

LOW COST, LIGHT WEIGHT SINGLE MATERIAL SOLUTION FOR SOFT TOUCH VEHICLE INTERIOR SUBSTRATES

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Abstract

The use of low-density glass-mat thermoplastic (LD-GMT) materials in automotive interior applications has increased over the last 4 years. Nearly 20% of all headliners produced in North America are molded from LD-GMT. Its popularity and use has also begun to spread to other soft-touch applications and to other global regions. The superior mechanical properties, ease of tailoring performance, efficiency of processing and adjustable thickness capability makes the AZDEL SuperLite LD-GMT product a versatile material solution for both structural and non-structural interior applications.

This paper is divided into 4 sections and will present:

- The basic composition, manufacturing process and properties of LD-GMT.
- Applications for LD-GMT and the benefits of its' use.
- LD-GMT performance when subjected to several generic interior standards.
- Design capabilities and the forming processes for LD-GMT.

Introduction

OEMs across the globe are continually challenging interior suppliers and integrators to develop and supply lower cost, lighter weight, higher quality and generally higher performing products. OEMs expect compliance with the requested performance improvements regardless of the vehicle segment. Low, mid and high segment interiors are equally affected. For the purposes of this paper, automotive, interior trim panels/applications will be divided into two basic categories. The first category will be classified as hard trim, which can be molded in color or painted. The second category will be classified as soft trim, which could be coated and wrapped with a decorative covering [1]. Lower class vehicles are more prone to contain hard trim. Mid to high class vehicles will contain a mixture of hard and soft trim but generally incorporate more soft trim. The benefits, which will be discussed in this paper, apply to soft trim and thus to mid to high-end vehicle platforms.

Composition, Processing and Properties

LD-GMT is a composite material comprised of chopped glass, polypropylene and additives. One type of LD-GMT is manufactured using a licensed patented technology of Arjo-Wiggins. An illustration of this LD-GMT process is contained in figure 1 on the following page.

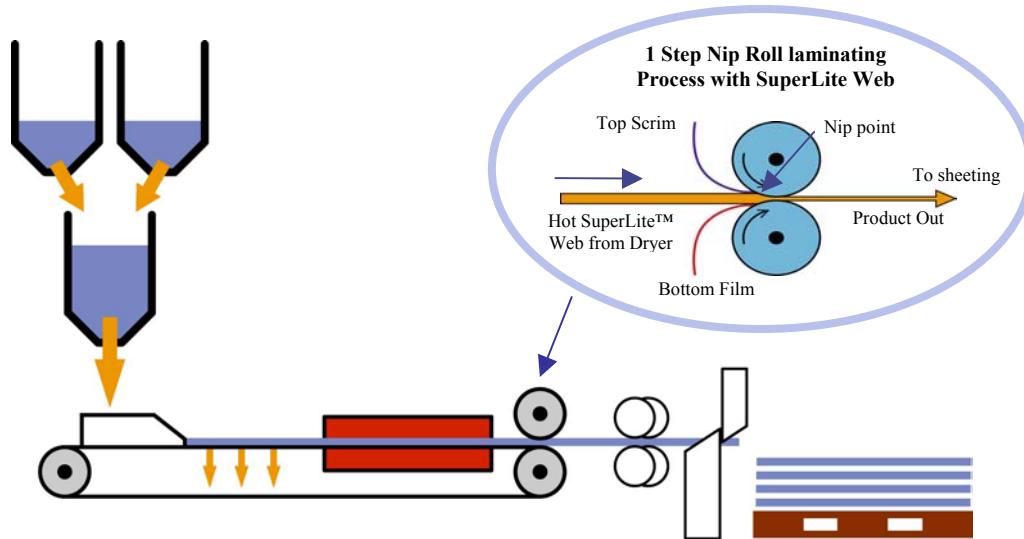


Figure 1

This process is similar to paper making. The raw materials are dispersed in aqueous foam and pumped to a porous forming belt via a head-box. The foam is removed initially with vacuum. The materials are then continuously run through a drying oven where the remaining moisture is removed and the polypropylene is brought to its melting temperature. Surface coverings, which enhance molded part performance, are applied as the chopped fiber web exits the drying oven. Finally, the cooled, rigid LD-GMT sheet is cut to desired length.

This process is also capable of using other natural and synthetic fibers and other polymers without the modification of the web forming process [2].

This LD-GMT product is priced and sold according to its' weight per unit area (grams per square meter or GSM) and surface covering package. It is available in a number of convenient standard widths up to 2 meters and no limitations to length. Basis weights between 600 GSM and 2000 GSM accommodate a wide range of physical properties and the surface coverings can be changed per application requirements. Surface coverings are used to:

- Prevent airflow (act as barrier)
- Change airflow resistance to enhance/tune sound absorption properties
- Provide a means for adhesion
- Aid in handling (prevent glass from effecting operators)
- Enhance mechanical properties (strength, impact)

The properties of LD-GMT are a function of three compositional factors, which are illustrated in below in figure 2.

