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Recyclable flame retardant nonwoven for sound absorption; RUBA®

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A flame retardant nonwoven fabric for sound absorption, using para-aramid fibre and polyester fibre as a substitute for conventional materials (such as glass wool, flame retardant foam and flame retardant polyester fibre) was investigated. A combination of nonwoven fabric and paper was studied, and the resulting sound absorption qualities and sound permeation loss were compared. By attaching para-aramid paper with less than 30 cc/sec/cm^2 of permeability to nonwoven fabric, the sound absorption performance at over 2000 Hz was better than that of glass wool. We named this material "Flame Retardant Nonwoven Fabric for Sound Absorption" RUBA®.

1. Introduction

Automotive manufacturers will adopt recyclable flame retardant materials for sound absorption because automotive recycling laws will soon begin to take effect in Europe and in Japan. Sound absorption materials were studied by using a recycled polyester fibrous assembly, but countermeasure for flame retardancy was not referred to in the monograph [1]. Since the material used for automotive interiors should pass flame- retardancy regulations, flame-retardant polyester (PET) nonwoven might be one candidate for substitution materials. However, the flame retardant has the potential to negatively affect the environment. In this monograph we examined a recyclable flame-retardant nonwoven fabric for sound absorption using aramid fibre and PET fibre for a possible substitute for conventional materials such as glass wool, flame-retardant foam and flame-retardant PET fibre. The flame-retardant properties are measured using ISO 9237 and FMVSS 302 (Federal Motor Vehicle Safety Standard), and the sound absorption properties are measured by the normal incidence absorption method found in ISO 10534-1.

2. Experiment methodology

2.1. Materials

The para-aramid staple fibre (SF) used in this study, obtained from DuPont-Toray Co., Ltd., Japan, was KEVLAR® SF: 1.5 denier-51 mm length, the meta-aramid SF, obtained from Teijin Co., Ltd., Japan, was CONEX SF 2.0 denier-51 mm length, the regular PET SF, obtained from Takayasu Co., Ltd., Japan, was TAKAYASU Ester SF: 3.3 denier-64 mm length, the low melting-point (LMP) PET SF, obtained from Toray Co., Ltd., was SAFMET SF: 4.4 denier-51 mm length, and the aramid paper, obtained from Oji Co., Ltd., Japan was para-aramid paper with different permeability. The adhesive, obtained from Dainippon Ink & Chemicals Inc., was EVA Powder 5015 M. The glass fibre fabric and wool were of a commonly used grade.

2.2. Evaluation equipment and methods

Flame retardance was measured using ISO 10047:1993 (Textiles–Determination of surface burning time of fabrics) and FMVSS 302 (Federal Motor Vehicle Safety Standard). Normal incidence absorption was measured using normal incidence absorption equipment–auto measurement type; Sotec Corporation, type 10041A based on ISO 10534–1:1996 (Acoustics–Determination of sound absorption coefficient and impedance in impedance tubes—Part 1: Method using standing wave ratio). Permeability was measured using ISO 9237:1995 (Textiles-Determination of the permeability of fabrics to air). Mass per unit area was measured using ISO 3801:1977(Textile-Woven fabrics-Determination of mass per unit length and mass unit area).

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3. Flame-retardance of nonwoven

3.1. Specimen preparation

Several types of nonwoven fabric were prepared for flame-retardancy evaluation. These samples were produced with different fibre contents from the aramid SF, the PET SF and the LMP PET SF by using needle punch laboratory equipment and water jet laboratory equipment.

Table I shows the sample identifications for measuring flame retardant based on the difference in fibre content and nonwoven fabric density. Sample ID numbers from NW01 to NW05 were produced using the needle punch laboratory equipment. Sample ID NW06 was produced using the water punch laboratory equipment.

3.2. Results and discussion

Since the LOI (Lowest Oxygen Index) of aramid fibre is 29, the aramid fibre is classified as a flame retardant fibre, yet it is expensive. PET fibre, on the other hand, is inexpensive but it also combustible. In the past, a lower priced flame retardant nonwoven fabric was proposed, using PET fibre and greater than 50% para-aramid fibre [2]. However, this nonwoven fabric still carried a high price, as the ratio of para-aramid fibre was greater than 50%. So we tried to find a way to reduce the para-aramid fibre content in the nonwoven fabric without using flame retardant PET.

