PHENOLIC MOLDING COMPOUNDS IN AUTOMOTIVE POWERTRAIN APPLICATIONS

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Abstract

The powertrain remains one vehicle system that itself has not undergone significant lightweighting as automakers strive to meet more stringent emission and fuel economy standards. The average light vehicle internal combustion engine (ICE) makes up over one-third of the total vehicle weight. Almost ninety percent of the engine's weight is traditional iron, steel or aluminum. The balance is a variety of rubber, glass and plastic materials.[1]

High engine temperatures limit use of the most commonly available composite materials including polyamides (nylon). However, newer grades of phenolic-based engineering thermoset (ETS) materials / molding compounds are higher in strength, temperature and corrosion resistance allowing for their use in an increasing number of under-the-hood and powertrain applications. Together with smart design, automakers are converting more powertrain components from metal to engineering thermosets for both weight and frequently cost savings when significant post machining of metal is required to meet tight tolerances.

This paper describes selected past, present and future uses of phenolic-based engineering thermoset materials for lightweighting of powertrain components.

Introduction

Bakelite® was the world's first commercially produced plastic. Invented in 1909 by Dr. Leo Baekeland, Bakelite became one of the most versatile plastics ever produced.[2] Its early uses ranged from consumer goods (e.g. telephones, jewelry) to industrial applications (e.g. electrical insulators, airplane propellers). Automobiles have used Bakelite molding compounds for gears, pulleys, electrical housings and brake components since the days of Henry Ford. Phenolic-based molding compounds fell out of favor with automotive engineers as metals and other plastics became easier and less expensive to manufacture. More recently, ETS materials with improved performance have been replacing steel and die cast aluminum as a way to reduce the cost and weight of certain components. Table 1 compares the properties of older, "standard" Bakelite grades with today's Bakelite engineering thermoset materials designed for automotive use. Newer ETS grades have 2-3 times the tensile strength and modulus of general purpose molding compounds.

Table I. Mechanical Property Comparison: ETS vs. Standard Grade Molding Compounds

Property	Test Method	Units	BAKELITE PF 31 Standard Grade	BAKELITE® PF 6510 Engineering Thermoset Grade	BAKELITE® PF 1110 Engineering Thermoset Grade
Density	ISO 1183	g/cm^3	1.42	1.70	2.06
Compressive Strength	ISO 604	MPa	250	260	325
Tensile Modulus	ISO 527-1/2	MPa	7,500	16,500	29,500
Tensile Strength	ISO 527-1/2	MPa	50	100	150
Elongation at Break	ISO 527-1/2	%	0.05 – 0.25	0.05 – 0.25	0.05 – 0.25
Flexural Modulus	ISO 178	MPa	7,500	15,500	27,000
Flexural Strength	ISO 178	MPa	95	200	260

The main advantages of phenolic-based ETS materials include:

- Metal-like mechanical properties
- Dimensional stability at elevated temperature
- Lightweight
- Less costly versus die cast aluminum when significant machining is required

Established Automotive Uses of Phenolic-Based ETS Materials

Water Pump Housings

Water pump housings made from phenolic-based (PF) ETS materials have been in common use as a replacement for steel and die cast aluminum since the early 2000s. ETS materials are lighter weight, corrosion resistant and frequently less costly than potential alternatives.[3] A test of the material according to ISO 175:2011-03 examines the effects of immersion in liquid chemicals. Figure 1 shows the effects on Bakelite grade PF 6510 immersed in engine coolant at 120˚C. The test indicates minimal dimensional change and absorption of less than 3% after 3000 hours.