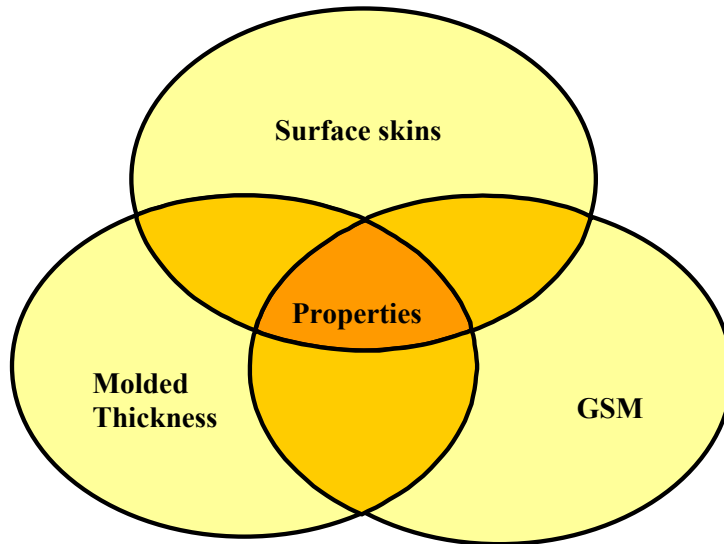


Figure 2

The combinations of thickness and GSM have the largest effect on the properties resulting from a molded LD-GMT panel. LD-GMT, when re-heated to 190-205° C, will increase in thickness to nearly twice its' manufactured thickness. This loft-ability is due to a relaxation of the glass fibers that were stressed during the nip roll lamination portion of the products manufacturing process. The void content and density of an LD-GMT sheet change as the sheet lofts prior to molding. The degree of loft facilitates a wider range of moldable thickness. There is a linear relationship between basis weight, loft and moldable thickness [3-4]. Figure 3, below, illustrates lofted height and moldable height for a series of area weight products.

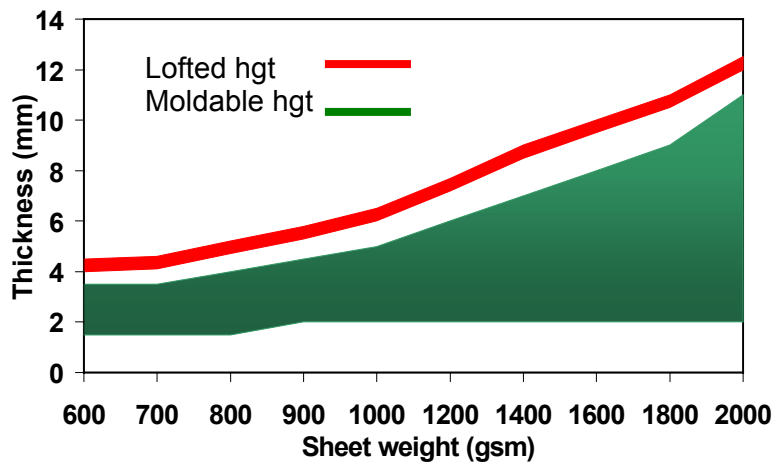


Figure 3

Molded thickness is one of the key characteristics that enable the LD-GMT product to tune its' properties to suit different application requirements. Figures 4, 5 and 6, displayed on the following page, illustrate the range of properties obtainable for different area weight products at different thicknesses.

