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Influence of bonding compression and air gap on the acoustic absorption of spunbond–resinated felt composites

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Abstract

Spunbond-resinated felt is a common composite material used for automotive purposes. Reducing vehicle noise requires lightweight, cost-effective sound-absorbing materials. This study focuses on researching more lightweight and low-cost materials through examining how bonding compression and an air gap affect the acoustic absorption of Spunbond–Resinated felt composites with varying grammage (800–1400 g/m²) and thickness (15–22 mm). The novelty of this research is in the use of lower grammage and the existence of an air gap compared with the existing product and previous study. Acoustic absorption tests were conducted using an impedance tube with air-gap depths of 0, 10, and 15 mm behind the samples. Additional tests were conducted on compressed samples, 50% of the original thickness, to observe the effect of increased density. Results show that felt with 1200 g/m² provides the best overall absorption. Thickness compression reduces absorption by approximately 13–23%, whereas the introduction of an air gap significantly enhances absorption, particularly for lower-grammage materials. Notably, an 800 g/m² felt combined with a 15 mm air gap outperformed a 1400 g/m² felt without an air gap. These findings demonstrate that appropriate grammage and air gap design can enhance sound absorption, enabling lighter materials such as 800–1000 g/m² felt to meet noise-reduction requirements.

Keywords:
Composite, resinated felt, compression, air gap, NRC, sound absorption.

1 Introduction

The phenomenon of sound propagation in air is influenced by several parameters, including temperature, barometric pressure, and humidity, all of which have been thoroughly studied [1] [2]. In the context of vehicle cabins—enclosed spaces with controllable temperatures—noise has become a major concern for researchers focusing on soundproofing and acoustic comfort. Studies have shown that interior noise levels in passenger cars can reach up to 90 dB, which poses a health risk to occupants [3]. Major sources of noise in vehicles include engine vibrations, tire-road interactions, and aerodynamic wind noise [4]. Therefore, sound insulation in areas such as the engine compartment plays a crucial role in noise control strategies. In automotive design, the integration of additional materials for sound insulation is challenged by the industry's emphasis on lightweight construction, which contributes to improved fuel efficiency and reduced emissions [5]. To meet both acoustic and manufacturing requirements, noise-reducing materials must possess several characteristics: broad-frequency sound absorption, mechanical durability, flame resistance, weather resistance, aesthetic appeal, ease of molding and cutting, and low density [6].

The Noise Reduction Coefficient (NRC), calculated as the arithmetic mean of the absorption coefficients at 250, 500, 1000, and 2000 Hz octaves, as shown in Eq. 1, is typically used to evaluate the effectiveness of sound-absorbing materials. A material is considered effective if it has an NRC value greater than or equal to 0.20, with materials used in practical applications often exceeding an NRC of 0.4 [7]:

$$NRC = (\alpha 250 + \alpha 500 + \alpha 1000 + \alpha 2000)/4 \tag{1}$$

Two standard laboratory methods are commonly used to evaluate the sound absorption performance of materials: the impedance tube method and the reverberation chamber, often referred to as the alpha cabin [8]. Several recent studies have explored advanced approaches, such as Finite Element Analysis (FEA), for noise prediction and modelling the acoustic effects of different materials under vibration-induced noise scenarios within a 20–200 Hz frequency range [9]. Zhenqing Liu et al. [10] employed computational air modelling to examine how various sound-absorbing materials placed on the interior trim affect in-cabin acoustics, using Statistical Energy Analysis (SEA) to simulate sound transfer paths.

1.1 Sound absorption mechanisms

Sound waves are classified as mechanical waves, requiring a physical medium (solid, liquid, or gas) to propagate. The process of sound absorption involves three main mechanisms: viscous effects, heat transfer, and vibrations in the fiber [11]. Sound absorption is a very well-known and commonly used solution to reduce noise over sound that is still caused by vibration. In fact, the best approach to controlling noise is to eliminate or reduce it at the source, either by direct action at the source or by action that limits it [12]. The sound absorption coefficient, α, is given by the ratio of the intensity of the sound absorbed by it. I_{Abs}, to the intensity of the incoming sound I_i, and depends on the angle of incidence and its frequency. The sound absorption coefficient can also be calculated by the ratio of energy, following Eq. (2) [13]. Where α is the coefficient absorption, E_A is absorption energy, E_I is incident energy (Fig. 1).

