

DEVELOPMENT OF THE FIBER REINFORCED THERMOSET DAIMLERCHRYSLER 4.7L V-8 ENGINE VALVE COVER

*Steve Crawford
DaimlerChrysler*

*Mark Dixon
Dana Corporation*

*Paul Gramann
The Madison Group: PPRC*

Abstract

This paper will review the development and design of the DaimlerChrysler 4.7L V-8 engine. The new plastic cover module, comprised of a glass reinforced vinyl ester thermoset, was developed in just 12 months and replaces a magnesium component. Significant cost savings were realized, while incrementally improving noise, vibration, and harshness (NVH). Extensive finite element analyses (FEA), including mold filling analysis and anisotropic property calculation, were utilized to ensure robust system performance. This collaborative effort eliminated the prototype step for the cover housing, which in turn reduced development time and cost by allowing the component to move directly from design to production. This capability also allowed NVH improvement to be realized over the already favorable acoustical performance of the previous die-cast magnesium component.

Background of Plastic Valve Covers

The use of plastics in powertrain components has steadily increased since the early 1980s, particularly with the valve covers. Increased plastics usage is driven by the desire for better fuel economy with larger and more powerful engines, reduced emissions and weight, and improved noise vibration and harshness. As these improvements are sought, demands on the mechanical and thermal behavior of the material are proportionally increased. With the introduction of 48 volt systems in the near future, these demands are guaranteed to increase, thus further reducing the pool of materials that one will be able to select from.

One of the early uses of plastics in the engine compartment was in the early 1980s when a polyamide valve cover was used on the 6.0 liter engine for the General Motors Cadillac [1]. This cover was found to be lighter and less costly than stamped steel. In the late 1980s the development of a thermoset valve cover by GM

for 3800 V6 engine took place [2]. Thermoset materials were thought to be ideal candidates for this application since the solidification process by a cross-linking reaction prohibits the material to re-melt once molded. Bulk molding compound (BMC) was chosen because of its superior heat resistance properties, specifically, the ability to resist creep at high temperature. Creep is the ability of the plastic component to move or deform while under stress. Creep behavior becomes a concern as the temperature and stress in the component increases.

The different processes used to mold valve covers from thermoset materials include compression, injection-compression and straight injection molding [3]. Compression molding was initially used due to the favorable mechanical properties that result from reduced fiber breakage during the process. To reduce costs, injection-compression quickly became the process of choice due to the decrease in cycle time, operator interaction and tooling costs. Mechanical properties were kept high by the use of the compression phase. Later in the 1990s injection molding was investigated to further decrease cycle time and part cost. Fiber breakage concerns were resolved by modifying material properties. Specifically, the viscosity of the material during molding was lowered, the onset of reaction was delayed, and the reaction rate was increased.

The transition from metal to plastics over the past twenty-plus years has been quite successful “with well over 50 million BMC covers on the road today – without one material related failure [1].” This statistic is particularly noteworthy when one considers the environment these covers are in. Plastic continues to replace metal components throughout the vehicle. Research continues to decrease part cost while maintaining or increasing part dependability.

Replacing Magnesium with Plastic

The function of the valve cover is to restrict the pressure and splash lubrication in the engine heads. In most cases a slight negative pressure is created by the PCV system, which redirects the oil vapor in the crankcase back through the intake. In rare conditions, which are designed for, the system will develop pressure.

During the late 1990s magnesium made significant strides in the powertrain of the automobile. This was due to the decrease in density when compared to other materials, such as, steels (75%), aluminum (30%) and composites (20%). New magnesium alloys and processing techniques, specifically Thixomolding®, became popular to produce net-shape parts in a single step process involving high-speed injection molding of semi-solid thixotropic alloys [4]. There was a perceived notion that the lower density would decrease the cost of the part. This was the case for the DaimlerChrysler 4.7L engine used on the RAM truck, Grand Cherokee, Durango and Dakota trucks.

