NEW APPLICATION TECHNOLOGIES IN PHENOLIC MOLDABLE COMPOSITES

1. Why PF-GF have an increasing share of new engine components

Plastics are replacing metal parts for a wide range of uses in the automotive industry as well as other industries. The increasing pressure to reduce costs and weight in the car industry is leading to an increase in the use of plastics instead of the traditional construction materials, such as metal.

As well as performing outstandingly, a modern engine must have the following characteristics:

. Low weight

. Low fuel consumption

. Good noise insulation

. Low exhaust emissions

. Low cost

A high proportion (around 40%) of a car's fuel consumption and harmful emissions is dependent on the weight; so plastics, with their low specific masses, are suitable engineering material.

Plastic parts for engines continue to be developed to replace metal. While it used to be simple parts, now complete, complex components are developed in plastic. The demands on materials are becoming ever stricter, and it will not be long before we reach the limits of engineering thermoplastics. The areas of use in which very high demands are placed on the materials are the areas which are of interest to glass-fibre reinforced phenolic moldable composites (MPC).

1.1. Comparing characteristics

Glass-fibre reinforced phenolic moldable composites are being used increasingly for new developments for under the bonnet applications, on account of the special properties this group of materials possesses. The differences between the characteristics of the various engineering plastics do not become fully apparent until you compare them at higher temperatures and for long periods.

Here are some of the important characteristics of the Vyncolit materials that are widely used in the European automotive industry ;

- VYNCOLIT X655 - 80 % glass-fibre and mineral-filled phenolic moulding compound

. VYNCOLIT X613 - 45% glass-fibre and glass-bead filled phenolic moulding compound

. VYNCOLIT X6952 - 55 % glass-fibre filled phenolic moulding compound

PROPERTIES			X613	X655	X6952
Relative Density	ISO 1183	g/cm³	1.60	2.08	1.70
Flexural Strength	ISO 178	MPa	210-230	170-190	250-280
Flexural Modulus	ISO 178	GPa	11,5-13,5	23-25	16-18
Strain to Failure	ISO 178	%	1,50-1,70	0,75-0,85	1,50-1,70
Tensile Strength	ISO 527	MPa	70-90	70-90	100-130
Charpy Impact Strength	ISO 179	kJ/m²	14-16	6-8	18-22
Compressive Strength	ISO 604	MPa	280-320	340-380	220-270

Fig. 2: Material characteristics

The following engineering thermoplastics were tested for comparison:

. PPS - 40% glass-fibre reinforced

. PPS - 65 % glass-fibre and mineral-fibre reinforced

. PPA - 45% glass-fibre reinforced

1.2. Stress-strain comparison

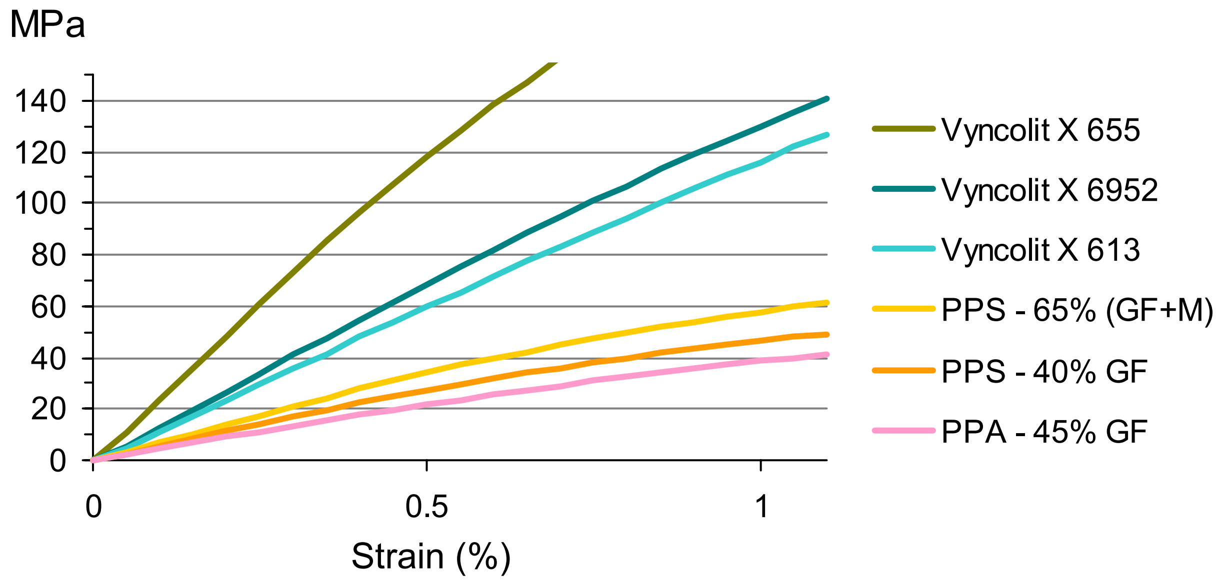

Fig. 3: Stress-strain diagram

Although the modulus of elasticity and elongation at the break of engineering thermoplastics are high at room temperature, the rigidity drops drastically as the temperature rises (in this case up to 140°C). Even at room temperature, the engineering thermoplastics have a short elastic range, and this becomes even smaller at higher temperatures. PMCs do not have this plastic zone, which is definitely an important factor for the engineer.

1.3. Characteristics after storage at 140 °C

It is very important for the motor-engineer to know how the engineering plastics behave after they have been stored in a particular medium at the maximum rated temperature. To determine this, the characteristic being investigated has to be measured at the storage temperature, rather than leaving the test piece to cool to room temperature before measuring as is normally the case.

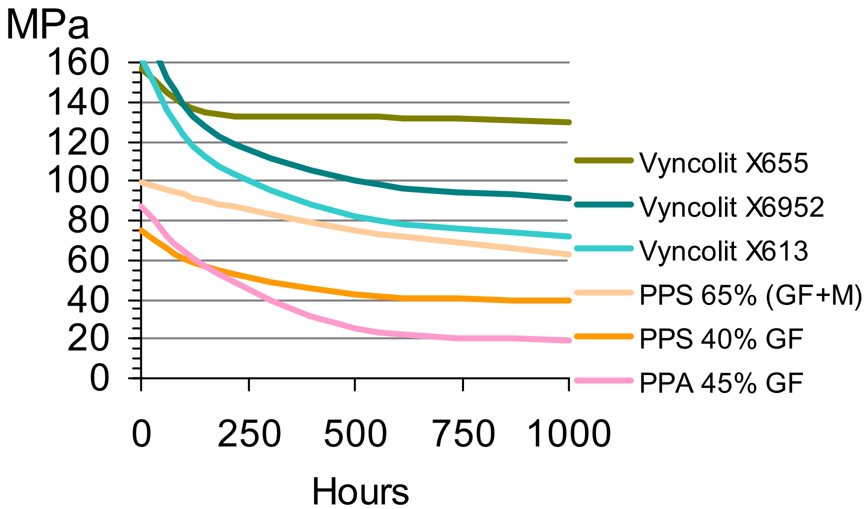

Fig. 4: Flexural strength in glycol/water at 140.C

These results clearly show that PMC retains its characteristics better, even at extreme temperatures, for long periods and in aggressive mediums.