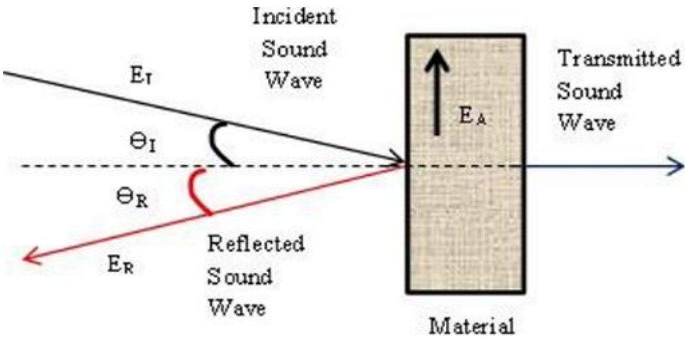


Fig. 1. Sound absorption scheme diagram in materials [13].

$$\alpha = E_A/E_I \tag{2}$$

1.2 Sound absorption materials and their characteristics

Materials that reduce acoustic energy as sound waves pass through them are known as sound-absorptive materials. The movement of air and friction dissipate some of the sound energy as heat [14]. Recent studies have shown that material density and backing conditions, including the presence of an air gap, can significantly change acoustic absorption [15]. It was found that the sound absorption coefficient increased when absorbent plastic fibers were combined with an air gap [16]. Acoustic impedance is responsible for a material's ability to reflect sound waves, influencing its sound absorption performance. Eq. 3 demonstrates how higher-density materials, due to their increased mass, improve sound absorption [17]. High-density materials provide a larger surface area per unit volume, effectively absorbing sound waves, especially those associated with porous fibers. The increased surface area of fibers results in higher friction loss, causing more energy to be dissipated as heat. Where ρ_0 is the density of air, c is the speed of sound in air, and R_N is the normal-incidence reflection coefficient.

$$Z = \rho_o c\,(1 + R_N)/(1 - R_N) \tag{3}$$

Several works have investigated porous resonators, foam, nonwoven composites, and fiber, both synthetic and natural materials [18][19][20][21][22]. But still, limited research has focused specifically on spunbond–resinated felt systems [23][24][25]. In current industrial practice, felts with different grammages are used as-is, without optimization of structural parameters such as bonding compression or backing cavity.

Previous models for predicting sound absorption coefficients have incorporated variables such as airflow resistivity, thickness, compressibility, composite density, fiber diameter, and bonding pressure. Nonwoven fabrics can significantly attenuate acoustic energy through their high porosity and small fiber diameter [26]. A decrease in the sound absorption coefficient was observed with increasing compression. For instance, the LHL fiber composite, which consists of a three-layer material (polylactic acid-hemp-polylactic acid), exhibited the greatest reduction in performance under compression due to significant changes in material thickness, as shown in Fig. 2 [27]. The performance of sound-absorbing panels is also affected by material homogeneity and thickness. Minor inconsistencies in the material can significantly influence [28].

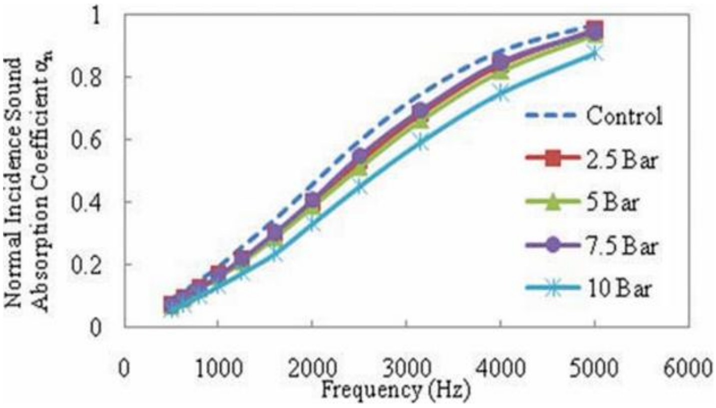


Fig. 2. Absorption coefficient of LHL composite materials [27].

