

Damping properties and NVH Modal Analysis Results of Carbon Fiber Composite Vehicle Components

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ABSTRACT

With the continuing challenges of future fuel economy targets carbon fiber composite materials are one facet of a lightweighting strategy to enable reduced fuel consumption. In general, use of lightweight materials such as carbon fiber composites in vehicle design generates vehicle NVH performance degradation. To address this potential issue at the design phase, there is a need to develop correlated CAE models for carbon fiber vehicle parts to evaluate the NVH impact of carbon fiber composite material use in vehicle design.

To develop correlated CAE models for lightweight vehicle design with the use of carbon fiber composite vehicle body parts, an experimental study was conducted to determine the material and NVH characteristics of the carbon fiber composite materials.

In this paper, the damping properties and NVH modal analysis results for structural carbon fiber thermoset composite panels and body parts (B-pillar upper insert and B-pillar lower insert) is presented. NVH modal analysis results include modes (natural frequencies), mode shapes, and modal damping. Damping properties of the carbon fiber composite parts are measured with a laser vibrometer up to a frequency of 1000 Hz. NVH CAE simulation results for B-pillar upper insert correlates well with the test data. Sound transmission loss test results for the a few carbon fiber composite panels are presented to highlight the high frequency NVH characteristics of carbon fiber composite material.

Average damping loss factor of the carbon fiber composite parts is approximately 1%. Even though carbon fiber composite material damping loss factor is five times greater than that of steel, it is significantly less than laminated sandwich steel which has a damping loss factor of approximately 25% [1][2].

Initial findings of the NVH performance impact of thermoset carbon fiber composite material use in vehicle design are also discussed.

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INTRODUCTION

Government regulations and consumer demands for more fuel efficient vehicles are driving greater applications of advanced lightweight materials such as carbon fiber composites, magnesium alloys and aluminum alloys, etc. in vehicle body structures. Vehicle exterior panel designs are very important for reducing the transmission of external noise sources to the vehicle interior. Wind noise, tire/road noise, pass-by noise, and other noise sources can propagate to the vehicle interior through radiating panels enclosing the vehicle interior cavity. Changing the vehicle panel material from steel to aluminum while maintaining the sheet metal durability performance gives approximately a 50% sheet metal weight reduction but it creates a 6 dB NVH deficiency for panel sound transmission loss (STL) [3].

Besides studying the impact of the sound transmission loss performance of lightweight materials, there is a need to study the material damping properties of these lightweight materials to evaluate the NVH influence of these lightweight materials in vehicle design.

RADIATING PANEL NVH IMPROVEMENTS WITH DAMPING AND ABSORPTION TREATMENTS

To understand the radiating panels' impact on the vehicle NVH performance, these panels should be evaluated at the system level including their material damping and sound package treatments (damping and absorption treatments).

Damping treatments effectively improve the panel sound transmission loss of the panels in low frequency and the coincidence frequency regions; and have an added mass effect (6 dB by doubling the mass) in other frequency regions. Figure 1 shows the sound transmission loss test data for the 0.9 mm thick aluminum panel with and without the patch damping. Patch damping material treatment was applied the 100% of the panel surface. Application of patch damping treatment doubles the panel surface mass. Figure 1 shows the sound transmission loss improvement of an aluminum panel as a function of frequency by doubling the surface mass with patch damping treatment.

Absorption treatments are very effective for high frequency NVH improvement actions in lightweight vehicle design. Vehicle NVH degradation due to lightweighting actions can be overcome with the effective use of absorption materials [3][4][5]. Figure 2 shows the sound transmission loss test data for doubling the surface mass of the same panel with application of absorption material (dash insulator).

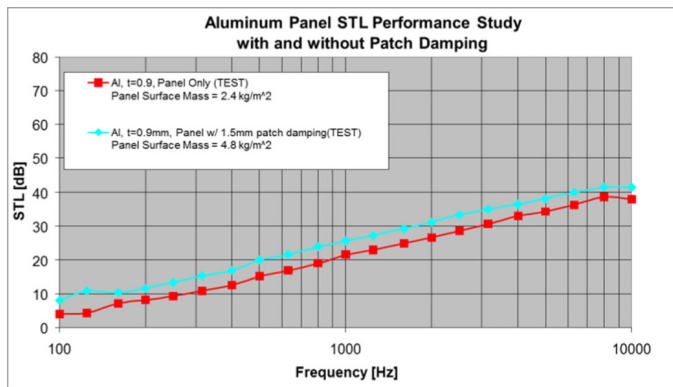


Figure 1. Sound Transmission Loss of aluminum panels with and without patch damping (doubling the surface mass with damping treatment)

