Development of Low Density GMT Headliners With Improved Acoustical Performance

Venkat Raghavendran & Enamul Haque, AZDEL, Inc

Abstract

Low-density GMT (glass mat thermoplastics) materials are being used increasingly in automotive interior applications. These composites have found wide acceptance amongst various automotive OEMs for overhead systems. The superior mechanical properties, availability in various basis weight grades, ease of processing and ability to be molded to differing thickness makes the AZDEL SuperLite a versatile material for both structural and non-structural headliners.

In this paper we have presented the acoustical performance of these low-density composites. Various combinations of this headliner substrate with face fabrics and covering materials were made and their normal incidence sound absorption coefficient was obtained according to ASTM E1050 test method. By varying the areal density, molded thickness and the types of skins on the surface of the composite, the porosity and the airflow resistance can be tailored to provide optimal sound absorption across a broad range of frequencies. The effect of these factors and their interactions are discussed.

Introduction

The demand for quieter vehicle interior is becoming more imperative now than ever in the past. Engineers have been working on quieting the automobile interiors for a very long time. There is also an association of low noise levels with high quality and high manufacturing standards. To meet this demand, OEMs are requiring a more holistic approach to acoustic problem solving, toward a total-interior perspective on acoustics where the objective is to control the noise, not eliminate it. There was a time when the primary emphasis was to reduce the interior noise in the car, but now the emphasis is on not only reducing the noise, but also to make it sound more pleasant. Consumers want a certain kind of noise; they want certain vehicles to sound a certain way. For example, people want a high-end luxury sedan to sound different from an SUV although the overall trend is toward making them quieter [1].

The automotive market has seen a considerable change in the materials used in the headliners. The earliest headliners were made out of cloth with pockets sewn together for inserting wire supports. The sound dampening was achieved by cementing silencer pads to the underside of the roof. This was a labor-intensive process and became uneconomical as the automotive volumes increased [2].

The next generation of headliners was made out of cardboards that were die cut and scored for easy assembly and hardboards made of wood fiber mat with phenolic resin binder's pressure formed into the headliner contour. Both these technologies suffered from poor acoustics, warpage and sagging when exposed to high humidity [3].

These were followed by fiberglass composites having phenol formaldehyde binders, polyurethane and Polyester fiber composites. These headliner substrates were better than the cardboard and hardboard headliners in terms of moldability, strength and design flexibility. They also had superior acoustical performance. A detailed description of their construction is available elsewhere [4 – 7].

The fiberglass substrate had excellent acoustical performance and was used as a benchmark for other headliners. However the fiberglass usage has been reduced in the USA because of increased modularity, breakage and operator handling. A fiberglass headliner once bent from shipping or installing generally has to be discarded, further, the odor issues that persists for a long period of time after molding due to either undercured or overcured binder, has further contributed to it losing its market leadership to urethane headliners [3]. The Polyester fiber substrate also has very good acoustical performance, but its low load carrying capacity, high cost and need of fiberglass reinforcement as backing for modular application has kept its market share low.

Recently, a new headliner substrate has been developed by Azdel Inc. using long chopped glass fiber mat and polypropylene resin that combines acoustical advantages of the fine denier glass fibers with a complete elimination of odor that plagued the fiberglass phenol formaldehyde substrates. Further, unlike the thermoset fiberglass product, this LD-GMT product has very good resilience and doesn't easily break during operator handling or crease when flexed for putting into the car body. With better design flexibility, structural rigidity 2.5 times greater than urethane substrates, toughness, dimensional tolerance and versatility for application of various types of fabrics, low system cost, this new LD-GMT composite is rapidly gaining acceptance in headliner applications. It is also ideally suited for modular applications like doors, instrument panels, external body panels, tailgates, modular roofs etc.

