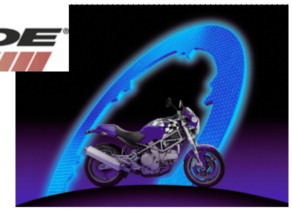
POLYMER-TO-CERAMIC™ TECHNOLOGY



POLYMER-TO-CERAMIC™ TECHNOLOGY FOR FRICTION APPLICATIONS

Starfire Polymer-to-Ceramic Composite (PTCC) materials are carbon fiber reinforced ceramic composites which utilize Starfire Polymer-to-Ceramic™ technology and produce tough, high thermally stable composites. These PTCCs can be designed and used for frictional, structural, and thermal applications. Manufacture of Starfire PTCCs is simple and does not require expensive equipment, is easily machinable, and is environmentally friendly. The processing of PTCCs relies exclusively on pyrolysis of the thermoset resin to form a ceramic—no hazardous precursors are required, and no conversion reaction takes place which can compromise fibers, interface coatings, and negatively impact production yields.

Why Ceramic Composites?

Carbon fiber reinforced ceramic composites are especially important because when compared with metal, they offer such advantages as significant heat and corrosion resistance, high strengths at elevated temperatures, and reduced weight for a host of uses. However, one weakness of the material system is brittleness which is significantly improved by reinforcing the ceramic with tough, carbon fibers. Depending on the cost target and application, different reinforcements are available to address brittleness and encourage tough behavior. For high stress applications, continuous fiber reinforcement is available, and for lower stress and cost sensitive applications, short, chopped fiber reinforcement is available. Table 1 below describes some typical properties for composites produced with Starfire PTCCs. Because Starfire Systems develops and designs custom polymers, the possibilities are endless for a PTCC to perform to a customer requirement.

Reinforcement Type – Starfire PTCC	Cost	Flexural Strength (ksi)	Tensile Strength (ksi)	Thermal Conductivity (W/m*°K)	
				Z-direction	X-Y-direction
Non-Woven	$$	20-24	15-18	4	---
2-D Laminate	$$$	35-42	35-40	2	10
Chopped Fiber	$	15-25	3-6	4	8

Table 1: Summary of Typical Data utilizing Starfire Polymer-to-Ceramic™ Technology

In a friction application for automobiles and motorcycles, using a PTCC rotor, with a 70% reduction in mass compared to an iron rotor, can reduce total vehicle and rotating mass which improves gas mileage, and improves acceleration and vehicle handling. In aircraft friction, using PTCC rotors to replace carbon-carbon is envisioned to yield reduced wear and increased brake life, reduced brake stack heights, and improved static coefficients, all at comparable cost of manufacture.

Other ceramic composite technologies do exist in production. Each offers distinct advantages and disadvantages, and each has a place in the market. Table 2 below summarizes three (3) competing technologies and some details related to their relative cost to manufacture, temperature capability, and strengths. Starfire PTCC materials utilize LPI technology and are considered the most cost effective and safest means to create ceramic composites available.

Riverside Technology Park - 2165 Technology Drive
Schenectady, NY 12308-1143
 Rev date: 03/12

Phone: 518.899.9336
Fax: 518.289.2261
www.starfiresystems.com

Material Type	Reinforcement Type	Cost	Technical Maturity	Temperature Capability (°C)	Thermal Conductivity – Z-direction	Toughness	Strength
LPI – Liquid Polymer Infiltration Technology (PTCC)	•Continuous Fiber/Fabric •Chopped Fiber •Non-Woven	$	Moderate	>1,400°C	Low	High	High
LSI – Liquid Siliconization Technology	•Chopped Fiber •Non-Woven	$$	High	1,400°C Max	Medium / High	Low	Moderate
CVI – Chemical Vapor Infiltration Technology	•Continuous •Fiber/Fabric •Non-Woven	$$$$	Moderate	>1,600°C	Medium	High	High

Table 2: Assessment of various leading fiber reinforced, ceramic composite technology

Applications in Friction

Figure 1: STARBlade® PTCC Motorcycle Rotor

Motorcycle, automobile and aircraft brakes made from Starfire PTCC materials are one logical selection of the material system due to its high thermal capability, high strength and toughness, and low weight compared to metal alternatives.

