CYMAT

ALUMINUM FOAM TECHNOLOGY APPLIED TO AUTOMOTIVE DESIGN

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Cymat – A Brief Introduction

The Company

Cymat's mission is to commercialize Stabilized Aluminum Foam (SAF), a revolutionary material with numerous automotive applications. Cymat is a public company, with its shares trading on Canada's senior exchange, the Toronto Stock Exchange, under the symbol CYM. The company is commercializing SAF by focusing on development of the technology in-house while partnering with Tier-1 manufacturers or OEM's to develop applications and to maximize sales and manufacturing capability. Cymat has exclusive worldwide rights to manufacture and sell SAF.

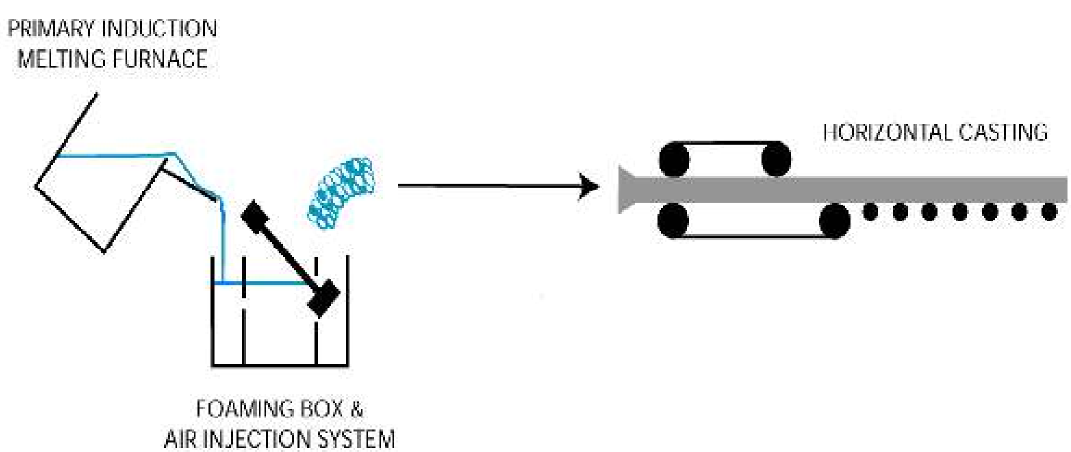
Manufacturing Processes

Stabilized Aluminum Foam is a unique material that is realized through a patented production process. The base material is a metal matrix composite (MMC) composed of aluminum alloy with ceramic particles added. The particles are necessary to stabilize the foam bubbles, since without the particles the bubbles would form but then immediately collapse. The stabilizing particles slow the drainage of the aluminum in the cell walls and increase the apparent viscosity.

1. Sheet Casting

Once melted, the MMC is poured into a foaming box. The foam is formed when gas bubbles exit the immersed rotating impellers (a component of the gas injection system). The foam collects on the surface of the molten material where it can be continuously drawn off to form a sheet. The foam structure is predominantly closed cell. The cell size is controlled by the gas flow rate, impeller design and impeller rotational speed. The rate and means by which the gas is introduced can be varied to produce foams with densities varying from 3% to 20% of the density of solid aluminum. Because many of the mechanical and physical properties of SAF vary with density and cell size, SAF can be tailored to suit the targeted application.

Cymat's production line is capable of casting up to 2300 pounds per hour of SAF. Sheets can be 0.5 to 5 inches thick, up to 5 feet wide, and up to 50 feet long.