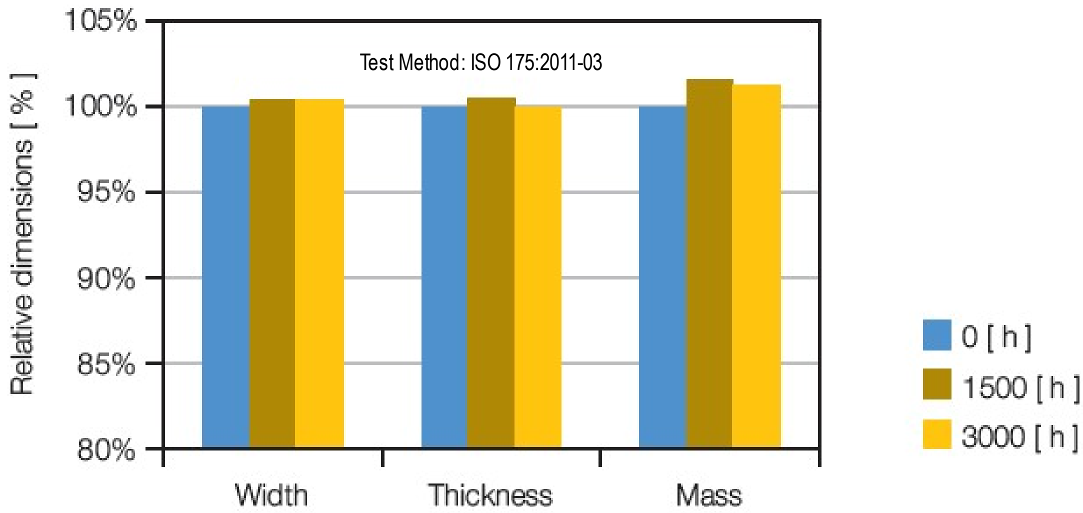


Figure 1. Chemical resistance of Bakelite PF 6510 in Glysantin G30 at 120°C.

DMA setup:
Machine: DMA Q800
Location: The University of Western Ontario
Date of test: 7-July-2016
Test type: Single cantilever beam
Temp range: Room temp to 200 degC
Temp ramp rate: 5deg/min,

DMA Coupons	Span	Width	Thickness
Water pump 08/03	17.50	11.97	2.70
Water pump 12/10	17.50	11.95	2.98
Water pump 14/02	17.50	11.90	2.96

Figure 2. Used water pump housing collected for property testing.

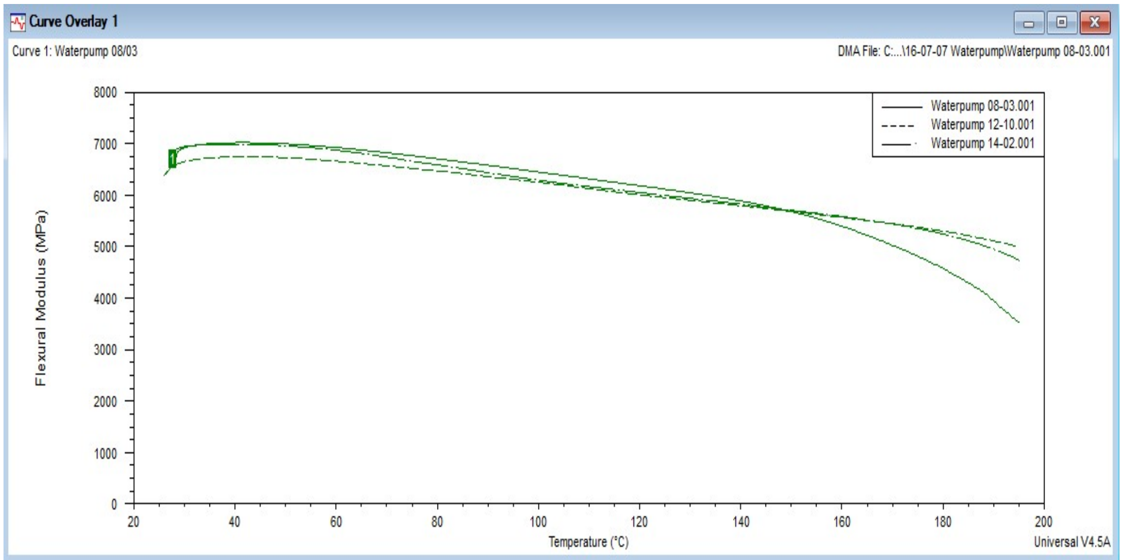


Figure 3. DMA testing of used/aged water pump housings.

DMA testing of water pump parts made with Bakelite grade PF 6510 and retrieved from used vehicles produced in 2008, 2012, and 2014 showed very consistent performance compared to one another. (Figure 2.) The samples maintained approximately 80% their room temperature modulus over the tested temperature range up to 200°C. (Figure 3.)