Table II and Photo 1 show the evaluation results of various kinds of nonwoven at the different fibre contents with less than 50% of aramid nonwoven fabric density for flame retardant property based on ISO 10047. As the ratio of para-aramid SF became greater than 20% and the density was less than 0.054 g/cm^3, the nonwoven fabrics showed self-extinguishing performance. The reason why mixed nonwoven fabric with less than 50% para-aramid SF content and PET SF showed flame retardant performance might be the lower density of nonwoven fabric and the use of short fibres. When the nonwoven fabric is set on fire, PET SF melt at first and then might adhere to the nearest para-aramid SF. NW02, NW03 and NW04 of Photo.1 backed the above-mentioned hypothetical mechanism. Therefore, all PET SF exposed to fire might melt and adhere to para-aramid SF. So there might be no combustible material in the area exposed to fire.

But in case of the PET SF nonwoven mixed with meta-aramid SF 30%, NW05 showed burned-out, although the nonwoven density was 0.063 g/cm^3. This phenomenon difference between para- and meta-aramid might be due to thermal shrinkage property difference of meta-aramid staple fibre when PET SF was melted under combustion.

4. Sound absorption

4.1. Specimen preparation

Several combinations of nonwoven fabric, which were needle punched nonwoven fabrics with density 0.03 g/cm^3 selected from the above result & discussion, and paper were prepared for FMVSS 302 evaluation, sound absorption and sound penetration evaluation. The nonwoven fabric was produced from the para-aramid SF, the PET SF and the LMP PET SF using commercial equipment. The carding process was performed two times for better evenness and better orientation. Webs with different fibre content and the same mass per unit area: 356 g/m^2 were needle punched under the usual condition: needle density of 100 pins/cm^2 and a feeding speed of 2 m/min. Needle punched nonwoven fabrics were developed on a hot air bonding machine for LMP PET fibre, which was set to an air temperature of 150°C at a feeding speed of 5 m/min and a 10 m bonding area. Several kinds of para-aramid paper were attached on the needle punched nonwoven

TABLE I Manufacturing conditions of nonwoven

Sample ID	Nonwoven fabrics LMP PET SF (%)	Reg. PET SF (%)	Para- or Meta	Arami d SF (%)	Thickness (mm)	Density (g/cm^3)	Mass per unit area (g/m^2)
NW01	26	64	Para	10	4.0	0.046	184
NW02	23	57	Para	20	3.9	0.044	173
NW03	20	50	Para	30	4.1	0.045	182
NW04	20	50	Para	30	6.2	0.054	333
NW05	20	50	Meta	30	2.8	0.063	175
NW06	20	50	Para	30	1.8	0.104	187

TABLE II Frame retardant test reslt of nonwoven

Sample ID	Nonwoven fabrics LMP PET SF (%)	Reg. PET SF (%)	Para- or Meta	Arami d SF (%)	Density (g/cm^3)	Mass per unit area (g/m^2)	Flame retardant ISO 10047
NW01	26	64	Para	10	0.046	184	burned-out
NW02	23	57	Para	20	0.044	173	self-extinguishing
NW03	20	50	Para	30	0.045	182	self-extinguishing
NW04	20	50	Para	30	0.054	333	self-extinguishing
NW05	20	50	Meta	30	0.063	175	burned-out
NW06	20	50	Para	30	0.104	187	burned-out

