RECENT CASE STUDIES OF ENGINEERING THERMOSETS FOR UNDER-THE-HOOD APPLICATIONS

Frank Bayerl, Sigrid ter Heide, Dr. Roman Hillermeier and Cedric Ball
Momentive Specialty Chemicals, Inc.

Abstract

The automotive industry is looking for options to reduce weight and increase engine efficiency to comply with new CO2 emission and fuel economy regulations. Increasingly, automakers are examining their use of materials even for the smallest components. Engineering thermosets are an effective lightweighting alternative to heavier conventional steel and aluminum die cast products. They combine outstanding temperature stability, long term mechanical strength, dimensional stability and high chemical resistance.

This paper focuses on two recent projects where (BAKELITE™) phenolic-based engineering thermosets have successfully replaced traditional metals in automotive under-the-hood applications and outperformed engineering thermoplastics also considered for the applications. First, a water pump housing made with engineering thermoset material is shown to have good chemical resistance to coolants without additional corrosion protection and to maintain its mechanical properties. Second, a vacuum pump made with engineering thermoset material has lower overall weight, higher dimensional stability and better fatigue properties than a similar design made from die-cast aluminum.

Finally, the paper describes the recycling options for engineering thermoset materials.

Introduction

New fuel economy and emission regulations are prompting significant changes to the way automakers design their vehicles and the components that go into them.¹ Numerous areas of the vehicle are being redesigned to reduce weight and increase engine efficiency. In cases where aluminum has been used as a lightweighting alternative to steel, engineers are seeking even greater savings from glass and carbon reinforced composite materials. Thermoplastics work in many instances. However, applications involving corrosive chemicals, high heat or structural loads may be best suited for engineering thermosets.

Case 1: Water Pump Housing

Water pumps circulate coolant through the cooling system of internal combustion engines to protect them from overheating. Under-the-hood temperatures reaching more than 200°C can destroy engine parts in a short period of time if not designed with appropriate materials. Water pumps must withstand the chemical impact of newer “long life” coolants, maintain mechanical properties and hold critical dimensions even at high temperature.

An automotive customer sought alternative materials for a water pump design that could maintain performance while reducing weight and cost. The incumbent material was die cast aluminum. The following paragraphs examine the behavior of various water pump housing materials under circumstances similar to the final application and were used as the basis for selecting a next generation production design.
Resistance to High Temperature

Under normal operating conditions, typical engine oil and coolant temperatures reach 120°C. Surface and ambient temperatures near the engine can easily reach 200°C for extended periods of time requiring engineers to design with materials that maintain their physical properties at these higher temperatures.

In Figure 1, flexural moduli were measured for PF 6510 and PF 1110 (30% glass fiber reinforced engineering thermosets) as a function of temperature. Comparisons were made against values for a 50% glass fiber reinforced polyphthalamide (PPA) and 40% and 60% glass fiber reinforced polyphenylene sulfide (PPS) materials. The results indicated a greater resistance of the engineering thermosets to high temperatures versus the other material candidates.

![Flexural Modulus of Candidate Materials vs. Temperature](image)

*Figure 1. Flexural modulus according to ISO:178 of engineering thermosets PF 1110, PF 6510 versus candidate engineering thermoplastic materials at elevated temperatures.*

Water Pump Material Dimensional Stability

Over time, long life coolants become acidic and can deteriorate water pump materials. Standard die cast aluminum must be post-treated to protect the component. However, this adds cost, complexity and sometimes environmental issues with which to contend. An improved design would not require post-treatment.

In addition to chemical resistance, dimensional stability as a function of time and temperature is critical to water pump operation. Most pumps rely on accurate movement and precise clearances in order to function. Materials that have high thermal expansion coefficients can cause interferences and premature wear. Figure 2 shows the dimensional stability of engineering thermoset PF 6510 after 1000 hours of exposure to coolant mixture at 120°C. Width and thickness dimensions remained nearly constant for the engineering thermoset while total mass absorption was less than 2.5%.
Dimensional Stability of PF 6510 in Glysantin G30 at 120°C

Figure 2. Relative dimensions (%) of engineering thermoset PF 6510 in long life coolant at 120°C, over 1000 hours.