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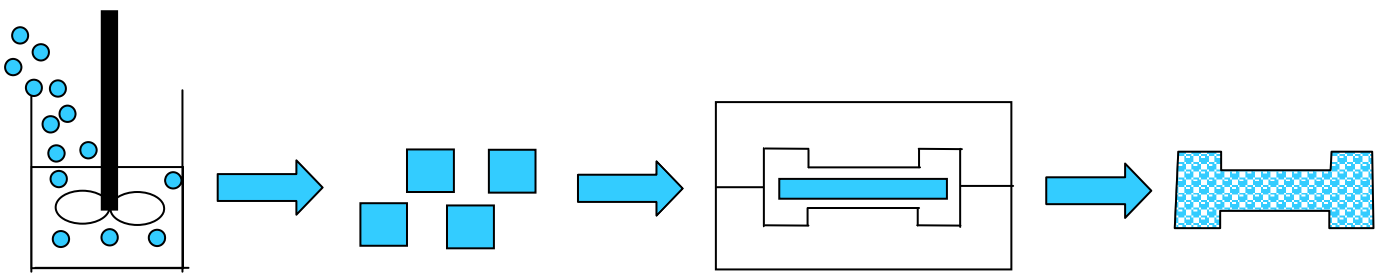
2. Low Pressure Casting
Cymat's Low Pressure Casting is similar to the aluminum die-casting process, which is commonly used to make aluminum wheels. Cymat's process involves injecting SAF into a mould. The pressure of injection is controlled so that it is sufficient to fill the mold precisely, while not being so high as to collapse the unique cell structure of SAF. This technology is currently in the developmental phase. Cymat has built experimental equipment for process development, manufacturing of simple products, and further exploration of the technology. Features of this process are that it produces 3 dimensional shapes that have foam on the inside and an aluminum 'skin' on the outside surface. This will allow Cymat to meet the requirement for components with complex geometries and coherent surfaces that can be painted or otherwise treated.

3. Precursor technology
Precursor technology involves adding a foaming agent to molten MMC, followed by rapidly cooling the melt to form a solid precursor with a defined shape. Under specific re-heating conditions the precursor will expand to fill a cavity. The result is a uniform-celled foam that leverages Cymat's existing processes realized at a substantially lower cost than comparable powder metallurgy methods used to produce complex shapes. Precursor technology will provide the ability to produce components with complex geometries and fill other complex and difficult to access parts.



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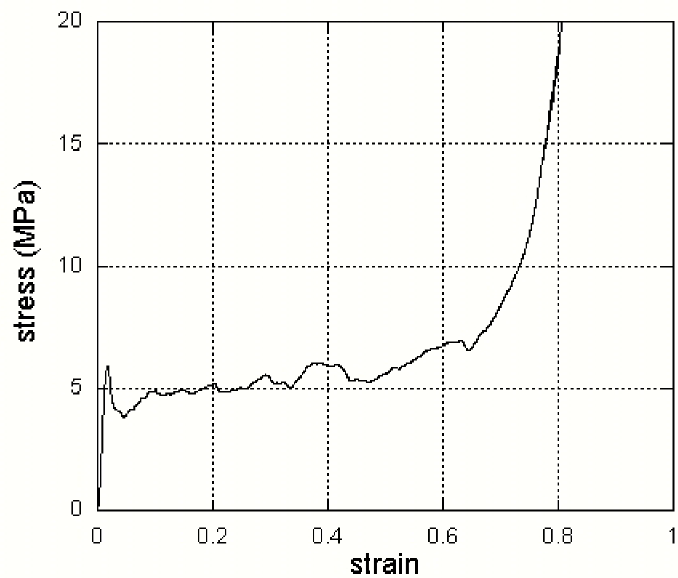
Material Characteristics

Cymat's Stabilized Aluminum Foam (SAF) is a versatile and cost effective material for use in a broad range of industry applications. Combining the unique properties of SAF with a streamlined manufacturing process, Cymat's products increase the performance of automotive components utilizing the following characteristics:

- High mechanical energy absorption in all directions
- Excellent strength and stiffness to weight ratios
- Constant properties over temperature and moisture ranges
- Recyclable
- Notch insensitive (holes do not affect material strength)
- Fire retardancy with no environmental degradation
- Acoustic and thermal insulating properties
- The properties of SAF do not significantly change with speed of impact

Many potential applications for SAF take advantage of the material's energy absorption capability. SAF is an ideal energy absorber because of the shape of its stress-strain curve in compression. A typical curve for SAF is shown below.



In compression, SAF exhibits a long plateau region in stress over very large strains, meaning it can absorb energy while exerting a constant force. SAF can be produced in a range of densities allowing for the force or energy absorption requirements to be tailored to the application.

