

Hard act to follow

Although ceramics are still being developed for use in corrosion-resistant coatings and sensors, the rising stars are ceramic matrix composite technology and metal matrix composite technology. **John Osborne** considers the prospects for greater use of ceramics

Metal matrix composites have been available to automotive engineers for many years but the high cost of producing them has deterred their widespread use. The aluminum type is the most common although magnesium MMCs exist.

Machining costs have been a problem since the ceramics portion of the MMC is very hard. MMCs should not be confused with ceramic matrix composites (CMCs) like those produced by Polymer Infiltration and Pyrolysis (PIP) processes. CMCs produced in this way can be easily machined during the early stages of processing before the full ceramic properties are formed. Spurred on though by success in aerospace applications and improvements in state-of-the-art MMCs and CMCs, ceramics are now becoming a more viable option for use in brakes installed in mass market cars.

Strong performance

3M is one of the companies which believes that MMCs have a bright future in cars and John Skildum is the company's Automotive Business Development Manager, based in St Paul, Minnesota, US. He said that currently 3M is using ceramic fibers for their strength and lightness in aluminum oxide MMCs. The ceramic fibers are used to strengthen the MMCs.

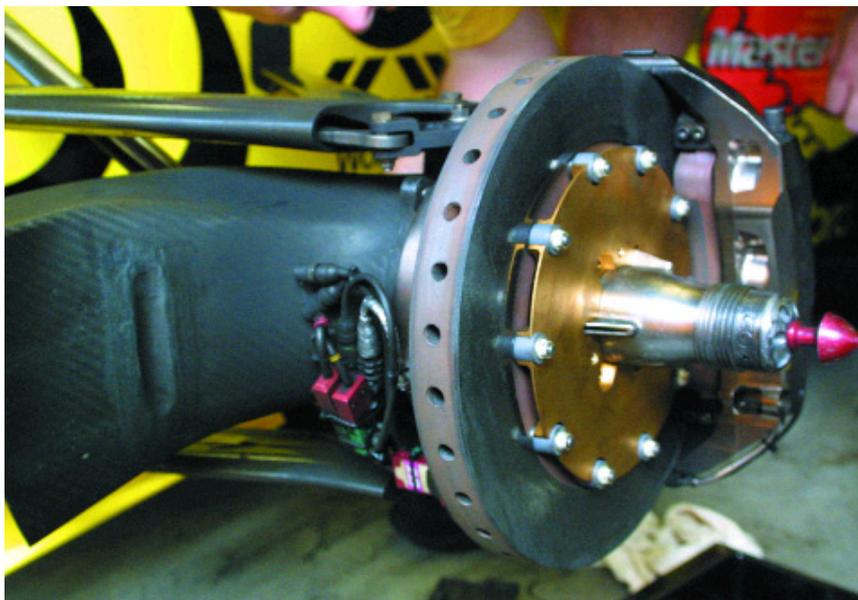
3M has developed a high performance material whose constituents are high strength, high modulus alumina fiber used to reinforce aluminum and its alloys. In addition to improvements in specific strength and stiffness over conventional materials, 3M claims that the resulting material system has the additional advantages of being non-magnetic, having the strength of steel at a fraction of the weight and having extraordinary compression strength. It is also lightweight, has excellent performance at

high temperature and excellent fatigue resistance, creep resistance and abrasion resistance.

3M added that it has developed Nextel Continuous Ceramic Oxide Fiber 610. It claims that this fiber is "one of the world's strongest ceramic oxide fibers". The company also claims that 3M sol-gel-based Nextel ceramic oxide fibers are low cost "and high performance suitable for composite reinforcement. Its composition of high purity alumina gives it high strength and modulus making it ideal as a reinforcement for metal matrix composites."

Niche with scope

Dr Carl Telford is a consultant who works for UK firm SRI Consulting Business Intelligence, a research firm based in Croydon.. He shares Skildum's confidence, although he said that MMCs currently have "fairly niche applications". However, Dr Telford said that "as both MMC technology and the structure of the MMC industry improve, these materials, particularly aluminum-matrix composites (AMCs), are likely to



Ceramics are now a more viable option for use in brakes in mass market cars



Surface Transforms plc are developing a lightweight carbon fiber reinforced ceramic

see use in other, high-volume applications. A major drive exists to develop materials that will help manufacturers lower engine emissions; materials that are stronger, more temperature resistant, and more wear resistant. MMC components are now seeing use in various powertrain components in current vehicle models, for example, MMC driveshafts and engine components. Thus the potential market for MMCs in such applications would appear to be strong."