In limited production volume, Starfire PTCC materials were utilized as motorcycle brake rotors under the trade name, STARBlade® as shown in Figure 1. These single-blade, non-ventilated C/SiC rotors were well received by the street driver and track racer alike as they offered amazing braking capacity with no fade. Structurally, it was shown these STARBlade® rotors were strong, tough, and durable enough to last >100,000 miles with virtually no rotor wear. Due to their reduced weight compared to metal brake rotors, handling was significantly improved for the bike rider. In addition to the motorcycle brake rotor, Starfire has demonstrated that PTCC materials have more than adequate strength, toughness, and durability to provide a braking solution for high performance automobiles. Figure 2 demonstrates that a STARBlade® PTCC automotive rotor can be molded nearly net in shape, including attachment lugs, cross drill holes and ventilation, and is comprised of a Starfire based chopped fiber reinforced molding compound. Starfire has also demonstrated in Figure 3 these composite rotors can be made in volume.

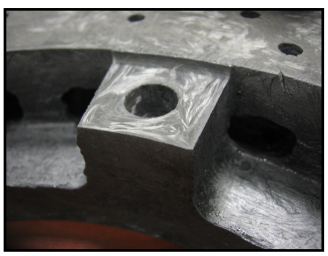


Figure 2: Single operation molded auto PTCC STARBlade® rotor with features

Figure 3: 394mm and 380mm PTCC STARBlade® rotors in-process for qualification testing

If molded net shape, the molded part requires only minimal finish grinding of the rotor surfaces, significantly reducing raw material and machining costs. The expected production cost of this Starfire PTCC rotor is lower than European carbon-ceramic brakes now offered only on high end performance cars, like Porsche and Ferrari.

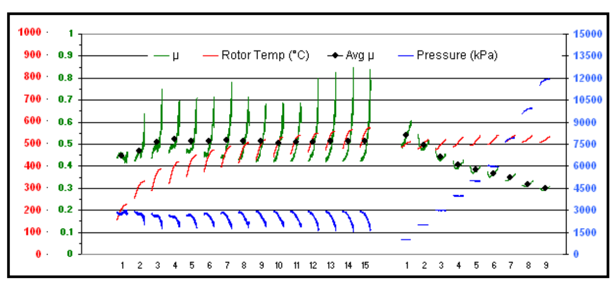


Figure 4: ISO 26867 Performance Test; 3609024; Fade, Hot Performance

Frictional performance and wear of Starfire PTCC auto rotors is outstanding. With an average coefficient of friction of about 0.46, stable friction and low wear are already possible using commercially available semi-metallic pads, and wear is expected to improve with specially formulated pad lining materials. For this test, high speed, low vehicle mass super-car conditions were selected to illustrate performance capability. Figure 4 shows a fade and hot performance section of a dyno test, and illustrates the stability of the friction coefficient with increasing temperature, but also shows some pressure sensitivity. In addition to outstanding performance, other testing has shown this STARBlade ® PTCC formulation to withstand

Riverside Technology Park - 2165 Technology Drive
Schenectady, NY 12308-1143

Phone: 518.899.9336
Fax: 518.289.2261
www.starfiresystems.com

torques greater than 4,800 N*m—4x greater than the maximum design allowable for this component. Exceptional performance was achieved despite utilizing commercially available pad linings which were not specifically designed for the Starfire PTCC ceramic rotor technology. Performance can only be improved once a pad lining material is specifically designed to match the unique properties of the Starfire PTCC rotor material system.

Performance of PTCC Rotors Compared to Iron Rotors

While PTCC rotors are 1/3 the density of iron rotors, they are also lower in thermal mass and thermal heat capacity(C_p), the capacity to store heat which comes about from the conversion of kinetic energy to thermal energy during braking. The current state of the art pad linings limit the overall capability of the ceramic brake system and start to exhibit fade characteristics when the pad linings reach their upper temperature and pressure limitations. This pad fade behavior is evident for both iron rotors, as well as ceramic rotors of any formulation. Starfire has evaluated, at nearly identical test conditions, a Starfire PTCC rotor (A) and a standard iron rotor (B) using pads designed for a generic ceramic rotor, and an iron

