COMPOSITE POWER-TRAIN COMPONENTS: REDUCING WARRANTY COSTS AND IMPROVING PART QUALITY

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Abstract

The purpose of this paper is to educate readers about new uses of composites in engine and transmission components. Historical use in under-hood applications are known and will be referenced, however drive-train components are an extension of this material and have enabled customers to save costs when compared to competing products. The material that is the subject of this paper, sheet molding compound CSP 949B, also enables components to be designed and produced that eliminate hardware and improve system performance.

When molded, CSP 949B withstands high temperatures, is chemically resistant, and is dimensionally stable. This paper will cover how several customers have used the material in non-traditional applications, resulting in cost reductions and quality improvements. Comparisons to competing materials will be presented, enabling the reader to calculate the cost savings from adopting this material for their application.

Introduction

The plastic-under-the-hood trend started in mid 1990 when automakers addressed the challenge of building vehicles equipped with small, fuel-efficient engines. Automotive engineers became more willing to work closely with materials suppliers to develop plastic-friendly designs. This changing mindset, while often challenging, has enabled the replacement of metal power-train components with fiberglass components made from Sheet Molding Compound (SMC).

There are numerous types of compression molded parts and processes. Parts are distinguished from each other by the type of material used, the length of the reinforced fibers, their size, and their surface quality. By default every type of material and part has its own unique variation of a compression molding or injection-compression molding process. This paper will focus on CSP 938/949B SMC, a material that has become widely accepted in the past decade for under-hood components in the transportation and agriculture markets. The CSP 938/949B SMC is a material created by combining reinforcing chopped glass fibers with a very complex specialty resin, capable of being formulated in an almost infinite number of ways. The formulation includes ingredients such as inorganic fibers, thickeners, curing agents, an internal mold release, a carrier polyester resin, and a low profile agent. The flexibility of this SMC formulation lends itself to a variety of end-use properties for molded parts enabling a wide spectrum of commercial applications.

The biggest challenge in converting parts from metal to SMC is convincing the engineering community that SMC parts solution can perform as well, or often better than, metal with the added benefits of weight and cost reductions due to metal. SMC pricing has remained stable over the past economic turbulence relative to steel. An SMC component can cut part weight by as much as 60% compared to a traditional aluminum part. SMC performance testing data proves that solutions meeting specifications for engine vibration, temperature, and chemical resistance are possible.

The performance characteristics of CSP 938/949B SMC enable engineers to create parts with greater rigidity and tighter tolerances than parts made from metal. Reducing the number of metal parts to a single power train part molded out of SMC is possible. Snap-fits, bosses, ribs, and attachment points can be molded in to eliminate hardware and assembly steps, reduce weight, and reduce part counts. Design flexibilities of this SMC allow engineers to simplify parts and integrate different functions. Part design freedom enables design engineers to create geometries that are sometimes not possible with metal. It is for these reasons that CSP 938/949B SMC has become a popular material for oil pans, rocker covers, and transmission oil deflectors.

Historical Background

In 1989 Continental Structural Plastics (Budd Company at that time) developed a sheet molding compound using improved performance resins and other ingredients to create a grade capable of withstanding use in automotive and diesel truck engine environments.

This material was introduced as BD-938CSP (blue molded in color) for the Detroit Diesel Series 60 engine oil pan and rocker cover. Severe developmental testing confirmed the integrity of this material. Parts were molded successfully at the Carey, OH and North Baltimore, OH plants of Budd Company. The application on the DDC Series 60 Engines continued with excellent acceptance for 10 years. In 1999 the molding of these parts was transferred to Continental Structural Plastics, Petoskey, MI and then was transferred back to the Carey, OH, plant, now CSP. These same parts are still being produced for service and low volume applications. At peak volume 45,000 oil pans (deep and shallow sump) and 35,000 rocker covers were produced annually.

Several years after the DDC oil pans and rocker covers began production, Budd Company introduced additional engine cover applications with a similar SMC material, 949B (deep gloss black) from the North Baltimore, OH facility. The engine cam covers were for the Ford 4.6L and 5.4L while the Cummins diesel application was a rocker cover. The material color is the only difference between the BD-938CSP and BD-949B. Material properties are identical.