1.4. Dimensional stability

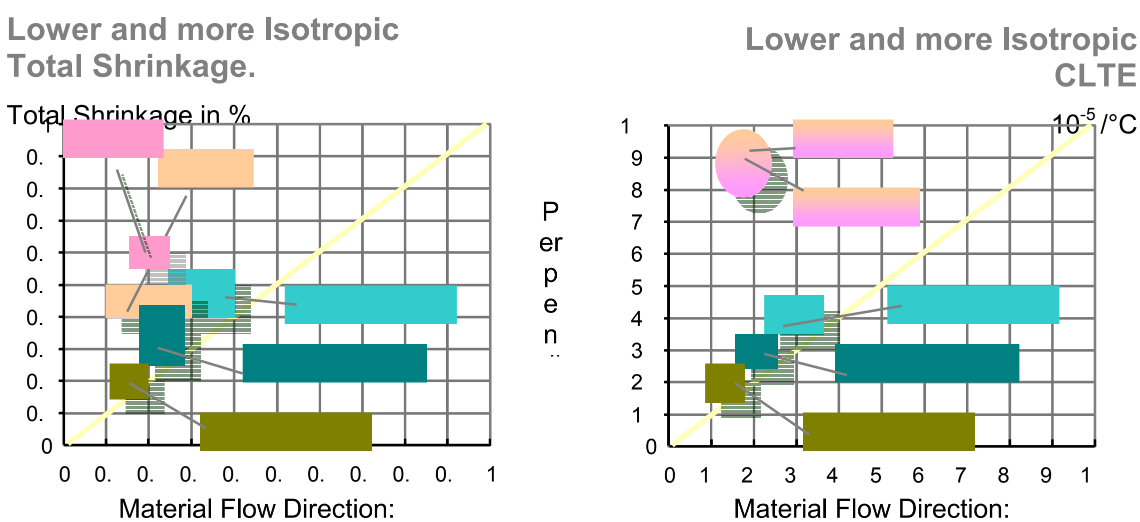

Fig. 6: Dimensional stability

The shrinkage and coefficient of thermal expansion are very important characteristics, which significantly influence the dimensional stability. The thermoplastics tested produce good results in the direction of flow, but they display more shrinkage and expansion in the transverse direction. This anisotropy leads to distortion after injection moulding or when the temperature rises.

The two diagrams show clearly that it is possible to make products with a very high dimensional stability using PMC.

2. Applications and development trends

2.1. Continuously variable air intake manifold

- BMW 735i and 745i

The main reason why the new BMW 8-cylinder petrol engine (3.6 l and 4.4 l) was developed was to improve on its predecessor's torque curve. Achieving this meant having to adapt the air intake system's channel length to precisely suit the torque curve they were trying to obtain, something they achieved by developing a unique and new, continuously variable air intake manifold system made from PMC.

The company PIERBURG decided at the very beginning of development to make the air intake system out of engineering plastics for reasons of weight and cost. They also soon decided to make the casing out of magnesium, this time for reasons of weight.

The plastic air intake system comprises a housing which forms the 8 air inlets to the cylinders as well as 8 specially shaped rotors. The central interior area around the rotor shafts serves as a plenum for the air. The rotors move around the central axis, allowing the length of the intake system to be smoothly adjusted between 230 and 670 mm, with the rotors moving through an angle of 236° in less than a second. There are 4 rotors for each of the cylinder blocks and, for reasons of rigidity, each set is mounted on a separate shaft. The two shafts are synchronised and rotate in opposite directions.

Pierburg began to develop the plastic construction using engineering thermoplastics such as glass-fibre reinforced PPS and PPA. However, the thermoplastic prototypes failed because of the complexity of the structure and their insufficient dimensional stability at high temperature. Thanks to the close cooperation between Pierburg, Baumgarten and Vyncolit, the problems were solved by using glass-fibre reinforced phenolic moldable composites.

vyncolit
A PERSTORP COMPANY

CONTINUOUS VARIABLE AIR INTAKE MANIFOLD IN MPC

Part	Housing	Rotor
Material	Vyncolit X 7250	Vyncolit X 6952
Density g/cm3	1.68	1.71
E-modul flex MPa	>12000	>16000
Tensile stress at break MPa	>190	>250
Strain to failure in flex %	>1.6	>1.5
Charpy impact kJ/m2	>12	>18
Coefficient of linear thermal expansion x10E6/°K	20/40	18/28
Max. temp. exposure °C	170	180

AIR INTAKE PARTS

Fig. 11: Material key figures

At the start of the development work, Vyncolit X7250 was tested for the housing. This choice of material was based on the necessity of isotropic characteristics, good workability and dimensional stability including at high temperatures of up to 160°C. With the optimum combination of fillers , reinforced with glass fibre and glass beads, combined with the material's good flow characteristics and exceptional dimensional stability, satisfactory results were very quickly achieved. Minimum wall thicknesses of 2.2 mm and flow lengths of 170 mm are not uncommon in these housing components.

For the rotors, the best results were obtained using the engineering plastic Vyncolit X6952, a 55 % short glass-fibre filled phenolic moldable composite with outstanding thermo-mechanical qualities. The necessary dynamic characteristics were attained by optimising the bonding between the matrix and the glass fibres. Both phenolic moldable composites have a high modulus of elasticity, even at 140 °C, which is one of the characteristics that brought about such successful results. Figure 3 shows a comparison of rigidity against elongation at 140 °C between these compounds and engineering thermoplastics.

This air intake module is made up of 17 thermoset components, 5 of which are different. The company Baumgarten succeeded in manufacturing these various parts fully automatically, which was not at all easy because of the complex geometries, having to inject around metal inserts and on account of the small tolerances.