Density Vs GSM for various thicknesses of 55% glass content LD-GMT

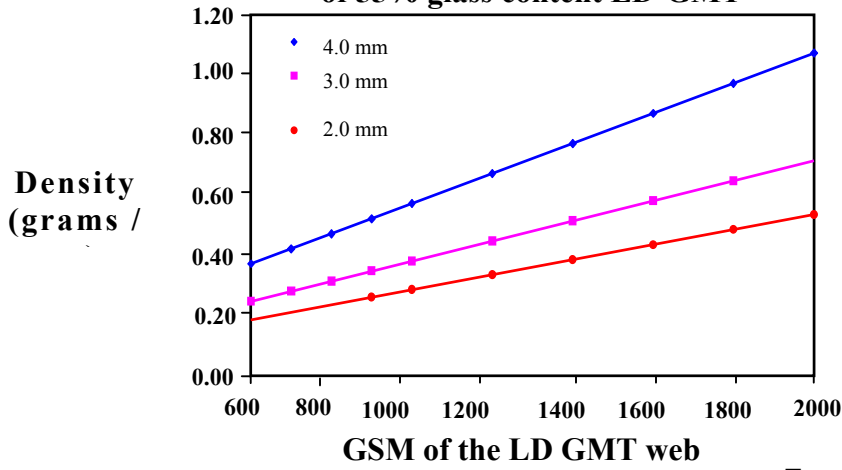


Figure 4

Tensile Modulus Vs GSM for various thicknesses of 55% glass content LD-GMT

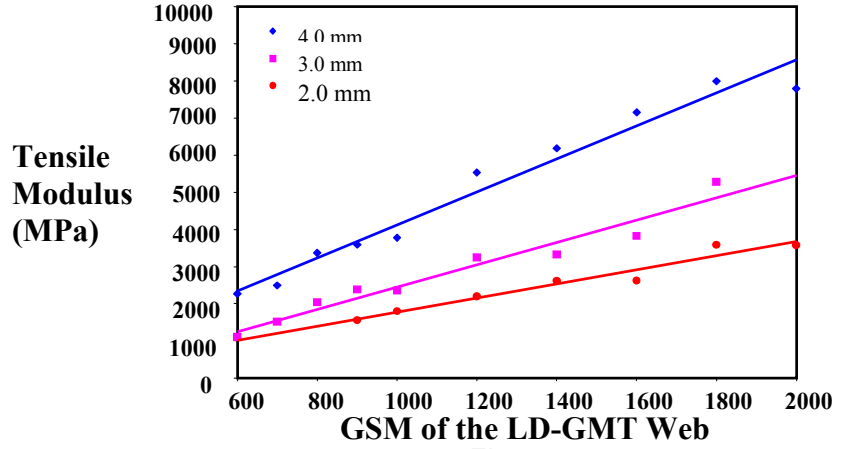


Figure 5

Flexural Modulus Vs GSM for various thicknesses of 55% glass content SuperLite

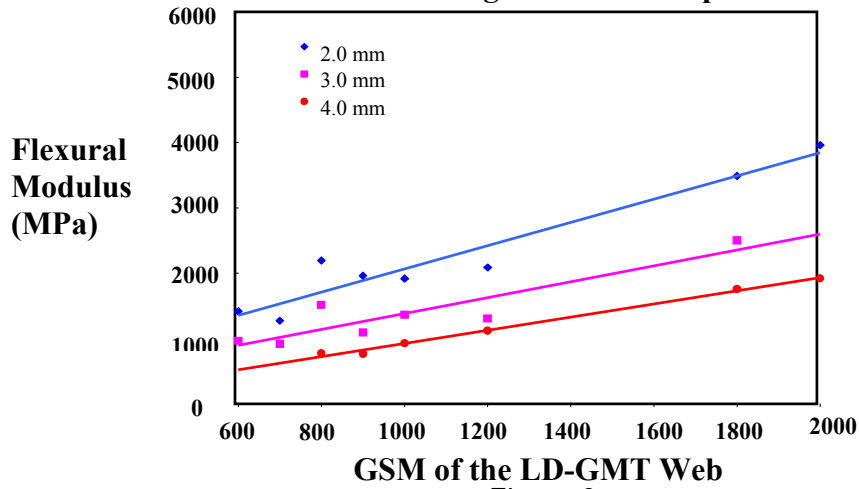


Figure 6

The Coefficient of Thermal Expansion (CTE) of the LD-GMT is extremely low. When tested between temperature ranges of -40°C to +70° C, 2000gsm yielded a test value of 18.9x10⁻⁶mm/mm/° C, which is comparable to aluminum, and 800gsm yielded a test value of 13.5x10⁻⁶mm/mm/° C, which is comparable to steel and SMC.

Property retention at elevated temps is an advantage compared to traditional polypropylene trim materials. Table 1 and Table 2 presented below illustrate property retention of LD-GMT at 23° C and at 90° C.

Table 1: Material test at 23° C (molded thickness 2.5mm)

GSM	Flex Strength (MPa) SAE J949	Flex Modulus (MPa) SAE J949
700	7.8	863
800	9.0	1215
900	9.5	1450
1000	16.0	1825
1200	19.5	2030
1400	34.5	2670
1600	46.0	3470
2000	53.0	4800

Table 2: Material test at 90° C (molded thickness 2.5mm)

GSM	Flex Strength. (MPa) SAE J949	Flex Modulus (MPa) SAE J949
700	3.75	705
800	4.65	840
900	6.50	1100
1000	8.35	1455
1200	9.50	1720
1400	16.60	2400
1600	22.50	3135
2000	44.00	3330

As seen from both tables, we see over 55% retention of flexural strength and 80% retention of flexural modulus [5].

