Scientific Research and Essays Vol. 5(12), pp. 1530-1535, 18 June, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

*Full Length Research Paper*

# Determination of sound transfer coefficient of boron added waste cellulosic and paper mixture panels

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Accepted 19 May, 2010

**When the studies about the effects of noise on the human health were investigated, it was determined that the noise has physiological, pathological, psychological and psycho-social results and affects sense organs, circulatory, respiration, digestion, excretory and nervous systems in terms of physiology. In this research, a sound insulation study was carried out in order to minimize the negative effects of sound on the people who work in enclosed spaces. For sound insulation, two unreflecting rooms were constructed by using boron-added cellulosic and pulverized paper mixture. However, α values (sound transfer coefficient) for the measured absolute values and the NRCs (Noise Reduction Coefficient) for 250, 500, 1000, 2000, 4000, 8000 Hz frequencies which are the most sensitive ones for human ear were calculated. The material used in the study was so efficient for high frequencies. The NRC and α value were obtained for clean paper mixture as 0.46 and 0.38, respectively and for waste paper mixture as 0.34 and 0.38, respectively with 3 cm thickness; for clean paper mixture as 0.55 and 0.81, respectively and for waste paper mixture as 0.31 and 0.72, respectively with 5 cm thickness. The mixture with 5 cm thickness can be easily used inside the walls of critical utilization areas like office, house, hospital, etc. that exist near and/or inside the traffic, bazaar, park, children park areas.**

**Key words:** Sound, noise reduction, insulation, indoor.

## INTRODUCTION

Occupational Safety and Health Administration (OSHA) performed studies especially for construction occupation. These studies estimate that construction workers are exposed to hazardous levels of noise and are therefore susceptible to hearing damage on daily basis (Alice, 2002; Ortiz, 2005). In the International Standard ISO (1999), a hearing handicap is defined as the disadvantage imposed by hearing impairment, which sufficiently affects one's personal efficiency in the activities of daily living and usually expressed in terms of understanding conventional speech in low levels of background noise.

Porous materials such as open cell foams and fibrous materials (fibreglass, rockwool) act as very good sound absorbers by converting sound energy to a small amount of heat. Note however, that most sound absorbing materials are poor performers for noise isolation, as they allow sound to pass through easily. This is why sound absorbing material is usually fixed onto a solid noise isolating material. The acoustical performance of absorptive panels is usually evaluated using the random

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incidence sound absorption coefficient. This absorption coefficient is often affected by the combined influence of diffusivity of the reverberation room and the area effect of the specimen (Maekawa and Lord, 1995).

T-shaped barrier insertion loss values to a surface were obtained over a significant range of frequencies. At low frequencies, the insertion loss was less than that expected for a rigid upper surface. Soft pressure release surfaces can be achieved by introducing wells in the surface (Fujiwara et al., 1998).

Closed-cell foams, e.g. polystyrene, are poor sound absorbers. Sound absorbing materials often need to have a protective facing to prevent damage. Common facings include perforated sheet metal (10% open area), perforated foil, or perforated vinyl.

An apartment building can usually be laid out in plan so that the most critical rooms (bedrooms, living rooms) are protected from adjoining apartments by a buffer zone of non-critical areas such as bathrooms, kitchens, closets and hallways. For separating such non-critical areas, a party wall having an average sound transmission loss of 45 decibels* (db) is adequate. The next best arrangement is to place quiet rooms such as bedrooms on the two sides of the party wall; in this case, the separation should be a 50-db wall (Northwood, 1960). In addition, the noise evokes activity in the auditory pathway, thereby reducing the dynamic range of auditory system responsiveness (Bandettini et al., 1998; Edmister et al., 1999). It is claimed that the low-frequency components of this 'noise' cause discomfort to the listener and interfere with speech perception by masking consonants at higher frequencies (Preves, 1991).

The attenuation of low frequency noise by means of passive silencers is associated with a high expenditure in material and volume. On the other hand, active systems provide good possibilities to influence the sound field, especially in this frequency range (Kruger and Leistener, 1996). As the clock rate approaches GHz and beyond, the problem of injected noise that would transmit through a common silicon substrate and jeopardize neighbouring devices becomes serious (Su et al., 1993).

