An Update on

Phenolic Resins

for use in

Mass Transit, Marine, Off Shore and Construction Applications

Peter Willson
Sales Director
Caleb Technical Products Ltd

Introduction

Fibre Reinforced Composites based on Phenolic Resin systems have been used for more than 20 years with excellent results to produce mouldings and laminates, which have been used in the Mass Transit, Marine, Off Shore and Construction areas where fire and high temperature resistant components are required.
They do not readily burn and if involved in a fire, produce minimal levels of smoke or toxic fumes.
The ability to produce parts with complex shapes, high strength to weight ratio, low maintenance costs together with ease of installation means that **Cellobond Phenolic Resin** mouldings are recognised as being at the forefront of the solutions in the production of Fire Safe components.
Their performance is compared with that of metals and alternative polymer matrices and some examples are given of recent applications.

Cellobond Phenolic Resins

The **Cellobond** range of thermosetting phenolic resole resins includes :-

Resins - with varying viscosities.

Catalysts - are used to increase the cure speed and lower the cure temperature. Catalysed Cellobond resins will cure at temperatures in the region of 60 to 80^{o}C. The range of resins with varying viscosity and catalysts of different reactivities make it possible produce parts by many differing processes.

Surface Pastes - (or in-mould primers) are used to produce a smooth surface finish, from the mould, to enable painting with low smoke / low toxicity paint systems.

Polyester Gel Coats - especially modified versions have been developed, as an alternative to Surface Pastes, to enable ready finished coloured surfaces to be produced direct from the mould.

Phenolics have an advantage over other available resin systems in that because their unique chemical structure they are inherently fire resistant. They do not readily burn and if involved in a fire, produce minimal levels of smoke or toxic fumes.
They **do not** require the addition of fillers or other fire retardant additives to enhance their fire performance.

In addition to the standard materials, speciality grades are available which have been formulated to have unique properties such as low water or high reactivity and also to suit applications such as the production of syntactic foams, pultruded profiles or sheet moulding compounds.

Manufacturing Processes

- Hand Lamination
- Spray Deposition
- Warm Press Moulding
- Resin Transfer Moulding
- Pultrusion (Catalyst Cure)
- Pultrusion (Thermal Cure)
- Vacuum Injection
- Continuous Lamination
- Resin Infusion (SCRIMP)
- Syntactic Foam

Fire Performance

When fully cured, the high strength of the chemical bonds formed gives phenolic-based mouldings an exceptional level of fire performance and resistance to high temperatures.
Phenolic composites are resistant to ignition and have extremely low levels of low flame spread when involved in a fire situation. These factors, combined with the minimal levels of smoke and toxic emissions that are produced in a fire, make Phenolics the product of choice in areas where public safety is important.

Materials are generally specified on the basis that they are both resistant to burning and that if they do burn there will be enough time for escape before there is danger to life.

Table 1 - Typical Fire Performance of Cellobond Phenolic Laminates

Test	**Performance**
LOI (Limiting Oxygen Index) BS 2782-method 14 ASTM D2863, NES 714	Ignitability >55%
Temperature Index (BS 6853)	> 420°C
BS 476 Pt 6	Rate of Heat Release - I <6, L< 12 (Class 0)
BS 476 Pt 7	Flame spread - Class 1
Cone Calorimeter	Rate of Heat Release - 128kW/m² (Q e 50 kW/m²) Effective Heat of Combustion - 22.3 MJ/kg
3m Cube - Smoke Test. BS 6853	Category 1 - Ao On < 1.0 Ao Off < 1.5
NES 711	Smoke Index - 4
NES 713	Toxicity Index < 5
NF F 16-101	Flame spread - M1, Smoke & Toxicity - F1

Mechanical Performance

In common with other resin matrices, phenolic composites can be designed to have high strength and stiffness whilst maintaining excellent impact resistance.

These properties coupled with the ease with which complex shapes can be reproduced consistently, this gives us the situation where composites are ideally placed to compete with metals as materials for use in the rail, motor vehicle, offshore and construction industries.

If adequate care is taken during the design stage, composite structures can be made to be as strong as metals and using specialist reinforcements, such as carbon fibre, they can produce products with enhanced tensile and flexural moduli.

The resilience of fibre-reinforced composites can lead to lower stress levels in a structure when compared to metallic parts. Fixing and installation are easily achieved and the issue of corrosion in service is negligible when compared to metals.
Composites may be manufactured in-situ if necessary and can be easily fabricated to take complex shapes.

The table below provides more extensive mechanical data for phenolic composites produced using a range of reinforcement types. This information is based on composites made with recommended reinforcements.