Benefits of LD-GMT for use in multiple soft touch interior applications

For the purposes of this paper, soft touch interior applications will refer to the following interior components:

- Pillar trim (upper and lower)
- Headliners/Roof trim (referred further as headliners)
- Parcel trays/package shelves/rear window trim (referred further as parcel trays)
- Cargo trim/boot trim/trunk trim (referred further as cargo trim)
- Instrument panels

- Door trim
- Load floors
- Seat backs
- Rear lift gate trim
- Back panels

As mentioned earlier, due to the vehicle segment and/or OEM, some of these applications may or may not involve the use of a soft touch appliqué. In brief, the benefits of using LD-GMT as a substrate for soft touch applications are as follows:

1. Lower system **Cost** potential (10 % ~ 20%).
 - a) Tooling and equipment costs are approximately 10 times lower than injection molding.
 - b) Multiple cavity tooling.
 - c) Fast cycle times.
 - d) In-mold decoration.
2. Lower system **Weight**. (Up to 50%).
3. **Quick Model changes** possible.
4. System **Flexibility** with a **Wide range of products**.
 - a) Barrier, absorber and barrier + absorber grades are available.
 - b) Recyclable and incinerator friendly grades are available.
 - c) Large selection of product weights (mass per unit area).
 - d) Large selections of add-on laminates for optimal cost/performance ratio.
5. 2-meter width capability.
6. **Good Odor / Emission / Aging** performance.
7. **Low CTE** (similar to Aluminum).
8. Good noise absorbing capabilities.
9. **Ductile Impact** (-40° C ~ +85° C).
10. Most conventional thermoplastic **Secondary ops / Fixations** applicable.
11. **Globally Available**

The price per pound of LD-GMT is comparable to the price per pound of a conventional glass reinforced thermoplastic material. The majority of the cost advantage is attributable to low cost tooling, fast cycle times, low labor requirements, low molding pressures and the ability to mold several parts at the same time. In most cases LD-GMT requires 300 kPa or less to mold a part with a decorative covering. In fact, many headliner designs can be molded with less than 100 kPa.

The low molding pressures equate to lower equipment and tooling costs. A low-pressure press and an aluminum matched thermoforming tool would be sufficient for molding most interior applications. This combination of multi-cavity tooling and lower tooling costs resulted in at least a 50% cost saving for the interior applications molded from LD-GMT for the recently launched Ford GT [6].

LD-GMT was the single material solution for the following Ford GT applications:

- A-pillar
- B-pillar upper and lower
- Cowl
- Instrument panel
- Back panel (bulkhead)

- Instrument panel HVAC duct
- Console side panels
- Door trim panels
- Headliner inner
- Headliner outer
- Header trim panel inner
- Header trim panel outer

The LD-GMT product design flexibility, including variable molded thickness and range of surface coverings allowed for adherence to all Ford's performance requirements. Only three separate LD-GMT grades are required to satisfy the required interior specification. The commonality of the material grades allowed the molding of dissimilar applications in the same tool set.

Photos of one of the multi-cavity tools used for the Ford GT and the resultant parts are displayed in figures 7 & 8 below.



Figure 7: 6-cavity mold for Ford GT – Photo courtesy of WK, Industries, Warren, MI



Figure 8: 2 molded parts from the same mold – Photo courtesy of WK, Industries, Warren, MI

Processing of LD-GMT can vary depending on the desired finished part appearance. The optimal process for cost is a “one-step” thermoforming process with attachment to an in-mold decoration in a low-pressure compression mold set. An illustration of a conventional LD-GMT production line designed for in-mold decoration is displayed in figure 9 on the following page.

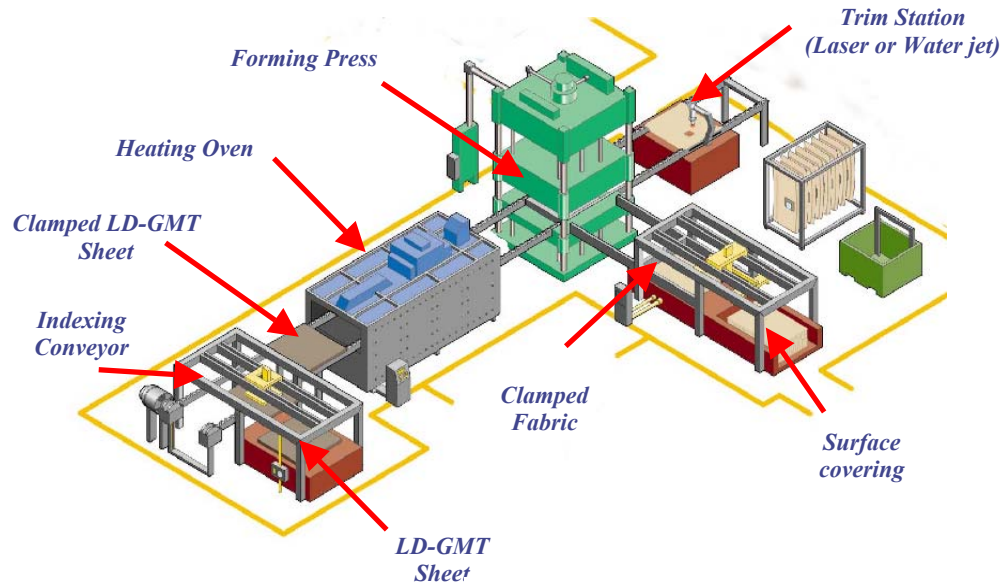


Figure 9

A line of this design would only require 1.2 persons to run and operate with a cycle time ranging from 30 to 60 seconds.

