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The Design Optimization for Sound Absorption Material of Multi-Layer Structure

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Abstract**—**Sound absorbing material is used as automotive interior material. Sound absorption coefficient should be predicted to design it. But it is difficult to predict sound absorbing coefficient because it is comprised of several material layers. So, its targets are achieved through many experimental tunings. It causes a lot of cost and time. In this paper, we propose the process to estimate the sound absorption coefficient with multi-layer structure. In order to estimate the coefficient, physical properties of each material are used. These properties also use predicted values by Foam-X software using the sound absorption coefficient data measured by impedance tube. Since there are many physical properties and the measurement equipment is expensive, the values predicted by software are used. Through the measurement of the sound absorption coefficient of each material, its physical properties are calculated inversely. The properties of each material are used to calculate the sound absorption coefficient of the multi-layer material. Since the absorption coefficient of multi-layer can be calculated, optimization design is possible through simulation. Then, we will compare and analyze the calculated sound absorption coefficient with the data measured by scaled reverberation chamber and impedance tubes for a prototype. If this method is used when developing automotive interior materials with multi-layer structure, the development effort can be reduced because it can be optimized by simulation. So, cost and time can be saved.

Keywords**—**Optimization design, multi-layer nonwoven, sound absorption coefficient, scaled reverberation chamber, impedance tubes.

I. Introduction

In parts requiring sound absorption performance such as automotive interior, nonwoven fabric is widely used. In order to achieve various required performances, a multi-layered material is usually used instead of a single material. It has been studied to develop a single material for recycling too. However, since automotive interiors have many goals, it is not easy to meet the required performance with a single material. A sound absorption coefficient, which represents to automotive internal noise, is one of the important performance indicators. It is not easy to meet the sound absorbing performance because automotive interior is composed of multi-layered material. In the automotive field, experimental tunings is widely utilized to meet the required performance for sound absorption in automotive development. It is disadvantageous in terms of cost and time aspects. There are many difficulties in the field like that.

In this paper, the process to estimate the value of the sound absorption coefficient for nonwoven with multi-layer structure using physical properties for each nonwoven will be introduced. And then we will show the method to predict the physical properties with the measured value of sound absorption coefficient too.

First, the sound absorption coefficient is measured by various thicknesses using acoustic impedance tube. And we calculate the physical properties of the material with it. It is calculated with inverse algorithm [1]. The measuring machines are expensive and it takes a long time because there are several characteristics that affect sound absorption. So, we take the method to calculate the properties with sound absorption coefficient. Many test data should be used to increase the correlation and increase the reliability. Second, the sound absorption coefficient of multi-layered structure is calculated using commercial analysis tool NOVA with the properties. Third, we verify the sound absorption coefficient calculated by commercial analysis tool with multi-layered prototype too. And we do correlation analysis of the calculated and measured values.

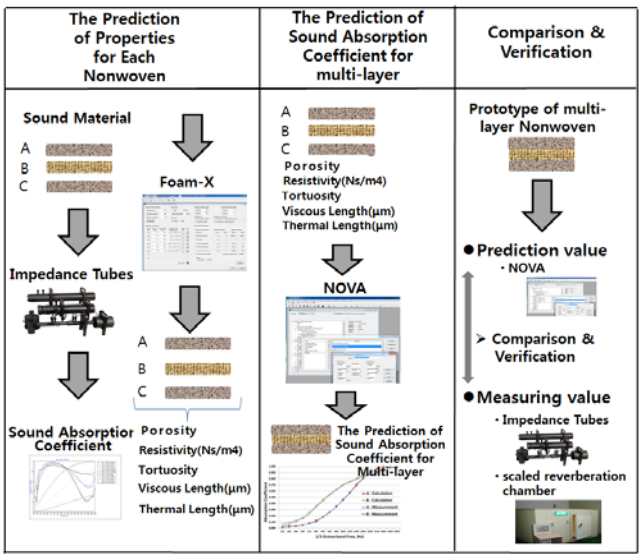

Fig. 1 The process for the prediction of sound absorption coefficient for automotive interior material with multi-layer

Fig. 1 shows the process of calculating the material properties affecting the sound absorption, the process of

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multi-layered structure using it, and the process of verifying and comparing the calculated and measured values.

II. The Prediction of Single-Layer Material Properties with Sound Absorption Coefficient

We measure the sound absorption coefficient to calculate the properties of nonwoven using impedance tubes. The calculated properties are porosity, resistivity, tortuosity, viscous length, thermal length, and so on. The sound absorption coefficient is measured with the absorbed sound amount in the impedance tube. We use a PET felt and a mixed felt as experiment material. Since the materials are excellent for sound absorption, those are widely used as automotive interior material.