In this study, waste paper collected from garbage and archieve paper taken from companies and offices are liquified with boron mixture and they were transformed into panels with 3 and 5 cm thicknesses. These obtained panels are placed into cells (anechoic room) and the isolation of the voice produced at different frequencies was examined.

## MATERIALS AND METHODS

A two-cell anechoic room, the details of which were given in the Figure 1, was built in a suitable place. Rubber blocks were placed under the anechoic rooms to damp the possible vibrations caused from the ground. The top of the rubber blocks was completely covered with closed PVC system except the interior part in which the boron added cellulosic panel was placed. For each cell, a door with rubber gasket was placed in order to check the input and output of the cells. The inner surface of the system was covered with 5 cm rock wool to reduce the outside noises and prevent the reflections in the cells in which noise was generated and transferred.

A signal generator was placed in one of the cells and a noise measuring device in the other which was able to make 1/3 octave analysis. Noise of central frequencies at 31.5, 63, 125, 250, 1000, 2000, 4000, 8000 and 16000 Hz that can be heard by human ear at medium or top levels was generated using the signal generator. The noises generated at various frequencies with various noise levels were later calculated as 100 dB. However, the α values were calculated for the measured absolute values. The NRC was determined for 250, 500, 1000, 2000, 4000, 8000 Hz frequencies that are the most sensitive ones for human ear.

The study was carried out for two different thicknesses, namely 3 and 5 cm. The space between the two cells was completely closed with 5 cm thickness-panel (Figure 1). The spaces left after placing the panel of 3 cm thickness were covered with the rock wool material. The panel mixture produced from waste paper constitutes 10% boron and 90% waste paper. The panels produced from clean archieve paper, on the other hand, constitute 12% boron and 88% paper. Moreover, the octave analysis was performed to crosscheck the system when the signal generator was closed. The noise entering the sound transferring cell was neglected because 10 dB difference occurred between the measurements when the signal generator was operating and not operating.

$\alpha$ = (absorbed sound/generated sound)

$$NRC= (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})/4$$

## RESULTS

For 3 and 5 cm thicknesses, the study was performed first with central octave bands that are the most sensitive ones for human ear and then with other frequencies to test the material. Being so important for human ear, the 250 - 8000 Hz range should be especially taken into consideration (Tables 1 and 2).

NRC calculated for human ear is found to be 0.272. This value was determined as better levels for high frequencies (Figure 2).

In the panel with 5 cm thickness, resonance was formed at frequencies 63 and 10000 Hz for clean paper mixture and at frequency 250 Hz for waste paper mixture. However, when noise isolation capability of the material is taken into consideration at central frequencies (500, 1000, 2000 ve 4000 Hz) which are perceived by human ear most sensitively, it will be very efficient in inner wall and side coating for using as backfill and/or panel. Cellulosic boron material can be used as sound insulation material for both clean archieve paper and waste paper. When the data obtained from the 5 cm panel were considered especially, it was evident that the material was having the same properties with many products used for the same purpose in the market (Tables 3 and 4).

NRC calculated for human ear is found to be 0.272. This value was best determined at higher frequencies (Figure 3).

In the panel with 3 cm thickness, resonance was formed for both clean paper mixture and waste paper