In addition to the aforementioned cost and weight advantages, OEMs could benefit from the sound absorption capability of LD-GMT. Using LD-GMT in numerous interior trim applications may increase the

Some designs and tooling configurations may require additional manufacturing steps to obtain required surface appearance. One example that would require additional manufacturing consideration is vehicle / component designs that leave an exposed trim edge visible to the vehicle's interior occupant.

Traditional methods for concealing exposed edges are mostly manual, labor intensive and can be time consuming if a slow curing adhesive is required. Should an edge wrap or other edge concealment be required on an LD-GMT part molded in a one step process, edge-wrapping would be difficult and associated costs would likely offset the majority of the savings obtainable with a multi-cavity tool. One potential solution has been developed for LD-GMT that reduces the secondary processing costs and could potentially add additional value. This solution is discussed below and is illustrated in figures 9 and 10.

The methods of molding LD-GMT in a multi-cavity tool arrangement, without a decorative covering are the same with the exception of the covering application. The decorative fabric is applied in a secondary thermoforming work cell. An additional tool will be required for this operation. A low cost Epoxy vacuum mold is believed to be acceptable for volumes below 200,000 units (providing appropriate handling). The tool should be cast/cut to a size that differs from the design. The molded/trimmed LD-GMT part must be allowed to overhang the peripheral edge of the tool by the distance required for edge folding. Two techniques can be used for the

attachment of the covering and will depend on the coverings ability to allow or block airflow. The illustration in the adjoining column will help with the explanation.

The decorative covering must be coated with an adhesive. Initial experimentation was performed with a thermoplastic web adhesive and this is the practice that will be described. After the LD-GMT sheet is formed it is transferred to the vacuum forming station and placed on the epoxy vacuum form tool. The decorative covering is clamped and transferred to an infrared oven to bring the adhesive to bond line temperature and soften the skin for forming. After heating, the decorative covering is shuttled over the vacuum mold containing the molded / trimmed SL sheet. Vacuum is then applied. The LD-GMT sheet is naturally porous with a relatively high void content and allows airflow without pre-treatment. The vacuum pulls the covering over the LD-GMT part, adheres the two components and completes the edge fold. Lastly, the excess edge fold area is trimmed.

The procedure explained above is suitable for barrier materials. Porous materials will require the use of an impervious, flexible bladder to pull an adequate level of vacuum for adhesion [7].

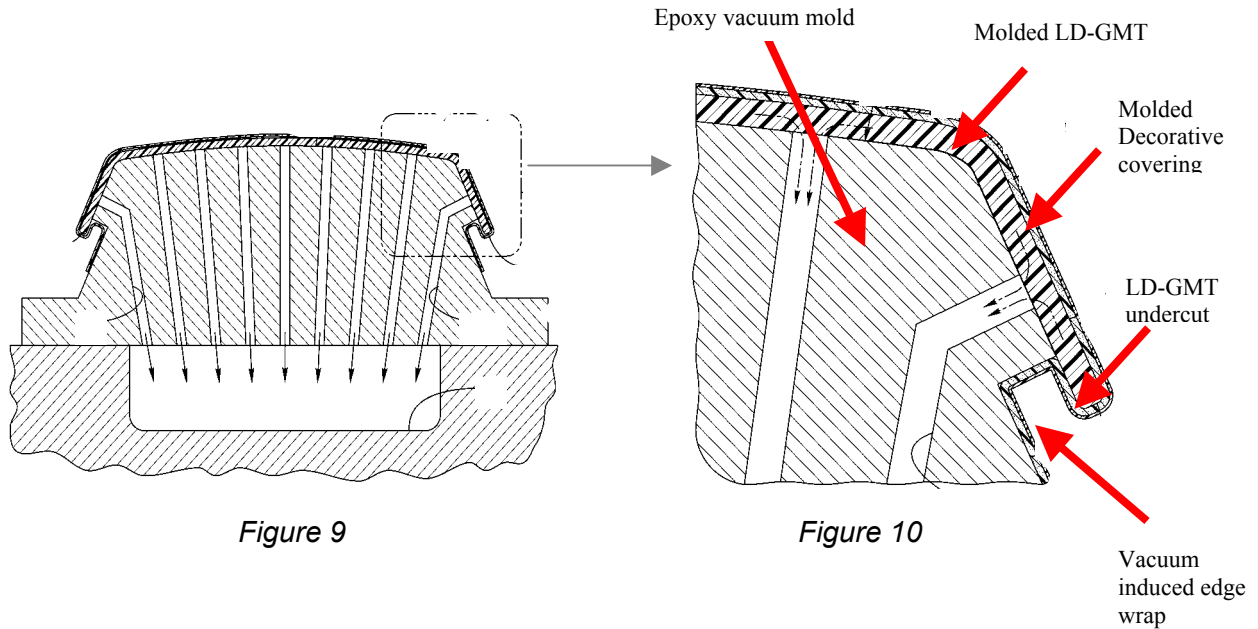


Figure 9

Figure 10

Samples molded with this method were tested for adhesion to BN-151-5, which is a Ford specification for a 180-degree peel. Twenty specimens were tested with a minimum peel value of 28 N / 25 mm after an extended heat age.

