Hitting

Polymer-derived ceramic matrix composites are increasingly being developed for friction applications. Darren Welson of Starfire Systems Inc, New York, USA, describes his company's work.

Above: A 394mm Starfire chopped fibre ceramic matrix composite (CMC) automotive rotor. Below: Comparison of key physical and mechanical properties of carbon-reinforced CMCs derived from SMP-10 and Polyramic

Pre-ceramic polymers forming carbon or oxygen-rich silicon carbide (SiC), silicon nitride, silicon oxycarbide (SiOC), and silicon oxynitride have been commercially available for over 20 years. They are processed using a polymer infiltration and pyrolysis (PIP) technique, which involves vacuum impregnation of polymer into a porous part and subsequent pyrolysis to elevated temperatures.

Advantages of PIP over traditional ceramic forming techniques include simple and lower cost equipment, process temperatures as low as 850°C, shorter cycle times, and the capability to produce large and/or complex parts. Pre-ceramic polymers also give control of the resulting ceramic composition by chemical modifications at molecular levels. Many early generation pre-ceramic polymer challenges have been remedied, including imprecise stoichiometry, general handling and safety difficulty, low ceramic yields and poor strength composites. With technical maturing of these polymers, acceptance has grown significantly.

Early friction materials such as carbon fibre-reinforced polymer derived composite in motorcycle brake rotors performed well, but their cross-market adoption was limited due to the high-cost polycarbosilane polymers used. A lower cost version with polycarbosilane performance was needed to enter the friction materials market.

As a result, Polyramic, a family of siloxane-based ceramic-forming polymers, were developed over the past two years by Starfire. They are capable of ambient handling, are non-toxic, non-corrosive, create no corrosive effluents and have significant char yields. Polyramic components have been fabricated using standard composite fabrication techniques, including lamination and compression moulding, and employ re-useable standard moulds and fixtures.

The composites are inorganic polymers with organic functionality, such as methyl, vinyl, phenyl and hydride. A relatively low-cost proprietary manufacturing process and a synthesis technique, which minimises waste and energy inputs, has been developed at Starfire using conventional polysiloxane synthesis methods and resulting in a relatively inexpensive polymer compared to other ceramic forming polymers.

All are liquid resins with viscosities between 20-100,000m Pa.sec, depending on composition and targeted end use. These cure into solid thermoset resins in a temperature range of 120-300+°C, making them convenient for laminating or moulding into robust green parts. A cured composite can be pyrolised at elevated temperatures to form ceramic matrix composite (CMC) parts. Polyramic resins can be used to infiltrate and densify these composite parts to final conditions.

Polycarbosilane SMP-10-based motorcycle brake rotors have niche market acceptance, in professional racing, due to their high cost. After a review of the relative costs of metal rotors against the cost of ceramic rotors, successful development and manufacture of brake rotors using a lower cost Polyramic polymer could allow additional adoption into the market.

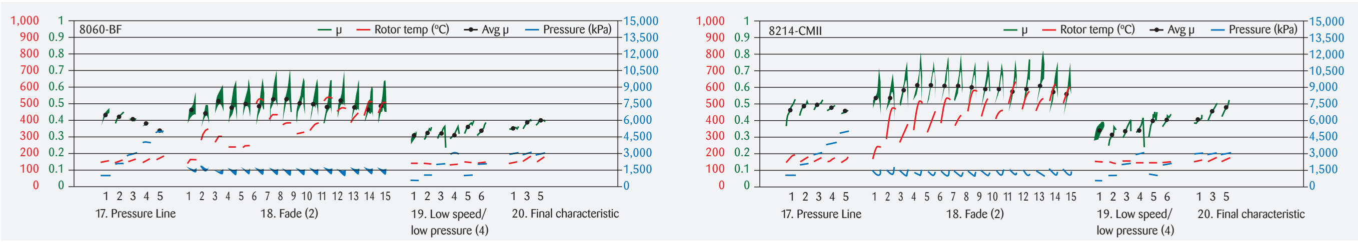
Parameter	C/SiC – Baseline	C/SiOC	C/SiC and C/SiOC
Architecture	2D laminate	2D laminate	Discontinuous fibre reinforced
PIP polymer	Polycarbosilane SMP-10	Polyramic RD-212a	Polyramic RD-212a* Polycarbosilane SMP-10
Fibre volume %	36%	36%	30%
Flex strength	276MPa	262MPa	125MPa
Flex strength standard deviation	17MPa	10MPa	20MPa
Flex modulus	76GPa	76GPa	38GPa