In this paper a detailed description of varying the thickness, porosity and basis weight of this LD-GMT composite on acoustical performance is described. A design of experiment was conducted with the above-mentioned variables as the factors and the acoustical response of the headliner was studied. The results show that by varying the material properties, it is possible to tailor the frequency response of the headliner. This versatility in modulating the frequency response should help in meeting the varied acoustical needs of various automotive platforms at different OEMs.

Materials and Methods

A design of experiments was done with Azdel SuperLite ™ LD-GMT product. The design of experiment (DOE) was a full factorial study with three factors at three levels (3^3) as shown in Table I. The three factors studied were the substrate thickness, substrate basis weight and the porosity of the headliner shown in Table II. The levels were chosen such that it reflects the design variables of the LD-GMT grades and useful to the non-structural headliner market.

A 55% glass fiber reinforced LD-GMT having a core basis weight of 800, 900 and 1000 grams/m^2 was used. The LD-GMT material is manufactured using a licensed patented technology of Arjo-Wiggins. The process is similar to papermaking, but with a novel approach to the fiber-dispersing medium. In papermaking, the raw materials are dispersed in very large quantities of water, whereas in this process, the dispersing fluid is aqueous foam [6, 8].

To vary the porosity of the LD-GMT product, polyester scrims with different levels of porosity were laminated on the surface. A multi-layer hot melt film and web adhesives were used to bond the polyester scrim to the LD-GMT and the coverstock. The coverstock was made of a polyester fabric 0.5 mm thick with 4 mm thick polyether foam backing. The coverstock material had a nominal basis weight of 230 grams/m^2. The three thickness levels used in the DOE were 2 mm, 3 mm and 4 mm.

The headliner samples are molded in two-steps. First, the LD-GMT is heated to around 190^{o}C in an infrared oven. Secondly, the coverstock fabric is then brought into contact and the headliner is molded in a one shot thermo-stamping operation. The LD-GMT when heated tends to loft up to twice its original manufactured thickness. The loftability of the LD-GMT is due to the relaxation of the glass fibers when the PP melts. This loftability allows the LD-GMT to be molded to different thickness. The void contents and density of the LD-GMT are related to the molded thickness. The amount of loft is linearly dependent on the basis weight and glass content [8]. The LD-GMT also becomes pliable and can be easily draped in a tool to conform to the contours of the tool.

For the present study the headliner samples were molded in a 300 mm x 300 mm square tool on a Lawton press. The samples were molded to substrate thickness of 2 mm, 3 mm and 4 mm. The specimen thickness was varied by molding the headliners on stop. The stop gaps were set to predetermined levels making appropriate compensations for the compression set of the coverstock material.

The normal incidence sound absorption tests were done according to ASTM E1050 standards via impedance tube method without any air gap between the specimen and the back plate of the impedance tube. The acoustical measurements were made using a two microphone Bruel and Kjaer (B&K) type 4206 impedance measurement tube with 4187 type microphones having a nominal sensitivity of 4 mV/Pa. Plane waves were generated in the tube by a random noise source powered by a B&K type 2706 power amplifier with a high pass filter. The standing waves in the tube were measured at two fixed locations using the aforementioned microphones. The signal from the microphones were sent to a B&K 3650C Pulse acoustical testing system with a dual channel FFT analyzer to determine the complex acoustical transfer function. The sound absorption coefficients are computed using a B& K 7758 materials testing systems software package running on a Pulse Labshop version 5.2.5.

The samples for the impedance tube were die cut to fit the small tube of the B&K 4206 impedance tube at 29 mm diameter and the sound absorption coefficient was measured for a frequency range of 1000 to 6400 Hz.

Results and Discussions

The three factors chosen for the DOE have interacting effects on each other and also affect other factors that control the sound absorption like volume density and airflow resistance. For instance the volume density of the LD-GMT is affected by both the thickness and the basis weight. Further, the porosity of the LD-GMT structure is also affected by the thickness. The effects of varying the factors and results of the complex interactions between them on the sound absorption at various frequencies in the 3^3 DOE are shown in Table III.