Other aforementioned benefits that make LD-GMT an ideal material to exceed growing OEM expectations is its low weight, excellent impact properties and sound absorption capability.

The Lear Corporation, Ford GT program team responsible for the engineering the vehicle's interior reported a weight saving of up to 30% for the applications molded from LD-GMT [6]. Weight savings of 50% could be achievable on other applications with lighter weight decorative coverings (knit or non-woven).

The impact performance has been tested to a number of different standards. The impact properties of LD-GMT set it apart from most other filled materials seen in the market today as the material exhibits a ductile failure at temperatures as low as -40° C, and has been tested at numerous strain rates [1].

LD-GMT has also been tested to the National Highway Traffic Safety Administration (NHTSA) method prescribed in the Federal Motor Vehicle Safety Standard (FMVSS) 201. This method measures the head injury criterion (HIC). The HIC number relates to head injury potential and is the integration of the resultant X, Y and Z accelerations over a time interval. FMVSS 201 requires a HIC value or 1000 or less [8-5].

The purpose of the testing was to compare the results of several LD-GMT energy absorption design concepts with other known energy absorbing materials.

The tests were first performed physically using a slightly modified test procedure and were then characterized for impact simulation at the BP1 hit location (on the headliner, slightly above the B-pillar). Correlation between the computer-aided simulation and the dynamic testing was very good. Of the several LD-GMT designs tested, a flat panel thickness of 18 mm produced the best results. The results were comparable to 20mm styrene/MPPO foam bead.

An egg crate design was also tested and would be the preferred energy absorber from both a cost and weight standpoint. The results of this design; however, did not yield satisfactory results. Further work will be done with LD-GMT in this area to allow further integration as interior trim energy absorbing assistance [5].

LD-GMT could add additional value by increasing the area of absorption material in the vehicle's interior. LD-GMT is widely used in headliners. It can act as an absorber (allow airflow) or a barrier (block airflow) depending on the surface skin selection. It has been proven to absorb noise that enters the interior of a vehicle. Experiments have been conducted to evaluate the affects of several factors on interior sound absorption. The affects of porosity, thickness, fabric type (soft touch decorative covering) and basis weight, have been calculated. The experiments were conducted in accordance with ASTM E1050 via impedance tube testing. The tests were conducted with an air gap of zero. It was observed that variations in the evaluated factors resulted in frequency responses differing by as much as 70%. The frequency response could be changed from a narrow peak to a broad plateau [3].

Most of the aforementioned interior trim materials are barriers. The use of LD-GMT, combined with an absorbing decorative covering could allow OEMs additional freedom to tailor interior absorption and could possible allow a cost savings via a reduction of add-on absorbing materials.

LD-GMT performance vs. general interior requirements

Much testing has been performed on LD-GMT. Most of the data is customer owned. The data presented in this paper has either been tested by AZDEL or GE Advanced Materials or has been issued in referenced papers. In some cases only a specification and pass/fail criteria can be provided.

In table 3 below is a list of some of the testing requirements passed for the Ford GT trim panels. Items 1-11 are all Ford SDS specifications.

Table 3: LD-GMT specification testing

1	MA-0018	V10	ODOUR
2	MA-0019	V9	FOGGING
3	MA-0024	V7	COLD IMPACT - INTERIOR COMPONENTS AND HARD INSTRUMENT PANELS
4	MA-0026	V4	BOND STRENGTH - PEEL ADHESION
5	MA-0051	VI	SHRINKAGE
6	MA-0052	V2	COLD FLEXIBILITY
7	MA-0053	V2	DIMENSIONAL STABILITY - INTERIOR TRIM
8	MA-0068	V2	LOAD DEFLECTION OF INTERIOR COMPONENTS
9	MA-0073	V2	HUMIDITY AND MILDEW RESISTANCE
10	MA-0101	V3	VEHICLE RECYCLING
11	MA-0146	V2	ROOM TEMPERATURE IMPACT OF INTERIOR PARTS
12	FMVSS 302		FLAMMABILITY

In addition, LD-GMT passes all current headliner and sunroof shade requirements for Nissan, Toyota, Ford, DCX (NA), GM, Holden, Honda. Side Air-Bag Inflatable Curtain (SABIC) performance has also been evaluated and approved on Toyota, DCX, GM and Honda platforms. All of these OEMs have headliner systems currently in production with SABIC systems.