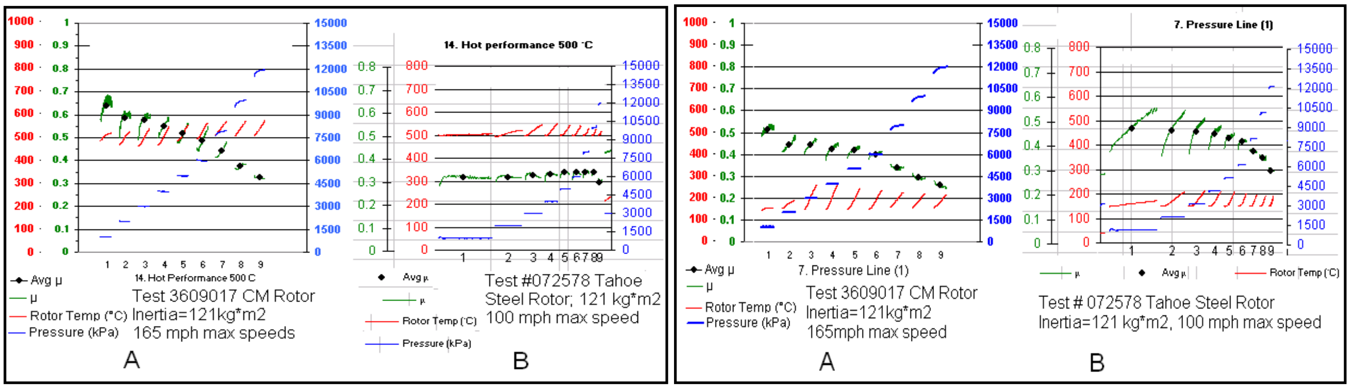


Figure 5: ISO 26867 Performance Test; PTCC STARBlade® Rotor, and Iron Rotor; Hot Performance and Pressure Line

rotor respectively as shown in Figure 5. The test simulated a large, full sized SUV vehicle operating at high speeds, started the test at rotor temperatures of 150°C and 500°C, and increased the brake caliper pressure to near its design maximum. In both cases, the systems demonstrate acceptable performance, with some variation, but showed noticeable pad fade. This performance fade is a pad dominated characteristic and it is clear performance degrades as the pads are pushed beyond their design limit and ultimately reduces the performance potential of the system.

The Starfire PTCC rotor formulation is more than capable of handling the energy required to function as a brake, however, even the current high-performance semi-metallic linings struggle to keep up. Starfire has the capability to formulate specialized polymers as pad additives and can, with the assistance of a pad lining formulator, co-develop a pad designed for the unique characteristics of the PTCC rotor technology. With a pad lining specifically formulated and modified for Starfire PTCCs, it is possible to have a ceramic braking solution which offers equivalent performance to that of an iron rotor, but with the reduced weight and improved wear consistent with a ceramic composite.

Alternate Friction Materials for Rotors and Pad Linings

When selecting a rotor and pad lining pair, it is clear there is no one 'best' material for all applications and conditions. What must be considered are factors such as: maturity of the technology, cost, size, performance, and thermal management. While some formulations show exceptional properties in one area, they may stumble in others. As ceramic composite technology is further matured, its reliability will continue to improve, ceramic manufacturing techniques will be more accepted, and cost will continue to go down. These benefits will continue to make ceramic technology more attractive for large volume manufacturing. Some relative characteristics of each friction technology are shown in Table 3 below.

Material	Density g/cc	Thermal Conductivity	CTE	Cost
Iron	7-8	High	High	$
Starfire PTCC C/SiC or C/SiOC	2.2-2.3	Low	Low	$$$
Carbon-Ceramic LSI	2.2-2.4	Medium	Low	$$
Iron Clad Aluminum	6.0	Medium	Medium	$$
Aluminum MMC	2.5-3.5	High	High	$$
Titanium	4.5	Low	Medium	$$$

Table 3: Comparative Typical Properties of Various Common Friction Materials

Riverside Technology Park - 2165 Technology Drive
Schenectady, NY 12308-1143

Phone: 518.899.9336
Fax: 518.289.2261
www.starfiresystems.com

Aircraft Brake Friction

Starfire participated in the Ceramic Composite Aircraft Brake (CCAB) program which was funded by the Air Force Research Lab (AFRL) and the Ohio Aerospace Institute (OAI) to develop a ceramic braking system for commercial aircraft with great success. Starfire won the Phase I sub-scale portion with outstanding properties and the lowest wear of all participants. Properties generated from this program are summarized in the table 4 below.