In 2002, DaimlerChrysler revisited the magnesium valve cover in a move to reduce part cost, weight and noise, vibration, and harshness. The primary materials that gave the best opportunity of success were Nylon 66 and bulk molding compound. Nylon 66 was quickly eliminated from consideration due to creep at higher temperatures and its lower operating temperature range. The system had to be able to withstand continuous temperatures in the 425-450 F°, which was too high for Nylon.

The primary goals for this project were to reduce part thickness, tooling costs, materials costs, overall part cost and noise, vibration, and harshness. This was all to take place during a complete development to production time of 12 months, rather than the typical 18 months. To significantly reduce development time it was decided that prototyping would be eliminated – an unheard of practice when redesigning a critical engine component. This savings mounted to 8-10 months of time. This also significantly reduced development costs. To assure that high quality parts were going to be made and huge modifications costs were not needed, extensive material testing and numerical modeling on the molding and structural response were completed. Further, Stereo Lithography parts were made from the CAD files and used for shipping containers and packaging studies.

One design goal was to ensure that NVH was that of or better than the current production magnesium part. Numerical modeling was used to calculate the natural frequency of the part and the excitation of the part to determine if improvement could be made. The actual testing confirmed that the design realized a 1 DBA improvement in the mid range area when the engine operates, which met the goals.

The material tested for this cover was Premix 1265, which is a production material used in many current valve covers. There was an option to use Premix 1266 (Polyester/vinyl Hybrid) due to a potential later cost reduction and better flow during molding. However, due to the lack of production testing the risks with using a material, which had a limited test background and history, were too high. For the fabrication process straight injection molding was investigated to reduce cycle time. The tool was made to have a grained surface texture, which offered an improved appearance over magnesium at a reduced cost. The graining also reduced the evidence of sink lines from the ribs of the part, which could have been an appearance issue.

To ensure successful molding of the part, numerical analysis was used to simulate the complete molding process. The mold filling simulation was specifically used to predict knit line location and air entrapment (if any), as well as, fiber orientation and anisotropic material properties. These properties were then to be used in a structural analysis to more accurately determine stresses, deformation and vibrations. Figures 1-4 show the predicted progression of the material through the mold. The figures show that a slight race tracking would occur at the seal. The race tracking actually assists the process since the flow length at the edge is the greatest. This allows the material that is flowing up and over the cover to stay even, eliminating knit line or gas entrapment. The fiber orientation at the gate is shown in Figure 5. Fiber orientation is predicted to be the highest at the gate and the last corners to fill. This will lead to significant differences in material properties along the direction of the fiber and transverse to it.

The 1265 material was 21-day heat age tested for durability in the lab. Additional testing included burn-off testing to insure that the glass content in the pocket area was high enough, short shot testing to confirm that the mold flow analysis was correct, Fig 6. Extensive dyno-testing for both hot, cold and hot/cold cycling testing, as well as, proving grounds testing and taxi cab testing in both warm and moderate climates was conducted. Finally, Production Evaluation Runs (PER'S) were conducted on thousands of parts before the decision to switch over to the thermoset covers was finalized. The PSO (process sign off) to approve production tooling running at production rate (3600 covers/day) was all completed in under 1 year and full volume production switch over was done in 15 months.

The two-cavity injection molding parts, identified as Left and Right are shown in Fig. 7. The gate side of the cover is shown in Fig. 8. The gate was designed with the help of numerical molding to reduce flow stress so that fiber breakage was at a minimum. The smoothed-out corners and a gentle approach into the sidewall helped achieve this goal.

Conclusions

This paper reviewed the development and design of the DaimlerChrysler 4.7L V-8 engine valve cover. Significant cost savings and development time were realized by using a thermoset composite material in place of magnesium. The prototyping phase was eliminated from the design process in place of simulation tools, which proved to be highly successful.