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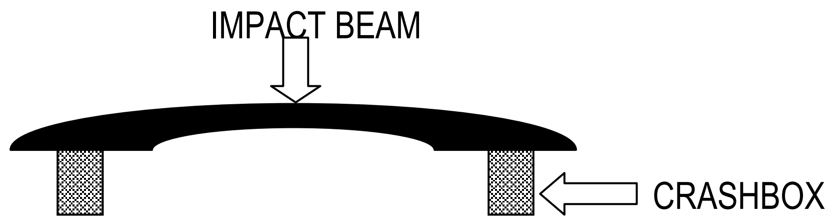
Promising Automotive Applications

Crashbox

A crashbox is placed between the impact beam and the front rail of the car to absorb medium speed collision energy, thereby reducing repair costs. Here the crashbox is an aluminum extrusion or welded steel section filled with SAF that will crush along its length to absorb energy. Crashboxes are more widely used in Europe due to insurance incentives.

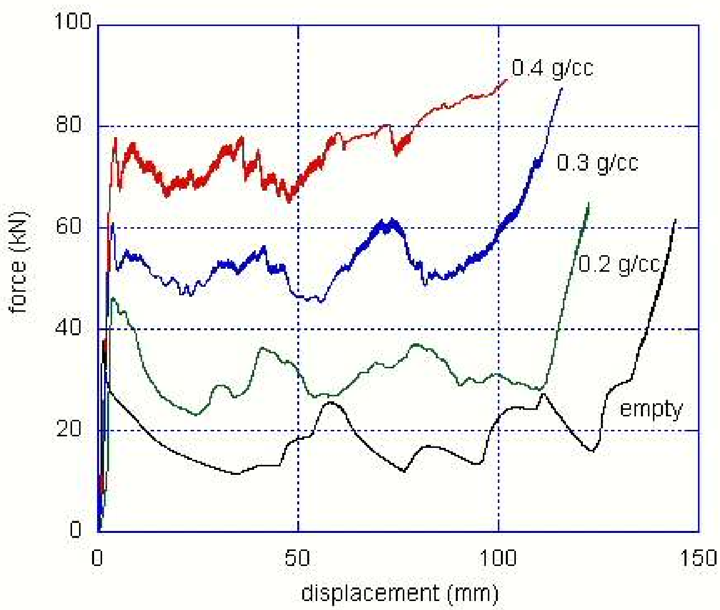


The benefits of SAF-filled crashboxes include:

- Eliminate damage to the front rail by absorbing the energy from collisions with speeds up to 20 km/hr, thereby localizing damage and reducing repair costs.
- Absorb energy in off-axis collisions more efficiently than hollow-section designs.
- Absorb more energy than an empty section of similar mass.
- Offer greater design freedom in the front-end by absorbing impact energy in a much shorter distance.
- A comprehensive engineering Body of Knowledge exists for crash box design.
- Behave the same regardless of speed and temperature changes.

The photographs below show a crushed crashbox and two examples manufactured by different processing routes. The crushed box illustrates the dual actions of SAF in the crashbox—not only does the foam absorb energy but it also causes the tube to behave differently (i.e. more folding) and absorb more energy than when empty. The square crashbox had a foam piece press-fit and the round section has been filled with molten SAF through a casting technique.

Below is an example of force-displacement curves for an empty tube and three tubes filled with foams of increasing density.



Sources:

Hanssen, A.G., *Structural Crashworthiness of Aluminum Foam-Based Components*, Ph.D. Thesis, Norwegian University of Science and Technology, June 2000.

Hanssen, A.G., Lorenzi, L., Berger, K.K., Hopperstad, O.S., and Langseth, M., "A Demonstrator Bumper System Based on Aluminum Foam Filled Crash Boxes", *International Journal of Crashworthiness*, Volume 5, 2000.

Gradinger, R., Seitzberger, M., Rammerstorfer, F.G., Degischer, H.P., Blaimschein, M., and Walch, C., "Aluminum Foam Filled Steel Tubes as Composite Shock Absorbers", *Metal Foams and Porous Structures*, ed. Banhart, Ashby and Fleck, MIT Verlag, 1999.

Rails

Much of the Body-in-White of a car, including the front and rear rails, is composed of hollow sections. These sections offer very good bending stiffness for weight but often fail prematurely because of localized damage. Traditionally, steel stampings are used for additional support at weak points in a rail such as curves but these additional parts add complexity and cost to the system. The advantages of using SAF filled rails are outlined below.

