CHAPTER 11

ACOUSTICAL PROPERTIES OF SANDWICH STRUCTURES DEVELOPED FROM CHICKEN FEATHER RACHIS MATERIAL

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1. INTRODUCTION

Noise as an air pollution is one of the most negative effects of industry as well as air pollution and water pollution. The fight against noise, which causes many health problems both physiologically and psychologically, has become one of the most important aspects of providing a healthy living and working environment.

Numerous sound insulation materials based on different principles have been developed to solve the noise problem.Among these materials the multi-layer constructions with sandwich structure form a group. There are studies in the literature about the ordinary sandwich construction sound insulationmaterials. In these studies, the effects of different characteristics of multilayer structures on the sound insulation properties have been investigated.

In his experiments on three-layered structures, Davern achieved the following result; the acoustic impedance of the material and the sound absorption coefficient depend on the porosity and density of the layers at considerable levels (Davern, 1977). Multilayer structures have been identified by their constructive analysis, in which the sound insulation properties of these structures are determined by their construction at significant levels. Dunn and Davern have made such an assumption by making an analytical analysis of three-layered echo-canceling porous materials that the outer layer should encourage the sound waves to enter the composition and the inner layers should provide sound energy reduction (Dunn &Davern, 1986).

An important component of multilayer sound insulation materials is the nonwoven surfaces. Numerous studies have been done starting from Zwikker and Kosten related to the sound absorption properties of nonwoven surfaces. (Zwikker&Kosten, 1949). These studies have shown that the porous materials exhibit high sound absorption coefficients at high frequencies, and low sound absorption coefficients at low and medium frequencies.

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In other words, porous nonwoven surfaces generally do not have the ability to absorb sound over a wide frequency range (Li et al., 2012).Accordingly, a number of studies have been carried out in order to improve the sound absorption properties of porous materials at medium and low frequencies. Some of these studies are related to the modeling of sound absorption of porous materials (Delany &Bazley, 1970;Allard &Champoux,1992; Allard et al., 1993;Narang, 1995; Voronina, 1996; Shoshani&Yakubov, 1999;Shoshani&Yakubov, 2000;Shoshani&Yakubov, 2000). Due to these studies it was possible to develop effective materials for sound absorption. The studies on the material thickness, density and porosity, the amount of fibers in the material, characteristics of the fibers, orientation, shape of the material surface, fiber content of the material have provided the significant improvement of the sound absorption properties of nonwoven surfaces(Lee &Joo, 2004; Lou et al., 2005; Taşcan& Vaughn, 2008; Taşcan et al., 2009; Tai et al., 2010; Nazire et al., 2011; Küçük&Korkmaz, 2012).

A number of studies have been carried out to improve the sound absorption properties of fiber-containing porous materials through the use of different fibers and the application of production methods (Thilagavathi et.al., 2010; Fatima &Mohanty 2011; Ersoy&Kucuk, 2009; Fouladi et al., 2011; Zulkifli et al., 2009; Al Rahman et al., 2013; Koizumi et.al., 2012; del Rey et.al., 2007; Wassilieff, 1996; Shahani et al., 2013; Shahani et al., 2014).

Supporting nonwoven surfaces with different materials has resulted inimproving the sound absorption properties at medium and low frequencies which has led to the development of multilayer sound insulation materials with better parameters(Joo& Lee 2003, Lin et al., 2010;Lin et al., 2011;Lin et al., 2011; Liu et al., 2012;Patinha et al., 2014).Sandwich structured sound insulation materials,which is a type of these materials,have been used successfully in many areas.

This paper is concerned with the development of sandwich structures that are obtained from processed chicken feathermaterials most of which are wasteand by-product in the production of chicken meat.

2. MATERIAL AND METHOD

2.1. Approach

Studies on bird feathers have revealed many interesting features of this material (Martínez-Hernández & Velasco-Santos, 2012). Among these properties, the internal structure of the material is in the foreground. Inhomogeneous structured bird feather consists of a rachiswhich forms the spine and a fibrous structure that comes from the rachis. Figure 1 shows SEM views taken by us from the side of the inner structure of the chicken feather rachis (CFR) (*a*) and the chicken feather fibers (CFF) (*b*). This internal structure consists of micro cells with sizes of 5-10μm in the fibers and 5-20μm in the rachis.