Frost & Sullivan, an international firm of market consultants, is also upbeat. On Monday, 1 March 2004 its Technical Insights division published a report called *Lightweight Materials – Global Developments and Growth Opportunities*, reference D265. According to that report ceramics are being developed in several automotive areas including brakes. It said that Starfire Systems Inc., a firm based in Malta, New York state has

begun work on a two-year project to develop ceramic brake materials for sports utility vehicles and light trucks. The project received \$150,000 of funding from the New York State Energy Research and Development Authority.

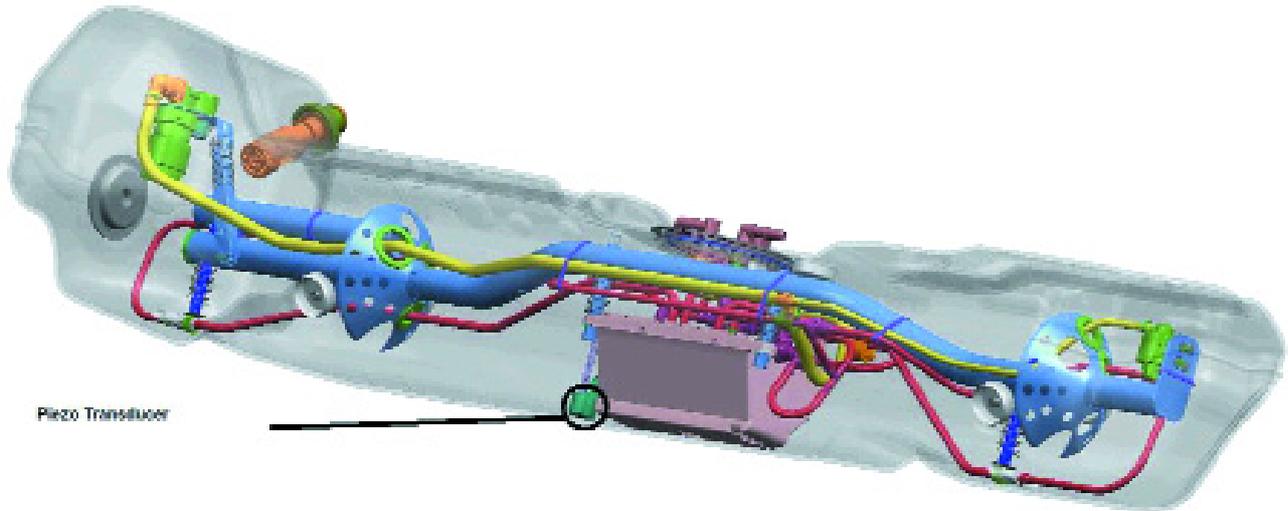
Starfire Systems Inc. intends to bring the technology which has only been the realm of high performance race cars, motorbikes and exotic cars into more affordable vehicles. The main advantage of the ceramic brake systems is the 75% weight advantage they have over conventional metallic brakes. This in turn leads to improved fuel consumption of up to 20% on a city cycle, as well as improved stopping and handling. They are also capable of working at higher temperatures, reducing the likelihood of brake fade, the reduction in braking power due to overheating of the brake materials.

Refractory ceramic

As an example, Starfire Systems has produced a 13-inch brake disc based on silicon carbide, an extremely hard and refractory ceramic. It weighs 6.5lbs, compared to a conventional steel component, which weighs 21.5lbs. The ceramic components have been tested on a 2003 Chevrolet Tahoe. They were tested on a stationary dynamometer and on the open road. Herb Armstrong, vice president of Sales & Marketing, Starfire Systems said it was still awaiting the results of the tests. Armstrong believes that Starfire Systems is poised to exploit ceramic composite matrix technology, a term he prefers because the company does not use conventional metal matrix technology. He believes that the company is in a stronger position than many of its competitors because "we use known methods of composite preparation that are different from the energy extravagant processes used to make metal matrix composites". He added, "Starfire Systems materials form ceramics at lower temperatures. By doing some machining earlier in the process and firing at lower temperatures we do not have to machine a very dense, hard material."