In a related study, D. Siano [29] investigated the performance of various sound-absorbing materials, such as basalt wool, tetha cell, tetha fiber, and polyester, for engine insulation panels. The materials were applied under the nylon engine covers of diesel engines, and experimental tests revealed that polyester (600 g/m², 40 mm thick) provided a 2 dB reduction compared to the original material. Material thickness is one of the key factors influencing sound absorption. The thickness of a material is particularly relevant in the low and medium-frequency ranges but less significant for high frequencies. Thicker materials provide better wave absorption and reflect less energy, contributing to better sound absorption. Research indicates that greater material thickness leads to an increase in the average absorption coefficient [30].

A previous study by Samuel B.T., et al. [7] related to implementing an air gap, shown to enhance the NRC for all simulated sample woven fabrics, as summarized in Table 1.

In another study, the polyester fabric with a grammage of 623 g/m² demonstrated improved absorption performance when paired with a 20 mm air gap compared to the sample without an air gap. The air gap serves as a cavity that allows sound waves to pass through and reflect from the rigid backplate. This reflection enhances sound absorption, similar to increasing the thickness of the material [31].

Specifically, this research examines sound absorption in composites made from Spunbond (nonwoven PET) combined with Resinated felt (recycled denim), although these materials have been individually explored for acoustic insulation, the combination of them remains underreported. Furthermore, studies investigating the simultaneous effects of material density by bonding compression and air gap configuration on acoustic performance are limited. This study addresses both gaps by developing and evaluating composite panels with controlled density and air gap variations, offering novel insights into the design of acoustic materials. This study investigates how changes in grammage, thickness, bonding compression, and the presence of an air gap influence the acoustic performance of these materials. The grammages of materials vary from 800 to 1400 g/m² and are observed within a frequency range of 80-6300Hz.

Table 1. NRC comparison-air gap effect [7]

Sample	Single woven	Single woven+air gap
TP	0.05	0.53
TR	0.05	0.46
TS	0.05	0.42
TT	0.05	0.44
SP	0.05	0.52
SR	0.05	0.36
SS	0.05	0.35
ST	0.05	0.43
TWP	0.05	0.49
TWR	0.04	0.46
TWS	0.04	0.42
TWT	0.04	0.42

2 Materials and methods

2.1 Materials

Resinated felt is a sound-absorbing material made from natural or synthetic fibers, which are compacted and bonded together using resin. The resin adds strength, stability, and improves the material's ability to absorb sound. The semi-cured resinated felt used in this study is a product derived from Oceancash Felt, a denim-based material. Denim, typically used for manufacturing jeans, is processed into felt like other felt materials, providing several advantages in terms of strength and durability [32].

In this study, Spunbond is a PET-based nonwoven material from Hasil Damai Tekstile. The Spunbond process involves spinning polyester fibers into fine fibers, which are then arranged and compacted into sheets or fabrics without weaving or knitting. The PET-based material is dense and elastic, providing a good balance between strength and flexibility [25]. Spunbond's sound-absorbing capacity is particularly effective at higher frequencies. However, its ability to dampen sound is not as strong as denser materials such as wool. Nonetheless, Spunbond can be used as an additional layer in acoustic systems, offering resistance to moisture, fire, and degradation, making it suitable for automotive applications.

2.2 Sample preparation

The objective was to evaluate the sound absorption of composite materials made from a combination of PET-based spunbond with a fixed grammage of 30 g/m² and denim-based resinated felt with various grammages of 800, 1000, 1200, and 1400 g/m², and each material thickness is 15, 18, 20, and 22 mm. It was bonded by hot compression, which DFK plastic dry was using as an adhesive. The process was conducted manually by arranging the two ingredients above the dies. This can be seen in Fig. 3. For evaluating bonding compression, two conditions are prepared in this process: compression with felt in its original thickness and felt compressed to approximately 50% of its original thickness.