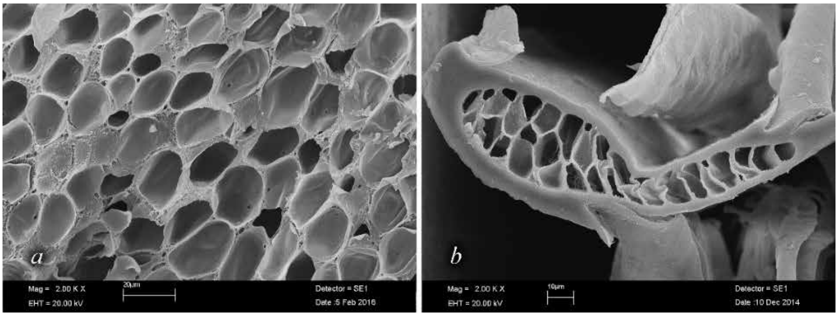

Figure 1.SEM images cross section of CFR (*a*) and CFF (*b*)

Chicken feather fibers are obtained by mechanical cutting the fibrous structure branched from the spine of the feather. This time the feather rachis is formed as the by-product, which constitutes about half of the feather weight.

In this study, it was aimed to develop materials for sound insulation from chicken feather material by taking advantage of the structural properties of that material. For this purpose, porous composite structures were developed by using different matrices from chicken feather rachis material and nonwoven structures were developed from fiber material.Each of these materials has a primary and secondary porous structure. It is envisaged that the complex structures to be obtained by combining them will exhibit higher sound insulation properties.

2.2. Material

2.2.1. Non-woven surface produced from the CFF

Nonwoven surfaces from the chicken feather fibers were produced in the Erciyes University Textile Engineering Department laboratories (Kayseri, Turkey). Feathers from the farm were washed, disinfected and dried, and then fiber was produced from these feathers. Non-woven surface samples were produced at different densities by thermal bonding using powder ethylene vinyl acetate (EVA) binding agent from the produced fibers. Some properties of this samples, coded as N1 and N2, are given in table 1 and the picture is given in Figure 2*a*.

Table1 Some properties of nonwoven surface samples for experimental work

	Features and parameters	Samples	
		N1	N2
1	The binder polymer	EVA	EVA
2	Sample content	20gr CFFand 10gr EVA	10gr CFFand 5gr EVA
3	Average sample thickness 0,001m	12,30	11,00
4	Weigh of sample to surface, kg/m^2	1,1719	0,5859
5	Weigh of sample to volume kg/m^3	95,2744	53,2670
6	Porosity of sample	0,8866	0,9366
7	The air permeability of the sample, m/s	$2{,}9\cdot10^{-2}$	$11{,}3\cdot10^{-2}$

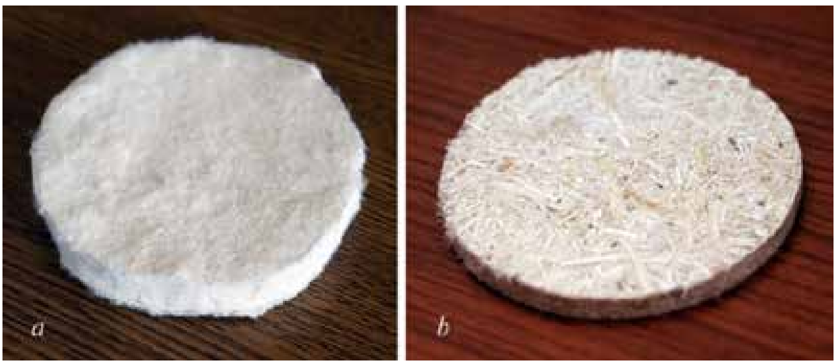

Figure 2. Samples produced out of CFF (*a*) and CFR (*b*)

Figure 3a shows the inner SEM image of the produced nonwoven surface sample. In this image, the binding polymer material particles can be observed as black stains.

2.2.2. Composite plates produced from CFR

Composite plates made of chicken feather rachis material were produced at Erciyes University Textile Engineering Department laboratories. The production of the fiber from the chicken feather is carried out on a special machine based on the separation of the fibers by mechanical cutting. During the process, the rachis is collected by separating into pieces. Granular composite structures were produced by hot pressing method by using a binder polymer (EVA) from rachis parts. Some features of these structures are given in Table 2 and the picture is given in Figure 2b. Figure 3b shows a SEM view of the inner section of the sample.