The most recent application of the BD-938CSP/BD-949B SMC is the John Deere tractor transmission oil deflector. The material maintains dimensional stability (no warpage) with good strength and stiffness at elevated temperature in an oil environment where any significant loss in mechanical properties would render a failed tractor transmission. Production of oil deflectors began in 2006 at Ashley Industrial Molding (AIM) in Ashley, IN.

Material Properties

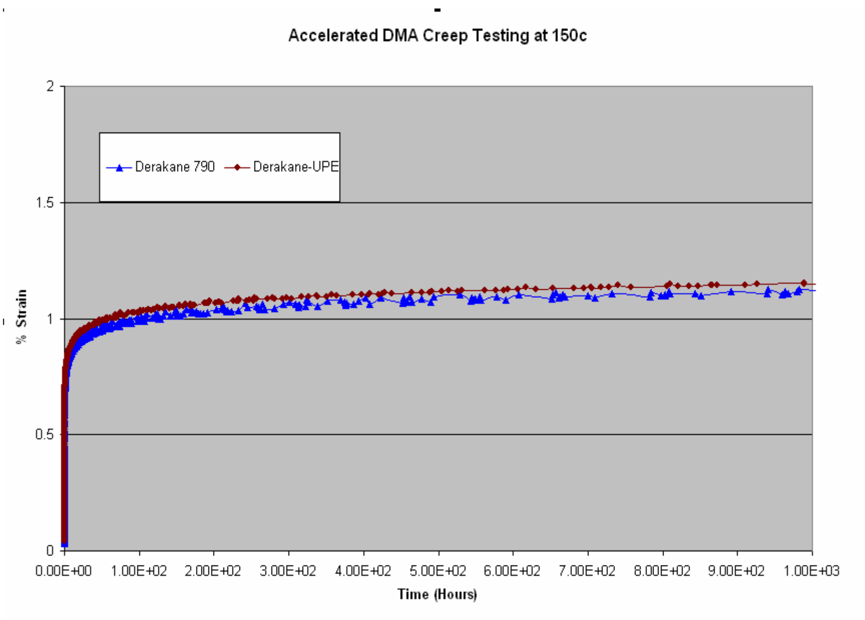
Table 1 below outlines material properties for this formulation and Figure 1 shows creep data. Table 2 breaks out material properties of BD-949B, six-batch submission. The properties reported are for Glass Content %, Moisture Absorption %, Specific Gravity, Flexural Strength, Flexural Modulus (tangent and secant), Tensile Strength, Tensile Modulus (chord), Izod Un-notched Impact, Izod Notched Impact, and Shrinkage. Results of mechanical property testing are good for a 30% glass content material with property retention at elevated temperature in air and oil excellent as reported in the next section.

Table 1. CSP 949B SMC properties

CSP 949B SMC
Diesel Grade, Vinyl Ester, Black SMC

Property	ASTM Test Method	Typical Molded Specification	Metric Equivalent
Specific Gravity	D-792-98	1.72	1.72
Water Absorption (24 Hours @ 23°C)	D-570-98	<0.35%	<0.35%
Heat Distortion Temp. °F, 264 PSI	D-648-98	>450°F	>235°C
Barcol Hardness	D-2583-95	55 - 65	55 - 65
Impact Strength (Izod Ft. Lbs./In. Notched)	D-256-97	14 - 18	0.75 - .96 KJ/m
Flexural Strength, PSI	D-790-98	26,000 - 29,000	179 - 200 MPa
Flexural Modulus (PSI x 10^6)	D-790-98	1.4 - 1.8	9.7 - 12.4 GPa
Tensile Strength, PSI	D-638-98	11,000 - 13,000	75 - 104 MPa
Mold Shrinkage (Cold Piece from Cold Mold, In./In.)	--	0.0005	0.0005 cm/cm
Coefficient of Expansion (75°F - 300°F)	D-696-98	9.7 x 10^{-6} in./in./°F	17.5 x 10^{-6} cm/cm/°C

