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TRANSMISSION LOSS (TL) VALUES OF WALL PANEL CONSTRUCTED FROM PADDY-STRAWS

Christina E. Mediastika[1)]

[1)] *Department of Architecture, Atma Jaya Yogyakarta University*
Jl. Babarsari 44 Yogyakarta, Indonesia 55281
e-mail: utami@mail.uajy.ac.id

ABSTRACT

A series of experimental study has been conducted to seek possibility in using paddy-straws - disposed materials of paddy plants - to be constructed as wall panels. The panel is aimed to improve sound insulation of building vertical elements regarding traffic noise issues in Indonesia. Paddy-straw is chosen as main materials to construct wall panels caused by its affluence and consideration of green materials. A pre-research has been carried out to seek suitable straw types and the most effective process of lamination. Earlier research has also reported that the panels complied with compression strength test.

The study that will be reported here is regarding its acoustic qualification to perform as sound insulation elements. The Transmission Loss (TL) test was carried out in standardized testing chambers in National University of Singapore. However, as difficulty arises in transporting panels of 10,25 mm2 as is required by the standard, a testing method known as composite wall method was conducted. The investigation and calculation showed that paddy-straws panels may provide TL of minimum 9,2 dB refers to centre band frequency of 500 Hz and varies accordingly to 1/3 octave band frequencies. This value is regarded as significant in order to provide quieter indoor environment.

Keywords: *paddy-straws, wall-panels, composite wall, transmission loss*

INTRODUCTION

Environmental noise pollution which predominantly caused by aggravation of traffic noise has placed building inhabitants as 'noise victims'. This is experienced by inhabitants of buildings in Indonesian busy cities. In this case, the use of high quality building materials entitling of sound insulation capability is of importance. However, lack of knowledge on noise impact on life and low revenue, put most Indonesians to employ ordinary building materials with poor sound insulation.

The wall panels constructed from paddy-straws that have gone through a series of preliminary studies is aimed to improve insulation values of building elements ordinarily used. Compared to floor and ceiling/roof, wall is a building element that is readily exposed to noise. In the case when walls having poor insulation values, attachment of additional wall panels that may increase the insulation values is substantial. In Indonesia, ordinary wall constructed from red-bricks (less dense compared to those used in developed country) offers insulation of approximately 30 to 40 dB only (Mediastika, 2000). This is considered insufficient compared to the surrounding noise which could reach up to 80 dB (Mediastika, 2000). There is a vast array of wall panels available in the market, but normally they are of high quality acoustic panels which correlate to the price. These types of panels assure sufficient insulation values, but not affordable to low-cost building. Hence, the availability of low price wall panels in the market becoming significant.

Paddy-straws, waste materials of paddy plants, are considered very potential raw materials. The potency is in the aired hollow within the straws, which naturally creates air gaps when go through lamination as a panel (Mediastika, 2007). This is match to the theory of wave-refraction, whereby sound intrusion is lowered when refraction is maximized. In ordinary walling construction, this is complied by air gap formed between two or more material layers (refer to Fig 1).

In Indonesian villages, as waste product, paddy-straws are commonly used for cattle food-supply or during incineration process of red-brick making. In fact, in developed countries, straws have been utilized for building materials. However, concerning climatic issues of warm humid, it is considered rather impossible to use paddy-straws as it is, since the climate will easily decompose them to turn into non-durable materials. Fortunately, this is not the case of temperate climates, where straws can be readily constructed as straw bales (Lacinsky and Bergeron, 2000).