The switch from magnesium to bulk molding compound has resulted in substantial per vehicle cost savings. The predicted life of the tooling is in the millions; for magnesium tooling was in the hundred thousands of shots, before the tool needed replacement. The thermoset cover did not have to be painted or blasted (as a post process) to give it a nice finish for appearance. The short in-process time of the composite reduced the internal float of parts being processed and also helped reduced price. The magnesium cover had to be sent out and cut wire blasted for surface finish and had to have an adhesive placed on the gasket to insure that the gasket was retained during shipping. The noise reduction was about 1 DB lower through the mid-range operation of the engine. Vehicle testing was conducted on Jeep® and truck vehicles and found to reduce the noise levels in the mid-range.

The covers have been in full production (no ramp up to 3600 covers/day) since December of 2002. The number of covers produced to date (July 2003) is approximately 1/2 million. An additional benefit was a reduction in warpage due to the decrease in part thickness.

References

1. L. Nunnery, Thermoset Technology: For the Molder, Bulk Molding Compounds, Inc.
2. Personal conversations with Wil Conner, Bulk Molding Compounds, Inc.
3. B. Davis, P. Gramann, T. Osswald, and A. Rios, Compression Molding, Hanser, Munich (2003).
4. S. LeBeau, R. Decker, D. Walukas, "Production of Magnesium Powertrain Components via Thixomolding®", Thixomat Company Literature

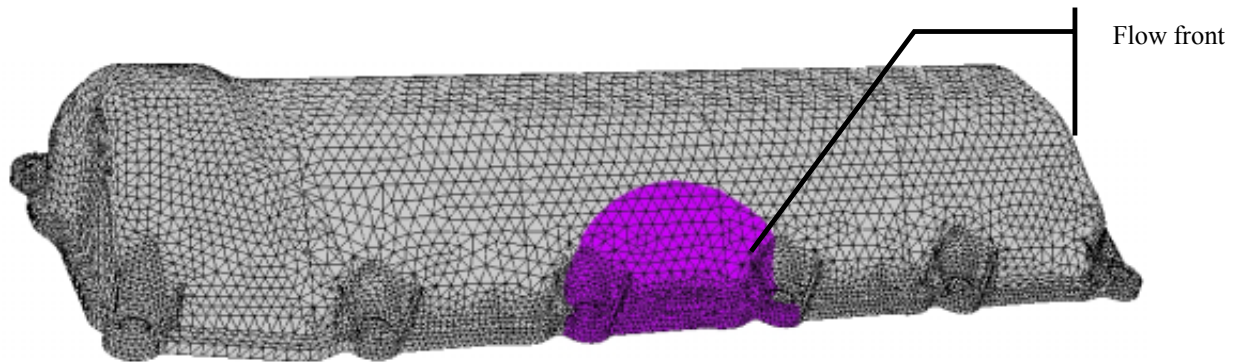


Figure 1. Predicted mold filling of the 4.7L valve cover.

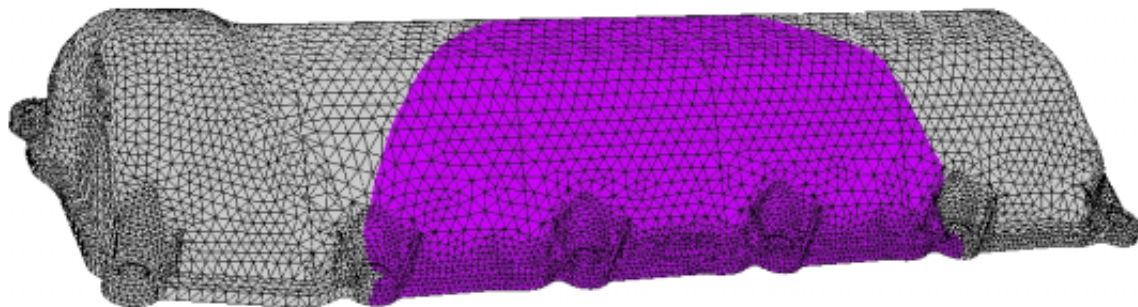


Figure 2. Predicted mold filling of the 4.7L valve cover.

