User-friendly composites that take the heat

For high-temperature composites, finding a good balance between performance, convenience and cost is a recurring challenge. With a new generation of glass-ceramic matrix composites processed like CFRP and designed for temperatures up to 1000ºC, Pyromeral Systems is opening new opportunities for composites in high-temperature applications.

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High-temperature composites are a major area of research today. Composite materials have been successfully used in many applications where temperature resistance is not an issue (i.e. exposed to temperatures under 300ºC), while helping reduce the weight of components and optimize their design. However, with the need to further reduce the weight of systems used in aerospace, defence, space, automotive or motorsports applications, there has been a growing interest for composite materials capable of replacing metals in areas exposed to heat or fire. Despite advances both in the field of organic-matrix composites and ceramic-matrix composites, practical solutions are still being sought for lightweight materials capable of replacing titanium, steel or Inconel in the 300-1000ºC temperature range. The purpose of this article is to present a class of glass-ceramic matrix composites marketed under the name PyroSic®, which specifically target this temperature range. These composites combine heat and fire resistance with good mechanical properties. They are also easy and affordable to use because the resulting parts are designed and processed with the same techniques and tools as conventional carbon-fibre reinforced plastics (CFRP). Examples of applications are also presented.

Description and processing

PyroSic materials are glass-ceramic matrix composites based on inorganic thermoset polymers. The glass-ceramic matrices specifically feature a glassy phase containing silicon oxide nanoparticles. These matrices are derived from geopolymeric systems and inherently resistant to heat and fire. PyroSic glass-ceramic matrix composites are reinforced with continuous silicon carbide fibres, which are chosen depending on the desired level of material performance.

These inorganic polymers are generally processed similarly to organic thermoset systems such as epoxy resins. PyroSic materials are processed by hand lay-up of prepregs, although other techniques can also be used (filament winding, braid lay-up or compression moulding). The initial curing temperature in an autoclave is typically less than 180ºC, and the required pressure is usually less than 9 bar. Thanks to these operating conditions, no special tooling materials such as Invar are necessary. Instead, conventional tooling materials such as machinable boards, graphite/epoxy tools or coated aluminium can be used both for prototypes and production parts. A postcure cycle at high temperature is usually needed to stabilize the glass-ceramic matrix. However, this treatment is conducted in air and in free-standing conditions, therefore eliminating the need for ultra-high-temperature tooling and complex furnaces. Unlike most high-temperature composites (ceramic matrices or glass-ceramic matrices), there is no need for chemical vapour infiltration, iterative densification or hot isostatic pressing.

Properties

Selected physical, thermal and thermo-mechanical properties of PyroSic glass-ceramic matrix composites are shown in Table 1 and Figure 1.

Table 1: Main physical and thermal properties of PyroSic composites

Property	Value
Density	1.8 to 2.2 g/cm3
Coefficient of thermal expansion	3 x 10-6 /K
Thermal conductivity (through thickness)	0.90 w/m.K
Thermal conductivity (in-plane)	0.95 w/m.K

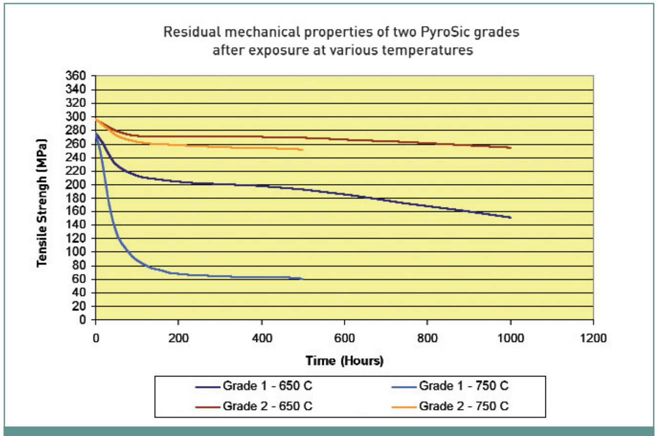

Fig. 1: Selected thermo-mechanical properties

The material's density – which is lower than that of titanium (4.5 g/cm³) and much lower than that of Inconel (8.2 g/cm³) – is an essential parameter to achieve significant weight reductions. It is also worth noting that the material can withstand short exposures to very high temperatures, e.g. retaining 95% of its mechanical properties after a 30-minute exposure to 1100°C.

Example of application – Heat shields

Heat shields and fire barriers are important components of motorsports and aerospace systems. They are also one of the most difficult applications for traditional materials, especially when structural properties are also needed. Heat shields made of PyroSic are frequently used in motorsports applications, where the material has proven to be a reliable solution for lightweight structural heat shields located in tight spaces and exposed to both extreme heat (close to 800°C in some areas) and high vibrations.