Figure 1. Creep testing data for CSP 949B SMC



BD-938CSP/BD-949B Physical Properties

Table 2. BD-949B PPAP submission

Continental Structural Plastics BD 949B PPAP 6 Batch Flex and Tensile Properties					
	6 Lot				
Properties:	Mean	Std. Dev.	X - 3*SD	X + 3*SD	Lowest Average
Glass Content, %	29.35	1.60	24.55	34.15	27.38
Mostiure Adsorption, %	0.17	0.05	0.02	0.32	0.10
Specific Gravity	1.70	0.02	1.65	1.76	1.68
Flex Strength @ 22C, Mpa	210	22	143	276	182
Flex Tangent Modulus@ 22C	10699	677	8668	12730	9882
Flex Secant Modulus @ 22C					
-@0.5 mm defl., Mpa	10677	681	8635	12719	9857
-@2.5 mm defl., Mpa	8339	1199	4741	11937	5760
Tensile Strength, Mpa	13188	1174	9667	16709	11647
Tensile Modulus, Chord, Mpa	12566	850	10017	15115	11551
Impact, Izod, unnotched, J/m	1117	120	758	1477	969
Impact, Izod, unnotched, kJ/m^2	88	9	60	117	77
Shrinkage ("-" is expansion)	0.06	0.06	-0.12	0.24	0.04
CALCUALTED ON 6 LOT AVERAGE					

Table 3 shows the mechanical performance of BD-949B at 23C (70F) and 150C (300F) in terms of Flexural Strength, Flexural Modulus (tangent and secant), Tensile Strength and Tensile Modulus. While there are some decreases at higher temp, the results are good when compared to a thermoplastic material such as Nylon, which was previously used in the oil deflector.

Table 3. BD-949B SMC at 23C and 150C Flex and Tensile Testing

Continental Structural Plastics BD-949B SMC 23C and 150C Flex and Tensile Testing 2/14/2009		
Temperature:	23C	150C
Material Property		
Tensile Strength, yield (Mpa)	81.1	57.8
Tensile Modulus		
Youngs (Mpa)	16260	9629
Flexural Strength, yield (Mpa)	203.6	98.6
Flexural Modulus		
tangent (Mpa)	7713	4098
secant, 0.5 mm (Mpa)	6716	2660
secant, 2.5 mm (Mpa)	7494	2101

Note: test specimens taken from molded plaques

Additionally, Table 4 shows the ASTM PPAP material submission properties along with the material callout: ASTM D4000 UP000 GF30 G34640 CD170 GB183 AA002 Z1 Z2.

Table 4. ASTM PPAP Material submission

Supplier Continental Structural Plastics 755 W. Big Beaver , Suite 700 Troy, MI 48084		Part Number A4710100113, A4710100213		
Name of Lab Continental Structural Plastics 1276 Industrial Ave. Van Wert, OH 45891		Part Name oil pan		
Type of Test	Material Spec. No./Date/Specification	Supplier Test Results & Test Conditions	OK	Not OK
	Material: BD-949B			
	Spec: ASTM D4000 UP000 GF30 G34640 CD170 GB183 AA002			
	Glass Fiber Reinforcement, 30% +/-2	29.2%	X	
	Tensile Strength, 65 MPa, min. (D638)	91 MPa	X	
	Flexural Modulus, 10,000 MPa, min. (D790)	10,614 MPa	X	
	Izod Impact, 425 J/M, min. (D256)	1,117 J/M, unnotched	X	
	Heat Deflection Temp, 230C, min (D648)	235C	X	
	Transition Temp, 170C, min			
	Specific Gravity, 1.68 – 1.85 (D792)	1.70 g/cm3	X	
	Comments: CSP's BD-949B has passed all the requirements of the ASTM callout above			

Figure 2, below, is the Tensile Stress Strain Curve at 23C. This data is from molded plaques and is a composite of 6 specimens, 3 longitudinal and 3 transverse. From this data Finite Element Analysis can be confidently run on solid-model part designs.