Larger pumps and pumps with full accessory drive loads must withstand as much as 1000 N of cantilever force on the housing under engine temperatures of 120˚C or higher. Figure 4 shows a water pump test fixture for applying a simulated pulley load. The ETS water pump housings each withstood a 3000 N load versus the OEM specification of 400 N. (Figure 5.)

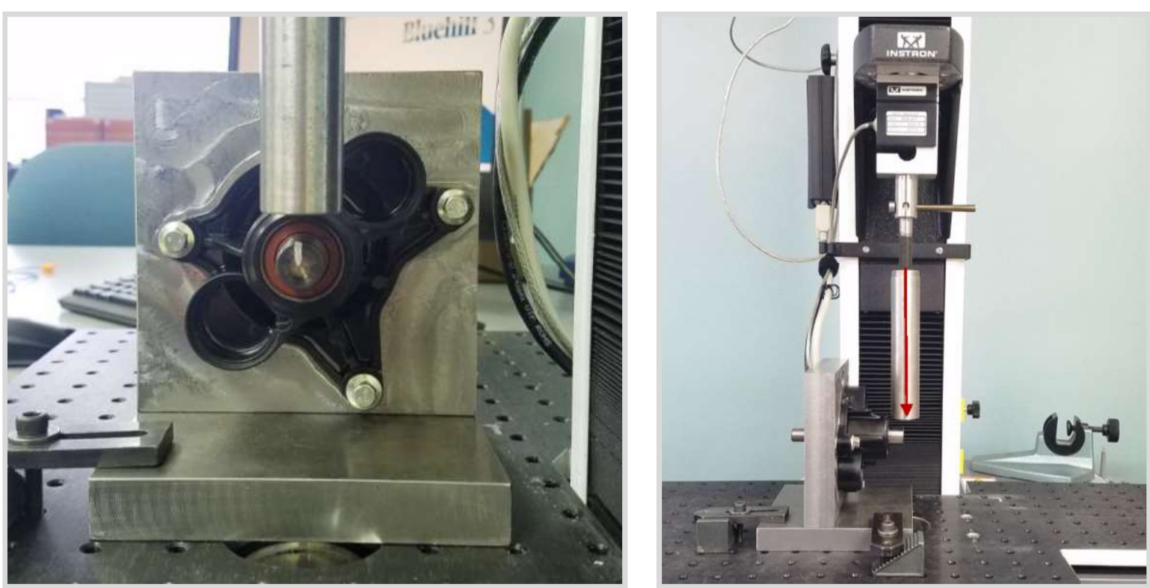


Figure 4. Water pump cantilever load test set up. (Techniplas)

