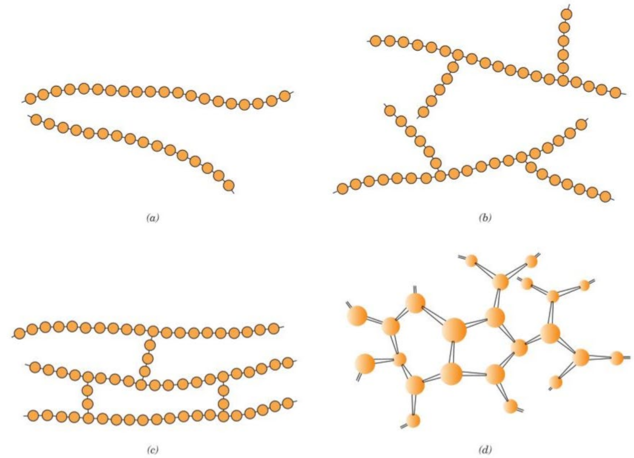


***Figure 9:*** *Polymer chain structures (clockwise): linear, branched, cross-linked, and network.*[13]

Achieving the best performance has always been prioritized over sustainability, however, there is an emerging societal shift where consumers are becoming more interested in options that are actually sustainable when there isn't a large performance loss (or decreased safety). Not only are consumers driving this change, but national and international organizations and governance bodies are beginning to mandate sustainability and environmental goals for different industries that are to be achieved by 2050. For example, in 2022 the Carbon Fibre Circular Alliance (CFCA) was announced as a multi-sport collaboration to increase the sustainability of sports equipment; at the time, sports equipment was the 3rd largest user of carbon fiber in the world, and as much as 90% of that carbon fiber ends up in a landfill.[4] The World Sailing Trust is leading the alliance, which is comprised of international federations, sports manufacturers, academics, and composite specialists, and is working to find ways to reuse the carbon components while maintaining the performance level of the product. The alliance is primarily focused on sports, however, their findings will be applicable in many other industries where carbon fiber composites are used, and advances in sustainability could even enable the adoption in new markets.


***Figure 10:*** *Top to bottom- Headlines from the announcements of Union Cycliste Internationale (UCI)[14] and the International Biathlon Union (IBU)[15] joining the CFCA; project announcement from the World Sailing Trust.[16]*

### *3.2 When to Choose CFRTP Composites*

CFRTP composites have a lot of attractive qualities, but it is important to do your due diligence before jumping right to them. When considering what material to use, you can use the following criteria as a general guideline for whether thermoplastic composites might make sense for your application:

- Production volumes are high ( > 1,000 / year)
- Cosmetics can either be addressed via a secondary process (decal, paint, etc.) or are not important
- Removing weight is critical (high strength-to-weight ratio)
- The ability to tune the mechanical properties is desirable (e.g. loads are not applied uniformly across component)
- Reducing vibration is beneficial for the user
- Withstanding high impact is a benefit to the user

This should not be taken as an exhaustive list, but rather as a reference check of whether the time and energy should be spent exploring this material choice (Figure 11). Of this list, one of the most common reasons why CFRTP composites aren't selected is due to low production volumes of an application; they are best suited for components with medium- to high-volume production because of the upfront tooling costs required, as the high-temperature and high-pressure processes to fabricate thermoplastic composite components require matched metal tooling for each part. Part size, geometric complexity, and resin selection help inform at what volumes the tooling cost breaks even. To help reduce this burden and make the whole process more economical, Re:Build Oribi has developed and deployed digital tools that help accelerate the product development process and determine if CFRTP composites are the right fit for the customer's application, and if yes, what the optimal production parameters are. For example, using 3D scanning techniques enables the design team to create digital twins of the component that can be brought into simulation software to understand and predict behavior in different conditions. This systematic approach is industry-agnostic and can help identify new areas where CFRTP composites can be used.

Surface finish and aesthetic requirements are another reason this material may or may not be a desirable choice. While there are various post-processing techniques and finishing options that can add a protective layer, improve visual appearance, or in some cases enhance performance, CFRTP composites are better options for applications where functionality is more critical than aesthetics, such as backpack frames, helmet shells (that are subsequently painted), or footwear inserts (that are not seen by the consumer). This should not automatically exclude them from consideration for more visible components, but it is important to define the cosmetic requirements up front, as it may drive the per part price up because of secondary finishing requirements to a point where there is no longer a cost savings.

On the other hand, one of the most convincing reasons why thermoplastic composites are an ideal choice is because of their high strength-to-weight ratio and the ability to create custom layups with automated machinery and minimal labor. During the layup process, you can design the composite to have specific mechanical properties that can, for example, provide reinforcement without adding weight, introduce variable stiffness across the component, and enable tailored directional flexibility without compromising structural integrity. Outside of sports, these properties make CFRTP composites good candidates for structural applications. Some examples of properties you can tune are shown in Figure 12.