Table 2 - Mechanical Performance

Glass Content (% weight)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Impact Strength (KJ/m2)	Comp Strength (MPa)	Comp Modulus (GPa)
None	80 - 115	3.0- 3.5	30 - 50	3.0 - 3.8	-	-	-
CSM (35 – 45)	150 - 220	5.5 - 7.5	100 - 150	5.5 - 7.5	70 - 80	150 - 200	6 - 10
CFM (25 – 35)	75 - 125	4.0 - 5.5	40 - 60	4.5 - 6.0	-	-	-
Woven Roving (50 – 60)	300 - 450	12 - 20	200 - 300	13 - 17	-	190 - 220	14 - 18
Woven Cloth (70 – 80)	300 - 600	17 - 24	300 - 400	16 - 20	-	-	-
Uni-directional (60 – 70)	800 - 1200	28 - 40	-	-	-	-	-

Design Considerations

Low density and high strength to weight ratio – GRP has a specific density between 1.4 and 1.9, which is 30 - 50% lower than that of aluminium and 75 - 80% lower than that of carbon steel. In specialist applications carbon fibre reinforcement produces even lighter materials.

Table 3 - Comparison of Resin and Metal Component Properties -

PROPERTY	Phenolic GRP	Polyester GRP		Mild Steel	Aluminium
		Unfilled	Filled	(painted)	(painted)
Density (g/ml)	1.4 - 1.5	1.4 - 1.5	1.6 - 2.3	7.8	2.7
Tensile Strength (MPa)	100 - 140	100 - 140	30 - 75	410 - 480	80 - 430
Tensile Modulus (GPa)	5.5 - 7.5	6 - 7.5	7 - 19	210	70
Elongation @ Break (%)	1.8 - 2.5	1.8 - 2.5	0.4 - 1.7	20 - 35	3 - 18
Flexural Strength (MPa)	150 - 200	150 - 200	100 - 125	200 (yield)	65 - 220 (yield)
Flexural Modulus (GPa)	6 - 8	6 - 8	6 - 15	210	70
Izod Impact Strength (KJ/m^2)	65 - 75	50 - 75	20 - 50	-	-
Coeff. Thermal Expansion ($^oC \times 10^{-6}$)	10 - 15	25 - 35	18 - 25	11 - 14	22 - 24
Coeff. Thermal Conductivity (W/m/K)	0.20 - 0.24	0.20 - 0.23	0.22 - 0.30	46	140 - 190
Temperature Index (BS6853)	> 420 ^oC	Fail	< 365 ^oC	> 420 ^oC	> 420 ^oC
UK Building Regs. (BS476 Pts. 6 & 7)	Class 1 / 0	Class 2 / 3	Class 1 / 0	Class1 / 0	Class 1 / 0
3 Metre Cube Smoke Test (BS6853)	Category 1	Fail	Category 2	Category 1	Category 1

Table 4 - Weight / Performance Comparisons between Metals and Glass Reinforced Phenolic Composites

Material	Comparable Weight to give:		
	Same resistance to elongation	Same Resistance to Bending	Same Load to Carrying Capacity
Steel	1.0	1.0	1.0
Aluminium Alloy	0.8	0.4	0.7
Uni-Directional Rod 70 % weight glass e.g. Pultrusion	1.2	0.4	0.2
Fabric Laminate 60% weight glass e.g. RTM	2.5	0.5	0.5
Mat Laminate 35% weight glass e.g.Hand-lay	5.7	0.6	0.9

Corrosion and Chemical Resistance – Both aluminium and steel require protective coatings to resist corrosion in the marine environment. Phenolic composites are less affected by corrosion.

Design Flexibility – Polymer composites offer enormous scope for design flexibility when compared to metals. The properties of the composite item may be adjusted to suit the demands that will be placed on it, either uniformly through the part or in specific areas.

Lifetime Cost Effectiveness – The ability to manufacture complex parts in a one-shot process (RTM or Vacuum Infusion) can be very cost effective. A similarly complex metal part may require many stamping and welding operations.
In addition the low cost of composite tooling means that design changes and short production runs can be made cost effectively.

The full benefit of composite parts is only realised when they are designed in composite rather than as a simple material replacement.

Application Examples

Mass Transit

Ever since 1984 Phenolic resin based GRP mouldings (the Dallas/Fort Worth People Mover) have been used in Mass Transit applications because of the inherent Fire Safety aspects of Phenolic Resin systems.

