HiSST: 4th International Conference on High-Speed Vehicle Science Technology
22 -26 September 2025, Tours, France

Pyromeral Materials: from car racing to hypersonic flight

Antoine ROSSO[1], *Guillaume JANDIN*[2]

Abstract

For now 40 years Pyromeral Systems has been developing, producing and manufacturing Ceramic Matrix Composites (CMC). Being a worldwide recognised solutions provider for car racing since the 2000's, its solutions demonstrate a lightweight combined with a very high robustness regarding vibration and thermal environments.

These characteristics are of highest interest for a potential application for hypersonic flight. Different examples are detailed:

- Fairing
- Air duct
- Heatshield
- RF window

Keywords: *Ceramic Matrix Composite, Oxyde-Oxyde, Materials*

[1] *MBDA France, Avenue Réaumur – Le Plessis-Robinson – France, antoine.rosso@mbda-systems.com*
[2] *Pyroméral Systems, Rue d'Ognon – Barbery - FRANCE, guillaume.jandin@pyromeral.com*

1. Pyromeral materials

1.1. Bridging the gap

Pyromeral Systems has been founded in 1984 in France. From the very beginning, it has focused its activity on medium to high temperature materials development and production, and on production of such material based parts.

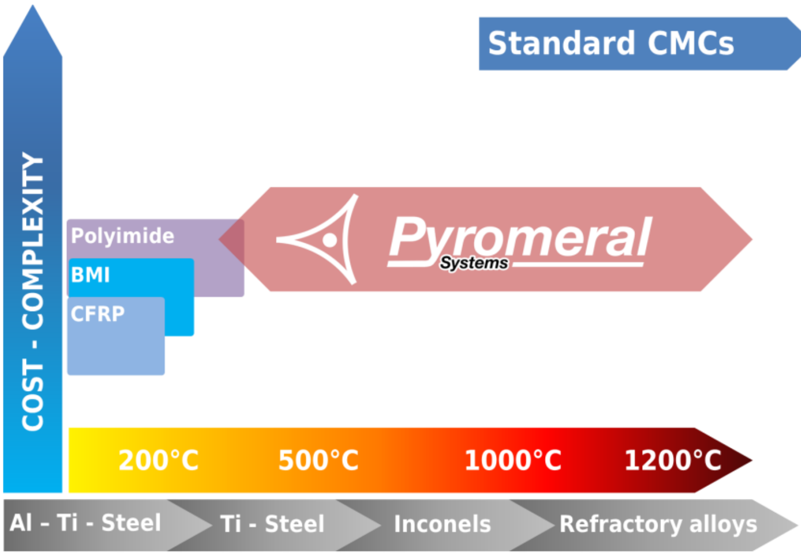

Fig 1. Temperature range of use for commonly used aerospace materials

The world of composites is currently dominated by two major families of materials: CFRP (Carbon Fibre Reinforced Polymer) and CMC (Ceramic Matrix Composites). Since their developments, these advanced materials have contributed to reduce the weight and improve the performance of vehicles used in aerospace, defence or motorsports industries.

On one hand, composites with organic thermoset or thermoplastic matrices reinforced with glass or carbon fibres are widely used at temperature below 300°C (570°F). They are easy to process with well-known techniques, and with systems that rely on fairly low temperatures, from 100°C (210°F) to 350°C (660°F).

On the other hand, carbon/carbon composites and other ceramic-matrix composites (CMC) deliver exceptional performance at very high temperatures (well above 1000°C / 1800°F), but their complex processing and high costs have limited their use to niche markets and specific applications where no other material could be used.

The use of a new family of glass-ceramic matrices resulting from the polymerization of inorganic polymers is the foundation of Pyromeral composites. These inorganic polymers are derived from alumino-silicate-based geopolymeric systems, and, as such, differ significantly from both organic polymers and conventional ceramic matrices. With this technology, Pyromeral composites bring a lightweight and convenient alternative to metals and other materials for heat shields, ducts and other components exposed to temperatures between 300°C (570°F) and 1000°C (1800°F). These materials are also used when superior FST (Fire, Smoke and Toxicity) properties are required. Short-term exposure to temperatures above 1000°C (1800°F) is also possible.