This research is quantitative and was conducted through an experimental study approach. The total samples are presented in Table 2.

Table 2. Combination test sample

Resinated felt (g/m^2)	Felt thickness (mm)	
	Original material	Sample
800	15	15
800	15	7.5
1000	18	18
1000	18	9
1200	20	20
1200	20	10
1400	22	22
1400	22	11

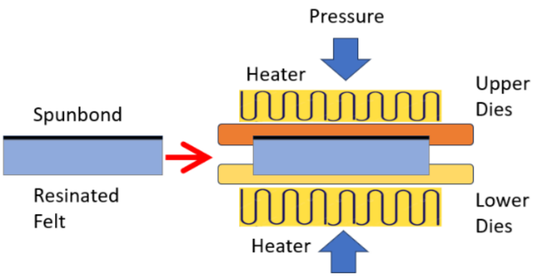


Fig. 3. Illustration of bonding compression.

2.3 Test method

The sample was measured according to the ISO 10534-2 standard using the Bruel & Kjaer impedance tube, BSWA model SW 477 and SW 422 for evaluating the absorption coefficient. Fig 4. Illustrates the impedance tube testing.

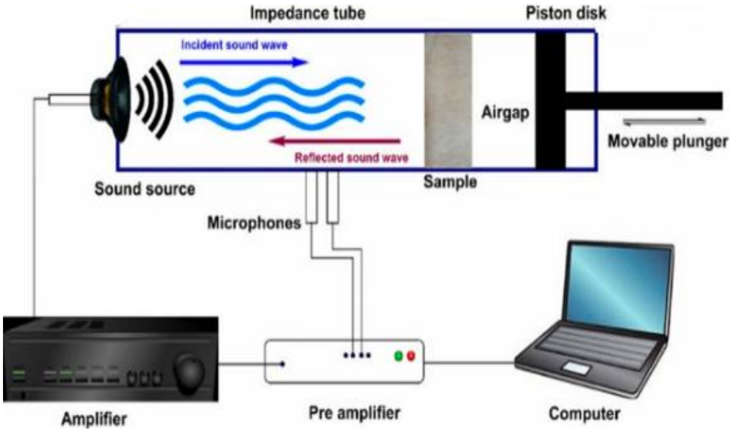


Fig. 4. Testing impedance tube [33].

The absorption coefficient is measured below the normal sound incidence, the frequency range is 80–6300 Hz, and the sample is laid with the difference of air gap against the hard wall whose sizes: 0, 10, and 15 mm, placed behind the sample during testing. This test was carried out using noise testing laboratory equipment from the manufacturer that specializes in the production of noise and heat-absorbing parts.

2.4 Data analysis

Each variant sample was tested three times to avoid biased data. The noise coefficient data of each variant test sample were plotted in a graph across the frequency range and compared to determine the optimum one that is more effective for noise absorption along the range. Determine the frequency range that provides more effective performance compared to others.

The NRC for each sample was calculated and compared among all the samples. Noted that the NRC value, which achieves the target based on the effect of bonding compression and the existence of an air gap for each felt's grammage specification.

3 Results

3.1 Result of the coefficient in different grammage and thickness

The results of the sound absorption coefficient for each resinated felt sample, with different grammages and original thicknesses, are presented in Fig. 5. Notably, all samples demonstrated better effectiveness in the mid-range to high frequency, above 1 kHz, confirming that the spunbond-resinated felt composite structure functions optimally under these conditions. Unfortunately, found that felt with a grammage of 1200 g/m² and a thickness of 20 mm was the best one for a wide range of frequencies. However, an anomalous dip in sound absorption was observed near 500 Hz for samples with 800 and 1000 g/m² grammage.