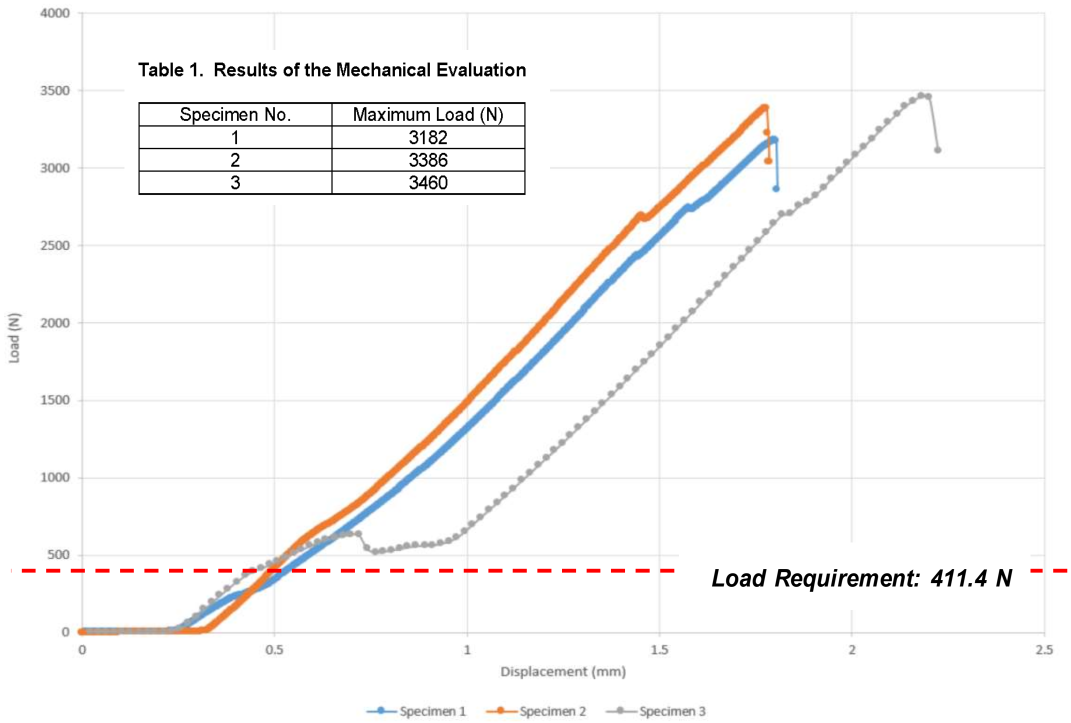


Table 1. Results of the Mechanical Evaluation

Specimen No.	Maximum Load (N)
1	3182
2	3386
3	3460

Figure 5. Water pump cantilever load test results versus OEM requirement. (Techniplas)

Thermoplastic materials are more susceptible to creep and fatigue failure based on property comparison shown in Figures 6 and 7. Finally, when comparing weight and cost, water pump housings can weigh 30% less and cost 10% less that their aluminum counterparts. (Figure 8.)

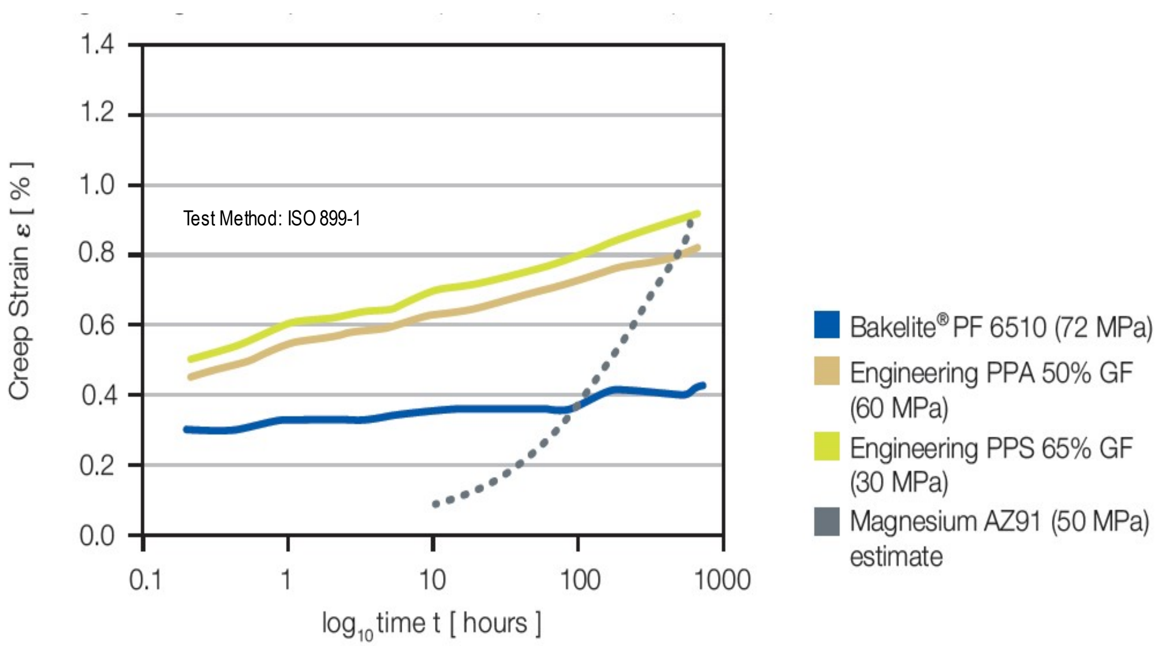


Figure 6. Comparison of creep strain at 120˚C.