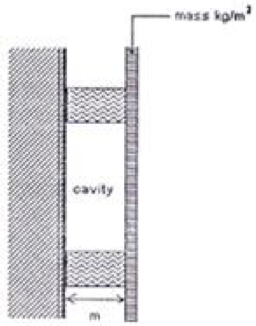

Figure 1. Ordinary wall panel attached to main wall with air gap to gain better sound insulation

Another challenge in using paddy-straws is limitation of information and technology among most Indonesian, which lead them in to questioning the strength, durability and performance of this waste. In this early stage, the panels will only be constructed as for non-structural wall which is attached to the main wall. The attachment is aimed to improve insulation values of ordinary wall, which in Indonesia is mostly formed by grey bricks (less dense concretes) and red bricks (less dense compared to red bricks utilized in developed countries). Beside consideration of cost and potency, the use of paddy-straws may also as one solution toward green building issues by reuse and recycling waste materials.

THEORETICAL APPROACH

An ideal insulator must comply with aspect of mass/density, thickness, and homogeneity (Freeborn and Turner, 1988/1989). The more mass/density of materials, the thicker the materials, and the more homogeny with no holes and crack of the materials, the better insulation will be provided. Aspect of material thickness is not always gained by the material it self, but can be substitute by the presence of air gap between two or more material layers. Many research concluded that air gap between layers will increase sound insulation capability of materials than the thickness of material itself (Templeton and Saunders, 1987). This is caused by effect of refraction, i.e. bending of sound wave motion while entering materials with different densities (refer to Fig 2). The more bending on sound wave motion, the more energy of sound is reduced, thus less energy to be transmitted over the materials. Air gap which naturally found within paddy- straws is the main aspect while considering straws as raw materials for acoustic wall-panels.

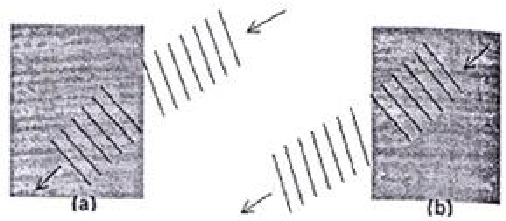

Figure 2. Sound wave refraction, bending downward while entering more dense material (a) and bending upward while entering less dense material (b). Air gaps within layers will maximise wave refraction.

METHODS

Pre-experiment on Straw Characteristics

Prior to the main experiment, a series of pre-experiment has been conducted, i.e. experiment to seek the most suitable straw characteristic to go into panel lamination and experiment to seek effective proportion of adhesive substance for panel lamination. The experiments use trial and error approach.

There is a vast variety of paddy plants. Referring to the origin, it is grouped into two-main, i.e. local paddy and cross-fertilization paddy. According to field conditions, it is also grouped into two-main, i.e. planted in more watering field and less watering field. Whilst according to rice characteristics, it is grouped into two-main, i.e. non-sticky rice and sticky rice (AKK, 1990). All these types of paddy-straws went into pre-lamination process and mixed with adhesive substances. This process reported that local paddy-straw is too soft, thus losing air gaps while being pressed during lamination. Whilst, cross-fertilization paddy-straw is capable to maintain the air gap and thus resulting panels as expected. The less watering paddy is too hard to be laminated thus resulting untidy and fragile panels. This is also the case of sticky rice straws. This pre-experiment concluded that cross-fertilization paddy-straws (which is in coincidence also more watering and non sticky rice), performed better as raw material to construct wall panels compared to the rest types of paddy-straws (Mediastika, 2006). Prior to lamination process, the straws have to be cleaned by water and then dry under the sunlight in order to kill germ and fungus.

Pre-experiment on Laminationn Process

At second stage, pre-experiment for lamination process was carried out. In response to climatic issue and ease of utilization, paddy-straws are not being used as it is, but be bounded together with adhesive substances and formed into a panel shape. This process is defined as lamination. There is vast variety of adhesive substance in the market, grouped as natural and synthetic adhesive, but whilst the aim of composing paddy-straw panels is to provide low-price materials, the use of high cost adhesive will be neglected. A moderate price adhesive substance for building construction that is widely available is cement powder and gypsum powder. Since both of them are powdered adhesive, a proportion of water has to be added carefully prior to mixing process (Mediastika, 2006).