As can be seen, by varying the factors, the sound absorption coefficients at different frequencies can be varied. The sound absorption coefficients can be varied by as much as 70%. Further, it can be seen that by varying the factors, the frequency response can be changed from a relatively narrow peak to a broad plateau. This differentiation in the frequency response can be used to tailor the headliner for different OEM platforms. A detailed description of varying each of the factors in the DOE is provided below.

Effects of varying the substrate thickness.

The factor that was seen to have the greatest effect on the sound absorption coefficient is the thickness of the LD-GMT substrate. A representative plot of effects of varying the thickness on sound absorption is shown in the figure 1. Figure 4 shows the main effect plot of the thickness. and figure 6 shows the coefficients of the critical factors based on the response surface analysis of the DOE. As can be seen from the these figures, the ability of the LD-GMT to absorb sound increases monotonously as the thickness is increased from 2 to 4 mm This increase in the sound absorption is greater at higher frequencies.

The sound absorption coefficient is known to increase with increase in the substrate thickness [9]. An increase in the substrate thickness creates a greater path for sound at a given wavelength to traverse through and lose its energy. However, the volume density of the LD-GMT at a given basis weights goes down as the thickness is increased and that can affect the level of sound absorption.

Effects of varying the porosity.

The porosity of the LD-GMT substrate was changed by laminating various scrims of similar basis weights, but with different air flow resistivity. The LD-GMT by itself is a highly porous material made with layers of randomly oriented fiberglass mat with polypropylene binder bridging the fibers. The varying levels of substrate porosity due to varying thickness further compounded the porosity differences due to lamination of different scrims.

A representative plot of the effects of varying the overall porosity on the sound absorption is shown in figure 2. The sound absorption coefficients are better at lower frequencies for lower porosity levels; there is a cross over to higher sound absorption at higher frequencies as the porosity levels are increased. Figure 4 also shows a non-monotonous increase in sound absorption at lower frequencies as the porosity levels are changed.

Further, at a given thickness and basis weight, the sound absorption is seen to monotonously increase with the frequency towards a relatively narrow peak at very high porosity levels. As the porosity levels are decreased, the sound absorption coefficient tends to level off over a broader frequency range, albeit at lower absorption levels.

There are significant interactions between the porosity and thickness. This interactions tend to negate each other significantly at low to mid level frequency range, but do not have much effect on sound absorption at higher frequencies (>3000 Hz) as can be seen in figures 5 and 6. This lack of interactions at higher frequencies is useful as the sound absorption can be tailored by independently varying the factors at frequencies, which are usually critical for in-car noise management.

Effects of varying the basis weight

The sound absorption coefficient is not affected by the changes in the basis weights within the range used in the DOE as shown in figures 3 and 4. The insignificance of the substrate basis weight on acoustics can be gainfully employed in designing headliners to meet various modular requirements across various OEM platforms without sacrificing the acoustical performance.

The comparison of the sound absorption coefficients of LD-GMT to other headliner substrates like polyurethane and cardboard is shown in figure 7. The superior acoustical performance of the LD-GMT substrate at higher frequencies is evident. It also shows how the results of the DOE were used to improve the acoustical performance of LD-GMT headliners.

Conclusions

A design of experiment was conducted to better understand the effects of varying factors that affect the sound absorption and design parameters for molding headliners from an LD-GMT composite. It was shown that there is a significant effect of the headliner substrate thickness on the sound absorption. It was also shown that, by varying the porosity level, the shape of the sound absorption peak could be modified to achieve either high level of sound absorption at a given frequency or a broad plateau over a large frequency range. This ability to differentiate the sound absorptivity increases the versatility of the LD-GMT headliner substrate for application on multiple OEM platforms. The basis weight of the substrate was also seen to have very low effect on the sound absorption. So headliners with different mechanical properties can be tailored without significantly affecting the acoustical performance.

