Verification of Sound Absorption Characteristics Constituted Porous Structure

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Abstract

This paper presents the verification the level of acoustic solver in LS-DYNA® and availability of LS-DYNA evaluating acoustic issue interior problem. We made sound in a Rectangular empty box made from aluminum and measured sound there by microphone in order to compare the experiment and simulation. We prepare fundamental material as sound absorption and attached it to the Rectangular empty box. In LS-DYNA, The characteristics of the sound absorbing material are considered as acoustic impedance boundary conditions. The analysis result is good agreement with the peak frequency measured in the experiment.

1 Background

Nowadays, LS-DYNA has been implemented acoustic solver which can be evaluated sound phenomenon. But there are not so many comparisons between experiment and simulation with LS-DYNA.
In this study, we are trying to verify the level of acoustic solver in LS-DYNA and confirm availability of LS-DYNA evaluating acoustic issue such interior or exterior problem.
Firstly, we prepare fundamental material as sound absorption and take the characteristics into consideration in experiment.
This experiment is dealt with interior problem. We make sound in a Rectangular empty box made from aluminum and measure sound there by microphone in order to get transfer function.
Secondly, the material for absorption is put to side wall in this box. We try to take absorption characteristics into consideration and confirm performance of LS-DYNA’s acoustic solver by comparison between measurement from microphone and the result of simulation.
Before this experiment, we have to measure absorption property of these materials. So, we do another test to get boundary condition of sound absorption.
Our goal in this study is verification to the usage of porous structure as absorption material.
Due to tiny room porous has, it is expected that sound wave reflects frequently and attenuate inside the porous.
We are going to do such an experiment and confirm thus hypothesis.

2 Theory

In frequency domain, the acoustic wave propagation in an ideal fluid in absence of any volume acoustic source is governed by Helmholtz equation given as follows:

$$\Delta p + k^2 p = 0 \qquad \text{(Eq.1)}$$

where $k = \omega/c$ denotes the wave number, c is the sound velocity, $\omega = 2\pi f$ is the pulsation frequency, $p(r)$ is the pressure at any field point.

Equation 1 can be transformed into an integral equation from by using Green's theorem. In this case, the pressure at any point in the fluid medium can be expressed as an integral, of both pressure and velocity, over a surface as given by the following equation:

$$C(r)p(r) = \int_{S_y} \left\{ G(r, r_y) \frac{\partial p(r)}{\partial n_y} - p \frac{\partial G(r, r_y)}{\partial n_y} \right\} dS_y \qquad \text{(Eq.2)}$$

Where $G(r, r_y) = \frac{e^{-ik|r-r_y|}}{4\pi|r-r_y|}$ is the Green's function, n is the normal on the surface S and C is the jump term resulting from the treatment of the singular integral involving Green's function. The normal derivative of the pressure is related to the normal velocity by $G(r, r_y) = \frac{e^{-ik|r-r_y|}}{4\pi|r-r_y|}$.

The knowledge of pressure and velocity on the surface allows calculating the pressure of any field point. This constitutes the main idea of the integral equation theory. In practical cases, the problems are either Neumann, Dirichlet or Robin ones. In Neumann problem, the velocity is prescribed on the boundary while in Dirichlet case the pressure is imposed on the surface. Finally for Robin problems the acoustic impedance, which is a combination of velocity and pressure, is given on the boundary. Hence, only the half of the variables is known on the surface domain.
To deduce the other acoustic variables on the surface, BEM can be used to discretize the integral equation. The simplest one is called collocation method. In this technique, the integral equation is written for each node of the boundary. Assembling the produced elementary vectors yields to a linear system for which the solution allows to deduce the other half of the acoustic variables. Although this method uses simple integrals, it involves non symmetric complex and fully populated system. In the variational indirect BEM, the equation is multiplied by a test function and integrated over the surface. For details, see the literature[1].

3 The comparison with experiment

3.1 Experiment

3.1.1 Overview

To inspect the availability of BEM acoustic analysis in LS-DYNA, the experiment was executed. We make sound in a Rectangular empty box made from aluminum and measure sound there by microphone in order to get transfer function. Figure 1 shows the experiment equipment. Aluminum rectangular frame was made sufficiently thick so that there was almost no influence from the outside. The sound absorbing material is attached to the wall of the aluminum rectangular body as shown in Figure 2, or attached to the jig as shown in Figure 3. We measured with two kinds of sound absorbing materials (melamine and polyester).