Design and Forming

Different forming techniques and their association to the desired part appearance were briefly reviewed in a former section. This section will provide a closer examination of these characteristics and their relationship to one another.

The design criteria developed for LD-GMT consists of basis weight vs. obtainable molded thickness, draft angles and radiuses. These criteria, as well as attachment schemes and will be discussed below.

Changing the tool stopgap can change molded thicknesses in LD-GMT according to the allowable range within each basis weight. Several factors aside from tool gap will contribute to the resultant molded thickness of a fully lofted part. The properties of the decorative covering (if in-mold decorated), the molding temperature, the part design and method of tensioning are important to consider when assigning a molded thickness. In some cases lab scale testing would be required to ascertain the moldable thickness ranges. Capable thicknesses of parts molded without a decorative covering are indicated in table 4 on the next page.

Table 4: Lofted and molded thickness capabilities

LD-GMT GSM	Glass Content	Lofted Height (mm)	Moldable Range (mm)
600	55%	4.0 – 4.5	1.5 – 3.5
700	55%	4.5 – 5.0	1.5 – 3.5
800	55%	4.7 – 5.2	1.5 – 4.0
900	55%	5.3 – 5.8	2.0 – 4.5
1000	55%	6.0 – 6.5	2.0 – 5.0
1200	55%	7.2 – 7.7	2.0 – 6.0
1400	55%	8.5 – 9.0	2.0 – 7.0
1600	55%	9.5 – 10.0	2.0 – 8.0
1800	55%	10.5 – 11.0	2.0 – 9.0
2000	55%	12.0 – 12.5	2.0 – 11.0

Draft angle are typical of most thermal formable materials.

- Walls <3” high: 1° to 2° minimum.
- Walls >3” high: 2° to 3° minimum.
- The greater the draft angle, the easier it is to remove the part from the mold.

As with molded thickness, it is best to examine the properties of the in mold decoration and the design wall thickness prior to cutting a specific draft angle. Small tool gaps can create shear forces down the vertical wall of the tool surface and force the LD-GMT sheet to be much greater in GSM and stiffness at the base of the mold. This may not be a problem and may even be advantages but it still must be considered. Consideration must also be given to in-mold decorative coverings (if applicable). Small draft angles may have a tendency to damage various decorative coverings.

In a one-step, in mold decoration process, the outside radius that is formable with LD-GMT is a function of the inside radius + the materials thickness at the radius. The minimum inside formable radius is effectively zero. The outside radius may be decreased by reducing the molded thickness at the radius as illustrated in figure 11 displayed below. There are still some limitations; however, due to the properties of the decorative covering.



Figure 11

Should a radius be desired that is not capable in a one step, in mold decoration process, secondary operations or multiple step forming operations could be considered. Examples of such techniques are indicated in figures 12, 13 and 14 below.

Vacuum form Vinyl in separate mold, then place cold vinyl skin in matched mold and under-mold substrate.

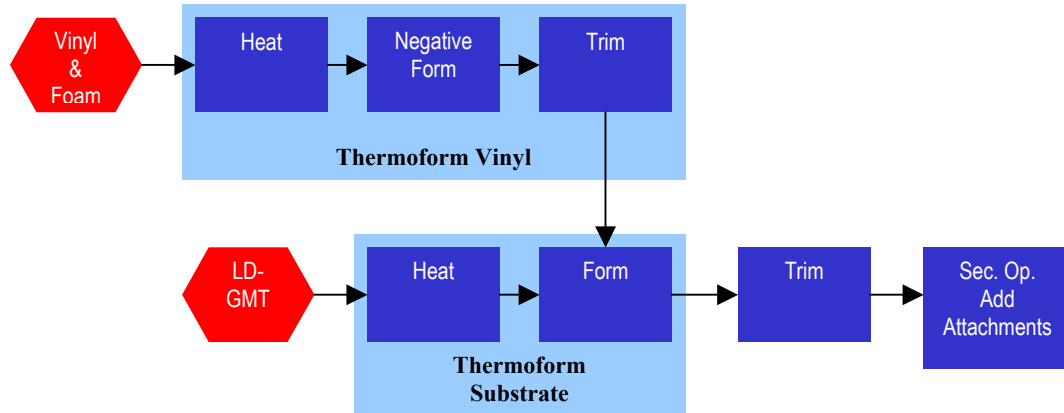


Figure 12

Vacuum form vinyl first in lower mold then form substrate over vinyl with matched mold.