Table 2 Some properties of the composite samples for experimental studies

	Features and parameters	Samples	
		C1	C2
1	The binder polymer	EVA	EVA
2	Sample content	50gr CFRand 12,5gr EVA	33gr CFRand 8,25gr EVA
3	Average sample thickness, 0,005m	5	5
4	Weigh of sample to surface, kg/m2	2,4414	1,6113
5	Weigh of sample to volume kg/m3	488,2813	322,2656
6	Porosity of sample	0,3896	0,5972
7	The air permeability of the sample, m/s	$2{,}9 \cdot 10^{-2}$	$6{,}7 \cdot 10^{-2}$

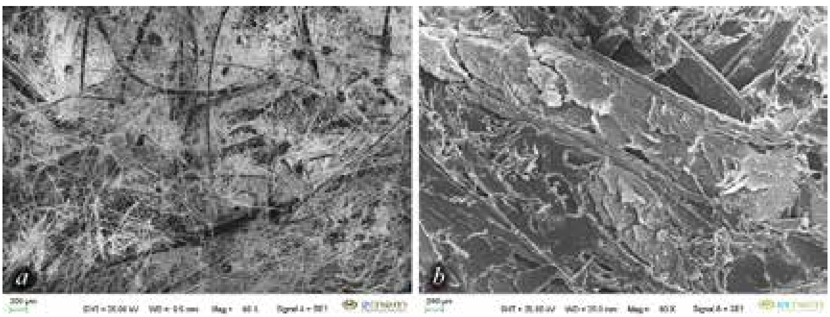

Figure 3.SEM image of the internal section of the nonwoven surface (*a*) and composite sample (*b*)

2.2.3. Traditional sound insulation materials

To compare sandwich construction samples made from chicken feather materials, samples were taken from traditional sound insulation materials and sound insulation parameters were measured. Some properties of these materials are given in table 3, and pictures are given in Figure 4.

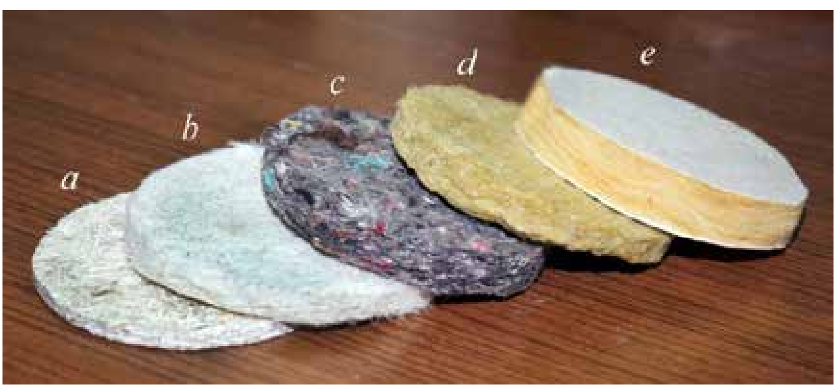

Figure4. Examples of materials used in experiments

a – composite plate produced from CFR, *b* – nonwoven structure produced from CFF, *c*- felt made from F, *d* – nonwoven structure produced from RW, *e* – nonwoven structure produced from GW

Table 3. Some properties of the traditional sound insulation materials

Fabric Code	Fabric types	Features and Parameters			
		Content	Thickness, 0,001m	Density for surface, kg/m^2	Density for volume, kg/m^3
GW	Glass wool	Glass fiber	15,69	0,3010	19,1814
RW	Rock wool	Basalt	14,12	0,3919	27,7534
F	Felt	Textile waste	13,05	0,3745	28,6990

2.3. Method

2.3.1. Production of sandwich structures

Sandwich structures are prepared as two different schemes which are*a* and*b* schemes. There is a nonwoven layer in the core of the samples prepared according to scheme *a* and there is a composite plate in the core of the samples prepared according to scheme *b* (Figure 5).

Examples of these structures are given in Figure 6.