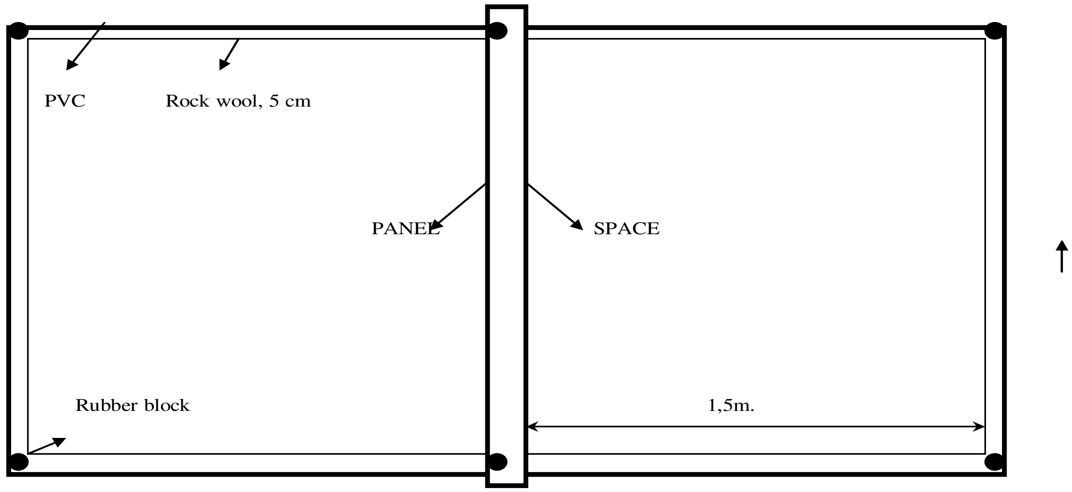


**Figure 1.** Testing mechanism prepared for boron added cellulose.

**Table 1.** Measurements and calculations for 5 cm. thickness (waste cellulosic paper density: 1.5 kg/m$^2$, clean archieve paper density: 2,588 kg/m$^2$).

| Frequencies (Hz) | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 |
|---|---|---|---|---|---|---|---|
| 1. Cell*, dB | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. Cell**, dB (waste paper) | 87.3 | 83.4 | 81.7 | 70.5 | 76.2 | 74.4 | 69.5 |
| TL, dB | 12.7 | 16.6 | 18.3 | 29.5 | 25.8 | 25.6 | 30.5 |
| α (waste paper) | 0.13 | 0.17 | 0.18 | 0.3 | 0.23 | 0.26 | 0.3 |
| 2. Cell**, dB (clean paper) | 70.9 | 80.0 | 71.5 | 61.5 | 52.8 | 48.4 | 42.8 |
| TL, dB | 29.1 | 20.0 | 28.5 | 38.5 | 47.2 | 52.6 | 57.2 |
| α(clean paper) | 0.29 | 0.20 | 0.28 | 0.38 | 0.47 | 0.52 | 0.57 |

Note : *1$^{st}$ Cell: Generated sound
** 2$^{nd}$ Cell: Sound passing through the panel
TL : Transmission level.

**Table 2.** Measurements and calculations for 5 cm. thickness (waste cellulosic paper density: 1.5 kg/m$^2$, clean archieve paper, density: 2,588 kg/m$^2$).

| Frequencies (Hz) | 4000 | 8000 | 10000 | 16000 | NRC |
|---|---|---|---|---|---|
| 1. Cell, dB | 100 | 100 | 100 | 100 | - |
| 2. Cell, dB (waste paper) | 66.5 | 59.7 | 44.8 | 28.7 | - |
| TL, dB | 33.5 | 40.3 | 65.2 | 72.3 | - |
| α(waste paper) | 0.34 | 0.40 | 0.55 | 0.72 | 0.31 |
| 2. Cell, dB (clean paper) | 33.6 | 27.1 | 38.3 | 18.2 | |
| TL, dB | 66.4 | 73.9 | 61.7 | 81.8 | |
| α(clean paper) | 0.66 | 0.73 | 0.62 | 0.81 | 0.55 |

mixture at 25 ve 16000 Hz frequencies. When noise isolation capability of the material for this thickness is taken into consideration at central frequencies (500, 1000, 2000 ve 4000 Hz) which are perceived by human ear most sensitively, it was considered that it will be very efficient in inner wall and side coating for using as backfill and/or panel.

## DISCUSSION

Some studies have shown generally that the single event energy dose of a noise event (EPNL or SEL), and not the maximum level (in PNL) is a better predictor of sleep interference (Horonjeff et al., 1978).