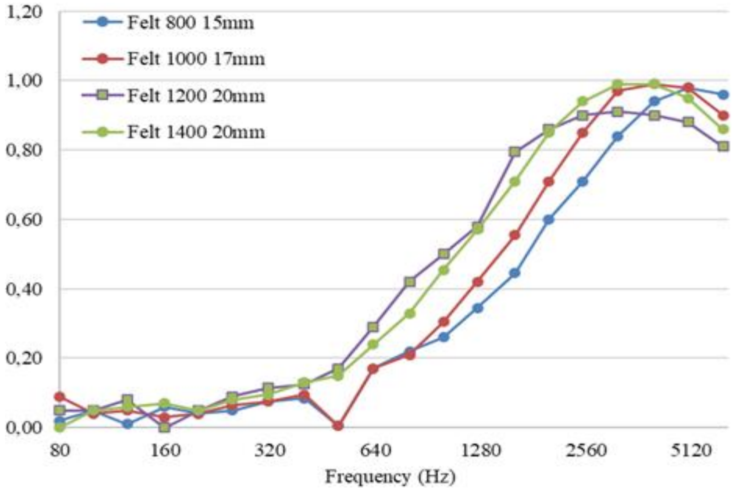


Fig. 5. Comparison of sound absorption coefficient at the original thickness of the felt.

The results of the sound absorption coefficient for each resinated felt sample with different grammages and compressed 50% thicknesses are presented in Fig. 6. It was shown that all samples also demonstrated better effectiveness in the mid-range to high frequency range, above 1 kHz. Higher grammage materials have superior absorption at this range of frequencies compared to others. Noted that at 160Hz is anomalous for felt 1200 g/m², it was the same anomalous phenomenon as Fig. 6 in a different effect.

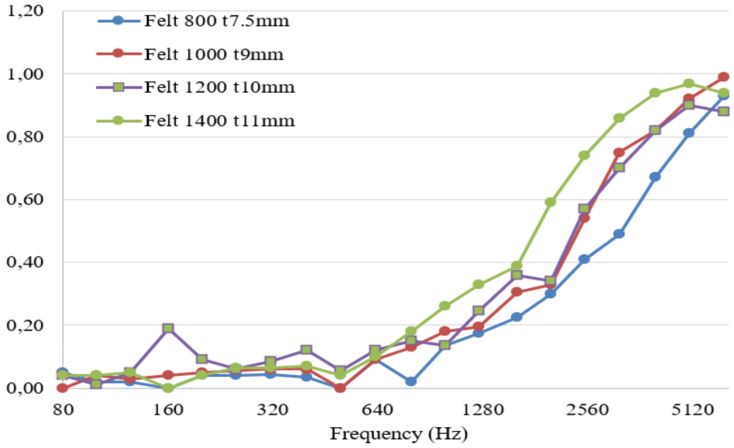
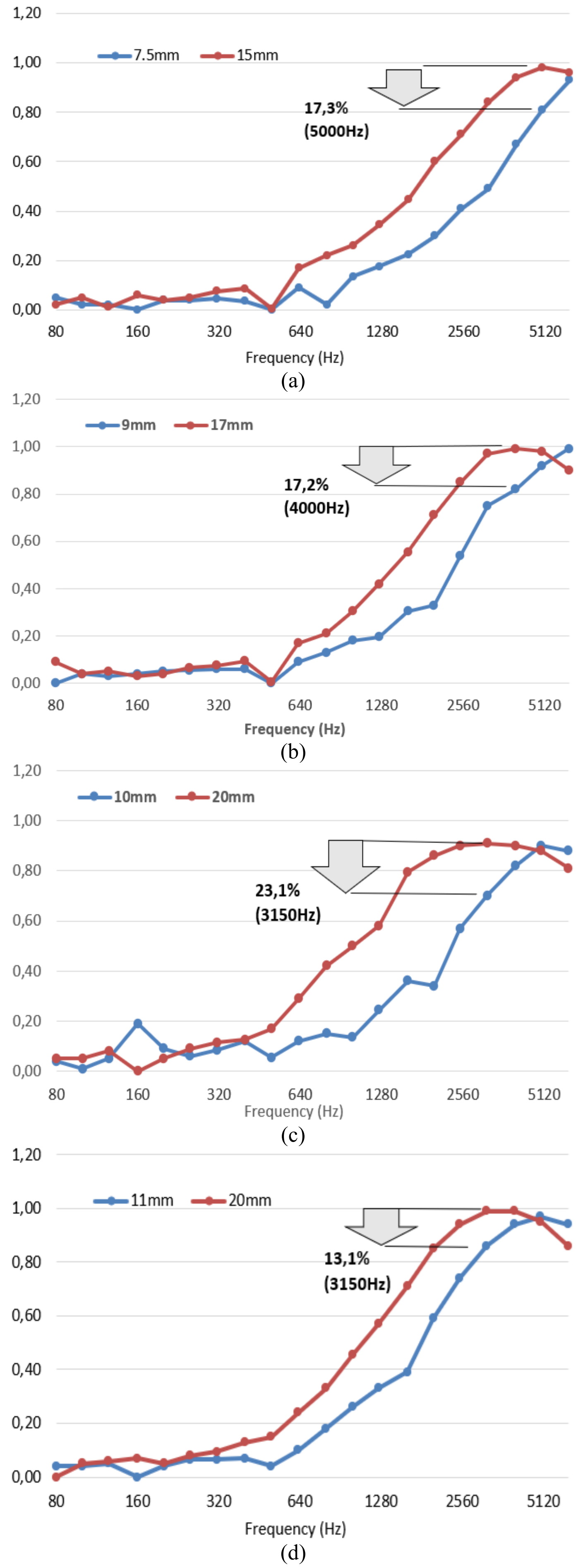