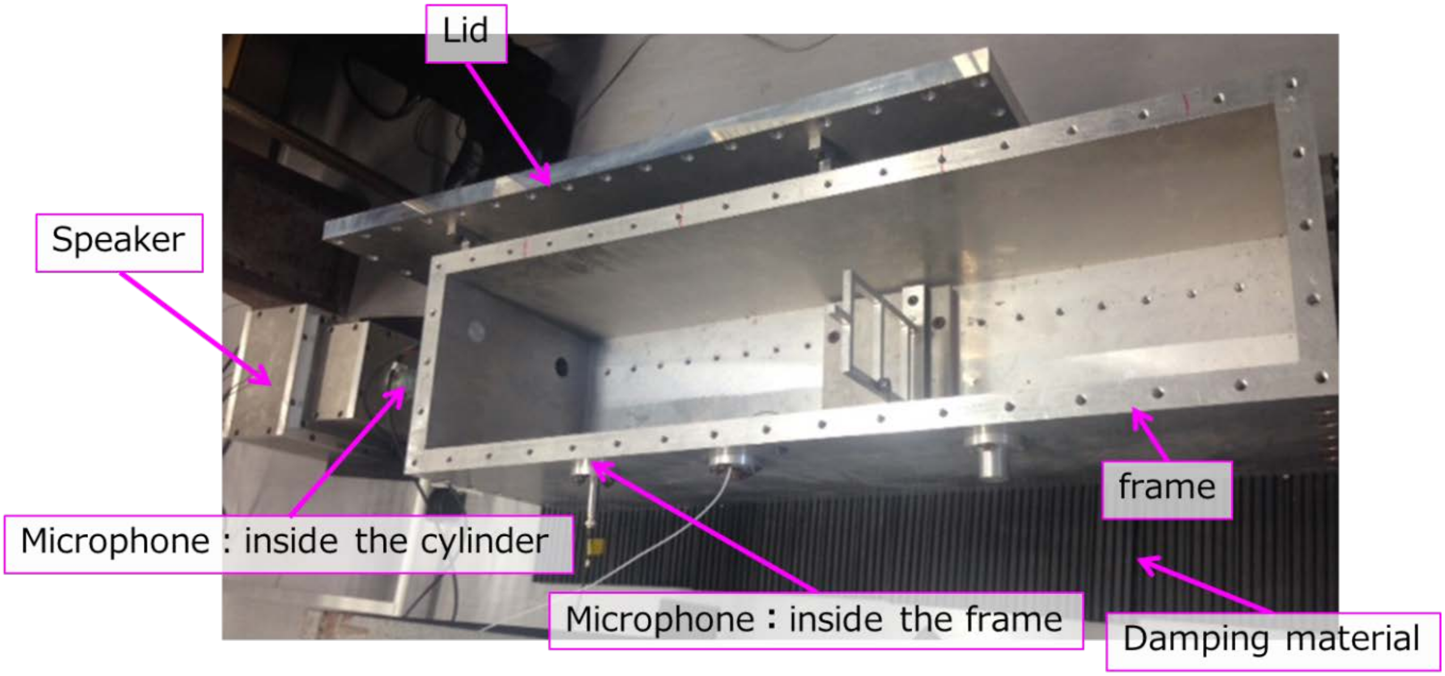

Figure 1 Experiment equipment

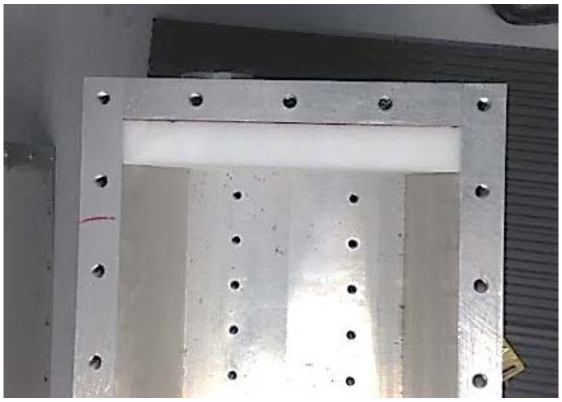

Figure 2 : Attached to the wall

Figure 3 : Attached to the jig

3.1.2 Sound Measurement

Since the speaker itself also has frequency characteristics and impedance, the transfer function defined as Ch.2 / Ch.1 is used to evaluate the acoustic characteristics. Burst random signal is used as input for the speaker. In order to reduce noise, the average value of 100 measurements is taken as experimental data.