These CMC materials are based on Carbon, Silicon Carbide or Alumina fibres. The parts manufactured with such materials use an Organic Matrix Composite like process, based on stacking of prepreg fabrics in low temperature moulds:

- Parts design: like C/Epoxy composite
- Low temperature moulds: Epoxy tooling block or Carbon moulds
- Low temperature autoclave (80-120°C)
- Post cure free standing (700-1000°C)

Fig 2. OMC-like manufacture of parts

This easy to manufacture approach allow to produce at reasonable costs and to manufacture relatively big and complex parts. This specificity combined with interesting thermomechanical properties and low density, have allowed these materials to become a world class reference in the car racing industry, used in the hottest areas (brake heat shields, exhaust, …) and can even be combined with insulation materials or organic material composites to create hybrid parts.

Fig 3, Fig 4 and Fig 5 illustrate different race car hot parts manufactured using Pyromeral materials.

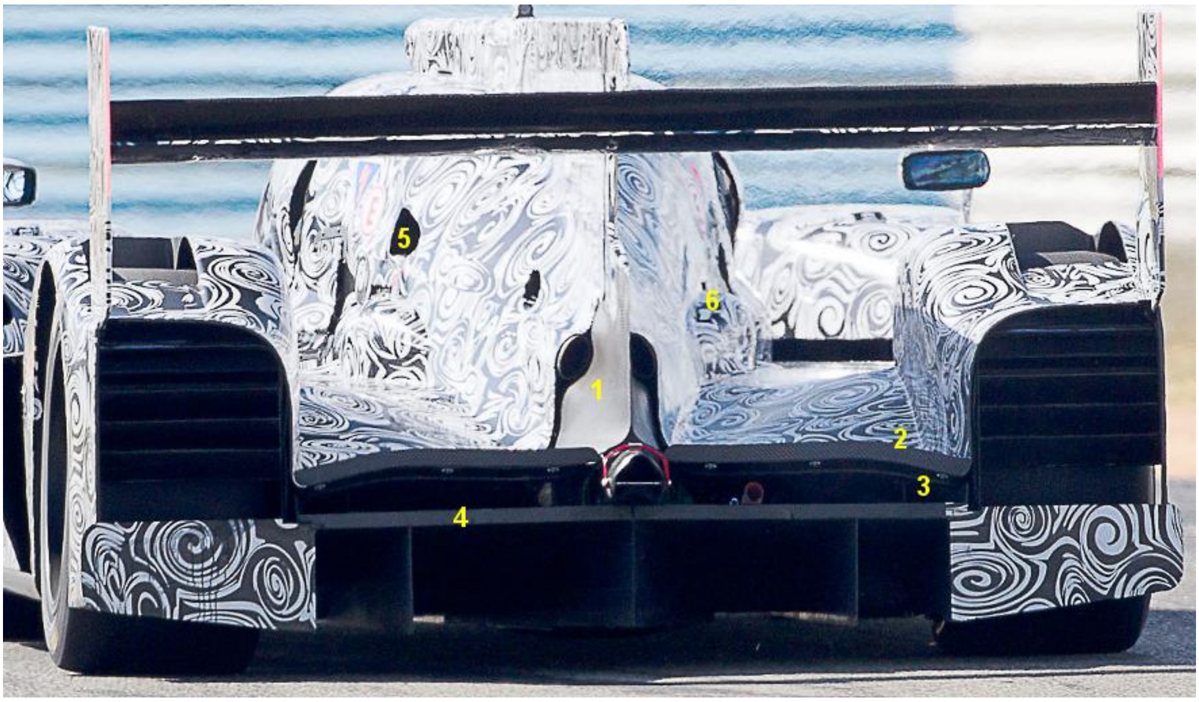

Fig 3. Audi R18 exhaust parts: 1 PyroSic Shark Fin / 2 PyroKarb Blown Diffusor/ 3 - 4 Normal composite Diffusor parts/ 5 Normal composite air exit/ 6 PyroSic near to engine body part