Acknowledgements

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Table I: The 3^3 design of experiment for characterization of the LD-GMT headliner substrate.

Specimen	**Thickness**	**Porosity**	**Basis weight**
X01M394	-1	-1	-1
X01M395	-1	-1	0
X01M396	-1	-1	+1
X01M385	-1	0	-1
X01M386	-1	0	0
X01M387	-1	0	+1
X01M376	-1	+1	-1
X01M377	-1	+1	0
X01M378	-1	+1	+1
X01M397	0	-1	-1
X01M398	0	-1	0
X01M399	0	-1	+1
X01M388	0	0	-1
X01M389	0	0	0
X01M390	0	0	+1
X01M379	0	+1	-1
X01M380	0	+1	0
X01M381	0	+1	+1
X01M400	+1	-1	-1
X01M401	+1	-1	0
X01M402	+1	-1	+1
X01M391	+1	0	-1
X01M392	+1	0	0
X01M393	+1	0	+1
X01M382	+1	+1	-1
X01M383	+1	+1	0
X01M384	+1	+1	+1

Table II: The factors and their levels in the 3^3 factorial design

Value Factor	-1	0	+1
Thickness mm	2	3	4
Porosity	Minimum	Medium	Maximum
Basis Weight GSM	800	900	1000

Table III: The normal incidence sound absorption coefficient of LD-GMT headliners used in the 3^3 factorial designs.

Specimen	Normal Incidence Sound Absorption Coefficient α (%) at					
	1000 Hz	2000 Hz	3000 Hz	4000 Hz	5000 Hz	6000 Hz
X01M376	13.0	26.2	35.1	45.0	47.1	47.2
X01M377	9.6	19.5	32.2	44.0	50.4	52.5
X01M378	10.8	23.0	35.2	44.3	47.7	49.9
X01M379	11.1	25.2	44.2	63.4	73.0	78.0
X01M380	11.2	26.3	46.6	65.7	75.4	79.3
X01M381	11.8	27.2	47.2	64.9	73.3	76.8
X01M382	13.1	30.3	53.4	81.6	96.5	93.8
X01M383	13.2	30.0	54.6	77.7	95.1	96.5
X01M384	14.9	34.8	63.1	83.4	93.8	87.0
X01M385	15.8	22.9	25.5	31.8	35.3	41.0
X01M386	14.4	27.1	33.3	37.7	40.5	45.5
X01M387	14.9	26.6	30.6	34.6	37.6	42.1
X01M388	14.0	31.8	43.7	50.7	56.7	55.1
X01M389	14.2	33.9	49.6	59.0	63.2	63.5
X01M390	16.0	34.5	46.0	57.0	66.6	64.2
X01M391	18.7	45.9	64.9	67.7	69.0	60.1
X01M392	18.0	46.7	68.1	75.5	74.0	68.9
X01M393	17.3	45.1	67.8	83.3	82.7	72.8
X01M394	12.5	15.2	17.3	23.7	28.6	31.2
X01M395	13.9	18.3	20.7	27.2	32.1	37.5
X01M396	12.1	14.8	17.1	22.8	26.2	30.3
X01M397	15.8	19.9	23.0	29.3	36.1	40.0
X01M398	16.8	28.1	34.6	41.3	50.2	48.5
X01M399	17.5	29.8	36.1	43.0	48.9	51.7
X01M400	20.1	39.6	55.5	65.7	72.7	68.8
X01M401	19.9	40.5	57.0	69.2	74.4	72.1
X01M402	21.3	40.0	50.5	62.3	68.6	66.4