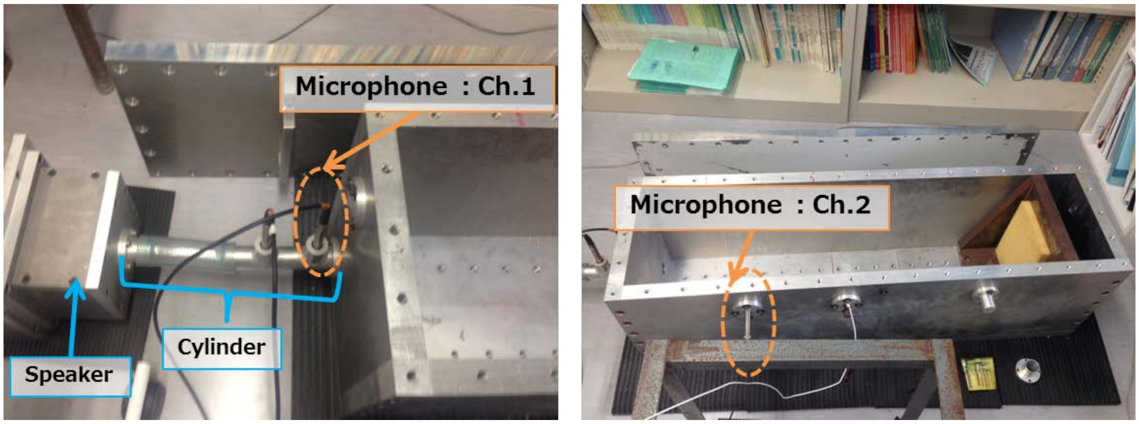

Figure 4 : Microphone and Speaker

3.1.3 Result

Figure 5 shows the experiment data when the melamine or polyester is attached to the wall. In the case of melamine, the frequency characteristic of the high frequency changed. On the other hand, in the case of polyester, the frequency characteristics did not change and the Sound pressure level declined. Figure 5 shows the case where it is attached to the jig, the peak frequency has changed due to the narrowing of the internal region.