Beforehand, critical characteristic of paddy-straw was scrutinized. This leads to conclusion on the best characteristic of each element to perform the best mixture for lamination, i.e. straws should be slightly moisturized, adhesive powder should also be in the exact ratio to the straws, which then be sprayed on to the moisturized straws. The best volume ratio between water: adhesive: straws is 1,5: 1: 3. When the three are mixed evenly, it then goes to lamination tray for 2x 24 hours and dry out of direct sunlight for approximately 14 days to be fully dry and ready for use. The fully dryness of panels is significant to minimize the presence of fungus that will decompose straws and decrease panel performance. Drying the panel out of direct sunlight is also important to avoid sudden drying that will cause panels to become fragile.

Compression Strength Test

There is no definite standard of compression strength (CS) when the panel is not aimed to be structural component as is panel of this study. However, CS test was once conducted to see capability of the panels to carry and maintain its own weight, i.e. for packaging and transporting, toward application as a construction material. Standard of General Regulation of Concrete Construction in Indonesia (*Peraturan Umum Beton Indonesia tahun* 1982) is use merely as a comparison. The test showed that laminated paddy straws have CS value of approximately 15 N/mm2 as the maximum, when the best mixture ratio is applied (Mediastika, 2006).

TL TEST AND DISCUSSION

Since the panels are aimed to improve insulation values of ordinarily employed walls, acoustic test regarding its insulation values is substantial. The insulation test or transmission loss test (TL test) was carried out in National University of Singapore, which is located within Department of Buildings, Faculty of School of Design and Environment. The rooms are standardized (ASTM E90-04 and ISO 140-3). According to ISO (ISO 140-3 part. 5.2.1) the specimen to be tested should be in 10 m^2 dimension with the shorter edge length not less than 2.3 m. The panel is to be installed between two testing chambers. However, there was problem arises in transporting such panel of 10 m^2 from Indonesia to Singapore. Besides, the panels itself is not designed as a structural ones that can be erected solely. A testing and calculation method known as composite wall is then utilized. At first, a double-layer gypsum panels filled with rock wool was tested for its TL values (refer to ASTM E90-04). It is known as filler wall. The values gained from the test are presented in Table 1.

Table1. TL values of the filler wall (two layer gypsum panels)

Freq (Hz)	TL_f values (dB)
100	25.9
125	34.6
160	37.4
200	41.2
250	41.8
315	44.5
400	48.7
500	52.0
630	54.2
800	57.3
1000	59.6
1250	60.5
1600	57.8
2000	54.2
2500	55.5
3150	58.5
4000	58.6
5000	58.1

The gypsum panels were then drilled in to dimension of 300 mm x 400 mm to put the paddy panels within. This is specific to the size of the prepared paddy panels (refer to Figure 3a).

Two layers of paddy-straws panels (each of 30 mm thickness) are put side by side in the hole to match exactly with the thickness of the rock wool filling. Once the paddy-panels were placed, the tiny leakage forming along side was filled with rock wool floss (refer to Figure 3b). The paddy-panel is known as specimen wall.

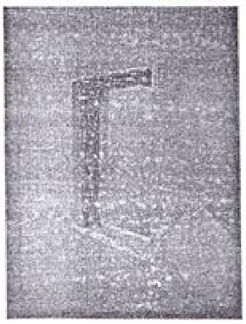

Figure 3a. Hole of dimension of 400 mm x 300mm was made on the existing filler wall (i.e. gypsum walls)

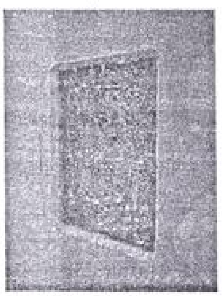

Figure 3b. Two layers of paddy-straws panels was put side by side, the tiny cavity gap between panels and wall were filled with rock wool floss to sealed it

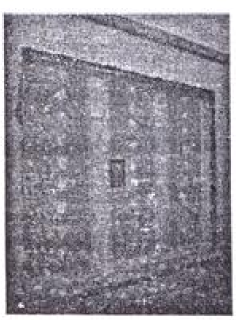

Figure 3c. Perspective view of the composite wall with the specimen within

Paddy panels that stays within gypsum panels forming a composite walls. The composite walls was then measured for its TL values (refer to ASTM E90-04).