The more we conduct the experiment by impedance tube, the more the predicted properties are accurate. Above all, the basic thickness of a sample for the experiment should be determined. We determined 10 mm for thickness. The experiments were conducted several times for 1, 2, and 3-layer of the same material. The samples and the result of the experiment for the sound absorption coefficient are shown in Fig. 2. The physical properties are calculated with the measured sound absorption coefficient by Foam-X [1]. The predicted values for open porosity, resistivity, ore tortuosity, viscous length, thermal length are shown in Fig. 3. If the prediction method is used to obtain the properties like this, time and cost can be saved.

III. The Prediction of the Sound Absorption Coefficient for Multi-Layer with the Properties

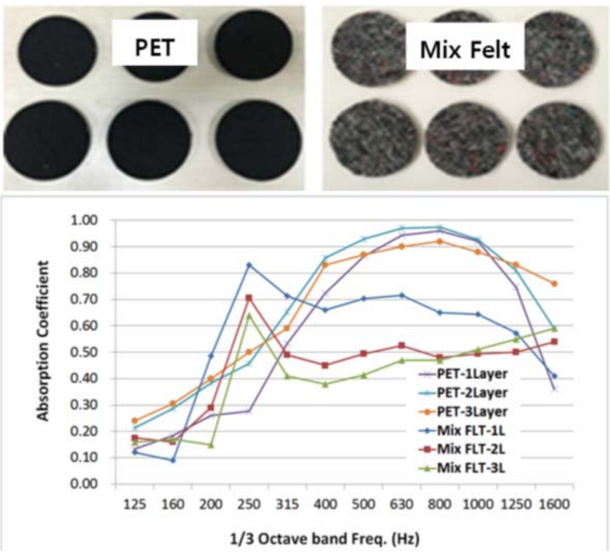

Fig. 2 The measured sound absorption coefficient by impedance tubes

As shown in Fig. 4, the sound absorbing coefficient of compositing multi-layer using the commercial software NOVA is calculated. A line is the sound absorption coefficient for 2-layer with PET and Mix Felt. B line is the sound absorption coefficient for 3-layer sample with PET, Mix Felt and PET. We need the properties such as open porosity, resistivity, pore tortuosity, viscous length, thermal length and bulk density to calculate the sound absorption coefficient for multi-layer [4], [5]. A bulk density was measured with Phi-X measurement system since Foam-X cannot calculate it as shown Fig. 5. Table I shows the PET properties for the prediction of the sound absorption coefficient for multi-layer [6].

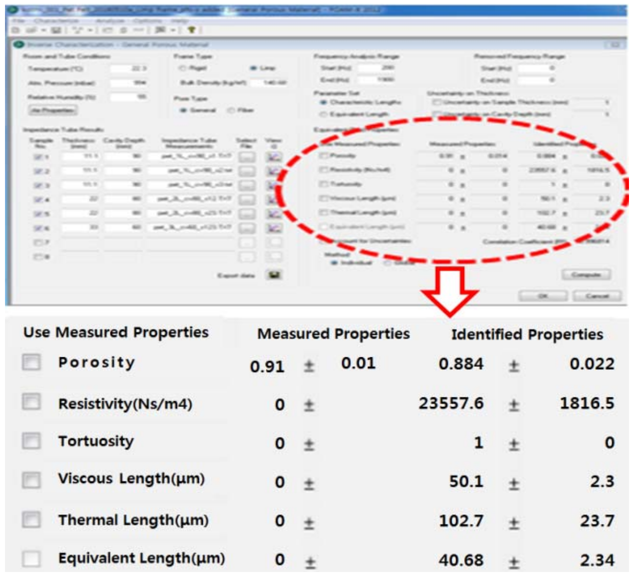

Fig. 3 The prediction by Foam-X with the measured sound coefficient

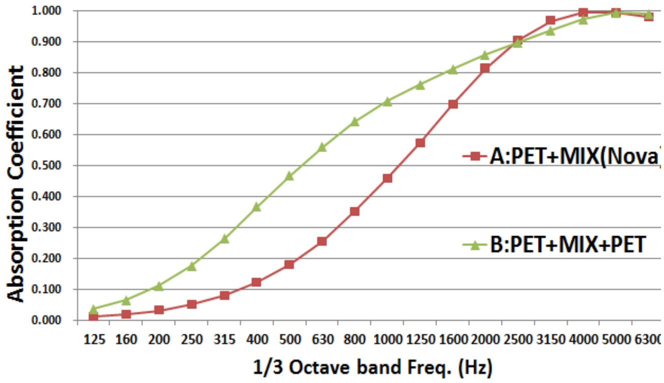

Fig. 4 The calculated sound absorbing coefficient

TABLE I
MATERIAL PROPERTIES

material property	PET Felt	Mix Felt
open porosity	0.884	0.896
resistivity(Ns/m^4)	23557.6	138721.1
pore tortuosity	1	1
viscous length(µm)	50.1	70.2
thermal length(µm)	102.7	143.1
bulk density (kg/m^3)	140.68	135.21