Although, some examples exist, the researches related

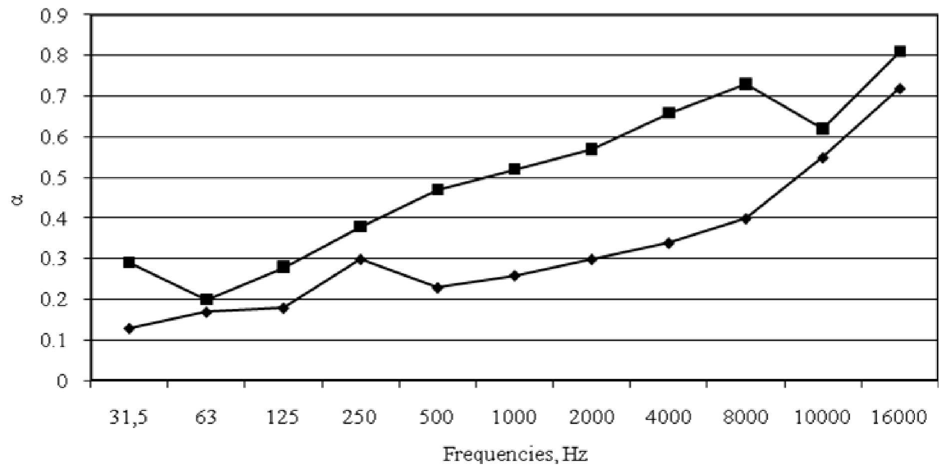


**Figure 2.** NRC values for 5 cm thickness (■: Clean archieve paper, ♦: waste paper).

**Table 3.** Measurements and calculations for 3 cm. thickness (waste cellulosic paper (density: 0.9 kg/m$^2$, clean archieve paper, density: 1,553 kg/m$^2$).

| Frequencies (Hz) | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 |
|---|---|---|---|---|---|---|---|
| 1. Cell, dB | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. Cell, dB (waste paper) | 94.4 | 86.7 | 89.7 | 82.9 | 81.2 | 77.2 | 65.7 |
| TL, dB | 5.6 | 13.3 | 10.3 | 17.1 | 18.8 | 22.8 | 34.3 |
| α(waste paper) | 0.056 | 0.13 | 0.1 | 0.17 | 0.19 | 0.23 | 0.34 |
| 2. Cell, dB (clean paper) | 90.1 | 76.2 | 79.0 | 76.1 | 70.6 | 63.7 | 56.8 |
| TL, dB | 9.9 | 23.8 | 21.0 | 23.9 | 29.4 | 36.3 | 43.2 |
| α(clean paper) | 0.09 | 0.23 | 0.21 | 0.24 | 0.29 | 0.36 | 0.43 |

**Table 4.** Measurements and calculations for 3 cm. thickness (waste cellulosic paper (density: 0.9 kg/m$^2$, clean archieve paper, density: 1,553 kg/m$^2$).

| Frequencies (Hz) | 4000 | 8000 | 10000 | 16000 | NRC |
|---|---|---|---|---|---|
| 1. Cell, dB | 100 | 100 | 100 | 100 | - |
| 2. Cell, dB (waste paper) | 64.8 | 81.2 | 64.5 | 61.5 | - |
| TL, dB | 35.2 | 18.8 | 35.5 | 38.5 | - |
| α(waste paper) | 0.35 | 0.34 | 0.36 | 0.38 | 0.25 |
| 2. Cell, dB (clean paper) | 52.4 | 49.3 | 46.6 | 54.1 | - |
| TL, dB | 47.6 | 50.7 | 53.4 | 45.9 | - |
| α(clean paper) | 0.47 | 0.50 | 0.53 | 0.46 | 0.38 |

with noise control treatments at natural ventilation inlets and outlets in the literature have been fairly limited (Irvine, 1993; Field and Fricke, 1997; Mohajeri and Fricke, 1996). The correct size and spacing of holes in the liner are important because they act as resonating sound absorbers. When sound impinges on the holes, some of the sound is absorbed by the cavities and the rest is reradiated (Schimmoller, 2000).

Single side branch Helmholtz resonators positioned along the duct run can achieve narrow transmission losses of up to 28 dB at selected frequencies (Chen et al., 1998) and adaptive mechanisms can achieve noise reductions of up to 30 dB in the bandwidth considered for time variant noise sources (Debedout et al., 1997). The noise removal in our study occurred higher than 40 dB especially with the panel of 5 cm thickness. This efficiency is so good and preferable for construction materials.