Figure 2. CSP 949 Tensile Stress Strain Curve

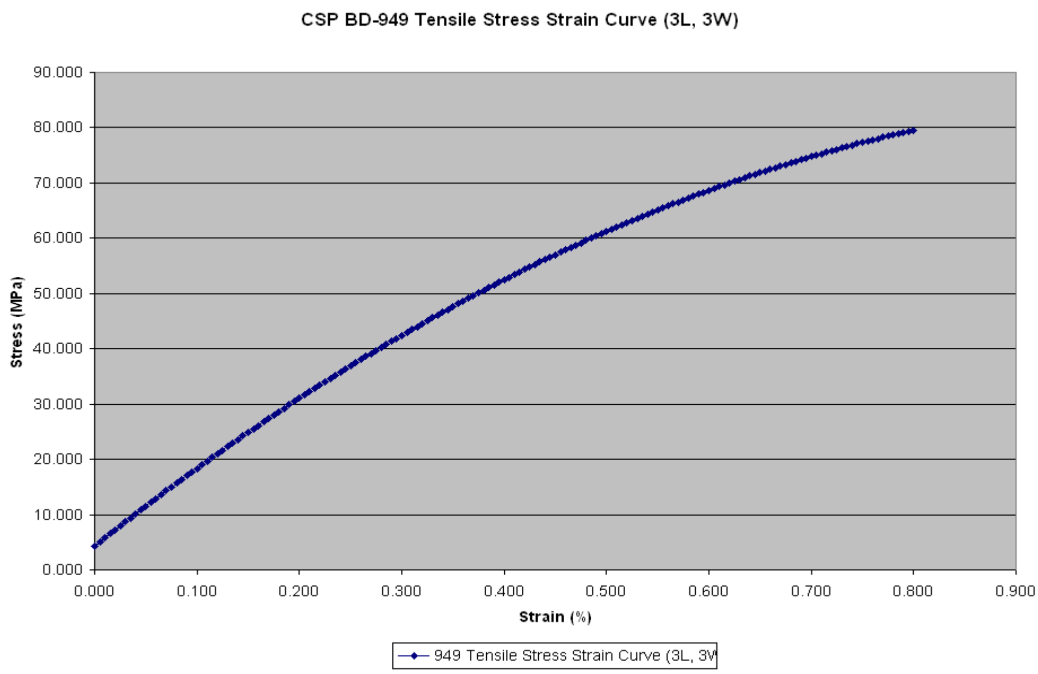
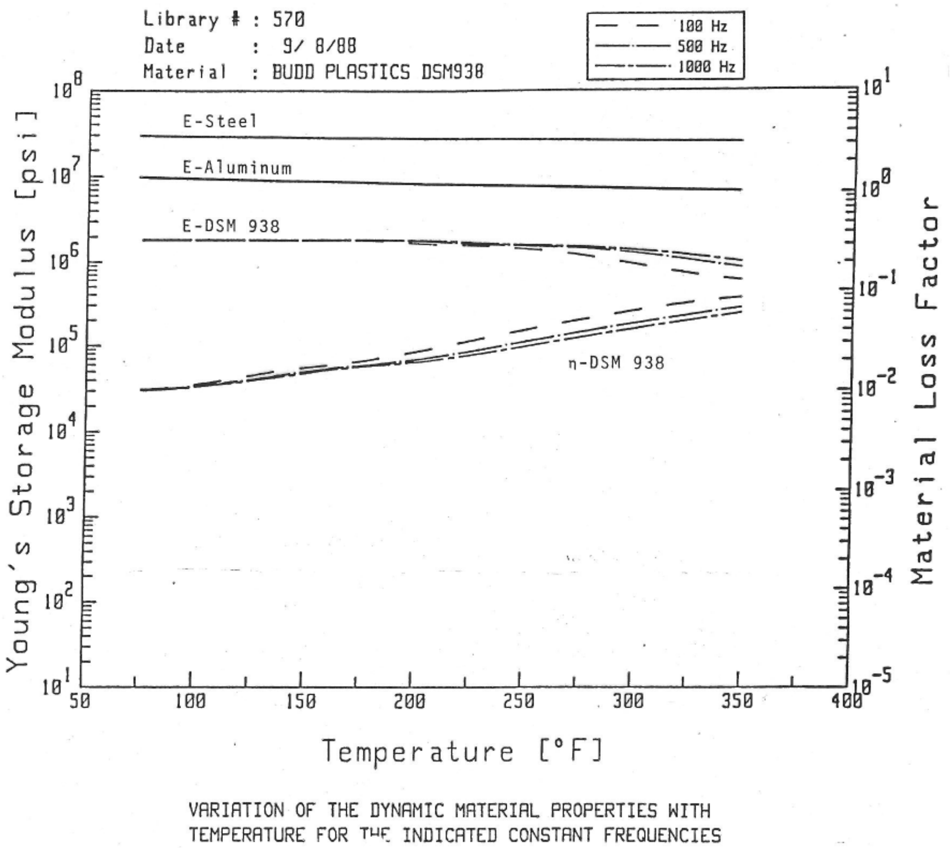