Fig. 6. Comparison of sound absorption coefficient at compressed thickness of 50% of the felt.

3.2 The effect of bonding compression

The bonding compression effect was examined by reducing the original thickness of the resinated felt by approximately 50%. It is shown in Fig. 7(a), Fig. 7(b), Fig. 7(c), and Fig. 7(d).

This compression reduced the absorption coefficient by up to 17%, especially at high and mid frequencies. Felt with 800 g/m² grammage exhibited a reduction in performance at optimum frequencies, 5 kHz, and 4 kHz for 1000 g/m² grammage. The higher grammages felt 1200 and 1400 g/m², both the optimum frequencies are the same around 3 kHz, but the reduction is significantly different 23% for 1200 g/m², and 13% for 1400 g/m² grammages. Reduction performance significantly occurred at felt 1200 g/m².



(a)

(b)

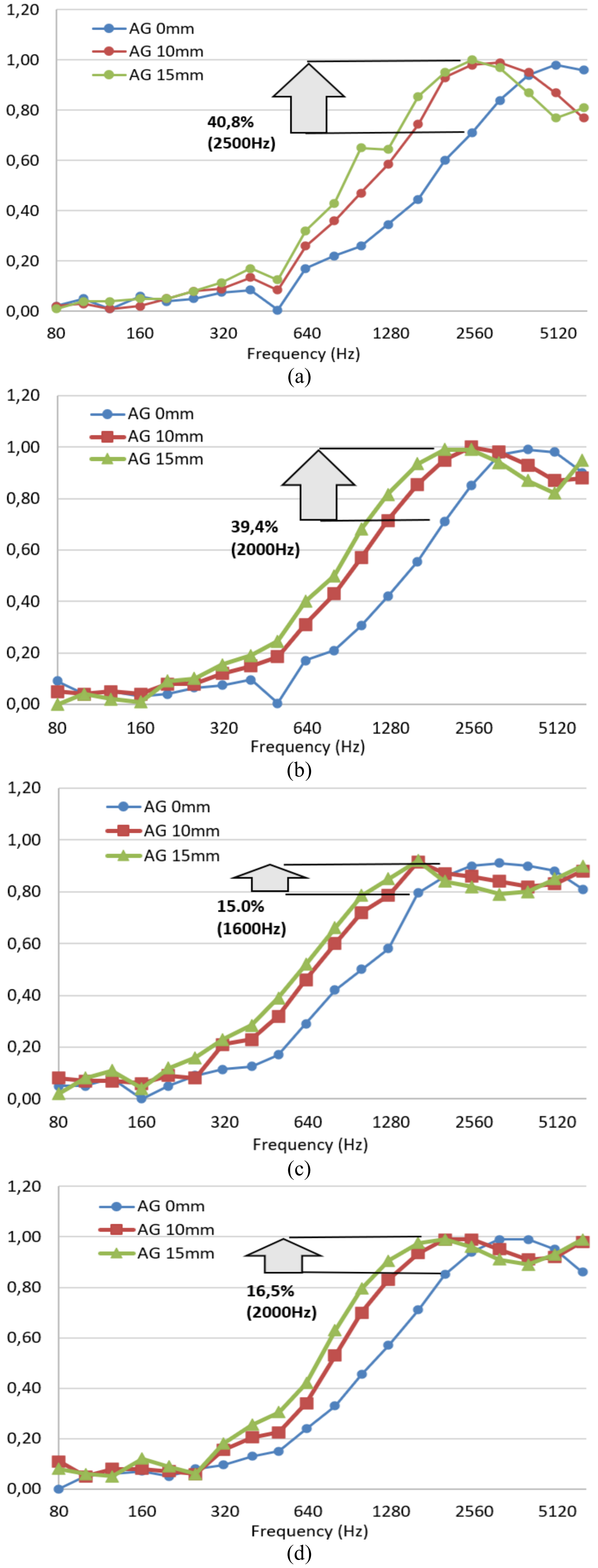
(c)