The Mercedes-Benz SLR uses fiber reinforced ceramic brake discs



TI Automotive's new fuel level sensor uses a suspended piezoelectric ceramic material to send ultrasonic waves within the fuel tank

Advanced fabrication

One of the processes that Starfire Systems uses is Polymer Infiltration and Pyrolysis. It is the latest technique resulting from worldwide research to develop a process that enables the fabrication of advanced ceramics more efficiently than conventional processes. This technique involves soaking a fiber preform or powder compact with a liquid polymer precursor that converts to ceramic material upon pyrolysis. Pre-ceramic polymers are available that form silicon carbide, silicon nitride, silicon oxycarbide, and silicon oxynitride.

According to Starfire Systems the advantages of PIP include simpler, less costly equipment, lower process temperatures, shorter cycle times, and capability to produce more complex parts. Also, polymers have the potential to control materials chemistry at the molecular level.

"While PIP is promising," said Armstrong, "it has had limited acceptance due to the shortcomings of most current pre-ceramic polymers. They are usually difficult to handle, require curing agents and, for silicon carbide, are high in carbon or oxygen content, which degrades high temperature

PORSCHE MAKES WEIGHT SAVING

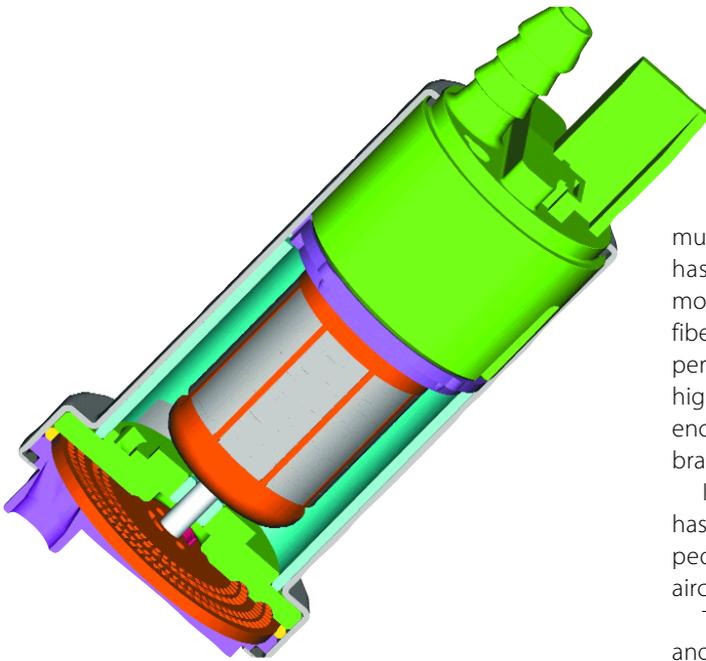
Porsche has demonstrated its commitment to CMCs by using them in composite brakes on its 911 Turbo S, a car that will be available from August 2004 from Porsche dealers around the world. This ceramics technology has been incorporated into the Porsche Ceramic Composite Brakes (PCCB) system. The automaker claims that it offers a 50 percent weight reduction per wheel over the conventional steel brake disc equivalent, as well as superior fade resistance under heavy braking.

The PCCB fitted on the 911 Turbo S has punched and internally ventilated ceramic brake discs with a diameter of 350mm at the front and back.

The 911 Turbo S will be available as a coupé and as a convertible. At 5,700rpm, it has an output of 331 kW (450 PS). This is 30 PS more than the output of the 911 Turbo. The basic price is €122,500 (\$150,924) for the Turbo S Coupé or €131,100 (\$161,519) for the Turbo S Convertible. In Germany, the coupé will be available at a price of €142,248 (\$175,245), including VAT and country-specific requirements. The convertible will cost €152,224 (\$187,527).

Larger turbochargers and a further improved intercooler are other features of the 911 Turbo S Porsche said that the engine's electronics have been revised and that the Porsche 911 Turbo S has a torque of 620 Newton meters, which is available between 3,500 and 4,500 revolutions. It reaches its maximum speed at 307 km/h. Porsche claims that that "the Turbo S with manual transmission (coupé) sprints from zero to 200km/h in 13.6 seconds. This is 0.8 seconds faster than the 911 Turbo."