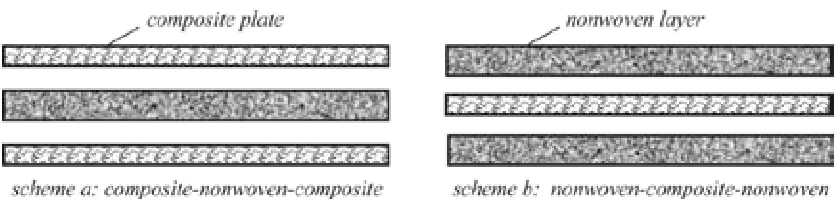

Figure 5. Schemes of preparing sandwich structures

In the experiments, two types of composite coded C1 and C2 and two types of nonwoven structures coded as N1 and N2 were used. These structures have different weight and density values. In order to see how the acoustic values of the sandwich structures produced from these materials with different weight and density values have been changed, a series of experiments have been performed and acoustic curves have been obtained.

Figure 6. Samples of sandwich structures produced on schemes *a* and *b*

2.3.2. Measurement of acoustic parameters

BSWA TECH branded impedance tube device was used to measure acoustic parameters such as sound absorption coefficient and loss of sound transmission of the samples of sandwich structures.

The test sample is placed on one end of the rigid and linear tube to measure the sound absorption coefficient. Planar waves are produced by a sound source. The sound pressure is measured from two points close to the sample. Two microphones are used for the test and the phase calibration is performed between the microphones. The transfer function between these two microphone signals is measured. Using the transfer function, the sound absorption coefficient and the impedance of the sample are calculated. The available frequency range is determined by the diameter of the tube and the distance between the microphones. The device scheme for measuring the sound absorption coefficient is given in Figure 7.

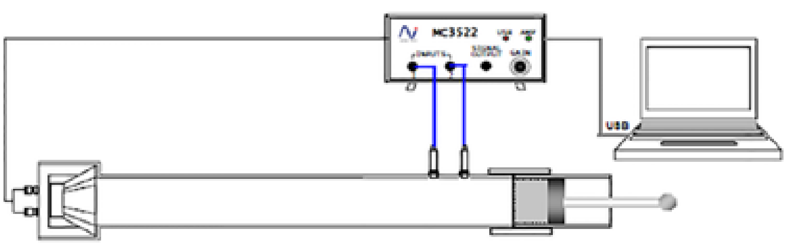

Figure 7. Sound absorption coefficient measurement

A modified impedance tube method with four microphones was applied for voice transmission loss test. For this measurement, the sample is prepared at the diameter of the impedance tube and placed at the end of the impedance tube.However, unlike the impedance tube measurement, there is a secondary tube after the sample (Figure 8)

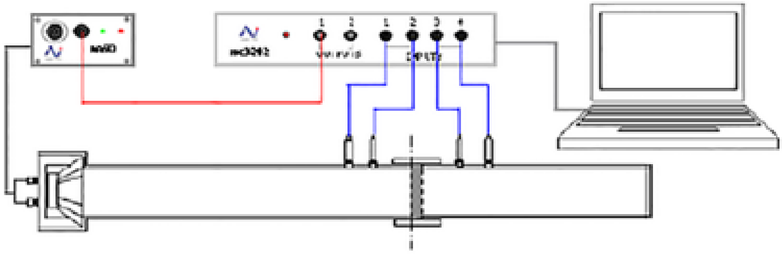

Figure 8.Sound transmission loss measurement

The planar waves from the audio source sent on the sample piece are measured on the first microphones as they were in the impedance tube measurement. Sound waves transmitted from the material to the secondary tube section are also received by the third and fourth microphones and the transfer functions between all the microphones are calculated separately.

In order to calculate loss of sound transmission, two different boundary conditions of the test fixture are measured. The opposite boundary conditions are chosen for the best measurement results. In the first condition the outlet of the secondary tube is closed with a hard lid and the sound waves are completely reflected back. In the second condition the outlet of the secondary tube is completely open and the sound waves propagate in space and do not return back into the tube due to the reflection from a surface. The device scheme applied in measuring the loss of sound transmission is given in Figure 8.

Measurements were carried out according to the following standards.

1. ISO 10534-1: 1996 Acoustics-Determination of sound absorption coefficient and impedance in impedance tubes-Part1: Method using standing wave ratio

2. ISO 10534-2: 1998 Acoustics-Determination of sound absorption coefficient and impedance in impedance tubes-Part2: Transfer function method.

All samples were subjected to two different test procedures. In these tests, the sound absorption coefficient and the loss of sound transmission values of the samples were measured.Circular parts with a diameter of 10 cm and 3 cm from each sample were cut and prepared for the measurements.