TABLE III Manufacturing conditions of nonwoven

	Nonwoven fabrics						Para-Aramid Paper	
Sample ID	LMP PET (%)	Reg. PET (%)	Para-arami (%)	Thickness (mm)	Density (g/cm^3)	Mass per unit (g/m^2)	Permeability (cc/sec/cm^2)	Mass per unit area (g/m^2)
NW07	20	50	30	12	0.030	356	–	–
NWP1	20	50	30	12	0.030	356	37	28
NWP2	20	50	30	12	0.030	356	65	28
NWP3	20	50	30	12	0.030	356	368	28
NWP4	20	50	30	12	0.030	356	19	36
NWP5	20	50	30	12	0.030	356	24	36
NWP6	20	50	30	12	0.030	356	36	36
NWP7	20	50	30	12	0.030	356	303	36
NWP8	20	50	30	12	0.030	356	320	36
NWP9	20	50	30	8	0.064	509	24	36
NWP10	20	50	30	10	0.048	476	24	36
NWP11	20	50	30	16	0.430	692	24	36
NWP12	20	50	30	32	0.430	1384	24	36

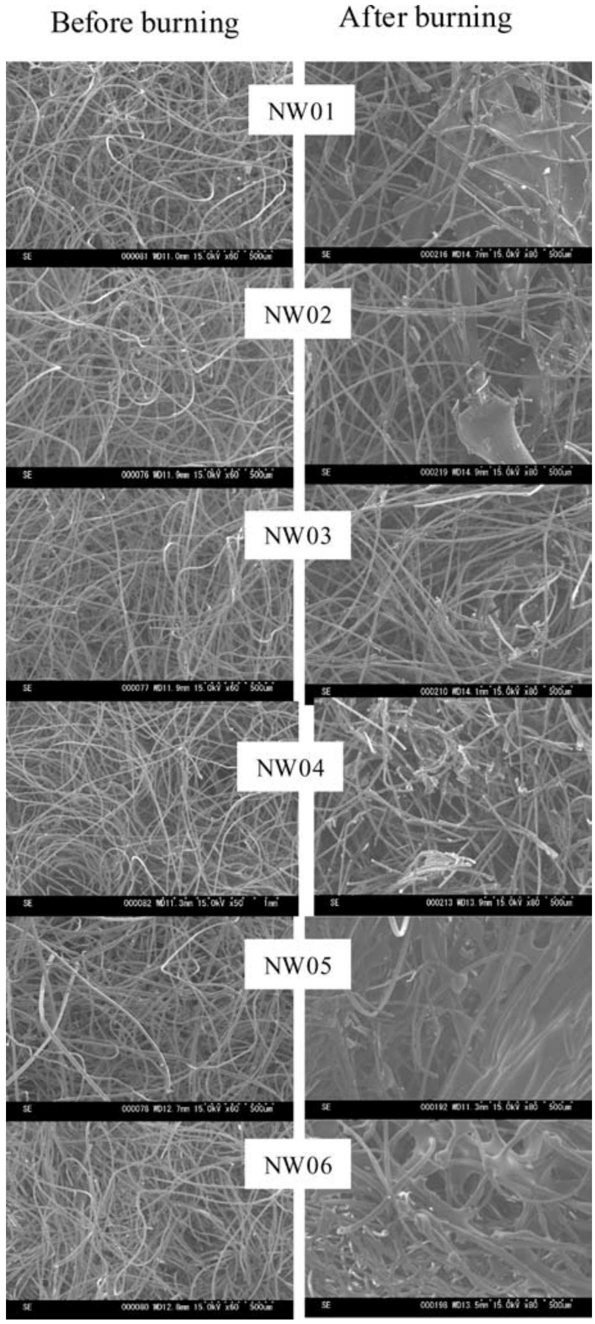

Photo 1 SEM photo of nonwoven burning test.

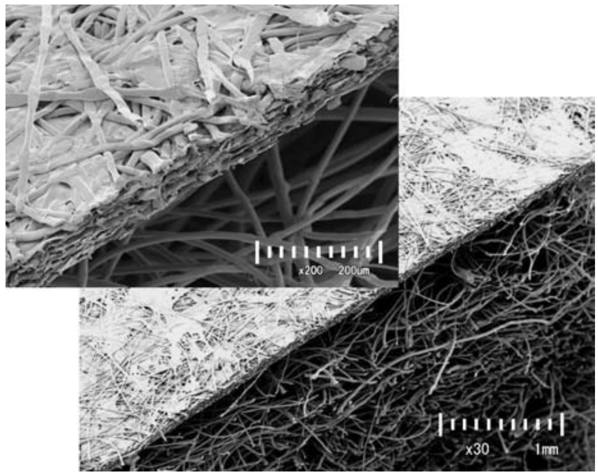

Photo 2 SEM Photo of cross section Paper attached on nonwoven.

fabric, on which thermal melting glue was sprayed in a hot air bonding machine where the glue was set to an air temperature of 130°C at a feeding speed of 5 m/min and with a 150 cm bonding area.