Figure 3 shows the damping characteristics of BD-938CSP compared to steel and aluminum. The Young's storage modulus reduction shows that this SMC material does not transmit vibrations at different frequencies (100, 500 and 1000 Hz) to nearly the degree of steel and aluminum. So for a noise generating component, sound is much less likely to be passed into the environment with the use of an SMC component, which makes for a quieter engine or transmission.

Figure 3. Damping curves of SMC compares to aluminum and steel



Another property of CSP-949B is a 32.5% glass content. This yields a high flexural modulus and imparts superior dimensional stability and high physical and mechanical strength. This SMC provides 1.8 million psi flexural modulus and higher heat resistance than Nylon. Add to these properties an excellent NVH rating and outstanding corrosion resistance that are not significantly degraded in high-temperature environments, and the material makes for ideal replacement of metal parts in transmission and engine components.

An additional benefit of using CSP 949B SMC is part consolidation due to the ability to mold smaller complex sub-component rather than fabricate them separately in metal parts. Parts molded with this SMC material also dramatically reduce secondary operations such as machining in metal parts. The CSP 949B SMC provides less part weight, increased cost savings, and extended design freedom compared with metal parts. SMC composite parts will typically be 20-30% lighter than equivalent steel parts yielding fuel savings and improved performance efficiencies over the life of a vehicle.

An important advantage when designing with this SMC material is the ability to incorporate ribs or gusset and bosses directly into the part to increase part rigidity. This improves the overall torsion and bending stiffness of the part which enables attachment of the SMC molded parts to the engine without the need of compression limiters.

Tooling costs for SMC molds are substantially lower than for metal forming or injection tooling. SMC empowers the designer and opens a host of complex part geometry possibilities and economical solutions.

Retention of Physical Properties Following Exposure to Elevated Temperatures in Air and Oil

For engine and transmission components, retention of physical properties during and after exposure to elevated temperatures in air and oil is important to system performance. Table 5 shows the results of testing and property retention in % after exposures of up to 180 days in 177C (350F) air or motor oil. Testing of all properties was performed at 23C (70F). Properties measured include Flexural Strength, Flexural modulus, Dynatup Impact Load and Energy and lap shear of adhesive bonding. Each property was measured after exposure in air or motor oil. At 180 days no property degraded more than 13% (87% retention).

Table 5. Summary of physical properties retention for CSP 949B

Summary of Physical properties retention for CSP 949B type

Physical Property	Flexural Strength, %retention	Flexural Strength, %retention	Flexural Modulus %retention	Flexural Modulus %retention	Dynatup Load, %retention	Dynatup Load, %retention	Dynatup Energy, %retention	Dynatup Energy, %retention	Lap Shear %retention	Lap Shear %retention
EXPOSURE CONDITION	350F AIR	350F OIL	350F AIR	350F OIL	350F AIR	350F OIL	350F AIR	350F OIL	350F AIR	350F OIL
TIME of EXPOSURE, days										
Day 0	100	100	100	100	100	100	100	100	100	100
Days 30	100	89	100	92	95	81	100	80	100	100
Days 60	99	88	100	94	89	95	99	95	85	99
Days 90	100	100	100	100	85	75	83	66	100	100
Days 120	100	98	95	93	85	92	69	91	100	100
Days 180	100	96	95	99	87	95	87	100	100	100

NOTE: All testing were done after the specified exposure days at room temperature which were performed in 1995.