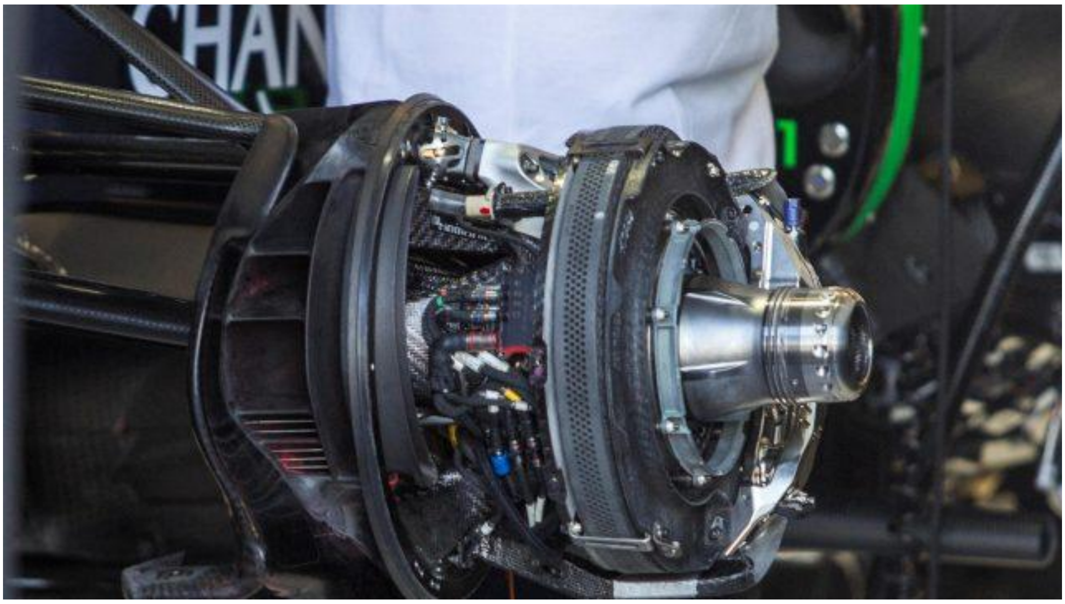

Fig 4. PyroKarb Heatshield in direct proximity from C/C brake disc (McLaren)