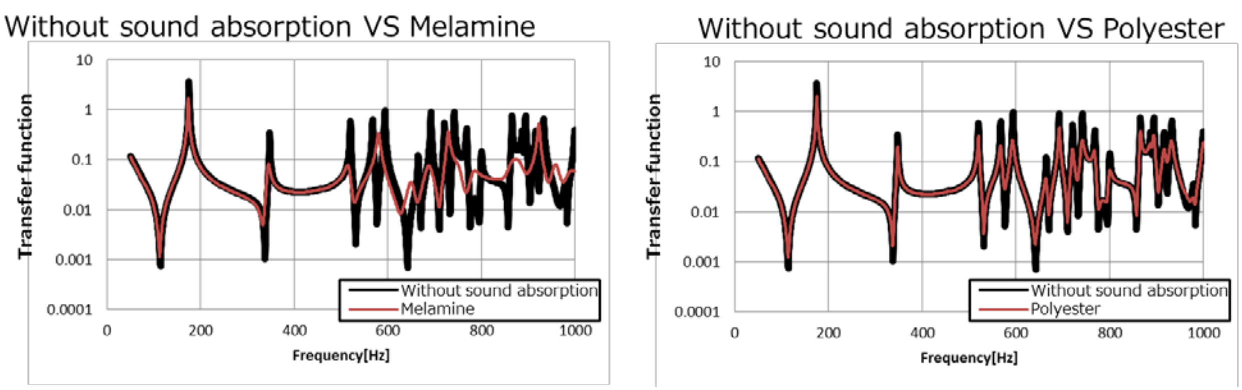

Figure 5 : Sound absorption is attached to the wall

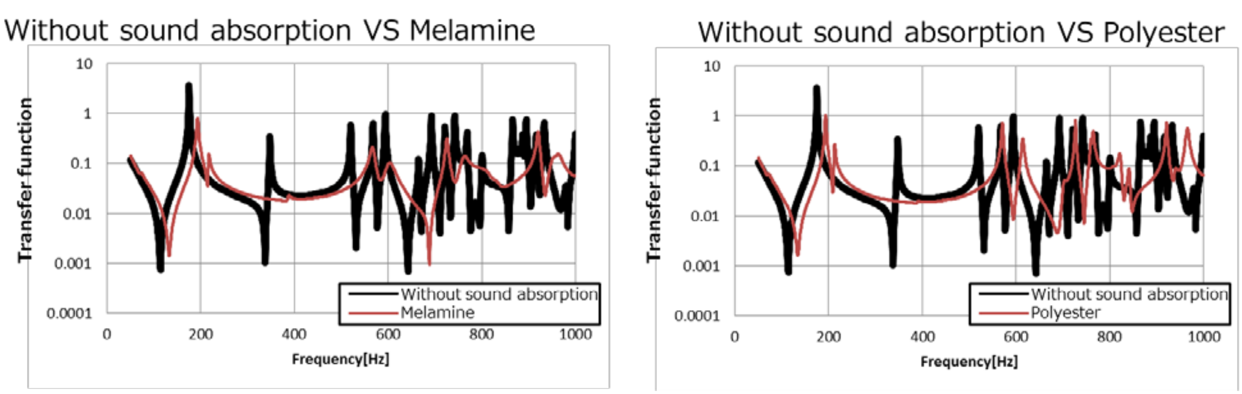

Figure 6 : Sound absorption is attached to the jig

3.2 Experiment

3.2.1 The Model

Figure 7 shows the external dimensions of experiment equipment. METHOD 3 (collocation BEM) is used because it can use impedance boundary conditions in acoustic simulation. In the case of the jig, the area behind the jig is not analyzed. The mesh is described in Figure 8. The experiment equipment is modeled by shell elements. The element size was made to be 0.04m or less. (8 divisions of 1000Hz wavelength ≒ 0.042m)