Table III shows the sample identifications for measuring flame retardancy, sound absorption, and sound permeation loss properties according to the difference of fibre contents, nonwoven fabric density, and paper permeability.

Thickness of paper was designed to around 70 μm, and was showed in Phot.2, which showed a cross section of aramid paper attached on nonwoven.

4.2. Results and discussion

(1) Permeability vs. sound absorption

As an illustration, Fig. 1 shows the effect of aramid paper permeability for normal incidence sound absorption at mass per unit area of paper of 27.5 g/m^2. By attaching pre-calendar aramid paper with permeability of 368 cc/sec/cm^2 on the nonwoven fabric NW07, the sound absorption of NWP3 was about 10% better over 2000 Hz than the nonwoven fabric NW07. But by attaching calendared aramid paper with permeabilities of 37 cc/sec/cm^2 and 65 cc/sec/cm^2 on the same non-

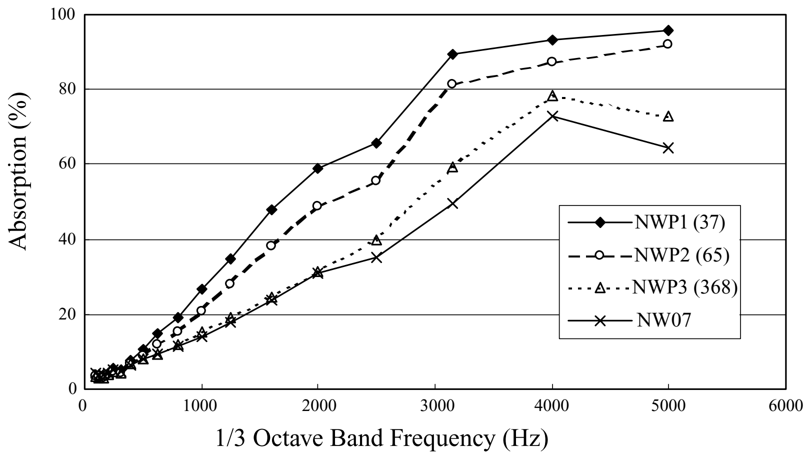

Figure 1 Paper permeability vs. normal incidence sound absorption (Mass per unit area of paper 27.5 g/m^2).

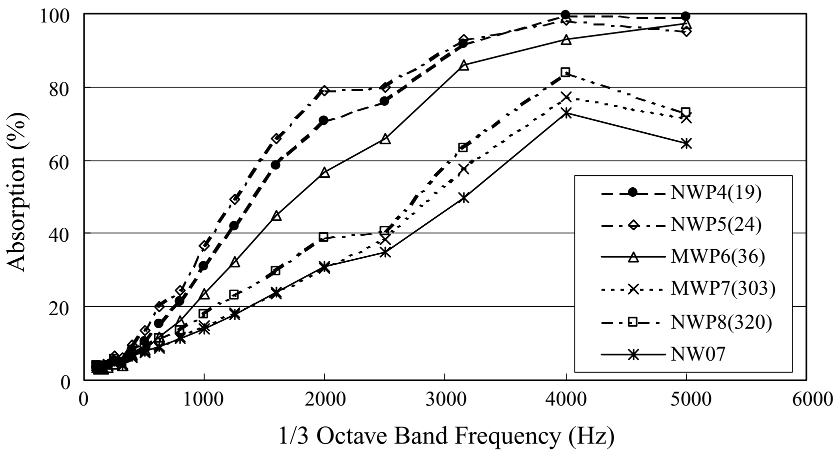

Figure 2 Paper permeability vs. normal incidence sound absorption (Mass per unit area of paper 36 g/m^2).

woven fabric NW07, the sound absorption of NWP1 and NWP2 increased considerably over approximately 800 Hz than NW07.