***Figure 11:*** *Reasons for selecting thermoplastic composites. Top to bottom: high production volume, lightweight, customized fiber orientation, vibration damping, toughness.*

# DESIGN CONSIDERATIONS


***Figure 12:*** *Examples of properties that can be tuned to meet design requirements by using CFRTP composites.*

## 4. Testing CFRTP Composites

An important part of the product development cycle is the testing and validation stage, where there is usually some combination of standardized, industry-agnostic tests (e.g. tensile/compressive, short beam shear, three-point bend, hardness, etc.) and industry- and application-specific tests (e.g. shooting frozen hockey pucks and frozen hockey sticks to test fracture performance in extreme conditions). The usefulness of all these tests varies, but the majority miss one crucial element of the equation: the athlete. In sports, the equipment must perform well, and the athlete must be convinced that they now have the tools to maximize their own performance. It can be difficult to quantify this feeling and create a design metric from it because for most athletes, in most sports, the feeling is subjective. It is up to the product development team to translate what the athlete is experiencing with the product into actionable, measurable metrics that can be tuned accordingly. Another challenge when designing for athletes (particularly elite athletes) is that the new product being tested may simply be different in some aspect compared to what they are used to. Many times, athletes have grown accustomed to the specific characteristics of their current equipment and if those are altered, the perception of the equipment quality changes (regardless of whether the performance is comparable to the incumbent product or not). When the CFRTP composite equipment is tested independently (without the athlete), the performance might be equal to or better than the traditional materials; when the athlete is brought in, there are new variables introduced that are difficult to quantify and vary between each athlete. Convincing an athlete that something new is better than what they’ve previously used, especially if that has led to great success, requires immense trust between the athlete and the development team of the product in question. To some, this part of the process may seem trivial, but it is vital to get it right if you want the product to be adopted by athletes at any level. And, of course, if professional athletes are using the product, the amateur markets tend to adopt the product as well.

## *Case Study:*

# BACKPACK FRAME

***Figure 13:*** *Mystery Ranch backpack frame designed and produced by Re:Build Oribi.*

Load transference systems in backpacks (the mainframe) are common in outdoor, hunting, fire, and military packs to help carry the load, and to properly distribute the weight and reduce the stress on the body of the carrier. These frames are a great example of when CFRTP composites make sense because of the high production volumes per year, the need for a strong but light material that has high tailorability (stiffness in some areas, flexibility in others), and the lack of surface finish requirements because it is 'buried' in the pack. As a case study, Re:Build Oribi worked with Mystery Ranch, a leading high performance backpack brand in the U.S., whose mission is to "minimize the burden on your back", to bring this concept to life (Figure 13). Design kicked off in 2007, and production ran from 2008 through 2016/2017 at a rate between 2,000 and 4,000 frames per month (depending on demand). Building the frame out of CFRTP composite allowed the frame to:

- Have the flexibility required to move with the wearer's body.
- Be durable under stress of use.
- Eliminate extra weight that must be carried.
- Be very stiff in the vertical direction to help carry the load in the pack.

Using unidirectional (UD) CFRTP composite tape with the fibers oriented parallel to the user's spine creates a frame that is stiff in the loading direction and has torsional control in the other direction, flexing with and adapting to the movements of the wearer. While the user probably isn't thinking about the pack in these terms, they benefit from a pack that conforms more naturally to their body and transfers the load so that it's more comfortable to carry for longer periods of time. Backpack frames typically meet the 'ideal' criteria for CFRTP composites: large production volumes; high-functionality and low visibility of the component; and tailored physical and mechanical properties.

So, what are these application-specific metrics that athletes care about? Some examples, shown in Figure 16, include ride quality in cycling, impact feel in racket/bat/stick sports, how much spin the ball gets (positive attribute in tennis, negative in golf), maneuverability and responsiveness, stability, and the acoustics and feel of hitting the sweet spot. Sport-specific auditory feedback complements the visual information the athlete uses to adjust their movements. When the ball hits the sweet spot – the area around the center of mass where the best performance is achieved – there is a specific sound that provides positive feedback that it was a good hit. With traditional materials, the auditory and tactile information passed on to the athlete has been fine-tuned and sets the standard; to date, CFRTP composites have struggled to replicate this feedback, presenting challenges to athlete adoption. As each sport adapts to a changing technological environment, athletes are becoming more attuned to even the slightest changes in their equipment. This makes having industry-specific testing and validation crucial to the product development life cycle.