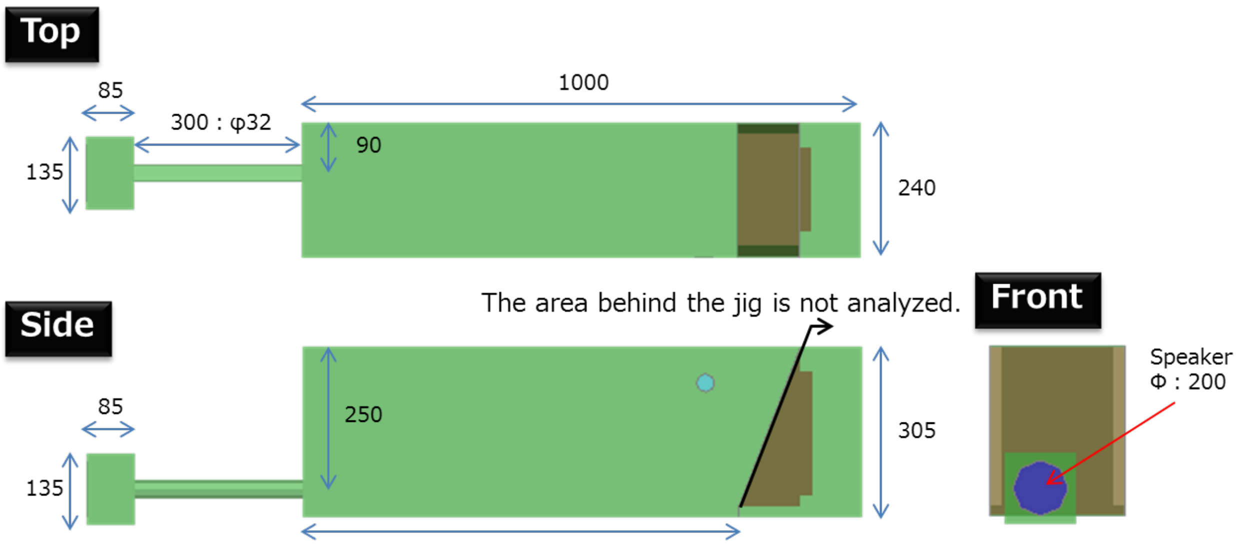

Figure 7 : External dimensions

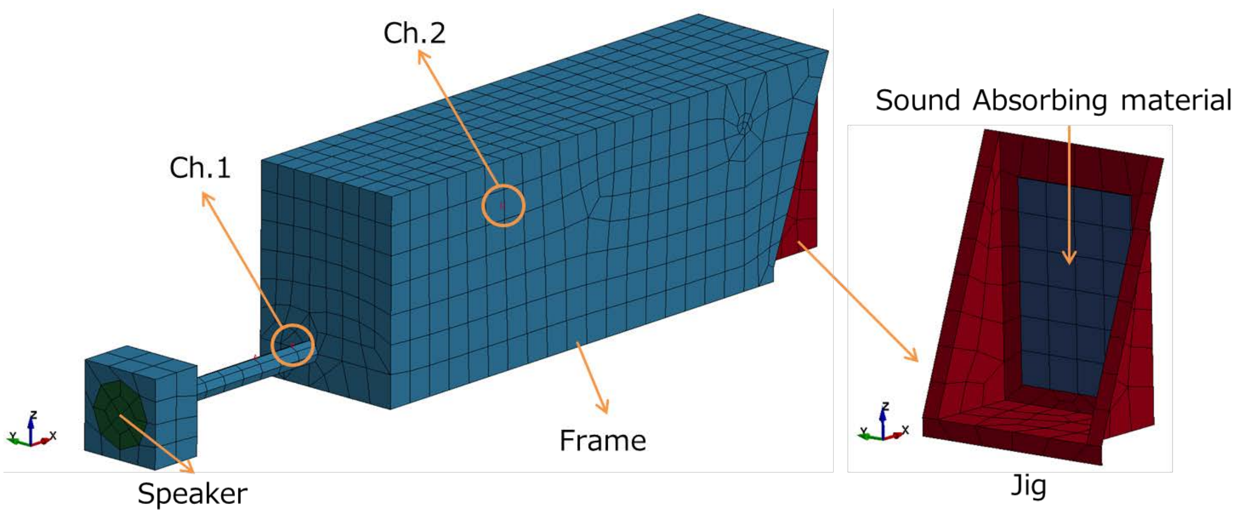

Figure 8 : Input model

3.2.2 Acoustic condition

It is filled with air in the frame (ρ =1.21kg/m^3, c =343m/s). The surface of frame and jig is assumed to be reflecting boundary condition and speaker is excited vertically by a uniform velocity 1 mm/s in the frequency range of 50-1000Hz. The characteristics of the sound absorbing material are considered as acoustic impedance boundary conditions. The acoustic impedance of the sound absorbing material was measured using the acoustic impedance tube shown in the Figure 9.