Table 2. TL values of the composite wall

Freq (Hz)	TL_c values (dB)
100	26.8
125	28.7
160	28.9
200	31.7
250	31.0
315	31.9
400	29.8
500	28.5
630	29.3
800	29.7
1000	30.2
1250	31.0
1600	32.9
2000	34.4
2500	36.3
3150	38.8
4000	41.6
5000	45.4

From TL values found for both filler and composite wall, TL value of the specimen (i.e. paddy-panels) then can be calculated using formula as follows (after ASTM E90-04):

$$\tau_c = \frac{\tau_f S_f + \tau_s S_s}{S_f + S_s} \tag{1}$$

where $$TL_c = 10 \log \frac{1}{\tau_c} \tag{2}$$

and where:

- τ_c *is sound transmission coefficient of composite wall*
- τ_f *is sound transmission coefficient of filler wall (i.e. gypsum wall),*
- τ_s *is sound transmission coefficient of test specimen (i.e. paddy-panel),*
- S_f *is area of filler wall (after test specimen is attached, i.e.* $10{,}25\ m^2 - 0{,}12\ m^2 = 10{,}13\ m^2$,
- S_s *is area of test specimen (i.e. paddy-panel of* $0{,}12\ m^2$*),*
- TL_c *is transmission loss of composite wall.*

To calculate TL_s of specimen, first we need to calculate τ_s, which is done by the following steps. For instance, calculate a τ_f value referring to 500 Hz sound frequency on Table 1:

$$TL_f = 10 \log \frac{1}{\tau_f} \tag{3}$$

$$52 = 10\log\frac{1}{\tau_f}$$

$$\tau_f = 6.3\times10^{-6}$$

Then, referring to 500 Hz sound frequency on Table 3, calculate τ_c as follows:

$$TL_c = 10\log\frac{1}{\tau_c} \quad (4)$$

$$28.5 = 10\log\frac{1}{\tau_c}$$

$$\tau_c = 1.4\times10^{-3}$$

Using the above result, τ_s (specimen) can be calculated as follows:

$$\tau_c = \frac{\tau_f S_f + \tau_s S_s}{S_f + S_s} \quad (5)$$

$$1.4\times10^{-3} = \frac{(6.3\times10^{-6}\times10.13) + (\tau_s\times0.12)}{10.13+0.12}$$

$$\tau_s = 0.120$$

Thus, TL_s is found by the following:

$$TL_s = 10\log\frac{1}{\tau_s} \quad (6)$$

$$TL_s = 10\log\frac{1}{0.120}$$

$$TL_s = 9.2 \ (\textit{refer to } 500\ Hz)$$

By using similar steps, TL values of the specimen for 1/3 octave band frequency may also be calculated, which is presented in Table 3

Table 3. Compilation of TL values of the filler wall and composite wall to calculate TL of paddy-straws panel

Freq (Hz)	TL_f (dB)	TL_c (dB)	τ_f	τ_c	τ_s	TL_s (dB)
100	25.9	26.8	0.00257	0.00209	-0.02889	-
125	34.6	28.7	0.00035	0.00135	0.064466	11.90673
160	37.4	28.9	0.00018	0.00129	0.094677	10.23756
200	41.2	31.7	7.6E-05	0.00068	0.051345	12.89502
250	41.8	31.0	6.6E-05	0.00079	0.062272	12.05707
315	44.5	31.9	3.5E-05	0.00065	0.052154	12.82712
400	48.7	29.8	1.3E-05	0.00105	0.088303	10.47268
500	52.0	28.5	6.3E-06	0.00141	0.120122	9.192383
630	54.2	29.3	3.8E-06	0.00117	0.100035	10.00272