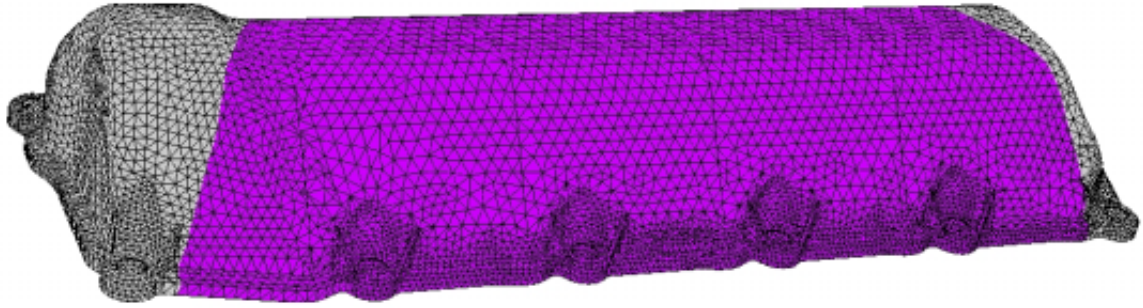


Figure 3. Predicted mold filling of the 4.7L valve cover.

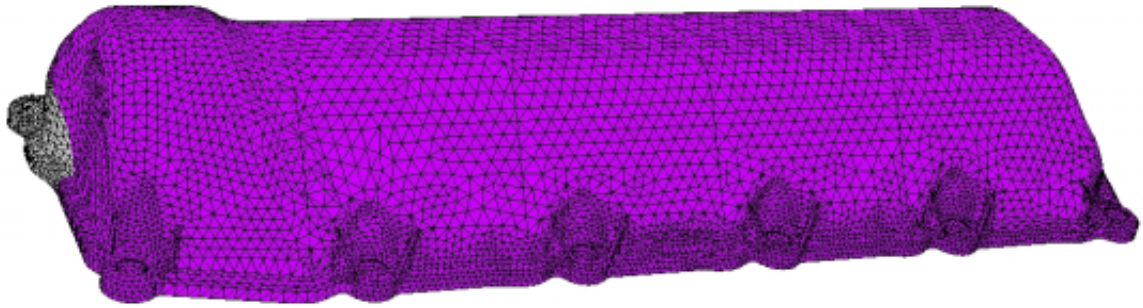


Figure 4. Predicted mold filling of the 4.7L valve cover.

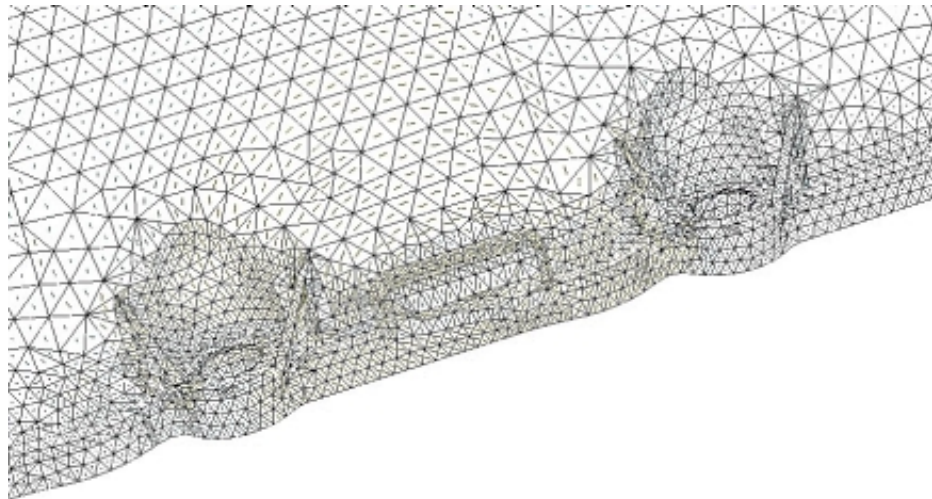


Figure 5. Predicted fiber orientation at the gate.