Fig. 12: Induction system - Vyncolit X 7250 casing

The entire air intake module including housing and rotors weighs 5.4 kg, also including metal inserts. This positive result was achieved on account of the low density of the two Vyncolit materials as well as an average wall thickness of only 2.5 mm for the housing. All of the test results, including the car tests and durability tests under challenging conditions, were successful.

2.2. Coolant circulation system

PMC was chosen because of its combination of characteristics such as good chemical resistances, beneficial thermo-mechanical properties, minimal cold flow, dimensional stability, easy transformation and cheap part prices.

Fig. 14: Vyncolit X613 covered vane rotors

Not only are the conventional water pump vane rotors made from PMC, but also the covered vane rotors. This construction leads to higher pump efficiency.

The production of the first complete plastic water pump started in the year 1999. It is the external water pump for the PSA Group 1.9-2.2 liter petrol engine. This pump is produced by MARK IV Systèmes Moteurs S.A., France.

This water pump is produced for the PSA Group's most important engine, the DV diesel engine. This 1.4 l & 1.6 litre diesel engine, with 8 or 16 valves, has a unique modular construction and is being gradually fitted to Peugeot, Citroen and Ford cars. PSA is expecting to produce between 6,000 and 9,000 engines per day. The engine weighs only 98 kg, 50 kg less than the previous 1.9 litre diesel engine; this weight reduction was achieved using an aluminium engine block and the maximum use of engineering plastics, including this water pump made from PMC. The pump was developed by Pierburg, Bailly-Comte and Vyncolit in cooperation, and production started in September 2001.

There is a lot of interest in plastic water pumps in Germany as well, with various pumps in the testing phase. The reasons for this interest are:

. Cost saving 20%

. Weight reduction 30-40% .

. Increased efficiency

All that compared against aluminium versions.

An FEA calculation shows very clearly the zone with the highest tensile stress. This stress can be minimised by redesigning until the required level is reached. Once the construction has been decided on, a flow simulation calculation (Sigma-soft) can be performed, after which the construction of the tools is defined.

By using these new techniques, the development time can be made much shorter and the risk of a negative development is reduced.

PSA, FORD and BMW have been using Vyncolit materials for thermostat housings and water inlets/outlets for many years. The reason for this is the simplified construction which does not require metal inserts to resist cold flow, as well as the chemical resilience, even to 'long-life' coolants. Vyncolit parts can also be produced more cheaply than aluminium parts.

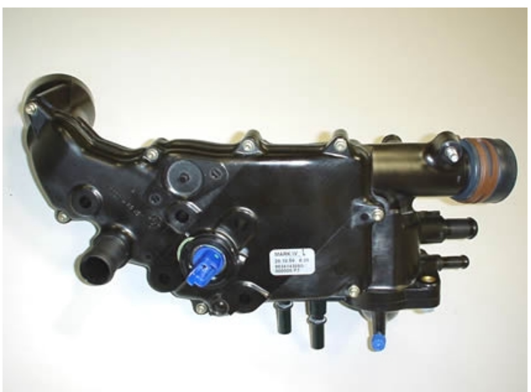

Fig. 20: Vyncolit X7010 thermostat module

This temperature control system, developed in conjunction with the company Mark IV, has a housing and a cover with a gasket, and is fixed directly to the engine block. The following functions have been integrated into it:

. Thermostat

. Temperature sensor

. Diesel pre-heater

. Inlet and outlet

. Warmer and colder zones

The total weight of the plastic component is 1.2 kg, which means a weight reduction of 40 % - 800 g - compared with the aluminium version. The main difficulty in developing this component was ensuring sufficient dynamic resistance, given the weight of the component when full, the numerous pipe connections, and the fact that the whole system is only fixed to the engine block using four central bolts. The material chosen was Vyncolit X7010, a MPC which displays exceptional dynamic resistance as well as good chemical resilience, resistance to cold flow and good mechanical properties. The component is fitted in cars such as the Peugeot 406 and 607, and the Citroen C5 with the 2.2 l HDI engine.