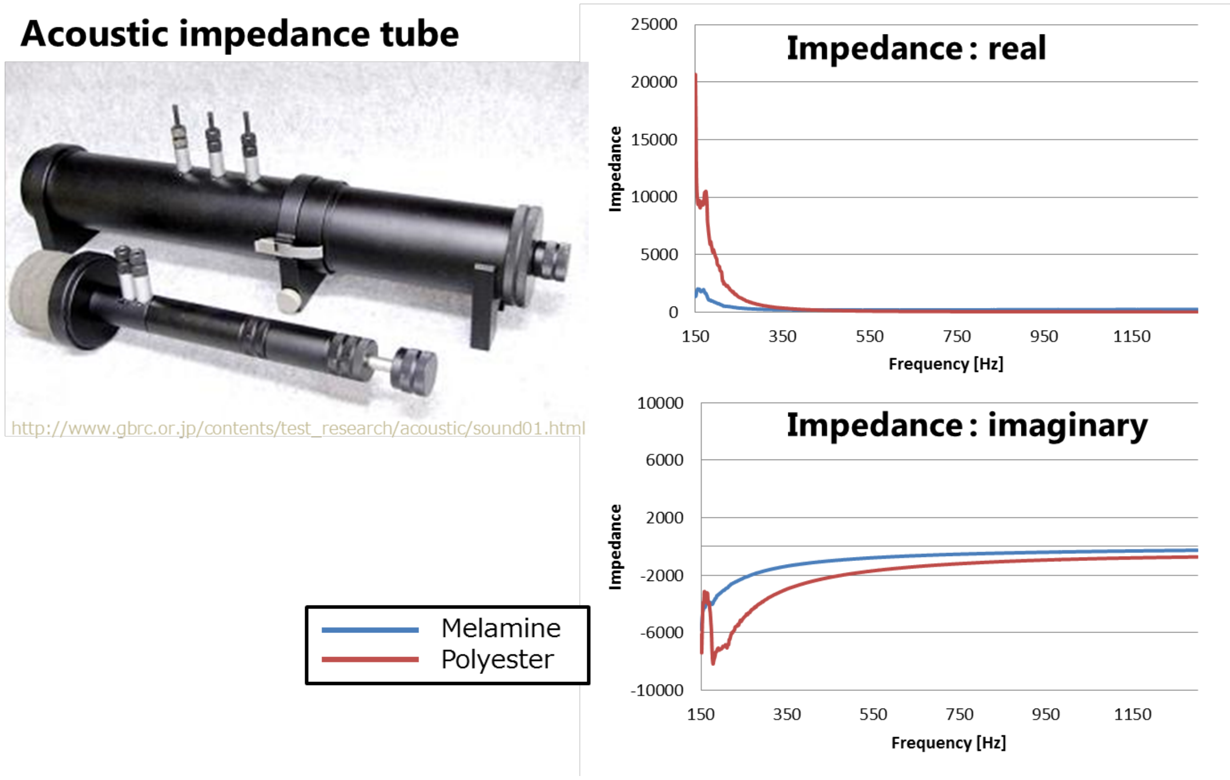

Figure 9 : Acoustic impedance

4 The result

Figure 10 shows experimental values and analysis results when the sound absorbing material is attached to the wall. The analysis result is good agreement with the peak frequency measured in the experiment. It takes 4 minutes 14 seconds to calculate in this case (mpp 16 core).
Figure 11 shows experimental values and analysis results when the sound absorbing material is attached to the jig. Although there is a difference between the experimental values and analysis results around 400Hz, The analysis result is also good agreement with the peak frequency measured in the experiment. It takes 4 minutes 1 second to calculate in this case (mpp 16 core).
In the case of simple shape like this experiment, acoustic analysis with LS-DYNA can be performed accurately.