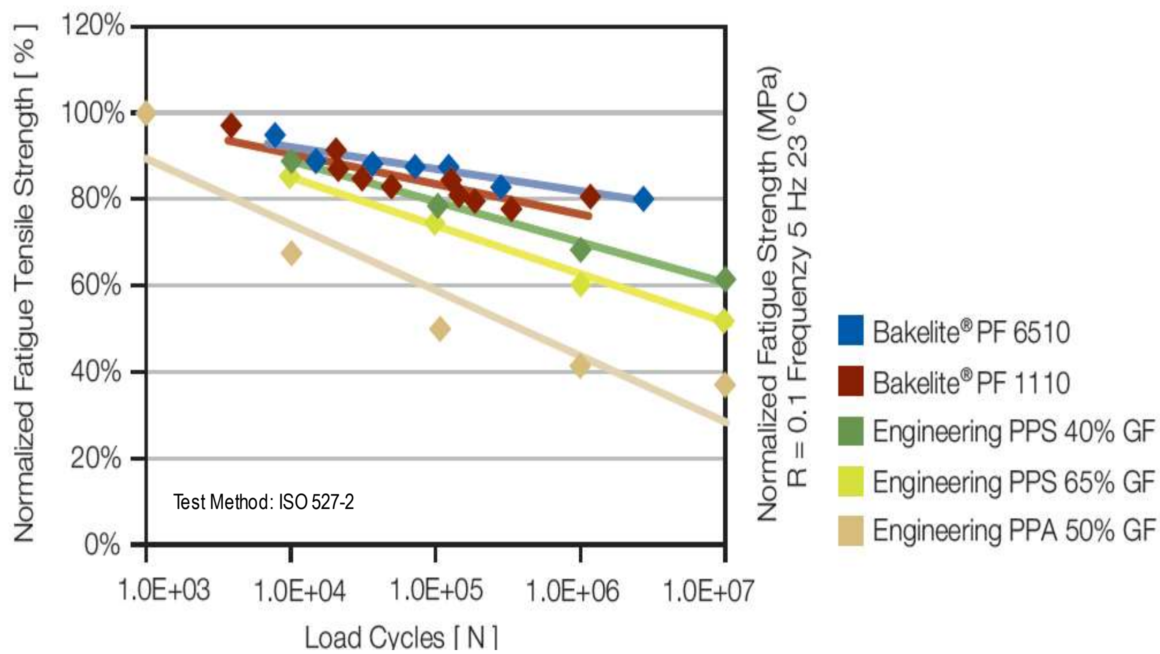
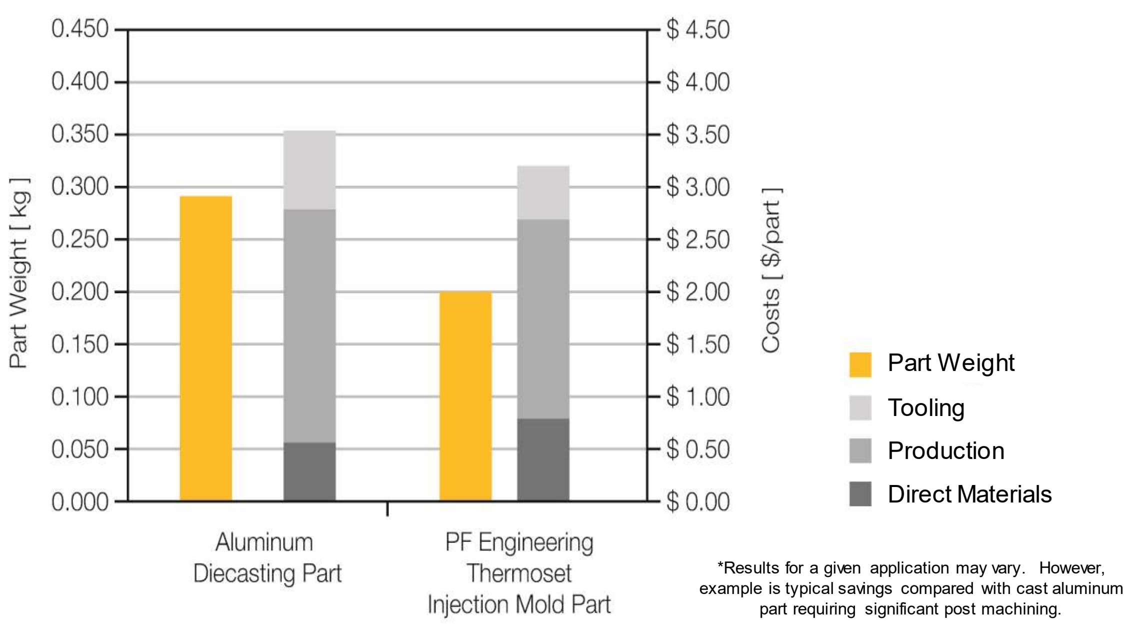


Figure 7. Comparison of fatigue strength property retention.