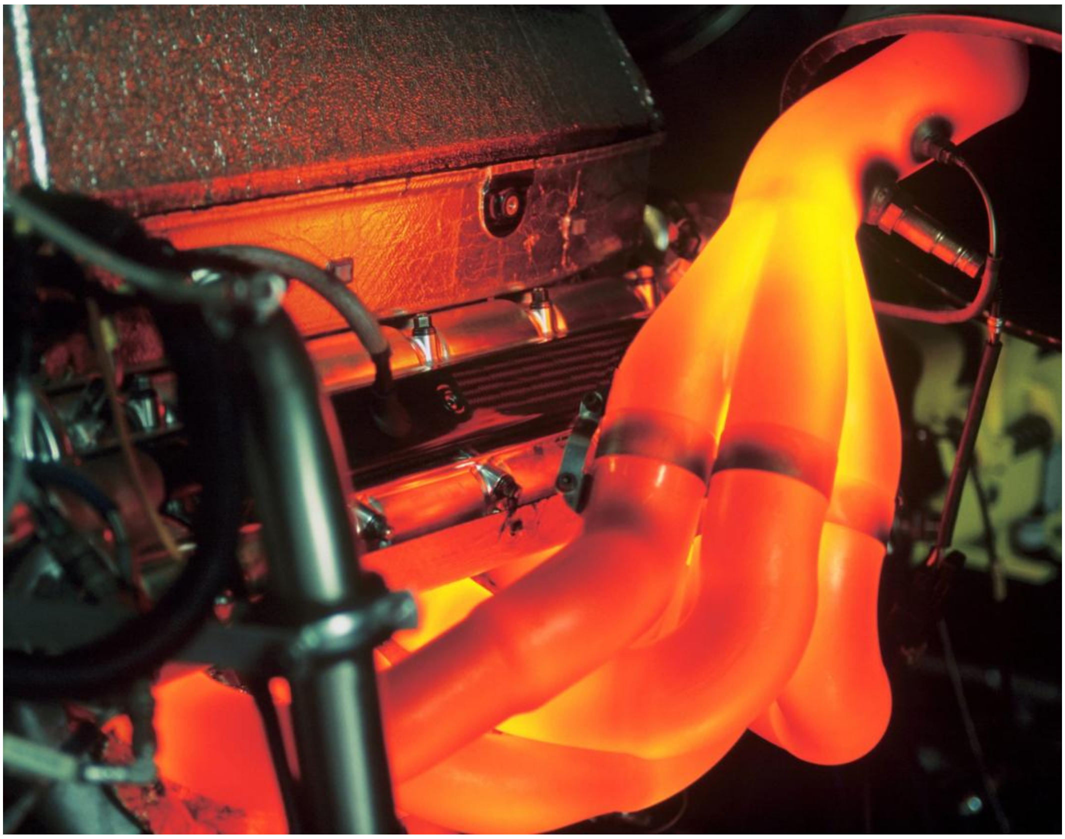

Fig 5. Composite exhaust on competition car

1.2. A wide CMC range

Pyromeral Systems has developed a family of materials, with different fibres and different matrix, answering to different needs.

- PyroSiC and PyroKarb

In Table 1 are presented the main characteristics of PyroSic and PyroKarb materials.

Table 1. PyroSiC and PyroKarb materials main characteristics

Properties	**PyroSiC**	**PyroKarb**
Fibres	SiC	Carbon
Density	1.85	1.65-1.7
Thermal Properties:		
• Thermal conductivity (Z)	0.9 $W.m^{-1}.K^{-1}$	0.3 $W.m^{-1}.K^{-1}$
• Thermal conductivity (XY)	0.9 $W.m^{-1}.K^{-1}$	1.2 $W.m^{-1}.K^{-1}$
• Coef. of Thermal Expansion	$3.10^{-6}.K^{-1}$	$3.10^{-6}.K^{-1}$
• Specific heat	773-1273 J/kg/K (40-757 °C)	773-1273 J/kg/K (40-757 °C)
Sensibility to impact Boeing test (2.9 kg)	5-10 J	< 3 J
Behaviour in fire (0.6 mm Th.): FAA test kerosene flame (15 mn):		
• Surface state	No perforation	No perforation
• Retention of the mechanical properties	95%	<40%
Humid aging after 30 days of immersion in kerosene , acetone and ethanol:		
• Retention of the mechanical properties	100%	100%
Tensile test (ASTM C1275-00):	(@20-650°C)	(@20°C)
• Fracture stress (MPa)	275 MPa	275 MPa
• Elastic modulus (GPa)	65 GPa	55 GPa

- PyroXide

In Table 2 are presented the main characteristics of PyroXide material.

Table 2. PyroXide material main characteristics

Properties	PyroXide
Fibers	Alumina
Density	2.4
Creep limit temperature	1000°C
Thermal Properties:	
• Coef. of Thermal Expansion	$8.10^{-6}.K^{-1}$
Flexural strength (ASTM C1341 06):	
• Flexural modulus @RT (GPa)	75
• Interlaminar strength @RT (MPa)	17
• Flexural strength @RT (MPa)	350
• Flexural strength @800°C (MPa)	220
• Flexural strength @1200°C (MPa)	120

The same reasons that allowed these materials to be of highest interest for the extremely demanding car racing industry deserve to be considered from a hypersonic vehicle needs perspective.

2. Potential applications for hypersonic flight

2.1. Proximity between car racing and hypersonic requirements

As discussed in § 0, Pyromeral materials have been developed for medium to high temperature applications, and optimised during the last two decades for car racing (mainly Formula 1). Even if car racing field seems miles away from hypersonic flight (and in some aspect, it is), some requirements are very close in this two fields of application.

- Mass demanding

Race car performances requires to have the lightest possible parts for each subsystems of the car. This allows to perform steep acceleration and be able to precisely tune the position of the centre of gravity, for stability in curved trajectories.