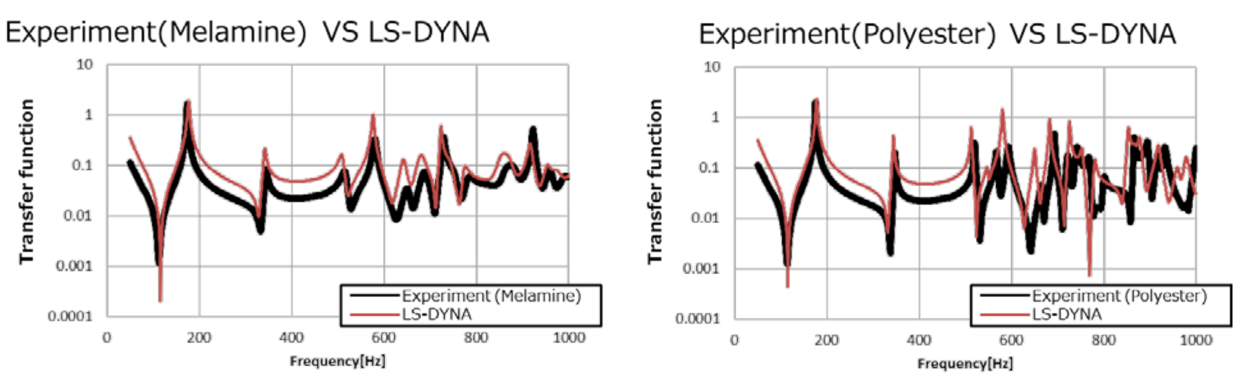

Figure 10 : Sound absorption is attached to the wall

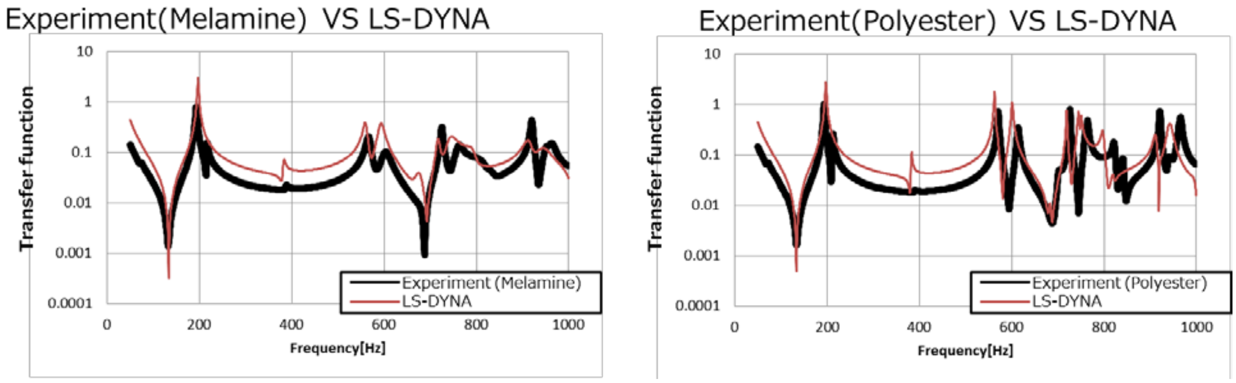

Figure 11 : Sound absorption is attached to the jig

5 Advanced examples (next plan)

Our goal in this study is verification to the usage of porous structure as absorption material.
Due to tiny room porous has, it is expected that sound wave reflects frequently and attenuate inside the porous.
We are going to do such an experiment and confirm thus hypothesis. The results will be introduced at the conference.

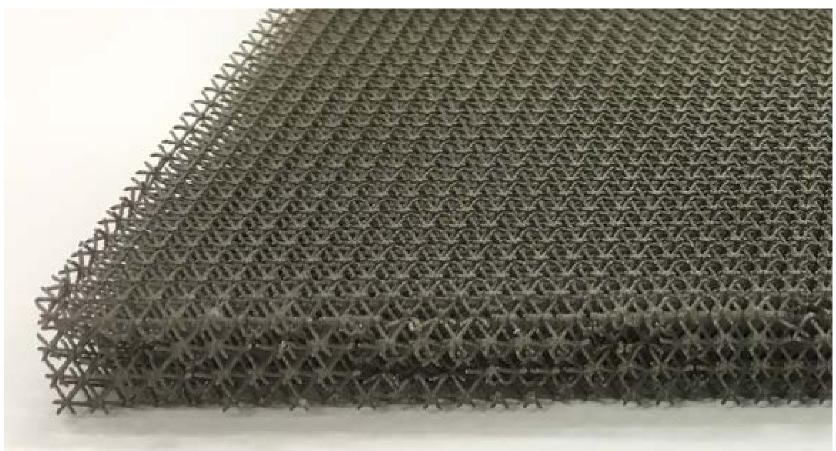

Figure 12 : Porous (next plan)

6 Summary

We have verified the level of acoustic solver in LS-DYNA and confirm availability of LS-DYNA evaluating acoustic issue such interior problem. In order to compare with the analysis of LS-DYNA, we conducted an experiment of internal acoustic problem with simple shape. The analysis result is good agreement with the peak frequency measured in the experiment. Acoustic analysis with LS-DYNA is helpful for designer to evaluate sound phenomenon.

References

1. Yun Huang, Mhamed Souli, "Simulation of Acoustic and Vibro-Acoustic Problems in LS-DYNA using Boundary Element Method", 10th International LS-DYNA User Conference, 8-37:8-44, 2008