TI Automotive's all-new dual-channel, single stage pump was developed by its research and development team in Caro, MI

performance. Starfire polymer derived silicon carbide is stable up to 1900°C (500°C higher than competing polymer precursors, substantiated by a NASA contractor for the CRV program). It cures by low temperature thermal cross-linking, affording rigidity for ease of handling and intermediate machining to near net shape. Harmless hydrogen gas is the only effluent of pyrolysis, allowing a very high 80-85% yield of silicon carbide ceramic."

Developing ceramics technology requires investment. On 20 February 2004 Starfire Systems demonstrated its commitment when it announced that it had appointed Stan Hemstad "a recognized leader in high temperature composites and pioneer in advanced ceramic friction materials." He is leading the commercialization of ceramic matrix composite (CMC) technology for friction applications including aircraft and automotive brake brakes and clutches.

Work is also continuing in this area at Surface Transforms plc. This company's head office is in Frodsham, Cheshire, UK and it has a manufacturing plant in Ellesmere Port. It has been developing a lightweight carbon fiber reinforced ceramic. According to azom.com application areas include aircraft and rail brakes, Formula One and other motorsport brakes and clutches in high-performance road cars.

The website said that the material "is up to 70% lighter than cast iron brake discs, providing dynamic improvements as well as a considerable energy saving. Unlike carbon-carbon, the new material has a very high level of oxidation resistance as well as excellent 'cold-friction', enabling safe use inside and outside the racetrack."

Racing brakes

Many ceramics developers are hoping that they can persuade the major automakers to adopt their improved ceramics technology. According to a report posted on azom.com on 9 September 2003 Mercedes-Benz unveiled its all-new SLR McLaren supercar at the Frankfurt Auto Show in 2003. The car

was a joint project between Mercedes-Benz and its Formula 1 partner McLaren, which has resulted in the adaptation of several racing technologies into the high performance road going sports car.

Acceleration and top speed are important, but the car must be able to stop quickly. For this reason Mercedes-Benz has again employed advanced materials taken from motorsports applications in the braking system. The SLR uses fiber reinforced ceramic brake discs. The ceramic brake discs permit higher operating temperatures encountered under high loadings, and reduce the likelihood of brake fade, often encountered in conventional brake materials. The ceramic brake discs are clamped by massive 8 piston callipers up front.

In addition to the ceramic composite disc rotors, Mercedes has also added an air brake to help bring the SLR back to more pedestrian speeds from velocities more associated with aircraft.

The air brake is integrated into the boot lid and raises to an angle of 65° when activated by heavy braking. The air brake in combination with the ceramic composite discs will, it is claimed, decelerate the SLR to stop at 1.3 G.

Surface treatment

Another area that ceramics are being applied successfully is in piezoelectrics. Morgan Electro Ceramics, located in Bedford, Ohio, US, has been working with Michigan's TI Automotive to produce a new fuel level sensor for Ford. The sensor uses a suspended piezoelectric ceramic material to send ultrasonic waves within the fuel tank to measure the level instead of the traditional 'float gauge' that is currently in most vehicles.

The 2005 model Ford GT will be equipped with a fuel tank system developed to meet the world's most stringent evaporative emissions requirements. Designed by TI Automotive, the system includes innovative fuel system technology. Fuel pumps, level sensors and other components are enclosed inside a blow-molded plastic fuel tank to limit evaporative emissions. Referred to as a "ship in a bottle" or SIB design, the system was developed to help automakers meet stringent new evaporative emissions legislation, including LEV II and ZEV legislation in California. The Ford GT will be the world's first production car equipped with TI Automotive's SIB technology.

Ford plans limited production of the GT in 2004. Inspired by the legendary Ford GT-40 racing car of the 1960s, a concept version of the Ford GT was shown at the 2003 North American International Auto Show in Detroit in January and at the 2003 Chicago Auto Show in February.

TI Automotive claims that the SIB system it has developed for Ford features the latest technology in tank-system architecture, level sensing, fuel management and manufacturing processes.

Such developments suggest that ceramics are increasingly being made for use in high tech sensor technology. However they are still making an important contribution in safety critical areas. Expertise developed while making aircraft brakes is now helping automakers. It will be interesting to see whether the materials experts can succeed in reducing costs sufficiently to enable ceramics to be widely used in the brakes fitted in mass market cars.