Creep Strain at 120°C

Figure 3. Creep Strain (%) according to ISO:899 of engineering thermoset PF 6510 (72 MPa) versus engineering thermoplastic PPA (60 MPa) and PPS (30 MPa) at 120°C, over 1000 hours.

Long-Term Creep Behavior

Water pump components that are subjected to sustained loads have a greater possibility of failure if creep strain exceeds design limits. Internal component/gears can slip due to dimensional changes. Housings and attachment locations can distort causing leaks, alignment issue or noise and vibration (NVH) problems. Figure 3 shows the long-term creep behavior of engineering thermoset PF 6510, PPA, PPS and AZ91 magnesium. Even at higher stress loading, results indicated a superior low creep strain of the engineering thermoset versus PPA and PPS. In fact, the measured creep of the engineering thermoset was low enough to avoid the need for threaded inserts in the water pump housing. Assembly screws were able to be directly fastened into threaded holes reducing the part complexity and number of required assembly steps.
Case 2: Vacuum Pump Parts

A vacuum pump produces vacuum for power brakes and other devices in diesel cars. It is consequently a critical part that must operate reliably when subject to vibration, dynamic forces and temperature cycles generated by the engine. To fit closely enough to avoid leakage, vacuum pump parts must meet design tolerances as low as 0.1%.

Similar to the water pump example, an automotive customer sought alternative materials for a next generation design that could maintain performance while reducing weight and cost.

Vacuum Pump Material Dimensional Stability

Several materials were considered for the replacement design based upon their thermal expansion behavior. Table 1 compares the thermal expansion coefficients of the candidate materials. Engineering thermoset material PF 1110 has coefficients of thermal expansion very close to those of steel (0.10 vs. 0.11) and behaves isotropically. By contrast, the engineering thermoplastic materials have higher coefficients of thermal expansion and illustrate anisotropic behavior.

### Table 1. Coefficients of thermal expansion for vacuum pump candidate materials.

<table>
<thead>
<tr>
<th>Construction Material</th>
<th>Steel (A380)</th>
<th>Aluminum (A380)</th>
<th>Magnesium (AZ91)</th>
<th>Engineering Thermoplastic High temperature resistant 50% glass filled PPA</th>
<th>Engineering Thermoplastic 65% mineral and glass filled PPS</th>
<th>Engineering Thermoset (PF 1110)</th>
<th>Engineering Thermoset (PF 6510)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Thermal Expansion ($10^{-6}/^\circ\text{C}$)</td>
<td>Transverse</td>
<td>0.11</td>
<td>0.22</td>
<td>0.26</td>
<td>0.15</td>
<td>0.19</td>
<td>0.10</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>0.11</td>
<td>0.22</td>
<td>0.26</td>
<td>0.40</td>
<td>0.36</td>
<td>0.10</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Figure 4. Coefficient of thermal expansion of engineering thermoset (PF 1110).
Figure 4 shows the detailed thermal expansion behavior of the engineering thermoset candidate material PF 1110. The material demonstrates a very low coefficient of thermal expansion of 13 to \(15 \times 10^{-6}/^\circ\text{C}\) up to 200°C. The automotive customer favored the engineering thermoset material on the basis that its thermal expansion was low and predictable - greatly facilitating the part design.

**Long-term Fatigue Strength**

Water and vacuum pumps experience dynamic loads from the vehicle's engine and from road inputs making fatigue strength an important consideration. Figure 5 compares the fatigue performance of the candidate engineering thermoset and thermoplastic materials. After 1 million cycles, the engineering thermoplastic materials lose 35% - 40% of their initial strength compared to 10 – 20% for engineering thermosets. The more consistent properties of the engineering thermosets made lifetime predictions easier for the design engineer.