*iteration listed for properties

Building blocks

Manufacture of 2D laminate composite, for aerospace, automotive and industrial areas, uses a

the brakes



T-300, 5HS carbon fabric, and slurry of Polyramic polymer with refractory particulate. Carbon fabric is prepregged, and sheets stacked to the desired fibre volume, layup orientation and dimensional requirements. This stack is warm press cured to form a laminate green body. Chopped fibre-reinforced composites are produced similarly for industrial uses, but use a proprietary bulk moulding compound (BMC) system consisting of short carbon fibres and a refractory filled moulding resin. The BMC is press mould cured to completely fill the cavity tool and to achieve the desired thickness to form a green body.

Each green body is pyrolysed in an inert environment to generate a porous composite ready for vacuum infiltration. Vacuum infiltration is conducted using a polymer, and is pyrolysed to ceramitise the infiltrated polymer. This process is repeated several times to completely fill porosity. The manufacture of the baseline 2D polycarbosilane baseline composites uses SMP-10-based slurry for manufacture of the laminated green body. Infiltrations of the baseline parts use SMP-10 exclusively.

Composite comparison

A comparison of baseline mechanical properties of SMP-10-based (C-SiC) and Polyramic based (C-SiOC) carbon fibre-reinforced ceramic matrix composites (CMCs) measured per international standard ASTM C 1341-06 three-point/four-point bend is listed in the table, far left. Starfire SMP-10 and Polyramic polymers were used in the development and manufacture of C-SiC and C-SiOC frictional rotors. The image (far left, top) shows an example of a completed chopped fibre automotive rotor. Two formulations of matrix polymer have been demonstrated – an exclusively SMP-10 (SiC) matrix, and an exclusively Polyramic matrix. All frictional performance data have been conducted on chopped fibre composites and a portion of comparative dynamometer friction performance evaluation is shown (see graphs above). Supercar test conditions simulated a 1,500kg vehicle with a rotor diameter of 394mm.

The table (far left) shows ambient physical and mechanical properties of the two 2D laminates is similar. However, SMP-10 derived CMCs are expected to show superior mechanical properties at higher temperatures owing to their greater thermal stability, stronger Si-C bond and higher apparent density. Although lower than that of 2D laminates, the mechanical strength of Starfire Polymer Derived Ceramic (PDC) chopped fibre composites has been shown by a Detroit, USA, auto maker to be more than sufficient for torque loads of an automotive braking application such as when tested at supercar conditions.

Heating up

As shown in the graphs (above), the chart labelled 8060-BF illustrates performance for a rotor containing an all SMP-10 matrix, while the chart labelled 8214-CM-II demonstrates a similar performance for a rotor containing an all Polyramic matrix. A complete substitution of Polyramic material in this application yielded nearly identical friction performance to an all SMP-10 matrix rotor. In both compositions, dynamometer testing confirmed the ability of a chopped fibre PDC system to survive the high torque and cyclic loading required for brake applications.

The most significant difference between each recipe is expected to be the thermal capability and resulting performance of the system. Highly dependent on friction lining, rotors with 100% SMP-10 matrix are expected to be capable of higher temperatures. For applications where temperature excursions greater than 1,000°C are frequent, stoichiometric SiC formed from SMP-10 is expected to yield a more stable friction system.

This work suggests that CMC applications which require oxidation resistance and mechanical strength at moderate temperatures of 800-1,100°C lower cost siloxane resins, such as Polyramic can be substituted for higher cost polycarbosilane polymers, such as SMP-10, without a loss in friction or mechanical performance.

Comparison of the characteristic friction data as a function of composition

Further information

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