Figure 1: Effect of varying the Thickness at a given basis weight and porosity

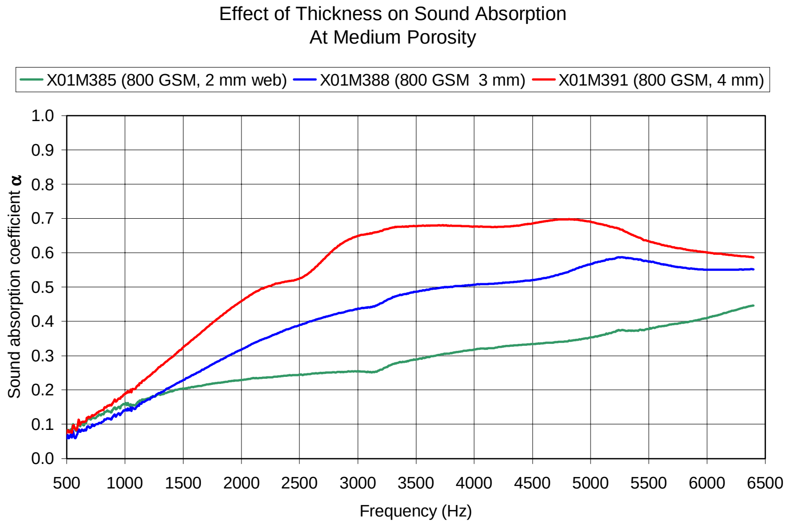

Figure 2: Effect of varying the porosity at a given basis weight and thickness

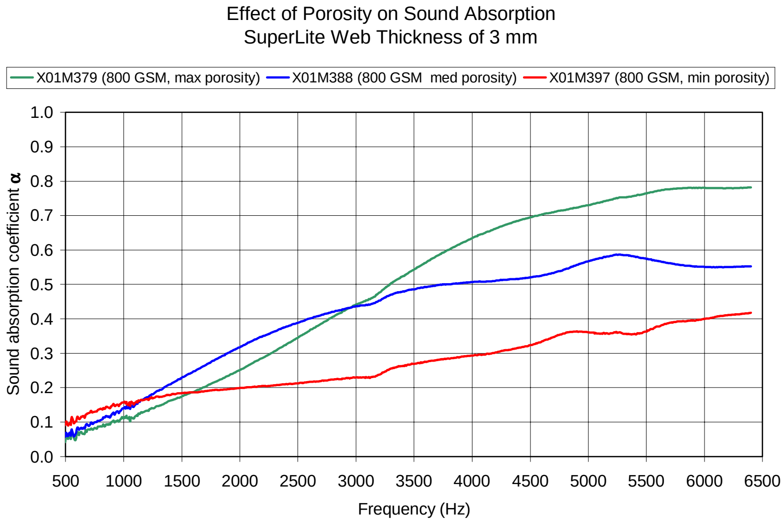

Figure 3: Effect of varying the basis weight at a given thickness and porosity

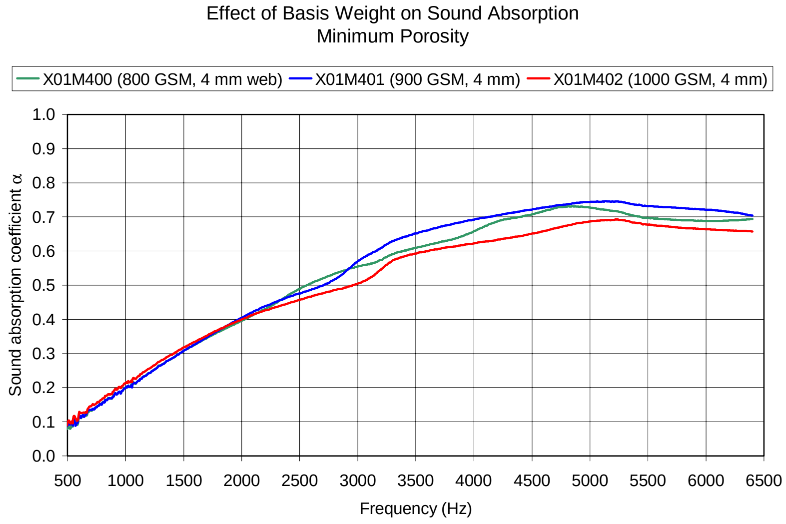

