A Study on the Strength and Sound Absorption Performance of Ultra Low Density Polyurethane with Nano-Cellulose Fiber

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나노셀룰로오스섬유 적용 초 저밀도 폴리우레탄의 강도 및 흡음성능 연구

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Abstract

Recently, polyurethane materials are commonly used as engine room sound-absorbing materials to reduce the weight of automobiles. Polyurethane materials have excellent sound absorption performance in the 800~2,000 Hz frequency range due to the structural characteristics of the material, but the sound absorption performance of more than 2,000 Hz is insufficient. In the case of electric vehicles, it is important to improve the high frequency noise generated by the motor, and the need for modification of polyurethane materials has increased.

High frequency performance can be improved by improving the air permeability of polyurethane cells through the bonding structure of polyurethane materials, optimization of blowing and gelling reactivity, and the amount of foaming gas. Increased air permeability of polyurethane materials reduces density and strength.

In this study, Nano-cellulose is a highly functional new material with light and high mechanical properties through a chain bundle structure. The dispersibility is improved by optimizing the content and particle size of nano-cellulose.

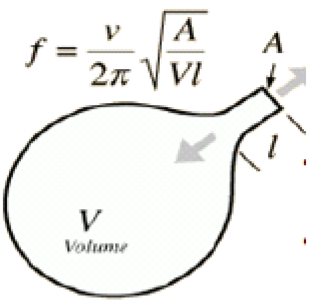
The goal is to develop ultra-low-density polyurethane with excellent sound absorption performance in high frequency areas over 2,000 Hz and improved strength. The strength of hood insulation and dash outer products can be improved by applying the developed polyurethane material. In addition, the quality of lightweight engine room sound absorbing materials for electric vehicles can be improved.

1. Introduction

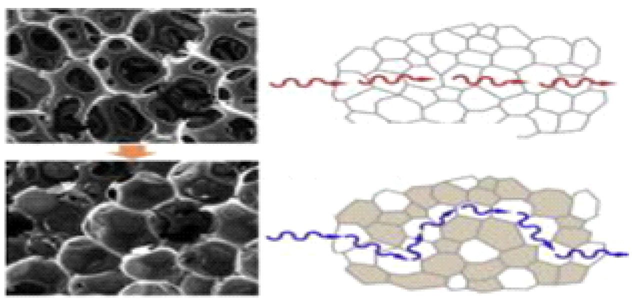
In order to reduce carbon emissions and improve the performance of vehicles, the power source of vehicles is changing from internal combustion engines to electric motors. Internal combustion engines are important for improving the noise below 200-1,000Hz, including booming noise, and for improving fuel efficiency through lightweight. Sound-absorbing materials are mainly used for lightweight, but they are vulnerable to noise in the high-frequency range. The future automobile market is dominated by eco-friendly vehicles, and the electric motor of the representative electric vehicle is important to improve the noise in the high-frequency range of the high-order order of 20 or more.

Polyurethane materials are widely used as engine room sound-absorbing materials to reduce the weight of vehicles. In the case of internal combustion engines, the density of polyurethane is generally 18kg/m3, and it shows excellent sound absorption performance in the frequency range of 800-2,000Hz due to its structural characteristics, but it is insufficient in the high-frequency range of 2,000Hz or more. In the case of electric motors, it is important to improve the high-frequency noise generated by the high-speed rotation of the motor, so it is necessary to modify the polyurethane.

Polyurethane materials implement sound absorption performance by converting and losing energy through the movement of sound in the bubble structure and the damping effect by the elasticity of the material due to the 'Helmholtz resonance principle'. Therefore, the sound absorption performance can be improved by improving the bubble size and air permeability through the optimization of the chemical bond structure, blowing and gelling reactivity, and the amount of foaming gas of polyurethane. However, if the air permeability of polyurethane increases, the density and strength decrease. In other words, compared to the conventional internal combustion engine polyurethane, we developed an ultra-low-density polyurethane (12kg/m^3) with improved air permeability to improve the sound absorption performance in the high-frequency range of electric motors, but it has the disadvantage of insufficient strength.



[Fig. 1] Helmholtz resonator



[Fig. 2] Different sound travel paths according to cell structure

In this study, we aim to develop an ultra-low-density polyurethane (12kg/m^3) with excellent sound absorption performance in the high-frequency range by adding nano-cellulose. Nano-cellulose is a high-performance material with excellent mechanical properties and lightness through chain bundle structure. By optimizing the content and particle size of nano-cellulose, the dispersion of polyurethane material can be improved. This can lead to the development of ultra-low-density polyurethane materials with excellent sound absorption performance in the high-frequency range of 2,000Hz or more. By applying polyurethane materials with nano-cellulose to products such as hood insulation and dash outer, we can expect the development of lightweight engine room sound absorption materials for electric vehicles with improved strength and molding quality.

2. Experiment

2.1 Manufacture

Wood is mechanically crushed into small pieces, and then subjected to high pressure and heat to decompose into nano-sized fibers. The diameter of nano-cellulose is 40-50nm and the length is 1-100μm. Then, after hydrophobic modification, it was completely dried at 24°C for 3 days to improve the dispersion. In this study, we prepared ultra-low-density polyurethane (12kg/m3) materials with 0.5, 1, and 2 wt% nano-cellulose additions, and confirmed the strength and sound absorption performance characteristics according to the nano-cellulose content.