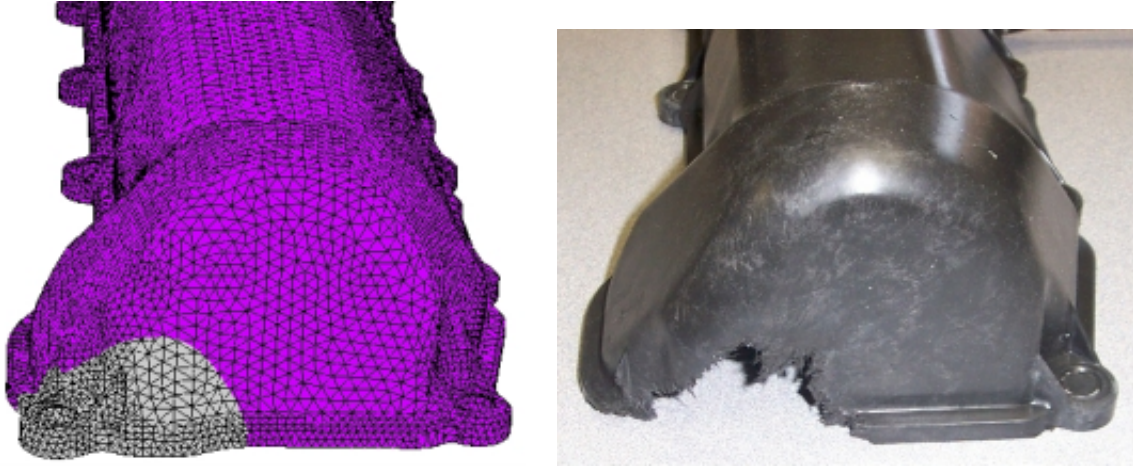


Figure 6. Predicted mold filling and short shot at end of fill.



Figure 7. Left and right sides of 4.7L valve cover showing runner.

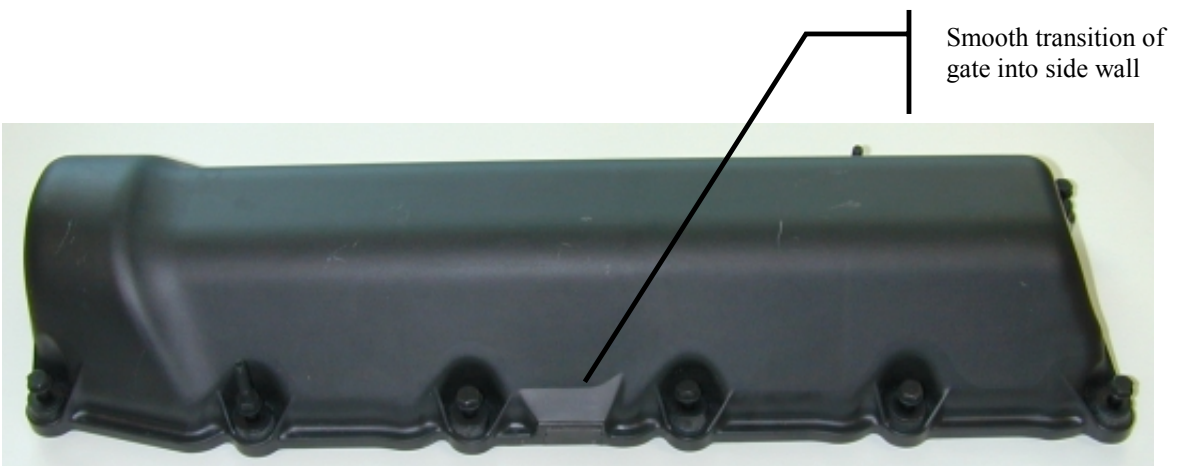


Figure 8. Gate at side wall of 4.7L valve cover.