Conclusion: After 180 days exposure to air or oil at 350F, the molded samples from 949B type SMC did not see any significant degradation in physical properties. The retention percentage was greater than 85%.

Material Applications

1) Detroit Diesel oil pan (Figure 4)

This part was designed as a replacement for a cast aluminum pan which was very expensive to produce and had issues with leakage. The aluminum pan required additional process steps of vacuum sealing of the casting pores, machining the mounting flange and holes, and painting the cover blue. The SMC part overcame all of the above shortcomings of the aluminum oil pan. Two designs were created, a deep sump and shallow sump. Further subdivision of these designs was made by drilling and mounting different oil return ports. The sealing and attachment isolators were made with silicone rubber, providing good leak protection while further damping noise transmission. The SMC is pigmented DDC blue to match the engine paint. No parts were returned due to material failures.

2) Detroit Diesel rocker cover (Figure 5)

The rocker cover was designed at the same time as the oil pans for some Series 60 engines. The SMC design replaced an aluminum casting which had the same shortcomings as the aluminum oil pans: expensive, machining requirements, vacuum sealing, and noise transmission. An integral breather port is molded into the top of the cover. The original design was mounted with central bolts which proved less robust compared with the peripheral bolts of the later design. Both designs used silicone seals and attachment isolators to seal well and further isolate noise. As the BD-938CSP is pigmented DDC blue, no painting is required to match the engine paint. No parts were returned due to material failure.

3) Cummins Diesel rocker cover (Figure 6)

Cummins recognized the benefits of using SMC in a rocker cover application and a wedge shaped cover was created out of BD-949B. This SMC is pigmented deep gloss black as required by the customer and avoids painting (the material is environmentally stable and will not rust or corrode in under hood applications). The design uses an adhesively bonded breather channel in the interior of the part. The CSP exposure and physical retention testing verifies adhesive bonding long term usage in hot air/oil. Several different configurations are possible with drilling different ports. No parts were returned due to material failure.

4) Ford 4.6 and 5.4L V8 cam cover (Figure 7)

Ford created a 4.6L V8 engine with a modular design which incorporated right and left hand SMC cam covers. The cam cover benefited from most of the advantages of SMC in an engine environment. Firstly, the SMC material can withstand all of the adverse conditions of elevated temperature in air and oil. Dimensional stability provides a robust, leak-free design. Low temperature properties of SMC, such as impact, are not reduced since it is reinforced with 1" long fiberglass compared to Nylon injection molded material which has short fibers. The SMC must resist combustion blow-by, so the gloss black 949B is formulated with ingredients not subject to acid attack. Additionally, it does not require painting. The designers were able to create a thin wall, lighter, cam cover compared to competitive composite covers.

These benefits allow maximum packaging efficiency, and a breather passage is adhesively bonded into the inside of the cover. Different configurations were made for various vehicles with breather tubes and filler ports in different locations. The cam cover seals and attachment isolators were installed at Budd Company's (now CSP) North Baltimore, OH plant and work together with the SMC cover to reduce NVH transmission to levels below that of metals. The overall design is less costly than a cast aluminum cover and is a superior design when compared to a stamped steel cover (less noise transmission, corrosion and rust free). Ford introduced the 5.4L left and right cam cover in SMC for light trucks. This incorporated a design with bolt hole ring ribs to reinforce the area around the screw holes against warpage. Both designs were well received for the duration of their use.