We fabricated the prototypes of 2-layer and 3-layer for comparison and verification. The prototypes for scaled reverberation chamber and impedance tubes are shown in Fig. 6. The samples are composed of 2-layer and 3-layer. The 2-layer is composed of PET felt and mixed felt. And the 3-layer is composed of PET felt, mix felt, and PET felt. We compared the data for two cases and verified the method. The curves of the sound absorption coefficient predicted by using NOVA and obtained by impedance tube are shown in Fig. 7.

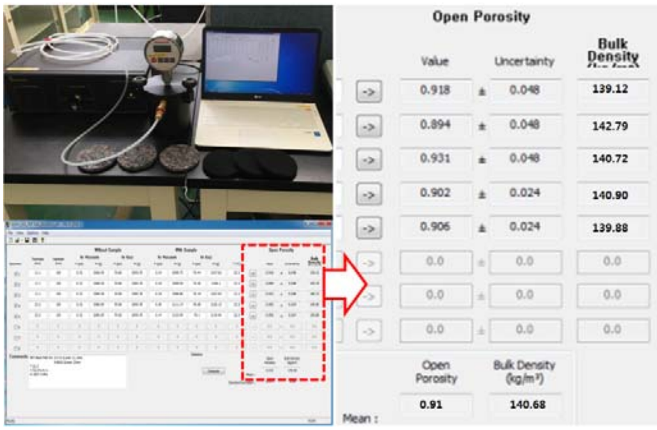

Fig. 5 The measurement of bulk density

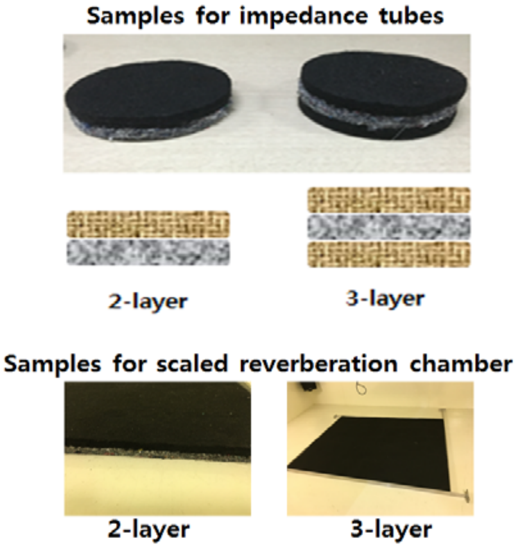

Fig. 6 The test sample with multi-layer

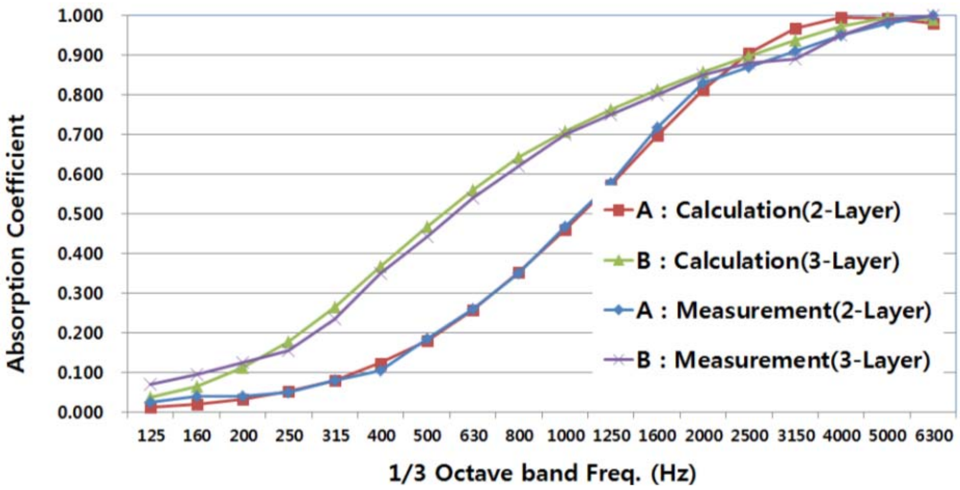

Fig. 7 The calculated and measured sound absorption coefficient with impedance tubes