Figure 4: The main effect of the factors in the 3^3 factorial designs

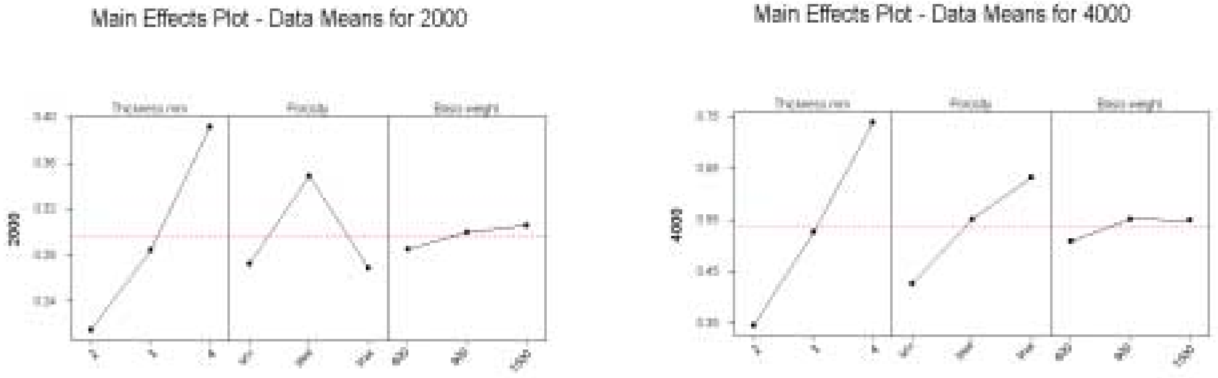

Figure 5: The interactions of the factors in the 3^3 factorial designs

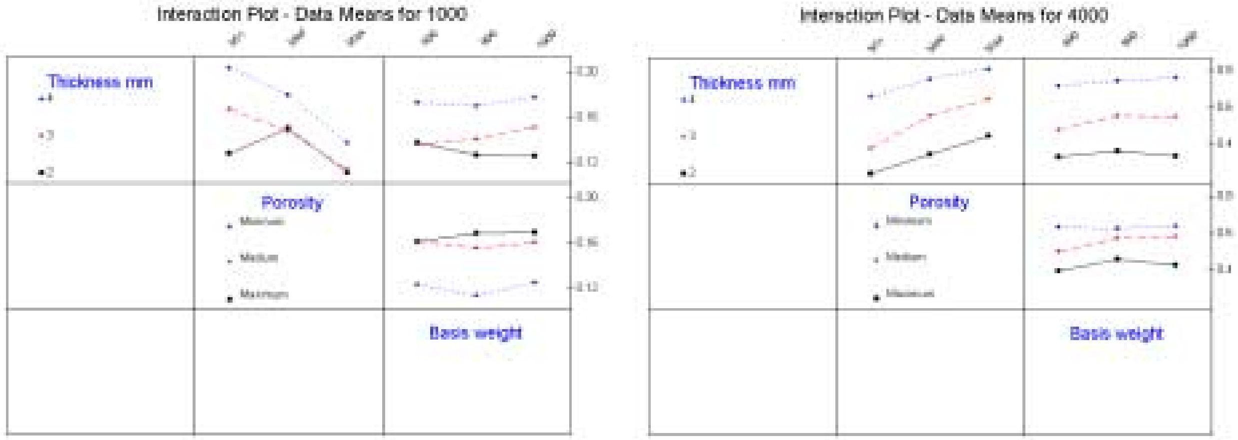

Figure 6: The coefficients of critical DOE factors from response surface analysis.

Figure 7: Comparison of the sound absorption coefficients of various headliners in the market