(d)

Fig. 7. Comparison of the coefficient of noise absorption–compression effect for each felt: (a) 800, (b) 1000, (c) 1200, (d) 1400 g/m².

3.3 The effect of air gap

The addition of an air gap behind the composite layer does not increase the maximum value of the sound absorption coefficient; however, it causes a shift in the material's effective absorption frequency toward the lower end of the spectrum, as shown in Fig. 8(a), Fig. 8(b), Fig. 8(c), and Fig. 8(d).



(a)

(b)

(c)

(d)

Fig 8. Comparison of the coefficient of noise absorption–air gap effect for each felt: (a) 800, (b) 1000, (c) 1200, (d) 1400 g/m².

It was found that when a 10 mm or 15 mm air gap was introduced, especially behind the lower grammage felts (e.g., 800 g/m^2), there was a clear increase in absorption performance of up to 40% at 2.5 kHz, even surpassing the performance of higher grammage, 1400 g/m^2 felts without an air gap.

3.4 NRC comparison

The result of the calculation of NRC was presented in Table 3. NRC value represents the noise absorption ability in the octave range of humans, which could be inconvenient. It shows that some of the variants had not achieved the coefficient target, below 0.20.

Table 3. NRC of spunbond-resinated felt, a comparison of different air gaps and compression, 50% of the original thickness

Felt (g/m^2)	Sample compressed by 50% of the original thickness				Sample compressed in the original thickness			
	Thickness (mm)	Air gap (mm)			Thickness (mm)	Air gap (mm)		
		0	10	15		0	10	15
800	7.5	0.12	0.33	0.40	15	0.23	0.39	0.45
1000	9	0.14	0.37	0.47	17	0.27	0.45	0.50
1200	10	0.15	0.50	0.54	20	0.41	0.50	0.54
1400	11	0.24	0.44	0.51	20	0.38	0.49	0.51

4 Discussion

As demonstrated in Fig. 6, it was confirmed at the original thickness that the PET-based spunbond-resinated felt composite structure functions optimally under mid-to-high frequencies. Higher grammage materials (e.g.,1400 g/m^2 with 20 mm thick) exhibit superior absorption at this range of frequencies compared to others. This is attributed to the greater mass per unit area, which enhances the material's performance to attenuate sound reflection and resonance. Similarly, increased thickness contributes to better performance because low-frequency sound waves, which have longer wavelengths, require thicker materials to be effectively dissipated through internal friction and pore resonance, this is strengthens the previous study [30].

Related to an anomalous dip in sound absorption was observed near 500 Hz for samples with 800 g/m^2 and 1000 g/m^2 grammage. This phenomenon could be explained by acoustic interference within the impedance tube system, as supported in the literature [1]. Certain resonant interactions between porous materials and the test apparatus may cause localized peaks or dips in absorption, affecting accuracy at specific frequencies. These resonances can amplify sound absorption at some points while suppressing it at others, particularly in the transition region between low and mid frequencies.