Fig. 2 shows the effect of aramid paper permeability for normal incidence sound absorption at mass per unit area of paper of 36 g/m^2. By attaching pre-calendar aramid paper with permeability of 303 cc/sec/cm^2 on the nonwoven fabric NW07, the sound absorption of NWP7 was about 7% better over 2500 Hz than NW07. And by attaching pre-calendar aramid paper with permeability of 320 cc/sec/cm^2 on the nonwoven fabric NW07, the sound absorption of NWP8 was about 3–10% better over 1500 Hz than the nonwoven fabric NW07. However, by attaching calendared aramid paper with permeability of 24 cc/sec/cm^2, 19 cc/sec/cm^2 and 36 cc/sec/cm^2 on the same nonwoven fabric NW07, the sound absorption of NWP5, NWP4 and NWP6 increased considerably over approximately 800 Hz than NW07.

From the results of Figs 1 and 2, it was shown that normal incidence sound absorption of paper attached on the nonwoven was strongly affected by the paper's permeability. In order to see an effect of mass per unit area of paper for the normal incidence sound absorption, the better lines of Figs 1 and 2: NWP1, NWP4 and NWP5 were put together in Fig. 3, where there was no difference regarding sound absorption between mass per unit area 28 of NWP1 and 36 g/m^2 of NWP6 for the paper permeability 36–37 cc/sec/cm^2. So the mass per unit area of paper did not play an important role from 28 to 36 g/m^2. Fig. 3 shows also that there was no difference between the normal incidence sound absorption of paper permeability 19 of NWP4 and 24 cc/sec/cm^2 of NWP5.

It was disclosed recently in applications for sound absorber made of thermal melting fibre [4–6] that suitable permeability ranges of surface layer were as follows.

Permeability	Nonwoven
0.05–100 cc/sec/cm^2	filament yarn[4]
1.5–10 cc/sec/cm^2,	SF + resin[5]
10–100 cc/sec/cm^2,	SF[6]

It might be difficult on press heating mold process to keep suitable permeability by using the above-mentioned nonwoven as surface layer, because easily deformation of the thermal melting fibre might result in change of permeability. So that sound absorption might vary widely over molded sound absorber. But permeability of aramid paper will not change, as the aramid paper will not be deformed during molding process.

Fig. 4 shows an effect of thickness of nonwoven was measured while keeping permeability 24 cc/sec/cm^2 and mass per unit area 36 g/m^2 of the calendared aramid paper (PAPER) of NWP5. By increasing the thickness of the nonwoven, the absorption of the

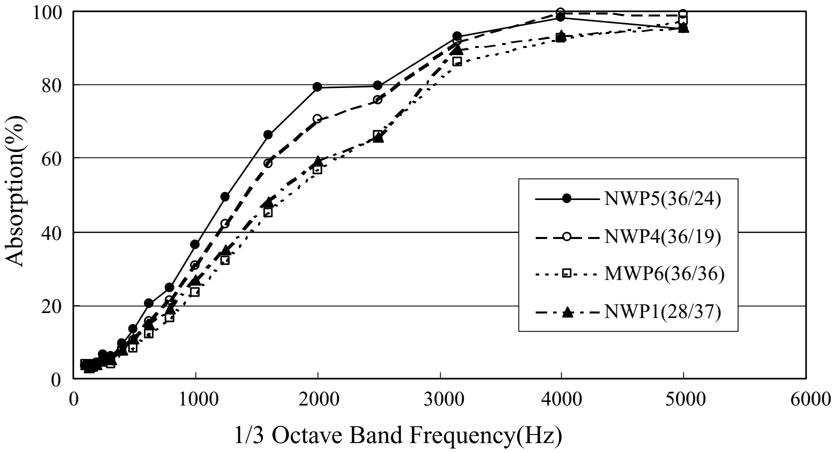

Figure 3 Paper permeability vs. normal incidence sound absorption.

