Glass-matrix carbon-reinforced materials: from Formula One to missile airframes

The MCM ITP project aimed at developing and assessing the glass-matrix carbon-reinforced PyroKarb materials from Pyromeral Systems to achieve a specific thermo-mechanical performance requirement at high temperature for a short- to medium-duration exposure of several hundreds of seconds. The project's objectives were to develop material technologies for an ambitious high-temperature airframe component and address the requirements of affordability, temperature resistance, high specific strength, high stiffness and low weight. It was found that this technology is suitable for structural components for future long-range missiles. The project demonstrated the feasibility of manufacturing complex parts with the Pyromeral material technology. The demonstrator was successfully tested at ambient temperature to evaluate compliance with the design requirements.

Compiled by Gilles Le Page,
Head of Materials and Processes Department, MBDA

The MCM ITP programme gathers:

DGA, Ministry of Defence, [dstl], MBDA, Pyromeral

Pyromeral material technology for advanced glass-ceramic fibre-reinforced composites offers significant weight savings in comparison with traditional metallic materials, improved high temperature performance and a perceived easier manufacturing process in comparison with Ceramic Matrix Composites (CMC). Studies have already demonstrated that CMC (C-C and C-SiC) technologies offer low weight and high temperature performance that can significantly enhance the operational capability of a weapon system in the range well over 1000°C, but their manufacturing processes are usually much more complex and costly.

Pyromeral technology uses a glass-ceramic matrix (nano-ceramic) based on alumino-silicate and organo-silicone chemistry. The technology uses a manufacturing process close to that of prepreg CFRP composites with a low curing temperature below 180°C and a post-curing temperature up to 1000°C. The process is relatively inexpensive. The fibre reinforcement is either silicon carbide (SiC), for the PyroSic™ family, or carbon fibre (HM, IM or HS), for the PyroKarb™ family. The technology can provide materials for applications in the intermediate range of 400°C up to approximately 800°C for short- to medium-duration thermal exposure where CFRPs are not suitable.

PyroKarb inorganic composite

The objective of the programme was to undertake a comprehensive study of the PyroKarb™ technology, which is assumed to address thermo-mechanical application requirements in the 400-700°C temperature range for short- to medium-duration thermal exposure, and address the requirements of affordability, material

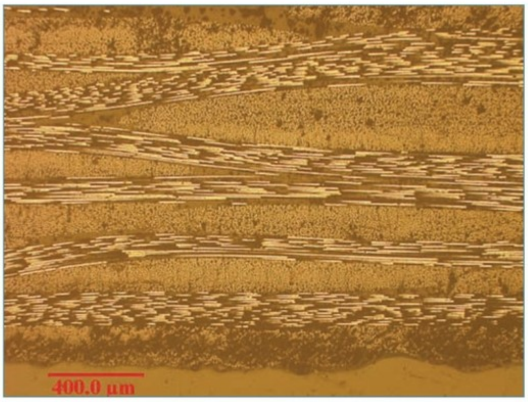

Fig. 1: Micro-section of PyroKarb HS 2x2 twill

availability and sourcing in Europe, high specific strength, high stiffness and low weight for structural missile component applications such as airframes.
Although the capability of carbon fibre is limited by its oxidisation behaviour, due to the short exposure duration, and low O_2 rate during free flight, the material is suitable for the application targeted by the project.

HM PyroKarb materials resulting from recent R&T at Pyromeral (2009) were not further considered in this programme because high-modulus carbon fibre is not readily available in Europe and is the costliest among all carbon fibre grades. Various high-strength (HS) carbon fibres and some intermediate-modulus (IM) carbon fibres are produced in Europe. In terms of mechanical requirements, the HS grade offers higher strength, greater availability in

the European market and lower price, and is perceived as a good compromise despite its lower specific stiffness.
The PyroKarb HS carbon-reinforced material was therefore selected for the project.

The study showed that certain parameters – raw material, fibre desizing and manufacturing process (impregnation with liquid resin, reduced cooling speed and maximum temperature) – have an influence on the mechanical properties of PyroKarb HS carbon fibres.

These process parameters are specific to HS PyroKarb and cannot be directly inferred from HM PyroKarb specifications.
After several iterations and process optimisation steps, Pyromeral manufactured plates with healthy materials (Figure 1) and significantly improved mechanical properties.

Characterisation of materials properties

The PyroKarb material was characterised and its properties measured at ambient temperature and in the 400-700°C range to provide data for finite element modelling of the demonstrator against the application's thermal requirements.
The effects of temperature included a slow decline in tensile strength up to 500°C. From that temperature to 700°C, the drop became slightly quicker.
The effect of temperature was more sensitive on the Young's modulus, with a significant drop over 500°C.
At 700°C and a short-duration exposure, there was no visual evidence of oxidation or degradation of the glass phase matrix.
For the PyroKarb HS 2x2 twill, the mechanical properties were in line with the expectations (250 MPa tensile strength).

Fig. 2: Conical demonstrator structure

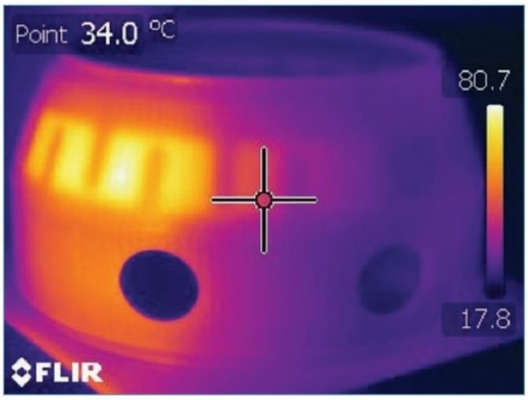

Fig. 3: IR thermography showing the hollow structure

Demonstrator design and manufacture

The demonstrator is a conical structure approximately 225-290 mm in diameter and 150 mm in length (Figure 2).
It includes stiffeners and a frame to support equipment, a hollow structure (Figure 3) in the truncated area to demonstrate the ability to produce such a shape for thermal protection insulation, and joining sections (front and rear) to join either a composite or metallic structure.

The part was manufactured according to MBDA's part design and manufacturing specifications in partnership with Pyromeral Systems.
This part of the project demonstrated it was possible to manufacture complex parts with the material developed during the project.
The mechanical testing of the demonstrator to evaluate compliance against the design requirements at ambient temperature was successful.

Exploitation

High-strength PyroKarb composites developed and optimized under the MCM ITP programme are very promising materials with good specific strength and stiffness at high temperature. Moreover, the PyroKarb manufacturing process is compatible with large and complex shapes.
The potential weight benefits of PyroKarb materials for missile structures were demonstrated and quantified during the MCM ITP project. Along the technology route, the need for appropriate joining techniques was highlighted as essential to prepare the technology's inclusion into future programmes. The PyroKarb technology is being considered for future missile airframe applications. ◻

More information: www.pyromeral.com - www.mbda.com

Focus

About MCM ITP: The MCM ITP (Materials and Components for Missiles, Innovation and Technological Partnership) is an Anglo-French initiative that provides a focus for collaboration and co-ordination of research on guided weapon technologies across MoD, industries and academia. The fundamental objective is to exploit collaboration between leading British and French industrial concerns and academic establishments in the delivery of low Technology Readiness Level (TRL1 to 4) technologies relevant to future guided weapons. The MCM ITP programme has been running for ten years covering about 200 individual projects.