Table 3. (Continued)

Freq (Hz)	TL_f (dB)	TL_c (dB)	τ_f	τ_c	τ_s	TL_s (dB)
800	57.3	29.7	1.9E-06	0.00107	0.091368	10.39074
1000	59.6	30.2	1.1E-06	0.00095	0.081480	10.90734
1250	60.5	31.0	8.9E-07	0.00079	0.067774	11.70830
1600	57.8	32.9	1.7E-06	0.00051	0.043667	13.60887
2000	54.2	34.4	3.8E-06	0.00036	0.030692	15.12155
2500	55.5	36.3	2.8E-06	0.00023	0.019786	17.06730
3150	58.5	38.8	1.4E-06	0.00013	0.011141	19.54514
4000	58.6	41.6	1.4E-06	6.9E-05	0.005793	22.29608
5000	58.1	45.4	1.5E-06	2.9E-05	0.002333	26.32085

From the value of τ_s presented in Table 3, referring to ASTM standard test method for laboratory measurement of airborne sound Transmission Loss (TL) of Building Partitions and Elements (E90-04) some corrections must be made when there is particular difference of log $(\tau_c S_c)$ – 10 log $(\tau_f S_f)$, as follows:

1. when the difference is more than 15 dB, calculate τ_s from Eq 1 ignoring the term $\tau_f S_f$,
2. when the difference is between 6 and 15 dB, calculate τ_s using Eq 1. This corrects for transmission through the filler wall (i.e.gypsum wall),
3. when the difference is less than 6 dB, reliable corrections cannot be made. Calculate τ_s from Eq 1 ignoring the term $\tau_f S_f$. Multiply the values obtained by 0.75 and then use Eq 2 to calculate a lower limit for the transmission loss of the test specimen. (This is equivalent to limiting the difference to 6 dB).

For the values presented in Table 3, some correction has been made according to the above guidelines, and the TL values of the paddy-panel which are shown have referred to the guidelines.

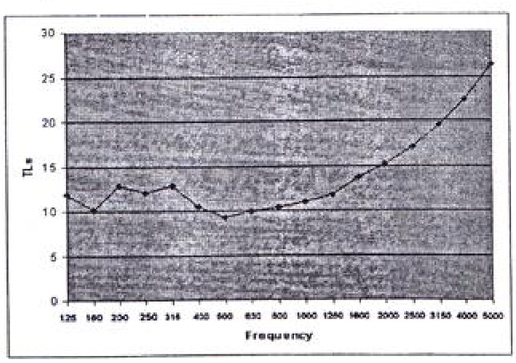

Figure 4. TL values of paddy-straws panel to frequency respectively

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

From Table 3 and Figure 4, we learn that paddy-panels offer higher TL values for high sound frequency and reach it maximum at centered band frequency of 5000 Hz: In opposite, TL value is lowest at frequency of 500 Hz, and remains similarly of 10 to 12 dB for frequency of 125 Hz to 1250 Hz. If the specimens have the same behavior when used in field, then attachment of this specimen to the main wall may increase TL value by approximately 10 dB (in general). The increase in 10 dB will provide quieter indoor environment (Mediastika, 2000).

The indirect calculation method of composite wall to calculate TL value of research specimen is widely used and is assumed to be valid. However, it will be ideal if this research can also proved the validity, i.e. by testing another layer of the specimen (added to those of the previous two layers that have been tested). If by putting this third layer we can achieve approximately 4 to 6 dB improvements, then we can more or less confirm the validity and accuracy of this method.

Unfortunately, within limited time and resources, it is considered impossible to do more testing and calculations at this moment of research. Therefore, it is recommendation for further research to carry on this task.

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