Lightweight heat resistant materials would be very interesting for flight application, particularly compared to superalloys and refractory metals.

- Vibrations proof

When reaching its full capacity of horse power a race car engine will generate high levels of structural vibrations and acoustic noise. The Pyromeral CMC material have demonstrated their ability to sustain this level of mechanical loadings for hours.

Even if rocket motors, ram- and scramjets or hypersonic flight aeroacoustics phenomenon generate vibration spectrum quite different from the ones encountered in car racing, the levels can be very similar, in structural conducted vibrations as in acoustics (130-150 dB).

This mechanical robustness makes these materials interesting candidates for hypersonic airframe applications.

- Extreme temperatures

As illustrated on Fig 1, one of the main issues associated to hypersonic vehicle airframe is the extreme thermal conditions to sustain.

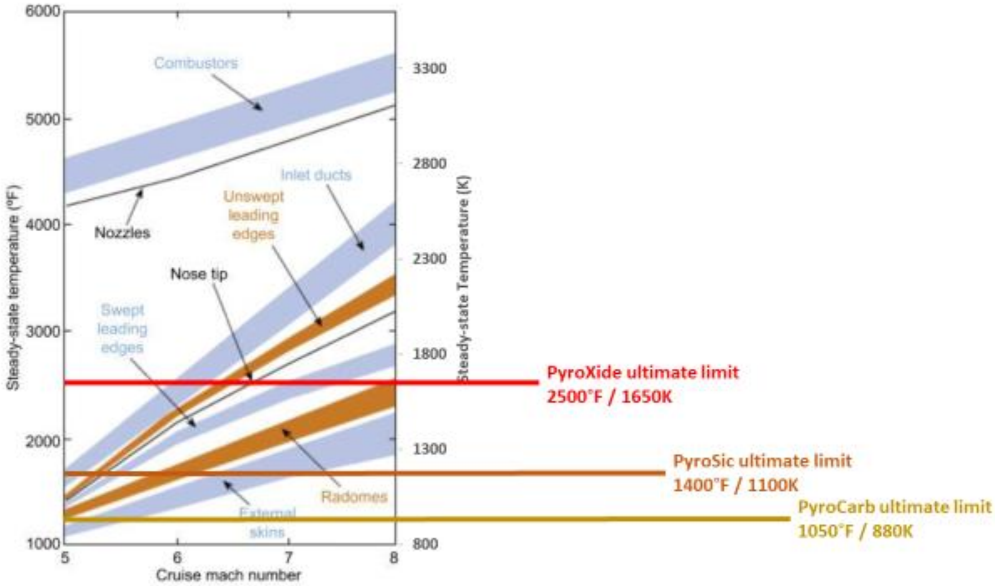

Fig 6. Pyromeral Systems material temperature range of use based on different structures typical temperatures (temperature ranges from [2])

2.2. Potential applications

Depending on the area of interest, a hypersonic vehicle requires the use of materials able to withstand medium to very high temperatures. Like any flying vehicle, the mass management is a critical topic. Composite materials, combining light weight, good thermomechanical properties and ability to optimise strength orientation appear to be a very interesting solution. Among different parts for which the use of these materials could represent a real opportunity, four examples are detailed hereunder:

- Fairings

Based on Fig 1, for vehicles flying at speed between **Mach 4 and Mach 8**, and depending on the area of interest, the different Pyromeral materials (PyroKarb, PyroSiC or PyroXide) can be of interest

Fig 7. General view of inflight hypersonic vehicle (from [3])

The leading edges will be limited to PyroXide, and only for the lowest hypersonic speeds. But on external skins, particularly the less exposed ones (leeward side), the different materials could be employed. Once more the highest speeds will require the use of PyroXide.

The heterogeneity of the material thermal expansion coefficient (between the different Pyromeral materials, but also between metallic parts and CMC parts) but also of the temperature repartition have to be carefully taken into account during vehicle airframe design.

- Air duct

For air breathing engines (ram- and scramjets) the external air has to be ducted form air inlet to the engine itself. For the lowest speed applications (**Mach 4 to 6**) these ducts can be designed using PyroXide.