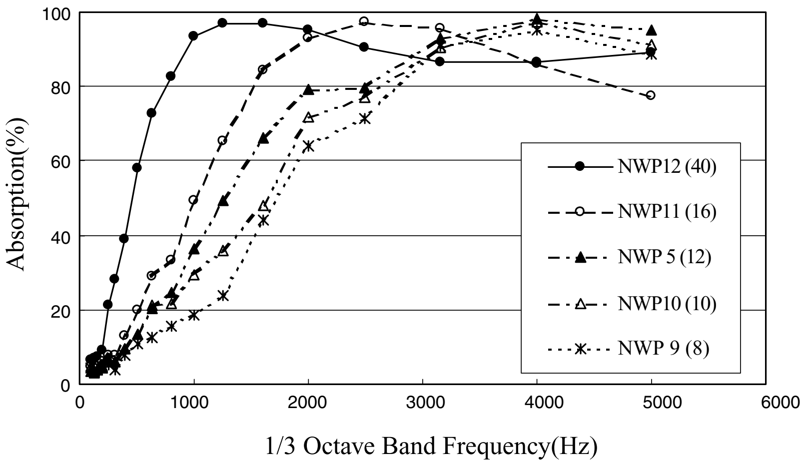

Figure 4 Nonwoven thickness vs. normal incidence sound absorption (PAPER: 24 cc/sec/cm^2, 36 g/m^2).

normal incidence sound absorption increased from lower frequency.

(2) Comparison with glass wool

The best line of PAPER attached on nonwoven fabric NWP5 in Fig. 3 and thicker nonwoven sample NWP11 were compared to glass wool with glass fabric at normal incidence sound absorption method in Fig. 5, where NWP5: 12t was almost the same with 20t glass wool and NWP11: 16t was almost the same with 25t glass wool except higher frequency.

We also evaluated NWP5, NWP11 and 25t glass wool by using "Method for measurement of sound absorption coefficients in reverberation room" (JIS A 1409:1998), which is a kind of random incident method and a more actual method than "normal incidence sound absorption". The result is showed in Fig. 6. NWP5: 12t was higher absorption over 1200 Hz than 25t glass wool. And NWP11: 16t was almost the same

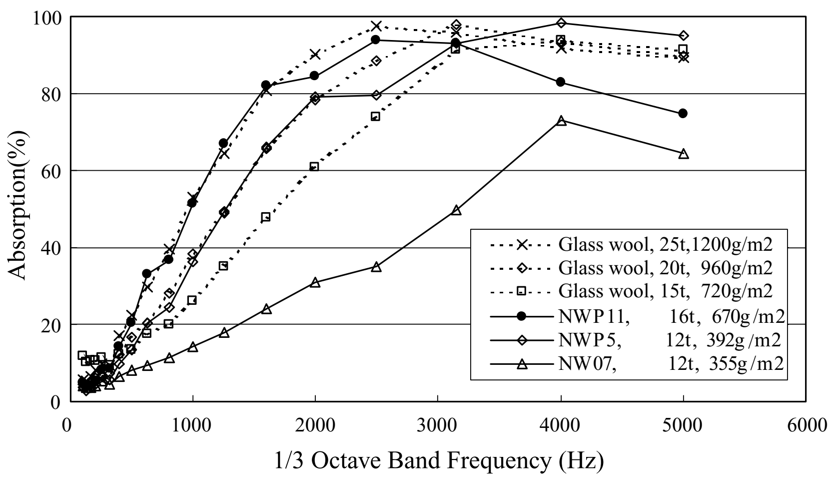

Figure 5 Normal incidence sound absorption (PAPER attached on nonwoven vs. Glass wool).