*Results for a given application may vary. However, example is typical savings compared with cast aluminum part requiring significant post machining.

Figure 8. Part weight and cost comparison between PF ETS material and cast aluminum water pump housing.

Pulleys

Pulleys are mostly in compressive loading as they operate which makes them excellent candidates for taking advantage of the compressive strength of ETS material. Spinning at up to 10,000 RPM, typical engine pulleys for alternators and water pumps see loads of 400 N – 1000 N at underhood temperatures of up to 200˚C. As with water pump housings, creep and fatigue are important for pulleys as they are subjected to the engine belt loads. Attempts have been made to use thermoplastic material for engine pulleys. However, thermoplastic pulleys can develop irregular shapes or flat spots due to internal friction and swelling stress. Reducing the mass of the pulley system reduces the rotational energy required by the engine contributing to improved fuel efficiency. (Figure 9.)

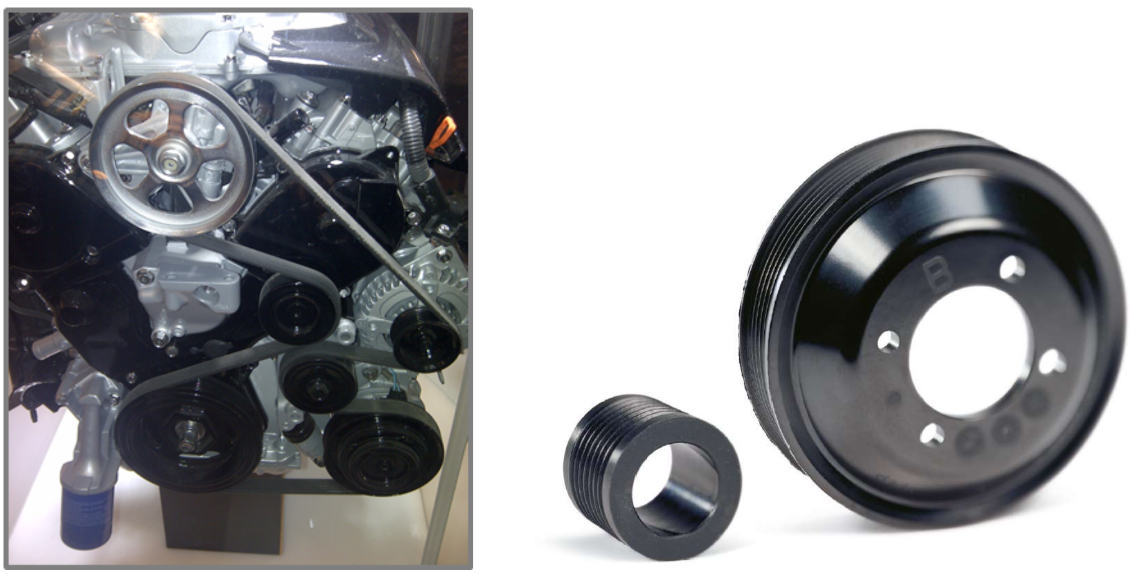


Figure 9. Lighter PF ETS multi-V pulleys replace heavier metal pulleys on accessory drive systems.

Advanced Uses of Phenolic-Based ETS Materials

Cam Carrier Assembly

The rediscovery of phenolic molding compounds to reduce weight has led some auto makers to try more ambitious uses of the material. An impressive example is Ford's MMLV 1.0 liter composite cam carrier.[4,5] Supported by U.S. Department of Energy research funding, this project replaced a portion of the engine head assembly made of cast aluminum with a Bakelite PF 1110 composite material. The composite version of the part saved 3.7 lbs. - 30% less that the part if it were made from aluminum and 15% off the overall assembly. In production, the part would be injection molded saving significant cost over the extensive machining required of the aluminum assembly. The part passed durability testing and showed improvement to engine noise, vibration and harshness (NVH) performance. (Figure 10.)

Figure 10. Ford Motor Company MMLV cam carrier made with PF 1110-CF engineering thermoset material.

