BMC – TAKING AUTOMOTIVE COMPOSITES TO A NEW DIMENSION

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Abstract

BMC composites have long been used in automotive applications because of the excellent mechanical properties, creep and thermal resistance. Components such as headlamp reflectors, engine/valve covers, front timing chain covers, and small electric motors have benefited from this technology for many years.

Recent advances in the formulations have opened up new opportunities in automotive under the hood applications. BMC composite material technology is quickly finding its way into applications that require extremely tight molded dimensions and dimensional stability over a temperature range. Some of these applications include Electronic Throttle Controls (ETC), Air Control Valves (ACV), and transmission components.

This paper investigates the critical characteristics of these performance parts and the properties of BMC composite which help make the system work.

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Background and Requirements

The replacement of metal components with plastic materials in the automotive industry is by no means new. Successful conversions more than 60 years old are documented. As the years have past, the “low hanging fruit” was efficiently converted to plastics. As we progress with the development of the automobile, the required technological performance is usually ahead of the developments in material technology, thus the use of metals and other materials is still prevalent.

In no area is this more evident than the engine compartment. Due to the extreme thermal cycles, chemical environment, and dimensional requirements, there are not many plastic materials that can survive on or around the engine. In addition, the engine is the heart and soul of the automobile, thus OEM’s are very reluctant and extremely cautious in replacing proven technologies with new materials. Plastic materials that meet the value curve (cost, quality, reliability) are not easy to find.

However the escalating cost of aluminum is further pushing the advancement of plastics in under the hood applications. Aluminum has experienced more than 50% price increase in recent months, rising from $0.80/lb to more than $1.25/lb. This price escalation is attributed to two items. The souring costs of energy, and the tremendous demand from the growth in China. Energy represents about 1/3 of the total production costs of primary aluminum. The volatility of energy costs in the last few years is well understood.

Figure 1: Aluminum pricing

The tremendous demand for materials in China can not be underestimated. Global capacity for aluminum production stands at 2,300,000 tons per month. Currently global production is clipping along at 2,000,000 tons per month (87%). Inventory is 3,060,000 tons (45 days). 31% of aluminum is used in automotive applications. It is evident that a more reliable alternative is needed.

The plastics industry is not without problems, also being impacted by the high energy costs and the availability of key raw material feed stocks. Composites, generally speaking, are less impacted by crude oil prices compared with engineering thermoplastics. Composites by definition are a mixture, compound, combination, or aggregate. As such they offer a possibility to optimize the performance to cost ratio. The incorporation of lower cost fillers and additives offer relief from the escalating costs of the organic materials which are chemically linked to crude oil and derivatives.

Ultimately it is the economic factor that drives the engine for change in the automobile industry. When it is possible to obtain a significant economic advantage, along with performance improvements, a new paradigm is created. An example of this is the headlamp reflector application. In the mid to late eighties, it was realized that the headlamp reflector could be successfully converted from glass to plastic. Many polymer based solutions attempted to penetrate this market including; polycarbonate, nylon, ABS, polyetherimide, and BMC composite. After a few short years the market sorted it self out with the best value (price to performance) alternative, at that was BMC. Since the early 1990’s, 98% of headlamp reflectors are designed and manufactured with BMC.

This same type of paradigm shift is taking place today in the Electronic Throttle Control

(ETC) industry. The ETC's and ACV's (Air Control Valves) have historically been manufactured with die cast, and subsequently machined, aluminum. It is known that plastic materials can properly function in an ETC application. The functional performance requirements include:

Repeatable molded part dimensions (very small tolerances)

Dimensional stability (Low CTLE) over a wide temperature range

Good Mechanical Strength and Impact Resistance

Creep resistance / torque retention

Resistance to automotive fluids and engine cleaners

Resistance to Environmental Stress Cracking

There are a number of materials being investigated to replace aluminum in the ETC market (Polyphenylene Sulfide (PPS), Polyetherimide (PEI), and nylon PA66), but again BMC composites are standing out as the clear value leader.