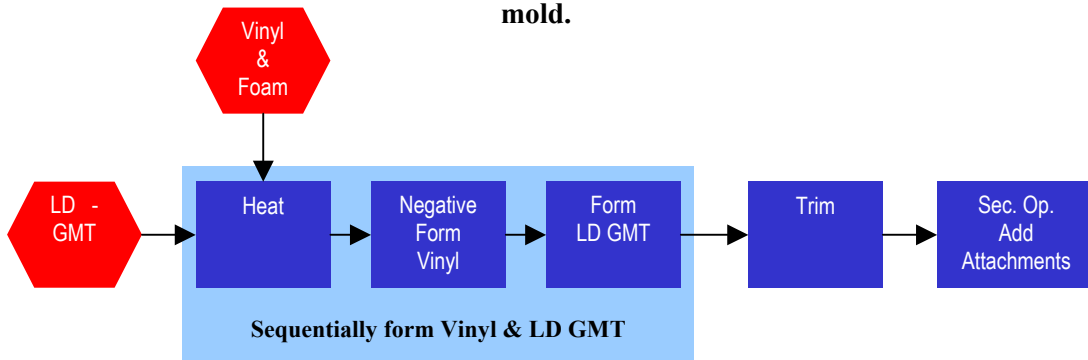


Figure 13

Vacuum form Vinyl in separate mold, then place cold vinyl skin in matched mold and under-mold substrate.

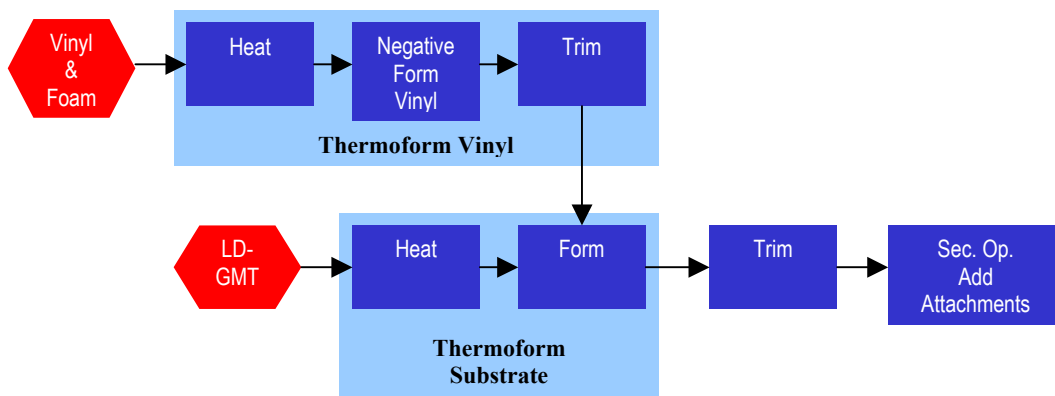


Figure 14

The surface coverings required to obtain the unique balance of LD-GMT properties limit the materials ability to flow. The limited flow of the material prevents the use of traditional rib designs and means of fixation.

These limitations did not present an issue for the use of LD-GMT in headliners as most headliner fixations are “pass-thru” attachments and are visible to the interior occupant. Soon after LD-GMT’s introduction as a headliner substrate, its properties and inherent benefits were recognized for additional interior trim applications. Many of these applications are fixed to the body in white’s (BIW) sheet metal with fasteners that are blind to the interior occupant. The need for a “blind” fastener was recognized and many products and practices were developed, tested and put into production on the Ford GT.

One such fastener is a LD-GMT “dog-house” style pushpin receptacle. This fixation is nested in the cutout / off-fall areas of the LD-GMT sheet and thus are virtually free-of-charge. An illustration of this fixation is displayed below.

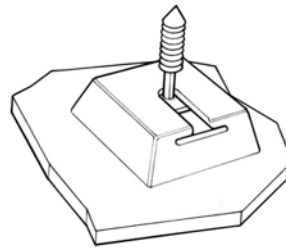


Figure 15

The strength and property retention at elevated temperatures of this fixation met or exceeded all of the durability expectations and requirements for all applicable trim panels on the Ford GT.

Conclusions

This paper has reviewed the basic composition of LD-GMT, it’s method of manufacturing, it’s conformance to general interior trim performance specifications and the benefits of its use as a single material solution for soft touch interior applications. The benefits indicated were:

- A Lower system **Cost** potential (10 % ~ 20%).
- A Lower system **Weight**. (Up to 50%).
- **Quick Model changes** possible.
- System **Flex-ability** with a **Wide range of products**.
- 2-meter width capability.
- **Good Odor / Emission / Aging** performance.
- **Low CTE** (similar to Aluminum).
- Good **Application Experience/Product Knowledge** base.
- Good **noise absorbing** capabilities.
- **Ductile Impact** (-40°C ~ +85°C).
- Most conventional thermoplastic **Secondary ops / Fixations** applicable.
- It is a **Globally Available**.

In combination, these benefits are believed to meet or exceed the current demands from the OEM community for a superior performing soft touch interior, at a reduced cost. The

development and validation of the Ford GT interior trim have shown that these benefits can be obtained from a single material source with as little as three separate product grades.

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