*Case Study:*

# FOOTWEAR

In footwear, it's becoming more common to see carbon plates incorporated into the shoe design because of their high strength-to-weight ratio and ability to provide tailored, directional support to the athlete depending on the desired performance outcome, whether that's optimized energy restitution, proper biomechanics, or injury prevention. Adding a carbon plate allows designers to influence the benefits the athlete experiences based on where the plate is placed and how the fibers are oriented. Toray Performance Material Corporation (PMC) suggests 5 ways that CFRTP composites can be integrated into a shoe: [9]

1. Spring / Propulsion Plate (purple) – extends into the forefoot to provide spring and resiliency (i.e. the material has high fatigue resistance allowing it to retain its form and performance through repeated use, such as running strides); tuning the stiffness and compliance of the material helps manage the energy absorbed from the foot striking the ground.
2. Heel Stability Plate (blue) – helps maintain proper biomechanics during running and provides stability during heel strike.
3. Turf Plate (green) – specifically for turf footwear; it limits the extension of the big toe and how much heat is transferred from the turf to the foot.
4. Shank Plate (orange) – makes the shoe lighter and adds arch support.

***Figure 14:*** *Schematic of a shoe with different areas where carbon plates could be beneficial. Image from Toray.* [9]

As an interesting reference, how companies have leveraged CFRTP composites to create innovative, high-performance footwear has been controversial. In 2019, marathoner Eliud Kipchoge ran a sub-two-hour marathon in Vienna wearing a prototype Nike Alphafly shoe (Figure 15), which contained carbon plates and airbags these are not the first shoes with a carbon plate). Presumably, the carbon plates created a propulsion / spring benefit that improved performance. Shortly after, World Athletics, the international federation for track and field, instituted new regulations that banned shoes that contain more than one plate or that had soles thicker than 40mm. While the Alphafly was not explicitly cited as being the reason for the new regulations, it was a tipping point. In addition to innovations in foam technology and increased understanding of biomechanic design, it's clear that adding carbon plates creates a performance advantage over traditional running shoes. Advantages include:

- Increased spring that returns more energy to the athlete to propel them forward.
- Reduced foot fatigue, allowing the athlete to maintain efficient biomechanics.

- Added stability that helps prevent injury and adds comfort.
- Lighter shoes that reduce the energy lost by the athlete's movements.

In summary, these advantages increase the efficiency of the runner, allowing them to run faster and longer while maintaining the same rate of perceived exertion when compared to less efficient shoes (i.e. non-carbon plated shoes).

*Figure 15: Nike Alphafly carbon-plated shoe.*[18]

# ATHLETE PERCEPTIONS

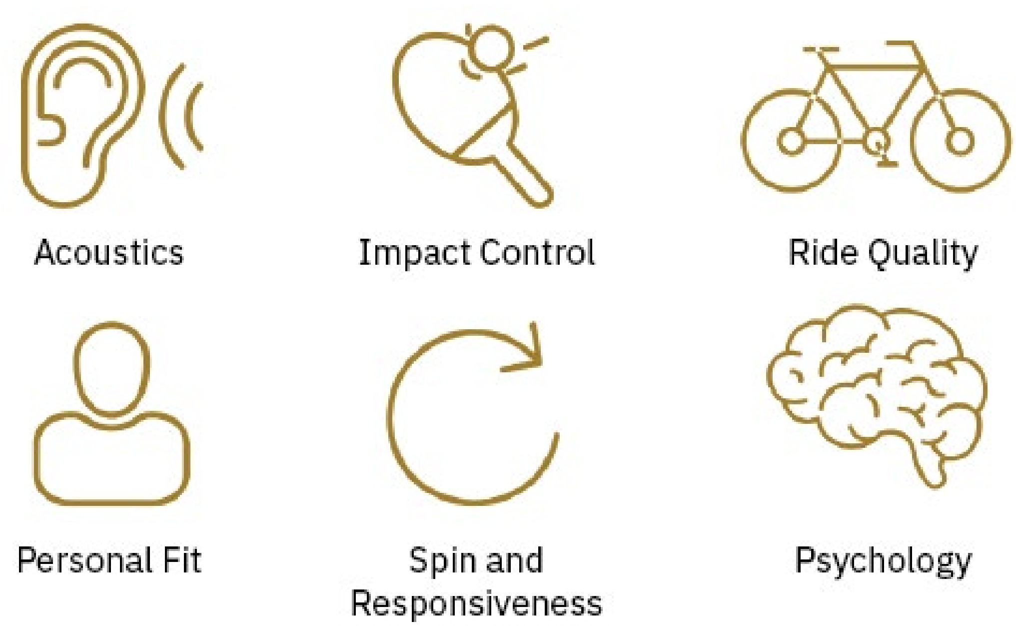


***Figure 16:*** *Examples of properties that are important to athletes to consider when developing equipment.*

## *Case Study:* HELMETS

***Figure 17:*** *Example of a CFRTP composite sports helmet.*

If we look at examples in markets tangential to high-performance sports, we'll find that CFRTP composites have been incorporated into helmets for a range of first responder and Special Forces/defense applications. These helmets demonstrate Re:Build Oribi's unique capabilities to manufacture components with deep-draws and complex geometries at high-volumes, and this process could be translated to helmets for sporting goods and recreational applications. The benefits of CFRTP composites in helmets are their high strength-to-weight ratio, impact resistance, and vibration damping. There is a good opportunity to leverage what has been learned in these ultra-high-performance applications to broader use in consumer markets.