5) <u>John Deere Oil Deflector</u>

The John Deere tractor transmission oil deflector was historically made from Nylon. As the operating environment is high-temperature oil, the CSP 949B material was identified as a replacement for the Nylon part. This change eliminates warpage and potential transmission failure due to contact of the deflector with the gears. The material's high modulus and lower specific gravity relative to Nylon enable a thinner, lighter composite part to be produced. The nominal part thickness of the oil deflector is 4.0 mm, the part weighs about 6 pounds, and the two-piece deflector is molded in a family tool. The parts are shown in Figures 8 and 9.

Figure 8. Oil Deflector Assembly

Figure 9. Oil Deflector, Installed

Advantages of BD-938CSP and BD-949B

1) Good moldability: These sheet molding compounds will mold complex part designs with variable wall thickness. Unlike steel or aluminum stampings, BD-938CSP and BD-949B can mold thin walls at 1.5 mm (0.060") which can be easily punched out for openings or left as a web. In the opposite direction, moldings can be made somewhat thicker than the nominal 2.5 mm (0.100") wall up to 6 mm (0.25") for bosses or reinforced areas for attachment. Stiffening ribs can also be accommodated when needed as thin as 2.0 mm (0.080").

Compliance with SMC best-practices design manual is recommended for minimal cure times and best performance.

2) Chemical resistance: Both BD-938CSP and BD-949B have enhanced chemical resistance. Vinyl ester technology is used for improved chemical resistance over polyester resins typically used in SMC. Other substitute ingredients are used to improve flammability and acid attack response.

3) Thermal stability in air and oil: The use of vinyl ester resin technology improves thermal stability in air and oil. Data previously presented in Table 5 shows excellent property retention after 180 days at 177C (350F).

4) Sound isolation: BD-938CSP and BD-949B possess improved sound isolation compared to steel and aluminum. These materials make good engine and machine covers which suppress mechanical noise. See sound attenuation curves at different frequencies of BD-938CSP SMC, Figure 3.

5) Molded-in-color capability: SMC can be pigmented to practically any color to avoid painting. For outside usage, UV additives can be included in the formulation to resist fading and weathering.

6) Good mechanical properties: As shown in Table 1, BD-938CSP and BD-949B have good mechanical properties due to premium resin and ingredient formulation. When parts are designed with best practices, reduced weight parts with equal or superior part performance can be made with these SMC's compared to thermoplastics or metals.

7) Design flexibility: SMC part designs can integrate adjacent features frequently requiring additional pieces such as brackets in stamped steel and increase cost savings.

8) Cost savings over metal parts at lower volumes: SMC mold costs amortized over lower volumes make piece prices less expensive than steel stampings which require progressive dies and possibly multiple parts. SMC parts can be molded more dimensionally accurate, thereby avoiding machining needed with castings.

9) Weight savings vs. metal parts: The specific gravity of BD-938CSP and BD-949B is 1.70. Aluminum is 2.60 and steel is 7.80. SMC parts can be made lighter, with thinner walls, and including the ability to integrate additional adjacent parts in to the SMC component.

Future Applications

Engineers and designers, OEMs and suppliers continue to find new uses for composite parts in engines and transmissions. These include applications that were unimaginable just a few years ago, as shown in our review of the mass-produced SMC oil pans, rocker covers and oil deflectors. The CSP 949B sheet molding compound has attributes that meet design engineer's targets for under-hood and transmission components. Additionally, lower tooling cost and part consolidation. This material and process has replaced steel, aluminum, and Nylon components. With creative design and forward-looking ideas, the future is bright for engine and transmission components made from CSP 949B.

Conclusion

With increasing pressure to decrease costs, improve quality, and reduce or eliminate warranty issues, the CSP 939/949B SMC brings many advantages for composite parts targeting part consolidation, corrosion resistance, reduced weight, and high-temperature environments with a lower tooling capital investment. This material also gives design flexibility and lower expense due to SMC's lower tooling and production tooling costs to produce parts that are light-weight, high-strength and can withstand high temperature environments. The CSP949B SMC material has high levels of thermal stability, which means that, once molded parts will maintain their dimensional accuracy across temperatures ranging from – 50 C to 200 C. This is why CSP949B SMC is a material of choice to use for engine cover components and reflector covers.

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