Technical Evaluation

Before any technical evaluation begins, typically cost feasibility must be completed, and this discussion will be treated no differently.

Table I: Raw Material Cost Evaluation

Material	Specific Gravity (g/cc)	Price ($/lb)	Price ($/in^{3})
Aluminum	2.7	1.25	0.1218
BMC Composite	2.0	1.00	0.0722
PPS (53% GF)	1.8	2.89	0.1878
PA 66 (30% GF)	1.7	1.67	0.0995
PEI (30% GF)	1.5	6.90	0.3711

As of this writing, even with the escalating costs of aluminum, it is still reasonable compared with some engineering thermoplastics, on a raw material cost alone basis. Aluminum is in a much better price / cubic inch position than PEI or PPS. However BMC composites or glass filled nylon offer some price relief.

The advantage that all of the plastic materials enjoy over aluminum is in the conversion costs, especially when the focus is large volume automotive parts. Molds for plastic materials generally have a service life 5 times as long as die cast aluminum molds. Cycle times are generally faster and energy requirements are less. Additional advantages with plastic materials are the design freedom, parts consolidation, and weight reduction.

Dimensional Stability

The net shape dimensions of the ETC are extremely critical. The gas pedal in your car is connected to the ETC -- this is the valve that regulates how much air enters the engine. So the gas pedal is really the air pedal. When you step on the gas pedal, the throttle valve opens up more, letting in more air. The engine control unit (ECU, the computer that controls all of the electronic components on your engine) "sees" the throttle valve open and increases the fuel rate in anticipation of more air entering the engine. Sensors monitor the mass of air entering the engine, as well as the amount of oxygen in the exhaust. The ECU uses this information to fine-tune the fuel delivery so that the air-to-fuel ratio is just right.

Figure 2: Throttle Valve in Partially Opened Position

Optimized fuel efficiency and engine performance is obtained when the valve movement is as smooth as possible and valve seating is absolutely repeatable. This is accomplished first and foremost by the tolerances of the manufactured parts (the throttle plate and the housing), as well as the dimensional stability of these parts over a wide operating range (-40°C to 150°C). The net shaped dimensions are controlled by the material characteristics and the molding process variables.