- **Underground / Metro**:
  London Underground -Northern & Jubilee lines
  Madrid Underground
  Bilbao, Rome, Rotterdam & Dublin Metro's

- **Overground**
  Channel Tunnel - Eurostar
  Gardemoen Express, Norway
  High Speed Talgo, Spain
  Hong Kong Shuttle,
  Heathrow Express,
  Scottish Regional Railways
  West Coast & Cross Country route, UK

Off-shore

- Fire and blast resistant panel systems, modules and temporary safe refuges
- Syntactic foam insulation and protective coatings
- Low pressure and pressure rated pipe systems.
- Pultruded profiles and grid flooring.
- Pipes, ducts and man-safe escape corridors.
- Pre-insulated process pipe.
- Steel faced, phenolic foam insulated panels.
- Filament wound beams.

Marine

Of all the key markets in which phenolic components are being chosen, one of the fastest developing is the marine sector.

Phenolic composites are now being used or tested in almost every segment of the marine market from special service craft, such as offshore survival capsules, through the rapidly growing fast craft market to the still relatively traditional yet highly design conscious cruise industry.

Of all the international conventions dealing with maritime safety, the most important is the International Convention for the Safety of Life at Sea (SOLAS), which deals with all aspects of the safe design and operation of marine craft and governs materials selection by marine architects. As vessel design and function diversifies there is pressure from the International Maritime Organisation (IMO) to introduce specific codes. The Code of Practice for High Speed Craft is an example of such progress.
This code recognises the role that composite materials can play in reducing the weight of vessels to allow more efficient and faster propulsion. In defining a new class of materials as 'fire restricting' they have set high standards of fire performance that amongst composites only Phenolics appear capable of passing.

Marine - Fire Performance – Compared to other composite resins the fire performance of Phenolics is unrivalled. This level of performance does not depend on additives and fillers.
In very many cases phenolic composites are the only organic materials capable of meeting the demands of the highest fire standards. Most recently this has been shown to be the case when a range of composites were tested against the requirements for a 'fire restricting material' under the IMO's High Speed Craft Code. Phenolics are finding more and more use:

- Public rooms on cruise ships. Phenolic panelling will not contribute to the fire load and gives off almost no smoke or fumes in fire.
- Lining panels and window masks complying with the High Speed Craft Code of Practice on Scandinavian, Spanish and British built high-speed fast ferries.
- Lining panels and overhead lockers in commercial vessels approved by US Coastguard. The exceptional fire performance of Phenolics made them a natural choice for confined spaces with limited exit.

Construction

There are few markets as generally cost conscious as construction. However as new finishing options are being developed the unique combination of properties offered by phenolic composites of strength, lightweight, corrosion resistance, durability and cost effectiveness are finding ever-wider recognition.

- Piping for Gas and Liquid Transport - Phenolic piping has been used for many years for methane drainage in mines. The lightweight phenolic product is easier to fit than traditional steel pipe and suffers less corrosion in this damp and aggressive environment.
- Cladding for New Build and Building Refurbishment – Phenolic composite cladding and phenolic composite faced insulated panels.
- Coloured composite cladding is available in a wide range of colours and textures. It is particularly suited to schools, hospitals, transport termini and municipal housing projects.
- Low density insulating pipe sections and laminate
- Phenolic Composites as Tunnel Linings – Phenolic linings have already been installed in the Clyde and Glasgow tunnels. With the publicity following the recent Tunnel fires in Europe, and the benefits afforded by Phenolics, this is an area of increasing interest.
- Air Conditioning and Ducting - Cellobond J2027L is approved by Factory Mutual for the manufacture of ducting.
- Cable Trays - Building fires demonstrate the dangers presented by burning cable sheathing. Because of its exceptional fire and flame resistance Phenolic pultruded cable trays can restrict the spread of fire that starts in the cable system, and in addition protect cables from external fire sources.

Conclusion

Where Fire, Smoke and Toxicity (FST) performance properties are required - Phenolic resin is the material of choice for the production of composite parts.

In use since 1984 and backed up by substantial data and in-service history proves that components made from phenolic resins are able to meet the requirements for Mass Transit, Marine, Offshore and Construction applications.

Their use allows Designers and Engineers to meet Safety concerns whilst permitting developments and improvements in weight savings and design freedom over traditionally used materials.

References

1. Brown D. - *'The 'Impact' of Composites on Railway Rolling Stock'*, Composites in the Rail Industry conference, 1997

2. Grigoriou T - *Phenolic Composites - The Use of Fire Safe Materials* – 1999

3. Orpin M R - *The Use of Fire-Safe Phenolic Composite Materials in Marine Applications* –1996

4. BP Chemicals / Borden Chemicals – *Mechanical and Physical Properties database*