- Strength, energy absorption and length of elastic range of a SAF-filled rail are improved by preventing premature failure at a flaw or curvature.
- Consolidating or eliminating small reinforcement stampings can reduce cost of the part.
- Weight of the rail can be reduced compared to a traditional stamped reinforced rail with the same energy absorption and strength.
- Energy absorption and strength of the foam-filled rail can be improved with the same weight as a traditional rail.
- Passenger safety is improved by reducing intrusion into the passenger compartment in the case of high-speed crashes.

Sources:

Kim, H.-S., Tho, C.-H, Wierzbicki. T., and Yang, R.J., "Crash Optimization of Aluminum Foam-Filled Front Side Rail of a Passenger Car", *Impact and Crashworthiness Laboratory, MIT, Report # 36*, June 2000.

Bumper

The demands being placed on bumper systems are becoming increasingly complex. Safety requirements for occupants and pedestrians demand more functionality. The consumer and the insurance industry desire systems that are easily repairable and that protect other, more expensive, components. Styling concerns limit the amount of space available to build in the required functionality.

In addition to its use in crashboxes, the advantages of incorporating SAF into bumper beam design include:

- SAF does not rebound after it is compressed, which reduces whiplash concerns.
- SAF can increase the threshold collision speed before the impact beam is damaged.
- Designs placing SAF in the back bumper would better pass the rear centerline pole test.
- SAF may allow for a thinner bumper profile and greater design freedom.

Sources:
Geyer, K. E., "A New Front Buffer for Suburban Railcars", *Cellular Metals and Metal Foaming Technology, Proceedings of the 2nd International Conference on Cellular Metals and Metal Foaming Technology*, ed. Banhart, Ashby and Fleck, MIT-Verlag, 2001.

Internal Occupant Protection

Internal occupant protection is largely concerned with reducing the severity of head injury experienced by the occupant in an accident. When dealing with potential head injury, the forces must be kept low; therefore SAF densities between 3% and 10% are suitable. Examples of internal automotive parts that could be made from SAF are headliners, headrests, and A and B pillar covers. SAF is an ideal material for resolving internal occupant protection issues that exist with current materials (such as polymeric foams) for the following reasons:

- SAF exhibits no rebound after compaction. This means that the occupant's head slows to a stop and does not accelerate in the opposite direction (whiplash considerations).
- The properties of SAF do not change with temperature.
- The properties of SAF do not significantly change with speed of impact.
- An SAF energy absorber can be precision engineered to meet HIC requirements exactly by varying the density of SAF used.
- SAF can absorb large amounts of energy in every direction.

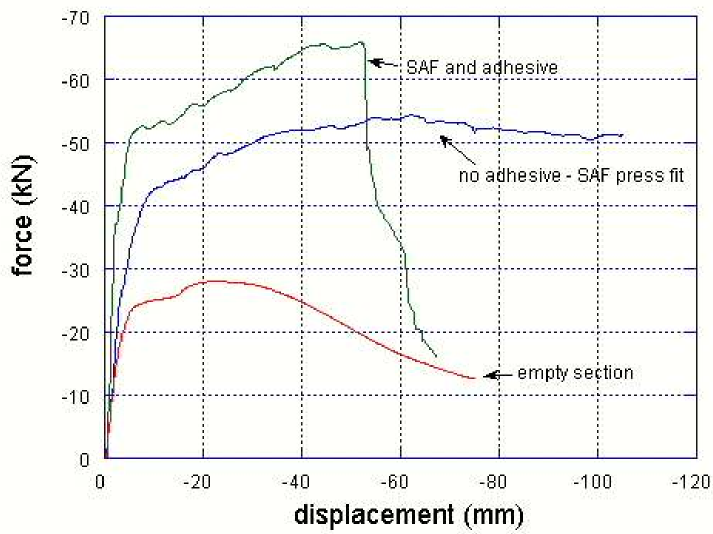
Sources:
Bellora, V.A., Krauss. R., and Van Poolen, L., "Meeting Interior Head Impact Requirements: A Basic Scientific Approach", SAE Technical Paper Series: *Progress in Safety Test Methodology* (SP-1596), 2001.
Kretz, R. and Gotzinger, B., "Energy Absorbing Behaviour of Aluminum Foams: Head Impact Tests on an A-Pillar of a Passenger Car", *Cellular Metals and Metal Foaming Technology, Proceedings of the 2nd International Conference on Cellular Metals and Metal Foaming Technology*, ed. Banhart, Ashby and Fleck, MIT-Verlag, 2001.