# 5. What's Next?

For all the progress composite manufacturing has made, there's still work to be done before CFRTP composites are a mainstream material choice. Innovative manufacturing processes and advances in material chemistry will continue to be driving factors for adoption, but if these learnings aren't disseminated in a way that educates decision makers – engineers, designers, manufacturers, supply chain, and even the end users – on who to talk to, when and why thermoset and/or thermoplastic composites should be considered, and how to effectively design with them, then we won't necessarily realize or leverage the benefits of composites, in the right way. We've shown how thermoplastic composites have been used in backpack frames, bicycle wheels, footwear, and helmets – but what other applications make sense? Some serious considerations are body protection equipment (PPE), ice- and rock-climbing hardware, boating components, motor sports, drones and other airborne systems, pipes in corrosive environments, solar modules, or structural components in the electric vehicle/mobility markets. But those are just a few examples that will hopefully spark more innovative ideas.

***Figure 18:*** *Inspiration for other applications of CFRTP composites; rock climbing hardware (left), F1/automotive racing (right).*

We're at an exciting point in time, where CFRTP composites are showing real promise, but the market hasn't fully realized or adopted the material, yet; as more data around the performance of CFRTP composite parts becomes available, the incoming material quality becomes more consistent and known in terms of how to design with it, and local manufacturing capabilities are built up to make the process more economical, the industry should see strong growth. Confidence in the reliability and performance of CFRTP composites has been increasing and this momentum will help composite specialists like Re:Build Oribi support the development of new applications for this material in existing (and new) markets.

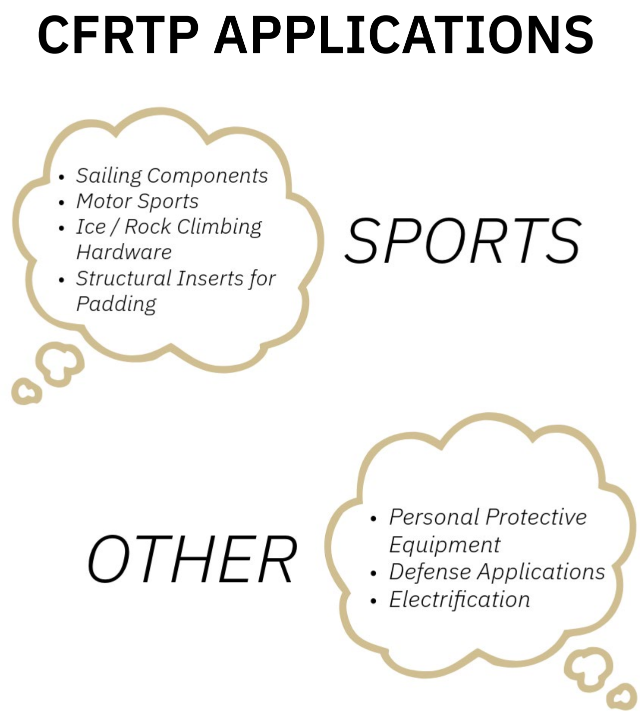


***Figure 19:*** *Examples of other applications for CFRTP composites.*

## Summary

- Continuous fiber-reinforced thermoplastics (CFRTP) composites are becoming a more viable material option, not just in sporting goods but in other markets, due to advances in processing technologies, material science, and digital tools.
- CFRTP composites make the most sense when:
  - Production volumes are high
  - Cosmetics can either be addressed via a secondary process (decal, paint, etc.) or are not important
  - Removing weight is critical (high strength-to-weight ratio)
  - The ability to tune the mechanical properties is desirable (e.g. loads are not applied uniformly across component)
  - Reducing vibration is beneficial for the user
  - Withstanding high impact is a benefit to the user
- Partnering with composite experts during the design phase can help evaluate whether CFRTP composites are a fit for your application.

## Contact


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RE:BUILD MANUFACTURING

## *About Re:Build Manufacturing*

*Re:Build Manufacturing is building a better future for its customers, employees, communities, and shareholders by revitalizing America's manufacturing base and creating meaningful, sustainable jobs in areas that have been deindustrialized. Close collaboration among our 1000+ employees – including over 400 engineers – and our expertise in product innovation, component production, systems production, and industrial automation enables us to solve complex multidisciplinary engineering and manufacturing challenges for our customers.*

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