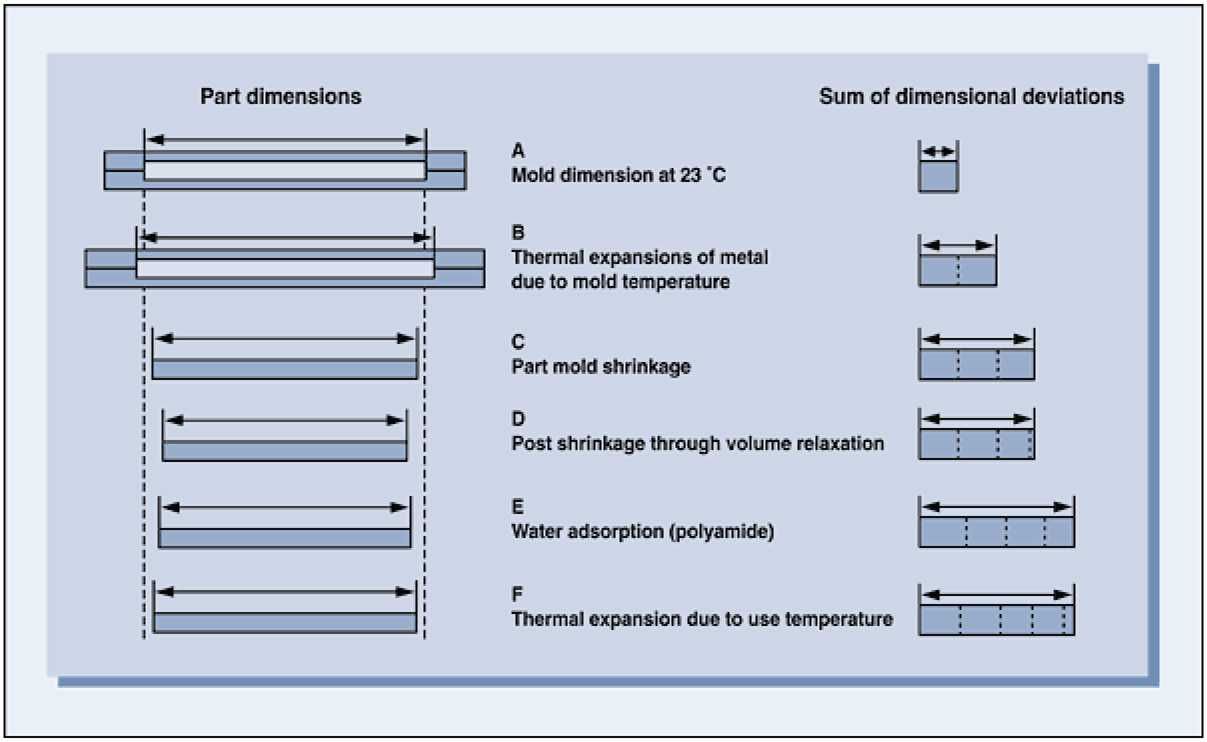

Figure 3: Factors Influencing Dimensions over Time

The most important characteristics of the material affecting the dimensions of the molded parts are shrinkage, coefficient of thermal expansion, and water/chemical absorption.

Table II: Comparison of Mold Shrinkage

Material	Mold Shrinkage (%)
Aluminum	0.70
BMC composite (Dimension X)	0.00
PPS (53% GF)	0.33
PA 66 (30% GF)	0.25
PEI (30% GF)	0.30

The BMC composite material can be formulated to yield “0” mold shrinkage and “0” post mold shrinkage. This means that after the parts are removed from the mold they are at their final net shape. Aluminum and engineering thermoplastics have significantly higher mold shrinkage than BMC Composite. Although some of this can be compensated for in the mold design, the variance part to part will remain higher, and further machining (or fixturing) of the parts may be necessary to obtain the desired dimensions.

Illustration 5 shows the repeatability of a bore diameter (94.97mm) over several days of production, with BMC Composite. In this case the material is holding a molded part dimension of +/- 0.01 mm; this is roughly 25% of the design tolerance allowed,