A and B Pillars

Foam can be inserted into pillars and held in place by adhesive, expanding polymer foams or by mechanical methods. Benefits are similar to those noted in rail-reinforced applications and include:

- Bending strength can be increased by as much as three times over hollow pillars.
- Absorbed energy in side impact and rollover accidents is increased.
- Performance in the roof crush test (FMVSS 216) is improved.
- Weight reductions can be realized by decreasing steel gauge.

Results from Cymat's testing of three-point bending of an empty section versus a filled section are illustrated below.



Sources:
Santosa, S., Banhart, J., Wierzbicki, T., "Bending Crush Resistance of Partially Foam-Filled Sections", *Advanced Engineering Materials*, 2(4), 2000.
Chen, W., "Experimental and Numerical Studies on Deep Bending Collapse of Foam-filled Hat Profiles", *Impact and Crashworthiness Laboratory, MIT, Report # 35*, June 2000.
Boa, Y. and Wierzbicki, T., "Strength and Fracture of Foam-filled Cast Aluminum Profiles Under 3-Point Bending", *Impact and Crashworthiness Laboratory, MIT, Report # 41*, November 2000.

Hoods

Impending legislation in Europe will require carmakers to make pedestrian safety an integral consideration in front-end design. One element of the legislation is protecting pedestrians from injury when the pedestrian's head hits the hood. Advantages of an SAF hood are given below.

- SAF has excellent energy absorption in the delicate head injury regime.
- The density of SAF can be varied as needed through the hood (or only placed in specific locations) to protect head injuries resulting from impacts with hard under-hood components.
- SAF provides a simple, passive solution (compared to very complex, active solutions that are being considered, such as airbags).
- SAF with a plastic cover protects the head and provides a Class A finish, protection from debris and vandalism, and rebounds after collision for appearance considerations (similar to the fascia on a bumper).
- SAF exhibits no rebound after compaction. This means it slows the head to a stop and does not accelerate in the opposite direction (whiplash considerations).
- SAF offers a unique combination of properties that make it ideal for a hood application: energy absorption, stable properties at elevated engine temperatures, good thermal insulation, and low noise transmission.

A photograph of the SAF, and the plastic used to cover it, after impact with a head-form at 40 km/hr is shown below – note that the SAF is deformed as a result of absorbing the impact, while the plastic that was covering it is unmarred.

Sources:
Bellora, V.A., Krauss. R., and Van Poolen, L., "Meeting Interior Head Impact Requirements: A Basic Scientific Approach", SAE Technical Paper Series: *Progress in Safety Test Methodology* (SP-1596), 2001.

SAF Cores for Castings

The aluminum foundry and die-casting industry typically uses sand cores to make hollow cavities in metal castings and rib structures where stiffening is required. SAF could be used to augment or replace these methods in castings made from zinc, magnesium and aluminum, with the following benefits:

- SAF would not have to be removed after casting (a sand core is usually vibrated out) therefore holes are not necessary in the casting.
- SAF core would reduce the weight of the casting by replacing redundant material (some possible examples of components for this application are connecting rods, pistons, lower control arm, transmission gear, engine block and brake pistons).
- The SAF core may cost less than the solid aluminum it replaces, depending on the application.
- SAF can collapse in an accident, providing energy absorbing properties to a casting.
- Complex rib structures could be replaced by one simple part incorporating SAF. This will lead to simpler die designs and processing methods.

An example of a foam core is shown below, including a sectioned view of the component on the right.

Sources:

Heinrich, F., Korner, C., Blenk, M., and Singer, R.F., "Encasing of Aluminum Foams by Die Casting: Foam Core Properties and Core Fixing", *Cellular Metals and Metal Foaming Technology, Proceedings of the 2nd International Conference on Cellular Metals and Metal Foaming Technology*, ed. Banhart, Ashby and Fleck, MIT-Verlag, 2001.

Lehmhus, D., Weber, M., and Wollenweber, K.-H., "Application of Aluminum Foam for Automotive Brake Piston", *Cellular Metals and Metal Foaming Technology, Proceedings of the 2nd International Conference on Cellular Metals and Metal Foaming Technology*, ed. Banhart, Ashby and Fleck, MIT-Verlag, 2001.