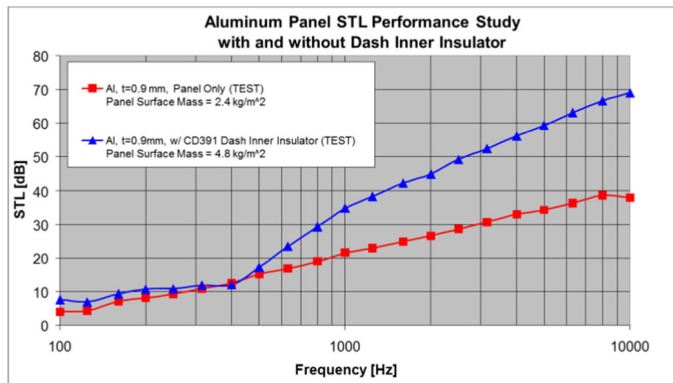


Figure 2. Sound Transmission Loss of aluminum panels with and without absorption material (doubling the surface mass with absorption treatment)

Figure 2 indicates that panel absorption treatment has negligible effect on the panel STL performance in the frequency range below 500 Hz but it has significant effect above 500 Hz. This effect is

around 10 dB at 800 Hz and it increases with increasing frequency and reaches to 30 dB at 10 kHz. This STL test result proves that absorption treatment is a weight effective solution to overcome the NVH deficiencies in vehicle design.

NVH PERFORMANCE OF CARBON FIBER PANELS

NVH performance of carbon fiber panels can be determined with damping and sound transmission loss measurements.

Damping loss factor measurements of carbon fiber panels were performed in the laser vibrometer laboratory. A vertically hanging 12 inch x 12 inch panel sample was excited on one side with a small impact hammer and laser vibrometer measurements were taken on the other side of the panel using a fishnet grid with approximately 1000 measurement points. From the transfer function measurements, the modal damping loss factors of the carbon fiber panels were calculated and averaged damping loss factor (DLF) values up to a frequency range of 1000 Hz were shown in Figure 3 for two different thicknesses (2.4 mm and 4.8 mm) and two different carbon fiber materials, Sheet Molding Composite (SMC) and Non-Crimped Fabric (NCF), comprised of approximately 50% by weight carbon fiber and 50% by weight vinyl ester (see Figure 4).

Average damping loss factor values of all carbon fiber composite panels varies from 0.9% to 1.4% as shown in Figure 4. Even though these damping loss factor values are five times greater than that of steel, it is significantly less than laminated sandwich steel which has a damping loss factor of approximately 25% [1]. To achieve the highest noise reduction potential of sheet metal lamination, the DLF value of the laminated panel should be greater than 20% [1].

Authors' earlier work [1] clearly highlights the effect of highly damped laminated panels on vehicle interior quietness and states that "increasing the damping loss factor of vehicle dash design from 4% to 25% could increase the Engine Noise Reduction (ENR) of a Vehicle by 1.7 dB according to the statistical energy analysis simulations".

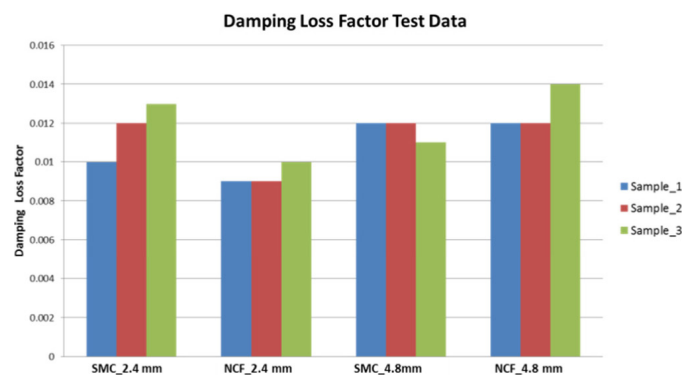


Figure 3. Average damping loss factor test results of carbon fiber composite panels for two different fiber materials (SMC and NCF) and two different thicknesses (2.4 mm and 4.8 mm).

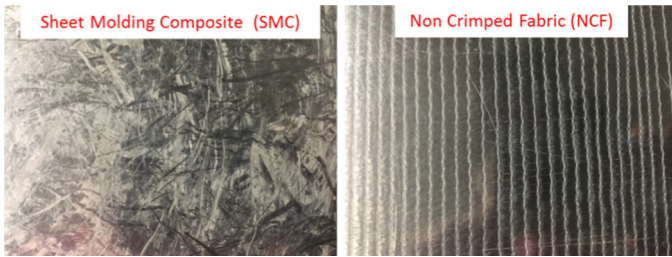


Figure 4. Pictures of SMC and NCF carbon fiber composite panels

Sound transmission performance of carbon fiber composite panels was tested mainly in the small sound transmission loss chamber as shown in Figure 5. Panels were installed in an opening of a wall separating between a reverberation room and an adjacent small semi anechoic room. The reverberation room was used as the source room with speaker system generating broad band white noise. The semi anechoic room was used as the receiver room with microphones to measure the sound transmission loss up to a frequency range of 10 kHz.