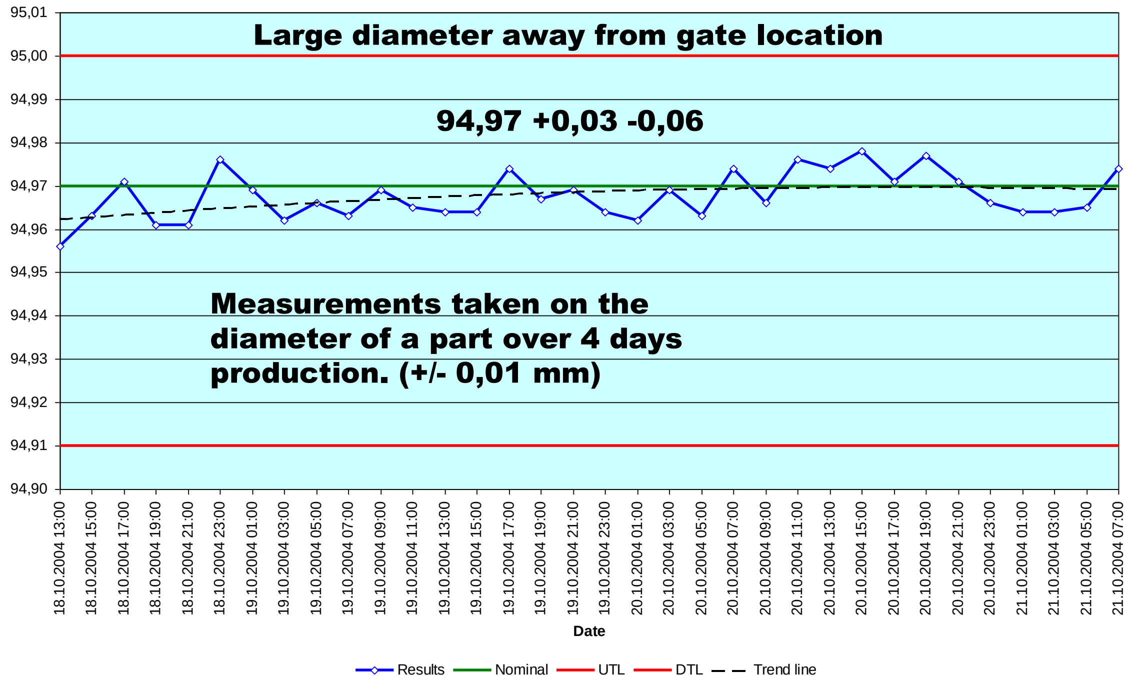

Figure 4: Process Capability – Molded Part Dimensions

Similarly on a smaller diameter dimension, with a smaller design tolerance, the BMC composite proves capable. In this case, several diameters around the circumference and throughout the height of the cylindrical shape are measured. The maximum and minimum diameters are recorded. The allowable design tolerance is +/- 0.015mm, and the system is using roughly half of this value. Again, this is molded to net shape, no post molding machining or fixturing of the parts is required.