Fig 8. Air duct

- Heat shields (combining insulation material, CMC and OMC for the cold face)

The ability of these materials to sustain relatively high temperatures and their lightweight, combined with their low thermal conductivity (compared to metallic materials) make them interesting candidates to design heat shields. These heatshields will allow to protect internal equipment to overheat generated by nearest hot point like engine, nozzle, leading edge, external skin…

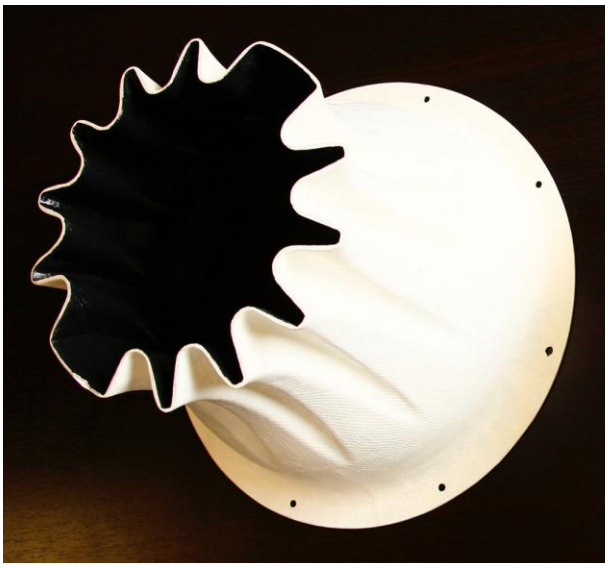

Fig 1. Heatshield around nozzle

In some applications Pyromeral have demonstrated its ability to enclose insulation materials in its materials, allowing to generate even more protective heatshields.

- RF windows

Last but not least, the RF transparency of alumina fibres (and of the associated matrix) allow to design radomes for **Mach 4 to 6** vehicles

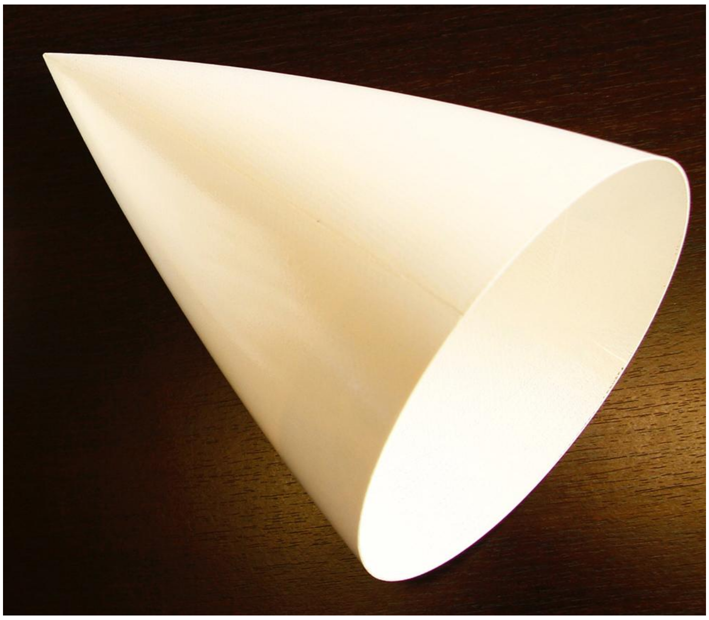

Fig 2. Example of RF transparent part application

References

- Journal article
  1. EUCAS, Dual-Mode Ramjet Technology Status of R&T effort led in France, François FALEMPIN and Laurent SERRE (2007)
- Book
  2. Composite materials for aerospace propulsion related to air and space transportation, A. Misra in Lightweight Composite Structures in Transport, 2016
- Online document
  3. Press release: AQUILA: MBDA to lead consortium for European interceptor against hypersonic threats - https://newsroom.mbda-systems.com/aquila-mbda-to-lead-consortium-for-european-interceptor-against-hypersonic-threats/ (20/06/2023). Accessed 17th July 2025