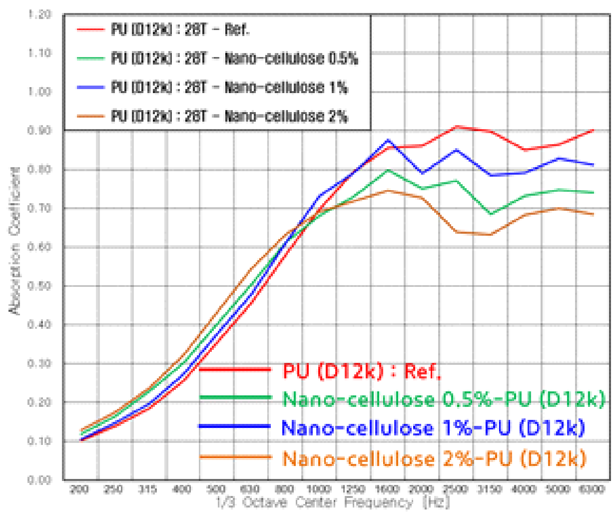
2.2 Measurement

The sound absorption performance of ultra-low-density polyurethane (12kg/m^3) with 0.5, 1, and 2 wt% nano-cellulose additions was measured using a B&K impedance tube according to ISO 10354-2, and air permeability was measured using a Mecanum SIGMA air flow resistance meter according to ISO 9053. Also, the compressive strength was measured using a universal testing machine (UTM) at 50% strain by applying ISO 844.

3. Results

3.1 Results of sound absorption performance

In this study, the sound absorption performance of ultra-low-density polyurethane (12kg/m^3) with 0.5, 1, and 2 wt% nano-cellulose additions was measured using an impedance tube. The sound absorption performance decreased in proportion to the amount of nano-cellulose added, and the sound absorption performance of Ref., which was not applied, was the best. However, in the case of nano-cellulose addition, the maximum sound absorption performance was confirmed when 1% was added.



[Fig. 3] Sound absorption performance of polyurethane (12kg/m^3) by impedance tube method

3.2 Results of compressive strength

The compressive strength of ultra-low-density polyurethane (12kg/m^3) with 0.5, 1, and 2 wt% nano-cellulose additions was measured at 50% strain under 50mm/min conditions using a universal testing machine (UTM). The compressive strength increased by 5-15% in proportion to the amount of nano-cellulose added. The compressive strength of ultra-low-density polyurethane (12kg/m^3) with 1wt% nano-cellulose application, which showed a peculiarity in sound absorption performance in 3.1, was 0.257kgf/cm2, which is a 90% decrease in compressive strength compared to the compressive strength of polyurethane (18kg/m^3) used in internal combustion engines (0.489kgf/cm2). In other words, the contribution effect of ensuring rigidity for improving the quality of electric vehicles is insufficient.

[Table 1] Compressive Strength of polyurethane (12kg/m^3)

	PU (D12k) Ref.	Nano-cellulose 0.5%-PU (D12k)	Nano-cellulose 1%-PU (D12k)	Nano-cellulose 2%-PU (D12k)
Compressive strength (kgf/cm^2)	0.231	0.241	0.257	0.265
Change (%)	-	4.3 ↑	11.3 ↑	14.7 ↑
Thickness (mm)	14	14	14	14

3.3 Results of airflow resistance

The air permeability of ultra-low-density polyurethane (12kg/m3) with 0.5, 1, and 2 wt% nano-cellulose additions was measured by measuring the air flow resistance. This means that the higher the air flow resistance, the lower the air permeability. In order to improve the sound absorption performance in the high-frequency range of electric motors, air permeability needs to be improved. The air permeability decreased in proportion to the amount of nano-cellulose added, and the air permeability of the Ref., which was not applied, was the best. This is similar to the results of the sound absorption performance measurement through the impedance tube, and the air permeability of the ultra-low-density polyurethane (12kg/m3) with 1wt% nano-cellulose application was confirmed to be the best. This result is similar to the air flow resistance of polyurethane (18kg/m3) used in internal combustion engines (54,302 Pa.s/m2), confirming the equivalent level of air permeability, and meaning that the contribution of ultra-low-density polyurethane to improving the sound absorption performance in the high-frequency range has disappeared.

[Table 2] Airflow resistance of polyurethane (12kg/m^3)

	PU (D12k) Ref.	Nano-cellulose 0.5%-PU (D12k)	Nano-cellulose 1%-PU (D12k)	Nano-cellulose 2%-PU (D12k)
Airflow resistance (Pa.s/m^2)	33,130	71,560	53,240	123,020
Change (%)	-	116.0 ↑	60.7 ↑	271.3 ↑
Thickness (mm)	28	28	28	28

3. Conclusions

3.1 Results of sound absorption performance

This study aims to develop a technology to improve the strength of ultra-low-density polyurethane (12kg/m3) material by reducing weight and improving sound absorption performance in the high-frequency range for the purpose of improving noise of electric vehicle motors.

Ultra-low-density polyurethane (12kg/m3) has the disadvantage of being weak, but the compressive strength was improved by 5-15% by adding nano-cellulose. The sound absorption performance and air permeability of ultra-low-density polyurethane (12kg/m3) with 1wt% nano-cellulose application were the best. However, this result is insufficient compared to the ultra-low-density polyurethane (12kg/m3) of Ref. without nano-cellulose application, and is equivalent to the conventional polyurethane (18kg/m3).

In order to develop ultra-low-density polyurethane (12kg/m3) with improved strength and improved sound absorption performance in the high-frequency range of electric motors, it is necessary to analyze the reason why the sound absorption performance of polyurethane with 1wt% nano-cellulose addition is the best. For this purpose, we plan to conduct additional research on various conditions such as the diameter, length, content, and dispersion of nano-cellulose.

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