Property	Unit of Measure	Value
Carbon Preform Type	---	Non-Woven
Density	g/cc	2.0-2.3
Flexural Strength, 20°C	ksi	24-25
Compressive Strength	ksi	63
Interlaminar Shear	ksi	12-13
Thermal Conductivity, 800C-1000°C	W/m*°K	5.0-5.5
Toughness	mPa*m$^{(1/2)}$	7

Table 4: Thermal and Mechanical Data of Starfire C/SiC PTCC manufactured for the CCAB Air Craft Brake Development Program

Phase II full sized testing yielded opportunities to optimize the design as Starfire C/SiC material experienced high wear. Although little testing of the full sized parts took place, Starfire feels the PTCC material system can be commercialized as a functional aircraft brake system and can yield the promise of a low wearing ceramic brake, one with similar mass to carbon-carbon but with better overall performance.

Heavy Vehicle, Industrial Brake

Starfire has tested PTCC rotor technology on heavy, industrial vehicle applications with mixed results. Initial tests were conducted using original equipment (OE) linings designed specifically for metallic rotors, instead of linings specifically designed for ceramic rotors, which would also include greater swept pad contact area. Figure 6 illustrates one of the two (2) tested systems, both yielded low wear, low effectiveness values. As tested, the systems were pressure limited due to the capability of the existing braking calipers used in the field today. Encouragingly, the rotors were capable of handling sufficient torque (>1,350 N*m), generated friction and yielded low wear, but fell short of a success due to a non-optimized pad lining. To improve performance on this and similar tests, Starfire has the capability to develop specialized polymer pad additives. With these additives, and with the assistance of a pad lining formulator, Starfire can co-develop a pad designed for the unique characteristics of the PTCC rotor technology. Additionally, this testing indicates a drop-in-replacement ceramic rotor is possible and can potentially offer a reduced-mass ceramic brake rotor option to existing vehicles in the field, provided an improved lining can be offered.

Figure 6: STARBlade ® PTCC Rotor Post Test

Versatile Hybrid Rotor Design – PTCC + MMC = High Performance

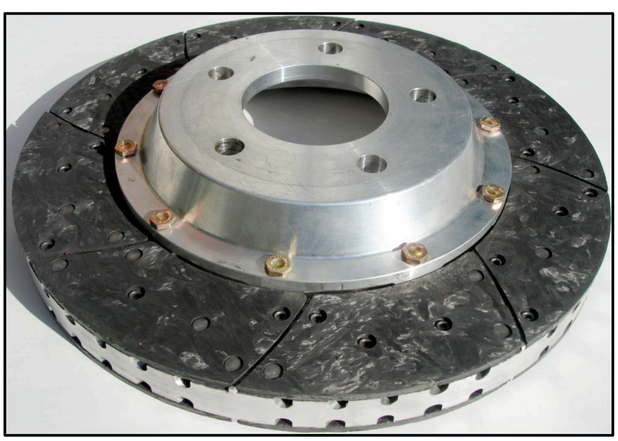


Figure 7: Turbine Rotors' Hybrid Rotor

Utilizing Starfire Systems' proprietary PTCC friction material and a metal matrix composite (MMC) core, Turbine Rotors has developed a patented hybrid auto rotor concept which offers the benefit of reduced weight compared to iron and steel, the high performance of an exotic ceramic composite friction material, all at a low price. At braking temperatures where normal metallic friction solutions soften, oxidize, warp and distort, or exhibit fade, the Turbine Rotors hybrid concept shines. This design, shown in figure 7, combines proven metal matrix composite casting technology to create a structural core, with the established technology of a Starfire PTCC frictional surface to offer a frictional system capable of getting noticed. With multiple PTCC friction surfaces to chose from, ranging from aggressive to low impact, the Turbine Rotors concept is game-changing technology for the racing community.

Riverside Technology Park - 2165 Technology Drive
Schenectady, NY 12308-1143
 Rev date: 03/12
Phone: 518.899.9336
Fax: 518.289.2261
www.starfiresystems.com