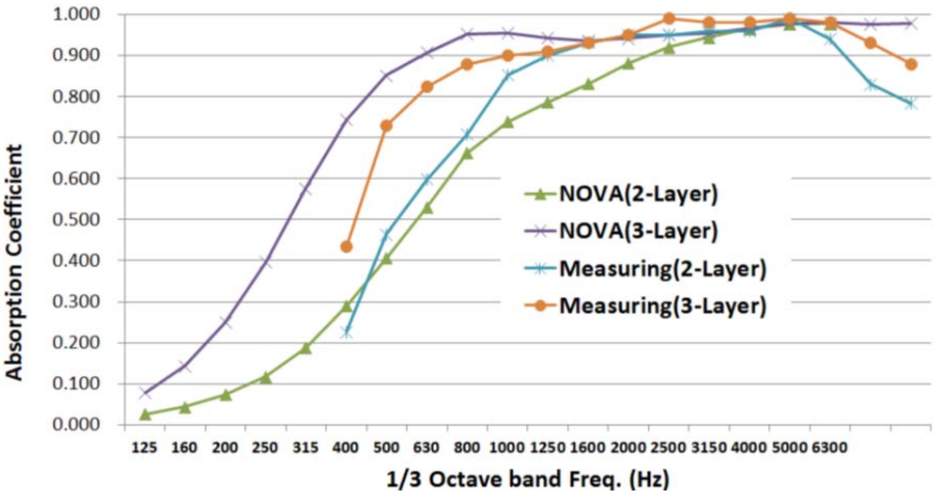

Fig. 8 The calculated and measured sound absorption coefficient with scaled reverberation chamber

The curves are nearly the same as shown in Fig. 7. The error is in 10%. It shows that the sound absorption coefficient for multi-layer with the calculated properties can be predicted. Thus, prediction method for multi-layer non-woven can be used for sound absorption design of automotive interior. The sound absorption coefficients calculated by software and obtained by the test are shown in Fig. 8. The curves are different from each other as shown in Fig. 8. The direction of sound progress is perpendicular to the side of nonwoven in impedance tube. The experiment condition of the scaled reverberation chamber is different from that of impedance tube. So, we need to identify it. And then, we will study correlation method for the scaled reverberation chamber in the future.

IV. Conclusion

The sound absorption coefficient for two materials using impedance tube was measured. The physical properties using commercial software Foam-X with the measured data were predicted. And using the estimated physical properties, we calculated the sound absorption coefficient for automotive interior materials with multi-layered structure. And then we confirmed that the measured value and the estimated value are similar to each other. It shows that the prediction method is reasonable for design of acoustic material with multi-layer structure. We verified that the predicted sound absorption coefficient is reliable for impedance tube. But the values are different from each other for the scaled reverberation chamber. So we will study the reason for difference and find the correlation factor.

In this paper, it was confirmed that this prediction method is very useful when we designed sound absorption material with multi-layer structure for automotive interior. It is difficult to meet the performance for the sound absorption since the automotive interior material is composed of multi-layer structure. We have to conduct numerous tuning tests to satisfy the performance for the sound absorption. It takes lots of time. But, the prediction method can save time.

Acknowledgment

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References

[1] J. T. Kim, “Measurement of acoustic parameters and prediction of absorption coefficient of porous soundproofing materials,” Master’ Thesis, KAIST, 1997.

[2] Foam-X Instruction Manual, “Acoustic property identification for foam and fiber materials”, Mecanum, Canada.

[3] C.M. Lee, Y. S. Wang, “A Prediction method of the acoustic properties of multilayed noise control materials standing wave-duct systems,” Belmont, Journal of Sound and Vibration, Vol. 298, No 1, pp.350~365, 2006

[4] T. Rostand, “On the holes interaction and heterogeneity distribution effects on the acoustic properties of air-cavity backed perforated plates,” Applied Acoustics, Vol. 74, pp. 1492~1498, 2013.

[5] H. J. Park, “A study on the effect of acoustic properties on the absorption characteristics of polyester fiber materials,” KSNVE, the Proceedings of KSNVE, pp.885~891, 2003

[6] M. E. Delany, E. N. Bazley, “Acoustical properties of fibrous materials,” Applied Acoustics, Vol 3, pp. 105~116, 1970.