3. TEST RESULTS

Figure 9 shows the graphs of the sound absorption coefficient, and the graphs of the change in the values of loss of sound transmission versus the frequency of sound, plotted from the results of measurements of composite and non-woven structures. The curves in these graphs are defined according to the code names in Table 1 and Table 2 of the composite and non-woven surface samples.

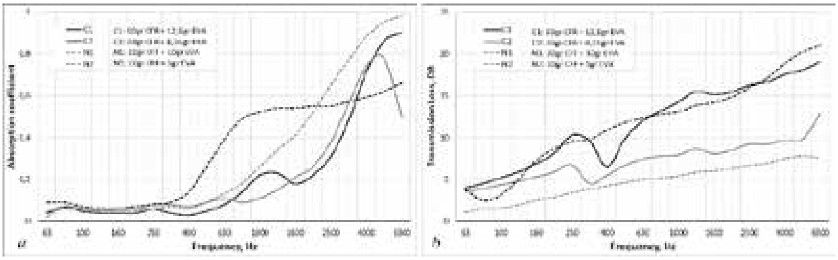

Figure 9. Acoustic curves of composite and nonwoven samples structures

Figure 10 shows acoustic curves of dual and triple combined structures formed from samples of C1 composite and N1 nonwovens made of chicken feather rachis and chicken feather fiber. These curves were plotted based on the measurement results of the change of the sound absorption coefficient and the loss of the sound transmission values according to the frequency of sound.

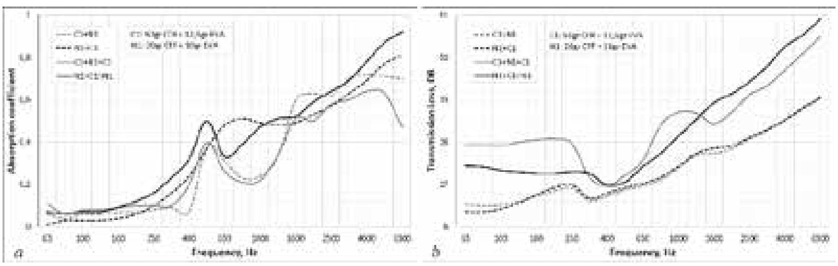

Figure 10. Acoustic curves of dual and triple combined structures with C1 and N1 content

Figure 11 shows acoustic curves for sandwich structures formed from N1 and N2 coded surface samples with C1 and C2 coded plates with different weight and density parameters produced from chicken feather rachis material.

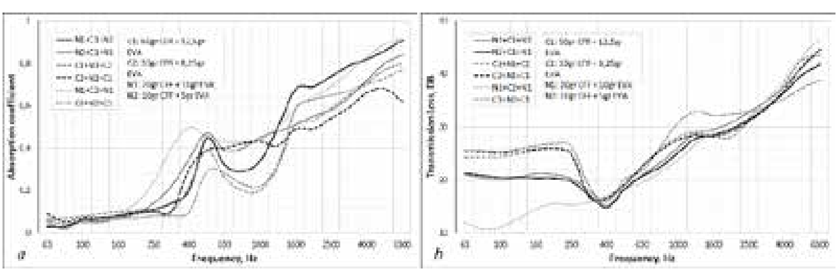

Figure 11. Acoustic curves of the sandwich structures with different contents

In Figure 12, acoustic curves of sandwich structures made of glass wool, stone wool and textile wastes, which are the traditional sound insulation materials, and chicken feather rachis material, are given.

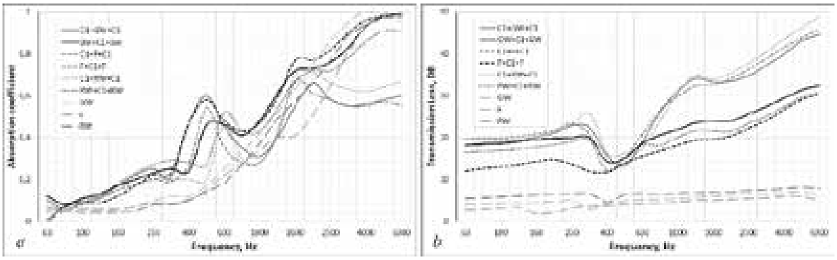

Figure 12. Acoustic curves of conventional sound insulation materials and sandwich structures made of CFR materials

4. DISCUSSION AND CONCLUSIONS

In Figure 9 we can see the graphs the variation of the sound absorption coefficient and loss of sound transmission values of the composite and nonwoven samples according to the sound frequency. As can be seen from these figures, the C1 code-named material has better acoustical properties than C2 material and N1 code-named material has better acoustical properties than N2.