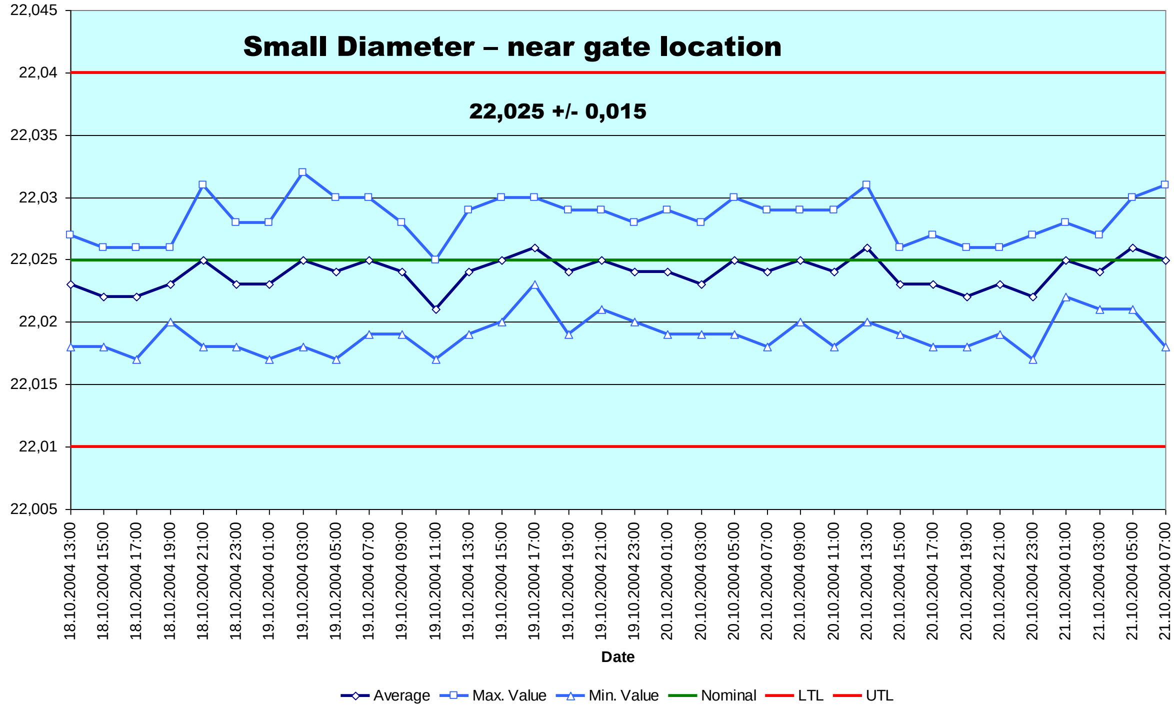

Figure 5: Process Capability – Molded Part Dimensions

Obtaining the desired net shape of the component is only part of the story. An important condition for the dimensions of an ETC is the use temperature. The component must maintain these dimensions over a broad temperature range (-40°C to 150°C) and through adverse environmental conditions (water, engine fluids, etc.). Thermoplastics show a relatively high thermal expansion compared to metals or BMC composite materials. Thermal expansion cannot be ignored for complex parts that are used at elevated temperatures. The Coefficient of Thermal Expansion is an important measurement of a materials dimensional change over a given temperature range.

Table III: Comparison of CTLE

Material	CTLE (um/m°C) RT to 150°C
Aluminum	20
BMC composite (Dimension X)	18
PPS (53% GF)	58
PA 66 (30% GF)	61
PEI (30% GF)	48

The CTLE of BMC composite material is approximately 1/3 of that from engineering thermoplastics. This means the critical dimensions of the BMC composite components will not change as much when the engine is taken from sub zero temperatures to an operating temperature of 150°C. In a valve application, controlling air flow into an engine, this means improved and repeatable performance over a broad temperature range.

Additionally, it is important to note that the CTLE of BMC composite is very close to that of aluminum. This means that if mating BMC composite components to aluminum components, there is be less stress induced from expansion and contraction of the materials.

Table IV: Comparison of Water Absorption

Material	Water Absorption (%)
Aluminum	0
BMC composite (Dimension X)	0.15
PPS (53% GF)	0.03
PA 66 (30% GF)	1.0 +++
PEI (30% GF)	0.25 +

With the exception on polyamide, the water absorption of these organic materials is very low, but naturally higher than aluminum. Moisture absorption and any subsequent change in dimensions or weight should be considered in the overall design tolerance.

The potential exposure to automotive fluids in the engine compartment is naturally a concern. BMC composite was exposed to several common automotive fluids along side a 30% glass filled Nylon (PPS and PEI samples were not available). The dimensions before and after 2000 hours exposure were measure and the net change, as a percentage of the original dimension was reported.

Table V: Dimensional Change (%) After 2000 Hours Exposure

Automotive Fluid	**BMC Composite**	**PA66 (30% GF)**
Coolant 93°C	0.05	0.18
Used Oil 150°C	0.00	-0.11
ATF 150°C	0.01	-0.12
Brake Fluid 150°C	0.14	0.08
Gasoline 24°C	0.03	0.06

With the exception of brake fluid, the BMC composite shows very little dimensional change when subjected to various automotive fluids.

Summary and Next Steps

BMC offers a complete composite solution for ETC applications, addressing the performance as well as economic issues, but there is always room for continuous improvement. The additives necessary to produce the material with exceptionally low shrinkage and thermal expansion coefficient are not the best for appearance and color. The molded components have a “mottled” or non-homogeneous appearance. This could be improved.

The specific gravity of BMC composites is high relative to engineering thermoplastics, thus continued effort is needed in density reduction. Success has been achieved in BMC composites for other components (specific gravity as low as 1.45 g/cc), and this success needs to be applied to technical engine components such as the ETC.

BMC composites are not the most well know material solution. They are not processed like engineering thermoplastics, nor are the part design or tool design the same. The body of knowledge regarding the use of BMC composites needs to be increased.

References

1. DSM Engineering Plastics – Website – “Engineering Plastics Overview“, July 2006.
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3. MatWeb – Website – “Material Property Data”, July 2006.