Small STL Chamber (12"x12" CF Panel testing)

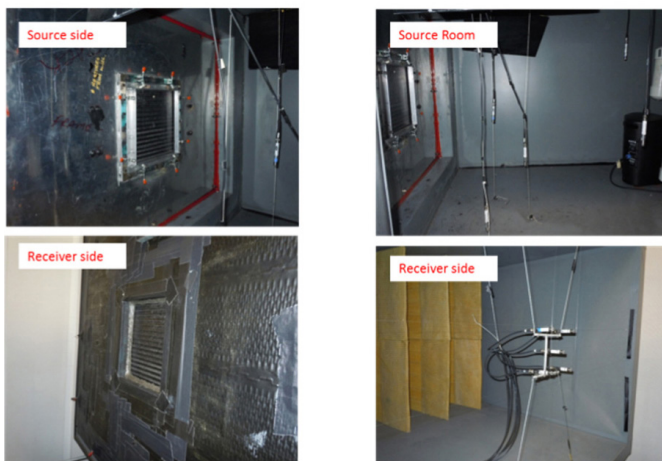


Figure 5. Pictures of SMC and NCF carbon fiber (CF) composite panels

Figure 6 shows the sound transmission loss (STL) test results of 4.8 mm thick carbon fiber (CF) panels manufactured with SMC and NCF materials. These panel STL tests were repeated with three panel samples. Sound transmission loss dip at 2 kHz is related to the panel coincidence frequency and has a significant impact on the high frequency STL performance.

The panel coincidence frequency occurs when the bending wave length of the panel matches the acoustic wave length in air. In this frequency region, maximum panel vibration energy is transferred to sound so the sound transmission loss of the panel becomes lower. This coincidence phenomenon causes a large dip in the sound transmission loss. The mathematical expression of the coincidence frequency f_c is given by

$$f_c = \frac{\sqrt{3}c^2}{\pi h} \sqrt{\frac{\rho}{E}} \quad (1)$$

Where,

f_c = coincidence frequency [Hz]

c = speed of sound in air [ms^{-1}]

h = thickness of panel [m]

ρ = density of panel [kgm^{-3}]

E = Young's modulus of panel [Nm^{-2}]

In the coincidence frequency range, panel damping property plays a significant role. The higher damping property increases the panel transmission loss in this frequency range.

Since both CF SMC and CF NCF panels has the same coincidence frequency, these composite panels have the same equivalent material young's modules and bending stiffness. Both SMC and NCF composite panels exhibit similar STL performance. Sample-to-sample variation is very small indicating a robust manufacturing process for fabrication of carbon fiber panels.

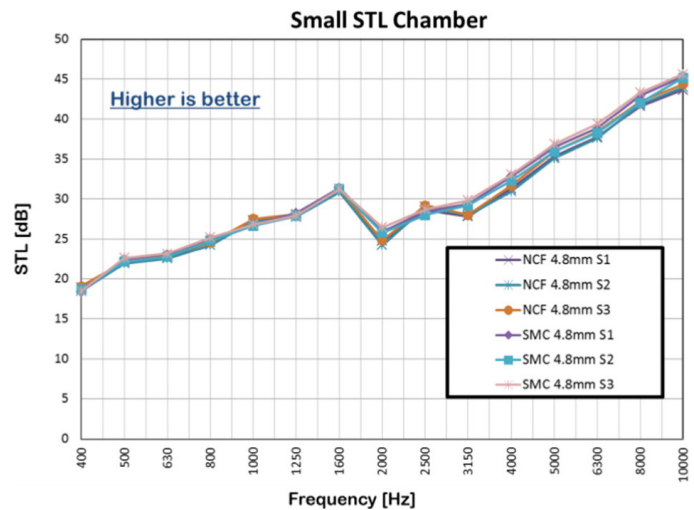


Figure 6. Sound Transmission Loss of 4.8 mm thick SMC and NCF carbon fiber panels for three different panel samples

Figure 7 shows the sound transmission loss (STL) test results of 2.4 mm thick carbon fiber panels manufactured with SMC and NCF materials. The coincidence frequency for the 2.4 thick panel occurs at 5.5 kHz. Both SMC and NCF composite panels with 2.4 mm thickness show similar bending stiffness and STL performance.