Fascia Integrated Exhaust Components

For most passenger cars tailpipe exhaust temperatures range between 200˚C - 220˚C with excursions up to 1000˚F under certain driving conditions. Vehicle designers have been using exhaust tips and fascia integrated exhaust ports to enhance the styling of their cars and trucks. (Figure 11.) Many engineers assume that these components must be metal. So, most current designs are expensive multi-piece weldments or die cast components that require anti-corrosion treatments. Due to the temperature, corrosion and fire resistant properties of phenolics, these exhaust components can be net shape molded at lower weight and much lower cost than either stamped metal or die cast components. Using a laboratory test set up (Figure 12), Figure 13 shows a virgin sample of Bakelite PF 1110 material before and after being subjected to 1000˚F for 20 minutes. Figure 14 shows a high temperature nylon sample (also considered for the application) after being subjected to the same conditions.

Figure 11. Fascia-integrated exhaust components can make use of high temperature resistant PF-based ETS materials.

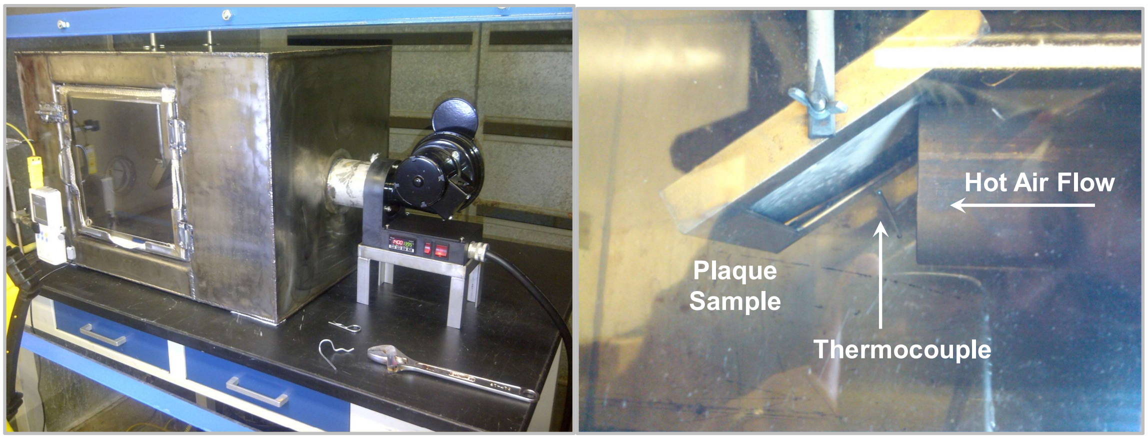


Figure 12. Lab Configuration for High Temperature Air Flow Testing

Figure 13. Untested (Before) and Tested (After) Sample Plaques: After 20 minutes at 1000°F, 60° Incline

Figure 14. Polyamide material (also considered for application): After 20 minutes at 1000°F, 60° Incline

Future Uses of Phenolic-Based ETS Materials: The Composite Engine

The concept of a composite internal combustion engine is not new. The "Polimotor" is credited with being the first plastic engine. Versions of this engine used epoxy resin as well as earlier formulations of Bakelite molding compound.[6] Although this engine demonstrated the engineering viability of the concept, challenges remained as to how to produce composite engines at a rate and cost sufficient to support mass production.

Three decades later, it is fully possible to produce the major components of a composite engine such as the block and head from composite materials. A single large automated injection molding machine would replace a plethora of infrastructure needed to make the large engine castings of today. Net shape molding would eliminate most machining steps. Improvements in physical property characteristics of phenolic based ETS make it possible to meet much more demanding requirements as demonstrated by the Ford MMLV cam carrier and other industry projects.

Conclusion

The internal combustion engine will continue to power automobiles for decades to come. They will become more efficient and less polluting to the environment. ETS molding compounds will play a key role in reducing the weight of ICEs for those applications where the temperature environment exceeds the capability of engineering thermoplastics such as polyamides, PPA and PPS, but are not so hot that metals are required. This is usually a continuous operating temperature range between 100°C – 200°C. The benefits are lighter weight and frequently lower cost when net shape molding can replace machining and post treatment steps. Phenolic-based engineering thermosets are a proven solution whose characteristics deserve a closer look for metal replacement.

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Acknowledgements

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Techniplas