On the other hand, the acoustical characteristics of the structures produced from the rachis and fiber material are selected from each other by general lines. Sound absorbing coefficient of structures made from rachis material shows only high values at high frequencies and low values at medium and low frequencies. On the other hand, the structures produced from fiber show moderate values even at medium frequencies. From this point of view, the N1 code-named material provides better absorption at medium frequencies than N2 (Fig, 9a). Apparently, this depends on the weight by volume (density) of the material being higher. When the sound transmission loss values of these samples are examined, it is seen that the values of C1 and N1 and the values of C2 and N2 structures are close to each other (Fig, 9b). We can say that an important part of the loss of sound transmission in nonwoven structure occurs because of the sound absorption and in composite construction it occurs because of the reflection of the sound.

When we put these two materials together and have two layered samples, we get the same sound transmission loss curves but it has better results than the single layered structures (Figure 10b, C1+N1 and N1+C1 structure curves). Apparently in the two-layer structures from the point of view of loss in the transmission of sound, the order of the arrangement of the composite and nonwoven layers does not matter. However, it is not possible to say the same about the sound absorption. There is a difference between the values of the sound absorption coefficients of these samples. This difference is not only due to the fact that the nonwoven structure has higher sound absorption ability than the composite structure but also it depends on the location of the layers. Here we can get such a result that in the case of two-layered materials, the layer with low density or high porosity must be in the front to obtain better sound absorption.

This situation is highly observed in three-layer sandwich structures. The sandwich structures subjected to the tests were produced in two schemes as shown above. Scheme 1:the layer made out of rachisis in the core;scheme 2:the layer made out of fiber is in the core (Figure 5 and Figure 6). As a result, there were significant differences between these structures, both in the sound absorption coefficients and in the loss of sound transmission (Figure 10andFigure 12, the curves of C1+N1+C1 and N1+C1+N1 structures). Supporting the two layered structure with a third layer improves the acoustic parameters. Composite outer layers gave better results at lower frequencies and non-woven surfaces gave better results at higher frequencies in terms of loss of sound transmission. In addition, the sound absorption coefficient of the samples with non-woven surfaces in the outer layers has higher values on the whole scale. From this it should be understood that along with the thickness, weight, density and porosity of the layers in multilayer structures, the arrangement of the layers also affects some of the acoustic properties of this structure.

Serial experiments have been conducted to see how the acoustic values of sandwich structures made from materials with different weight and density values change. According to the sound frequency, the variation of the acoustic values of these structures is given in the graphs of Figure 10.According to these graphs, when the low-density nonwoven layer N2 is at the front in the sandwich structure which has composite at the core provides better sound absorption at higher frequencies but better at mid frequencies when it is at the back. The voice transmission loss curves of both of these variants are approximately the same.

In sandwich structures with a nonwoven layer at the core, when the low density C2 composite layer is at the front, it provides better sound absorption only at medium frequencies.Except for this, in terms of both sound absorption and loss of sound during transmission, no changes are observed.

In figure 11, nonwoven based structures in the core C2 with composite based structures in the core N2 appear to have no significant differences in acoustic properties when compared to the C1 and N1 structures in the core in Figure 10. However, it is observed that the N1+C1+N1 structure has slightly better values. This composite structure, which has a thickness of 3.5cm, provides sound insulation of 20-60DB at 63-6300Hz frequency range.

Materials such as glass wool, rock wool and felt, which are traditional sound insulation materials, have high sound absorption coefficient at high frequencies, but low sound absorption at medium and low frequencies. Loss of sound transmission for these materials has much lower values. It is seen that the materials obtained by supporting the porous composite materials produced from chicken feather rachis exhibit higher acoustic values than the unsupported materials (Figure 12). We can see that the sound absorption coefficient and sound transmission loss values at the middle and low frequencies of all three traditional insulation materials are significantly increased.

All of these show that the use of chicken feather materials, especially porous composite structures, as sound insulation material offers good perspectives.

ACKNOWLEDGEMENT

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