For large ducts with problematic low frequencies above the initial cut-on frequency, some useful attenuation may be achieved using purpose built sensing and actuation mechanisms to "track" the more complex two or three

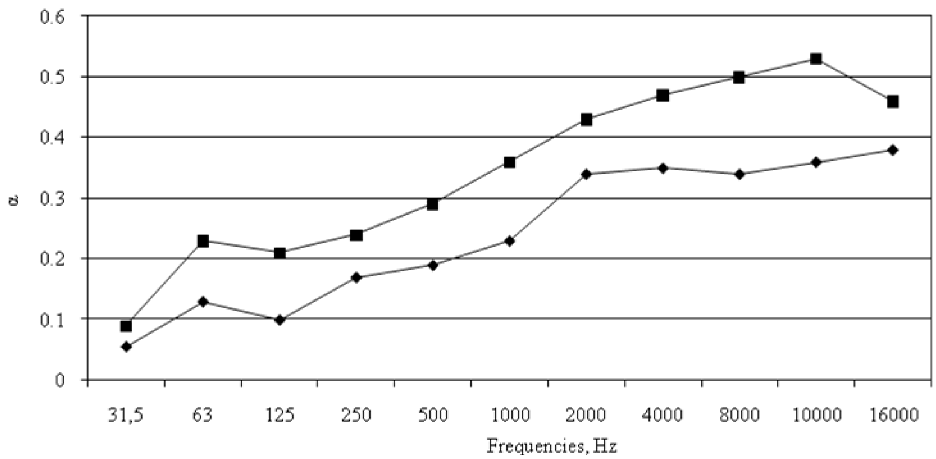


**Figure 3.** NRC values for 3 cm thickness (■: Clean archieve paper, ♦: Waste paper).

dimensional field over the cross-section of the duct (Bai and Lin, 1998). The increased efficiency of the Vac Damps over traditional surface treatment is confirmed on both the accelerating and ringing noises. Additional knowledge is gained concerning the effects of the pads on both the air and flexural wave components, the ace-lerating noise, their effects on the contact duration, and their influence on the shape of the impact noise field (Ross et al., 2001). More efficient results were obtained with boron added cellulose of 5 cm thickness for high frequencies.

There is the problem of noise transmission through the partition above the suspended ceiling. This may be prevented (Knudsen and Harris, 1951) by using ceiling panels backed by a heavy impervious layer that reduces sound penetration through the ceiling, or (Harris, 1957) by building adequate partitions in the space above the ceiling. Absorption coefficients for panels with non-flat subsurface have also been determined. In spite of some discrepancies, similarity is obtained when comparing the data with absorption coefficient by the reverberation method (Kimura and Yamamoto, 2001). Contour plots at a model frequency corresponding to a full scale frequency of 400 Hz showed an insertion loss of 24 dB or greater below the height of the barrier (Fujiwara et al., 1998).

Cellulose-boron and clean paper-boron mixtures can be used as insulation materials. When the data obtained from 5 cm-panel were especially considered, it was evident that the material was having the same properties with many products used for the same purpose in the market.

The material used in the study was so efficient for high frequencies. The NRC and α value were obtained for clean paper mixture as 0.46 and 0.38, respectively and for waste paper mixture as 0.34 and 0.38, respectively with 3 cm thickness; for clean paper mixture as 0.55 and 0.81, respectively and for waste paper mixture as 0.31 and 0.72, respectively with 5 cm thickness.

The mixture with 5 cm thickness can be easily used inside the walls of critical utilization areas like office, house, hospital, etc. that exist near and/or inside the traffic, bazaar, park, children park areas. For the reduc-tion of environmental noise, worker health and affected office areas, the absorbing panel is too appropriate to be used at the walls of industrial areas in which noise of high frequencies occurs. Since the material is not rigid but soft, it can be evaluated as a good absorber due to its non-reflecting property. Since the used cellulosic material is made up of wastes such as paper, etc., it becomes important in terms of environ-mental engineering when regaining of the wastes is taken into consideration.

## ACKNOWLEDGEMENT

The authors thank the Selcuk University Research Fund (BAP) for its financial support of the work undertaken here.

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