The technical attributes of heat shields made of PyroSic glass-ceramic matrix composites include:

- thin walls, typically ranging from 0.6 mm to 1.2 mm,
- possibility to design and manufacture complex shapes,
- dimensional stability and absence of distortion, even in case of fast temperature increases,
- no burn-through, even in case of fire,
- possibility to combine the high-temperature composite with another composite to improve durability and mechanical performance (hybrid composites),
- possibility to apply coatings to improve thermal management, e.g. reflective coatings for improved shielding against radiant heat.


Fig. 2: PyroSic heat shield

A typical structural heat shield made of PyroSic is shown in Figure 2.

Example of application – Exhaust ducts for motorsports

Race car exhausts are complex systems where the use of composite was hardly thinkable less than 10 years ago. The elevated exhaust gas temperatures (600°C to 1000°C), part complexity and high levels of stress and vibration were major challenges that made Inconel or steel the only viable options for headers, collectors, mufflers and tailpipes.

In 2006, Pyromeral Systems considered using PyroSic glass-ceramic matrix composites to manufacture composite components for exhaust systems, with the objective to reduce exhaust weight, improve thermal management, and give more flexibility to engineers when designing the components. The techniques used and the features of these composite exhaust systems are presented below.


Fig. 3: PyroSic exhaust component

Design and manufacturing

Due to the complexity of the parts (e.g. 5-in-1 or 4-in-1 collectors), advanced manufacturing techniques were used. For example, destructible mandrel materials were found to be compatible with the material, and they were used successfully to manufacture seamless hollow shapes. Additionally, it was demonstrated that, if properly designed, the components could be adhesive-bonded without loss of mechanical properties. Further productivity improvements were achieved by using braids instead of prepreg material, although braid availability was an issue. A typical PyroSic-based collector is shown in Figure 3.

More information ...

Pyromeral Systems, with locations near Paris in France, and Dallas in the USA, has been developing high-temperature composites based on glass-ceramic matrices and inorganic polymers for 25 years. With a backward-integrated facility that includes R&D laboratories, compounding equipment and autoclaves, the company performs all activities from tailored material development to the production of finished parts. In addition to heat-resistant structural composites, Pyromeral Systems also develops composite tooling materials for high-temperature processing (up to 400°C) of thermoset- or thermoplastic-matrix CFRP.

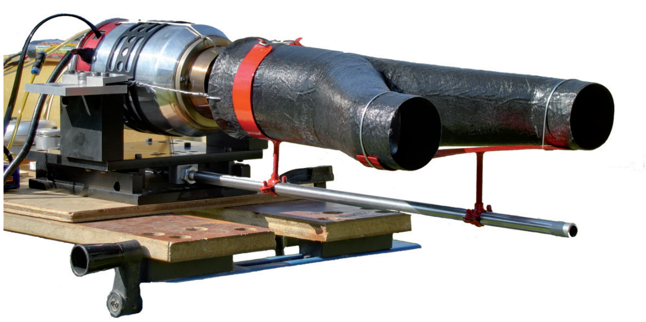

Fig. 4: PyroSic composite exhaust duct

Performance

Tests on actual engines showed that PyroSic-based exhaust systems can successfully resist the thermal environment (temperatures up to 1000°C) and vibrations generated by an engine. Due to the composite's low CTE compared with Inconel, thermal fatigue was not an issue. However, the tests also showed that the attachments used to connect the composite exhaust components to metal parts (e.g. headers or engines) should be carefully designed, as cracking around the attachments is generally the main cause for failure.

Overall, exhausts components exposed to temperatures up to 1000°C performed for approximately 30 hours. Additional research showed that entry-level PyroSic grades were generally best suited for very long-term exposures to temperatures ranging from 500°C to 659°C, which makes PyroSic a good candidate for titanium or Inconel replacement in many exhaust applications (Figure 4).

Conclusion

The development of glass-ceramic matrix composites featuring a glassy phase containing silicon oxide nanoparticles considerably simplified the use and producibility of high-temperature composites for temperatures up to 1000°C, or even above for short-term exposures. The possibility to manufacture durable, high-performance heat shields was demonstrated both through laboratory testing and practical motorsports applications. The use of these materials as a replacement for titanium, Inconel or steel in exhaust system components was also established. Practical design and manufacturing issues were solved to enable the small- to medium-scale commercialization and use of these materials. Weight reductions up to 65% can be achieved when transitioning from metals to PyroSic glass-ceramic matrix composites. Additional research is currently ongoing to expand the use of these materials in aerospace applications, to extend their range of service temperatures, and to develop a carbon-fibre-reinforced version of these glass-ceramic matrix composites in order to address the needs of applications involving lower service temperatures or just very short term exposures. ■

More information:
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