![Fatigue strength of engineering thermosets PF 1110, PF 6510, PPS (40% and 60% GF) and PPA 50% GF.](image)

**RELATIVE PART COSTS AND FINAL WEIGHT COMPARISON**

Engineering thermosets can be either injection or compression molded. Injection molding was the process used for both the water pump and vacuum pump parts based on their geometry and required production rates. Figure 6 provides a cost comparison between the injection molded engineering thermoset and die-cast aluminum pump parts. By replacing aluminum with engineering thermosets, the processing costs were significantly reduced. Detailed surfaces were molded into the thermoset part and did not require extra machining steps normally required of die cast aluminum. The total sum of direct material, processing and tooling costs was approximately 15% less for the engineering thermoset than the baseline part in die-cast aluminum. The engineering thermoset material saved an estimated 30% over the equivalent aluminum part weight.
Figure 6. Weight and typical cost reduction for pump parts composed of an injection molded engineering thermoset grade versus aluminum die-casting. The cost estimate assumes that capital equipment is already installed and does not include manufacturing overhead. The input data for aluminum die-cast is based on London Metal Exchange for direct material price and CustomPartNet estimator.4,5

ENGINEERING THERMOSET RECYCLING

Material recyclability is increasingly important to automotive manufacturers. It is possible to recycle engineering thermosets in four general ways. With mechanical recycling, cured thermoset scrap can be ground and reintroduced to the compounding process to make new parts. Molding compounds can contain up to 20% regrind depending on the performance requirements of the finished part.6 Chemical approaches involve pyrolysis or solvolysis whereby the matrix material is separated from the fiber reinforcement.7 Another approach promoted in Europe and Japan introduces the thermoset material to the cement making process. The inorganic parts reduce to ash and bond with the cement clinker. The organic material serves as a thermal energy source in the calcination process.8 Finally, incineration is considered a suitable method for disposing of thermoset waste. Figure 7 diagrams a typical life-cycle for thermoset automotive under-the-hood parts.
CONCLUSION

In two under-the-hood application examples, engineering thermosets were successful alternatives to die cast aluminum and engineering thermoplastic materials (Table 2).

Table 2. Summary comparison of engineering materials for under-the-hood components.

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>Die Cast Aluminum</th>
<th>Engineering Thermoplastic</th>
<th>Engineering Thermoset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Resistance</td>
<td>BASELINE</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Dimensional Stability</td>
<td>+</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Creep</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Mass Reduction</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Cost Reduction</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Recyclability</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

Engineering thermosets provided improved performance for properties such as chemical resistance, dimensional stability, creep and fatigue strength. Part weight, an important criterion for the customer, was 30% less than die cast aluminum while costing less to manufacture. Finally, there are several possible methods for recycling engineering thermosets.

REFERENCES


CONTACT INFORMATION

Momentive Specialty Chemicals develops and manufactures a wide range of products for composites applications including thermoset resin systems, fiber sizings, preform aids and additives. Send inquiries to moulding-compounds@momentive.com for more detail.

DISCLAIMER

The information provided herein was believed by Momentive Specialty Chemicals (“Momentive”) to be accurate at the time of preparation or prepared from sources believed to be reliable, but it is the responsibility of the user to investigate and understand other pertinent sources of information, to comply with all laws and procedures applicable to the safe handling and use of the product and to determine the suitability of the product for its intended use. All products supplied by Momentive are subject to Momentive’s terms and conditions of sale. MOMENTIVE MAKES NO WARRANTY, EXPRESS OR IMPLIED, CONCERNING THE PRODUCT OR THE MERCHANTABILITY OR FITNESS THEREOF FOR ANY PURPOSE OR CONCERNING THE ACCURACY OF ANY INFORMATION PROVIDED BY MOMENTIVE, except that the product shall conform to Momentive’s specifications. Nothing contained herein constitutes an offer for the sale of any product.

® and ™ denote trademarks owned by or licensed to Momentive Specialty Chemicals Inc.