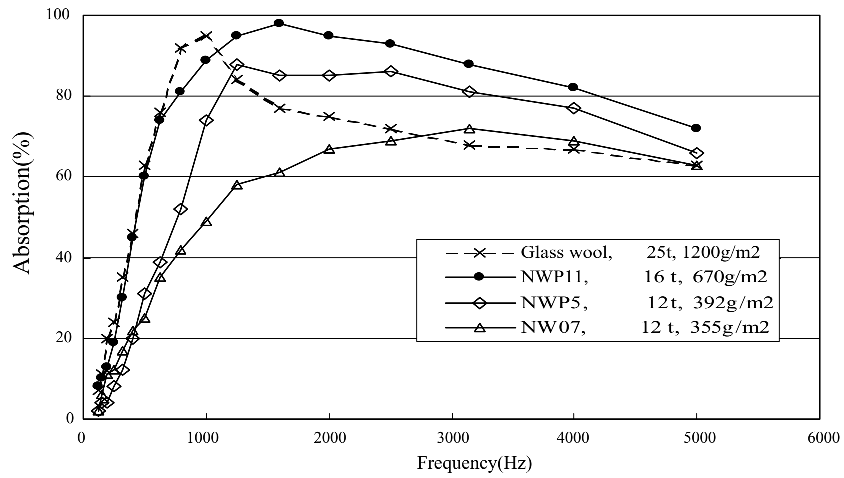

Figure 6 Method for measurement of sound absorption coefficients in reverberation room (PAPER attached on nonwoven vs. Glass wool).

with 25t glass wool at lower frequency and was higher absorption over 1200 Hz than 25t glass wool.

Fig. 6 shows that an effect of the PAPER attaching to the nonwoven: NW07 was improvement of sound absorption from 800 to 4500 Hz and was almost the same effect showed in Fig. 5. But there was a difference between sound absorption effect of "Method for measurement of sound absorption coefficients in reverberation room" and "Normal incidence sound absorption method" for comparing NWP11 and Glass wool.

Although Fig. 5 showed that sound absorption of NWP11 was less than Glass wool on "Normal incidence sound absorption method," Fig. 6 showed that sound absorption of NPW11 was greater than Glass wool over 1000 Hz on "Method for measurement of sound absorption coefficients in reverberation room." The correlation between "Normal incidence sound absorption method" and "Method for measurement of sound absorption coefficients in reverberation room" was studied [6]. Actually, "Method for measurement of sound absorption coefficients in reverberation room" might be used for adopting a sound absorber.

The reason why the "Normal incidence absorption" was improved by attaching paper with low permeability and also "Method for measurement of sound absorption coefficients in reverberation room" was improved from lower frequency was not clearly understood. One possible reason is as follows: Sound travels in waves, goes through the small holes of the paper and then goes into the nonwoven part, where sound waves are scattered between the paper and steel back plate, and air vibrations of the waves are transferred to short fibre vibrations, which result in thermal diffusion. As the sound waves were cooped between the paper and back plate, air viscosity of the waves among fibres of nonwoven might be increased. It might result in energy dispersion of the waves. Also as air compression and expansion of the sound waves might occur through small holes of paper into the nonwoven, the energy dispersion might occur.

In case of nonwoven fabric and glass wool, sound absorption might be created mostly by air viscosity of waves in the medium. But, in case of PAPER attached on the nonwoven; RUBA®, sound absorption might be created not only by air viscosity of waves in the medium and also by air compression and expansion of waves through PAPER. We have tested "Method for measurement of sound absorption coefficients in reverberation room" about <PAPER + nonwoven (PET100 g/m^2) + PAPER + nonwoven (PET200 g/m^2)> by comparing <PAPER + nonwoven (PET100 g/m^2) + nonwoven