At the compression 50% thickness, indicated in Fig. 6, the felt with a grammage of 1200 g/m^2 and a thickness of 20 mm was the best one for a wide range of frequencies. It was indicated that this specification matches the optimum absorption. The porosity is in the best condition, so the air resistivity is also best. On the other hand, the felt with 1400 g/m^2 was slightly down.

From Fig. 7, the comparison coefficient as an effect of bonding compression, it was also concluded that compression has led to a decrease in the sound absorption performance. Density up causes permeability or resistivity up, and it blocks the wave from coming into the porous holes across the materials. Reduction performance significantly occurred at felt 1200 because the felt characteristic is the optimum one in the original thickness. Compressing to 50% destroys and breaks its porous structure. Even though it was better compared to 1000 and 800 Felt with the same compression treatment. Felt with a grammage of 1400 has enough strength to keep its structure. Therefore, the compression does not have a significant impact on reducing its performance in sound absorption.

This reduction can be attributed to the loss of porosity and airflow pathways within the material structure. When compressed, the fiber density increases, limiting the viscous friction and thermal interaction that are crucial for absorbing sound energy in porous materials. These findings support previous studies, S. Amares et al. [13], Compression typically decreases sound absorption, especially for LHL composites with large thickness variations.

Relate to the effect of implementing an air gap that improved the absorption, this phenomenon occurs because the air gap functions as a passive resonator, enhancing the material's performance at low frequencies by increasing the propagation distance and extending the interaction path of the sound waves with the absorbing medium. This is explained by the Helmholtz resonance effect, where the air cavity acts as a resonant absorber, enhancing the absorption at specific frequencies, mainly in the low to medium range. The air gap serves to extend the effective thickness of the material system and increases the path length for sound waves, which facilitates better energy dissipation [31].

Numerical analysis concluded by calculating the coefficient from some octave, determined as NRC (average sound absorption coefficient value at 250, 500, 1000, and 2000 Hz), showing a significant improvement. Comparison of NRC values has the same indication that increasing density through bonding compression reduces 50% thickness was dissipating the sound absorption capability of the material, shown by the NRC values, which are below 0.2, except for felt with grammage 1400 g/m^2, which was 0.24. All the samples indicated a drop after the maximum of the sound absorption value, which was at high frequencies. This phenomenon was normal for porous fibrous materials.

On the other hand, implementing an air gap has a significant improvement. This study result shows that the performance of lower grammage material has the possibility of being better compared to higher ones by implementing an air gap. For example, the material grammage 800, thickness 15 mm, with an air gap of 15 mm, has NRC 0.45. It is better than material grammage 1400, thickness 20 mm, with an air gap 0 mm, the NRC was 0.38. The NRC data also shows that Felt 1200 has superior noise absorption performance both with compression 50% and without compression.

5 Conclusions

Noise absorption of spunbond-resinated felt with a grammage range of 800-1400 g/m^2 shows as a proper material for noise absorption. The felt with grammage 1200 g/m^2 in original thickness 20 mm has the best performance, indicating that its porous structure and the thickness were matched to the wider band frequencies. The structure was optimum resistivity, and it looks like 20 mm thick matches the ¼ wavelength of the sound. Higher grammages tend to start decreasing due to the possibility that air resistivity decreases, then loss of sound energy contact at its porous structure. An increasing density through the bonding compression with a reduction of 50% of its thickness reduced the absorption performance, causing the destruction and breaking of its porous structure. The only felt with grammage 1400 g/m2 even drops the performance, which could be kept better with NRC 0.24. Implementing an air gap has a positive result. A 15 mm air gap effectively improves the coefficient up to 40% at 2.5 kHz for 800 g/m^2 felt at the original thickness material. The noise coefficient reduction, reaching up to 97%, from 0.23 to 0.45. It concluded that implementing an air gap can achieve reducing the sound even better than the highest specification material, 1400 g/m^2. This provides valuable guidance for designers seeking cost-efficient and lightweight acoustic solutions. Manufacturability of the felt with a lower specification and its actual noise reduction in the cabin by implementing an optimum air gap thickness needs to be further observed.

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