The positive success of this temperature control system led PSA to decide to replace the aluminium water outlet for its TU engine with an outlet made of Vyncolit material, thus reducing the weight and saving on cost. The challenge in this case was not only the coolant, but also a separate hot oil side. The water outlet has two zones:

. Cooling zone with thermostat and temperature sensor

. Oil zone

The complete part is attached to the motor block with a silicone fluid gasket, and is aimed to provide complete insulation and sealing. The gasket can hardly tolerate any distortion, at any point in the engine's lifetime. This was a difficult task since temperatures on the two sides can differ by more than 50 °C. The material used - Vyncolit X7010 - has a low coefficient of thermal expansion, a high E-modulus at 150 °C, and chemical resistance against hot 'long-life' coolant and engine oil.

2.3. Transmission & Distribution Pulleys

- Sprocket

Fig. 22: Vyncolit W5016 toothed cam belt pulley

The first complete plastic sprocket was developed in conjunction with FORD and Contitech. Hybrid models have been in production in Japan for several years.

FORD's objective was to reduce the cost and weight as much as possible in comparison with the sintered metal version. To achieve this required the development of a toothed pulley without metal inserts. The choice of material was dictated by this demand, as well as by belt wear and dimensional stability.

The sintered metal sprocket was fitted to the camshaft using an M10 bolt and a separate washer, tightened to 80 Nm. Ford was not prepared to change this method of attachment.

The material used is Vyncolit W5016, a high mineral content MPC with very good dimensional stability and dynamic characteristics.

The phenolic pulley weighs 167 g, representing a weight reduction of 58 % from the sintered metal part (400 g), and 466 g reduction per vehicle (2 pulleys per vehicle). Since the beginning of this year, the Ford 4 cylinder Zetec SE petrol engine has been fitted with 2 Vyncolit sprockets. These pulleys are manufactured by the Winkelmann Palsis Motortechnik.

- Multi-V pulley

Fig. 24: Vyncolit 2940W multi-V pulley

The multi-V pulley made from PMC is the current state-of-the-art technology for water pumps, power steering pumps and generators in Europe. What is new is the development of pulleys for the air-conditioning compressor. Winkelmann Palsis Motor- technik developed and patented this technology; instead of a magnetic clutch they used a rubber/plastic solution which resulted in important weight reduction and cost savings. Furthermore, it improved the function of this pulley so much that the pulley system's air-compressor is reliably protected in the event of a failure. Production of this air conditioning compressor pulley began at the beginning of last year using the material Vyncolit 2940W, a glass-fibre and mineral reinforced, novolak-type MPC.

- Idler pulley

Figure 26 - Vyncolit 2940W idler pulley

5 .10E6 idler pulleys are already being manufactured each year from Vyncolit moulding compounds. MPC is used more and more often because of higher engine temperatures and belt wear.

2.4. Throttle body

Fig. 29: Vyncolit X7312 E-throttle casing

This is a development product made in our Technical Market Development Center in Ghent, Belgium. We are examining the maximum dimensional changes at different temperatures and air humidities. Because of its low levels of shrinkage and after-shrinkage, as well as its even and minimal elongation at temperatures as high as 140 to 150°C, we are of the view that PMC is the most economical material for this application.

2.5. Fuel-system engine components

- Fuel pumps

Fig. 30: Fuel pump parts

Fuel pumps made from PMC have existed since 1990, and about 15 .10E6 pumps are now being made from Vyncolit each year. The reason for this success is the excellent dimensional stability in fuel. The rotors are lapped and µm-tolerances are required. Lapped parts - without injection surface - are also required hardly to absorb any fuel (max. 0.5 % weight increase after 72 hours storage in FAM-B at 115°C).

3. Future trends

Other engine parts continue to be developed in engineering plastics. We consider it likely that the following new applications will be produced in PMC in the years to come:

. Oil pumps and oil-carrying parts

. E-throttle body

. Manual transmission parts

. Automatic transmission parts

. Exhaust parts - EGR

. Turbo system parts

. Vacuum pump parts

These are possible uses in the fuel cell area as well, such as:

. Bipolar plate

. End plate - cell frame

. Pumps

. Compressor parts

4. Summary

Comparing PMC properties with those of engineering thermoplastics at high temperatures shows clearly that PMC has better characteristics.

The many parts for which PMC has already been used demonstrate this. The more trust engineers have in this MPC, the more complicated the applications will become.

We believe there will be a growing market for these materials in the future.

The new components that have yet to be developed will place even greater demands on the materials. Only with very close, open cooperation between designers, manufacturers and rnaterial suppliers, coupled with the use of FE calculations – full-simulation technology - will it be possible to succeed in making such difficult components out of PMC.