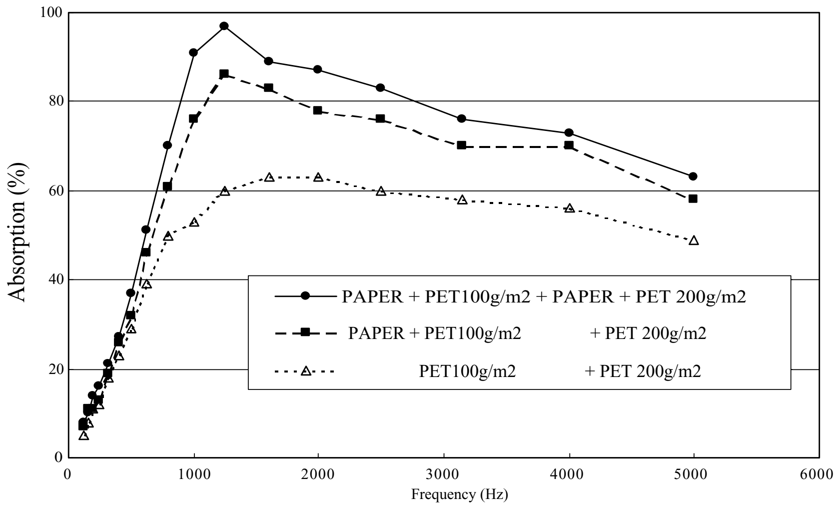

Figure 7 Effect of PAPER insertion into nonwoven fabric (PAPER with permeability 24 cc/sec/cm^2 and mass per unit area 36 g/m^2.

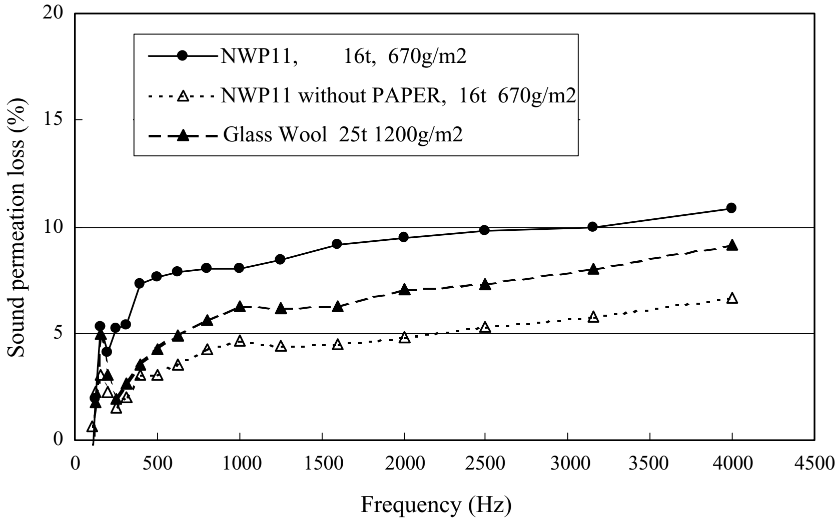

Figure 8 The sound permeation loss of aramid PAPER.

(PET200 g/m^2)>, where the calendared aramid PAPER with permeability 24 $cc/sec/cm^2$ and mass per unit area 36 g/m^2 was used. Fig. 7 showed the effect of PAPER insertion into nonwoven fabric that sound absorption was improved by inserting PAPER. This test result backed the above-mentioned hypothesis that sound absorption improvement by attaching PAPER is created mainly by air compression and expansion of waves through paper.

We evaluated the sound permeation loss of aramid PAPER attached to nonwoven fabric. The Fig. 8 showed that sound permeation loss increased from around 300 Hz versus the nonwoven and glass wool. The sound permeation loss is regarded as in proportion to mass of the medium, but aramid PAPER attached on nonwoven increased the sound permeation loss. This result baked also the above-mentioned hypothesis that sound absorption improvement by attaching aramid PAPER is created mainly by air compression and expansion of waves through paper.

5. Conclusions

We have determined that the best-nonwoven material is composed of a mix of para-aramid staple fibres and PET staple fibres keeping a lower weight ratio of aramid fibre to meet FMVSS02. And also we have determined that the combination of aramid PAPER and nonwoven delivers excellent sound absorption property, which is better than conventional glass wool. By attaching para-aramid paper with less than 30 $cc/sec/cm^2$ permeability to a nonwoven fabric, the sound absorption over 2000 Hz was better than that of glass wool. The sound absorption improvement by attaching aramid PAPER is created mainly by air compression and expansion of waves through PAPER might be verified.

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