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Effects of using Cement-Bonded Particle Boards with a Composite Component in Terms of Acoustic Performance in Outdoor Noise Barriers

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Abstract: Wood-cement composites are widely utilized in many countries for both interior and exterior applications because of their strength properties for building materials (e.g., siding, roofing, cladding, fencing and sub-flooring) and for acoustic properties such as in highway sound barriers. These composites have unique advantages over other conventional materials. Generally, these products combine the good qualities of cement (relatively high resistance to water, fire fungus, and termite infestation coupled with good sound insulation) with those of wood (high strength to weight ratio and workability). While reflective products like concrete have been the traditional material for outdoor noise barrier walls & enclosures, the advanced sound-absorptive materials found in Cement-bonded particle board products present a much more effective abatement option. Products like concrete or brick simply bounce sound waves off their surface in different directions. Cement-bonded particle board products actually absorb or completely eliminate the sound waves that hit them, significantly reducing overall noise. In this paper, acoustic performance of Cement-Bonded Particle Boards for applications will be discusses in different construction models. In this paper, sound transmission loss performance of Cement-Bonded Particle Board panels for especially noise barrier applications will be discusses in different construction models. In this research, the general form of the composite sound barrier panel is a sandwich panel type, there is one board at the front and one at the back and in between there is an insulation layer. Thickness of the cement-bonded particle boards and insulation layer were chosen according to model design. The analysis results show that the material derivative, density and layer thickness of the insulation layer to be preferred in the sound barrier composite panel application are among the main factors directly affecting the Sound Reduction Index (Rw) performance of the model design.

Keywords: Cement bonded particle board, Panel, Noise, Barrier, Analysis

Introduction

Wood cement composites are in general strands, particles or fibres of wood mixed together with Portland cement as a mineral binder and manufactured into panels, bricks, tiles and other products used in the construction industry (Semple and Evans, 2004). Wood-cement composites have much higher resistance to both decay (i.e. mould, rot, borers and termites) and to combustion than resin bonded boards or solid wood (Goodell et al, 1997; Ramirez-Coretti et al 1998). They can also be manufactured where available wood or plant waste resources are unsuitable for production of sawn timber or conventional resin-bonded wood composites (Ledhem,2000). More importantly, they are much better suited to high fire, weathering and bio-deterioration risk applications to which solid wood and resin-bonded composites are vulnerable (Dinwoodie and Paxton, 1991). Cement bonded composites emits no toxic wastes during manufacture (Van Elten, 2000) and employ an inert binder free from health risks associated with the use of resin bonded composites (Chen and Hwang, 1988).

Although Wood cement composites have high density, the relatively low strength of WCC panels limits their use to non-structural paneling or roofing applications (Oyagade et al, 1995; Wolfe and Gjinolli, 1999). A significant advantage of wood-cement composites to engineering applications appears to lie in the ability to absorb and dissipate mechanical energy (Wolfe and Gjinolli, 1999; Wolfe and Gjinolli, 1997). This, as well as good sound dissipation and absorption properties, has attracted research and development of wood cement composites as very practical and cost effective highway sound barriers (Wolfe and Gjinolli, 1999). Wood cement composites can be used in areas subjected to seismic activity and/or heavy wind loads such as hurricanes (Wolfe and Gjinolli, 1999; Wolfe and Gjinolli, 1997). Despite their higher weight strength ratio, wood cement composites have become popular in Europe and Asia for use as exterior siding, roofing and flooring applications. Some typical external applications well suited to WCC include agricultural buildings, prefabricated and mobile buildings flat roofing, industrial and exterior domestic cladding, tunnel linings, highway sound barriers, fire barriers and paving tiles (Van Elten, 2000).

Cement-bonded particle board is a composite product that is produced by pressing a mixture of wooden particles (chips/flakes) and Portland cement as the binding agent and hydration additives. It is an ecologically sound material. They are solid plates having smooth and hard surface used in «dry assembly» technology. The main binder is cement and therefore cement-bonded particle boards do not contain dangerous phenol and formaldehyde bonding substances, asbestos and other poisonous stuff.

Cement bonded particle board have shown to have long service life, retaining and even increasing its strength after years of exposure. A controlled outdoor weathering test of Cement bonded particle-boards in Britain over 10 years by Dinwoodie and Paxton found that the strength of Cement bonded particle-boards increased by around 45% over the first 3 to 5 years but then declined by about the same amount over the next 5 to 7 years (Dinwoodie and Paxton, 1989).

In recent years, some products for structural applications have been developed such as cement-strand slab, cement-bonded composite beams and cement-bonded oriented strand boards. In comparison to wood and conventional wood products, cement-bonded particle boards are highly fire resistant, having a high mechanical strength, water & moisture and insects resistant especially in warm and humid environment where such materials are demanded for construction materials and ecological cleanness required at the same time. Enhanced strength and durability of wood-cement composites with aging has been attributed to 'mineralisation' or'petrification' of the wood elements by cement minerals (Bentur and Ackers, 1989). Air borne sound reduction varies between 30 and 37 dB for the frequency range 100- 3150 HZ according to thickness of Cement bonded particle-board panels. When used in stud partitioning, a reduction of over 60 dB could be achieved with suitable construction.

In this paper, sound transmission loss performance of Cement-Bonded Particle Board panels for especially noise barrier applications will be discusses in different construction models.

Noise and Sound Barriers

Noise is defined as unwanted sound and can come from man-made and natural sources. Sound levels are measured in decibels (dB) and typically range from 40 to 100 dB. Because human hearing is limited in detecting very high and low frequencies, "A-weighting" is commonly applied to sound levels to better characterize their effects on humans. A-weighted sound levels are expressed as dB(A).

Because noise in our daily environment varies over time, and sustained noise levels (such as a nearby highway) interfere with our daily activities to a greater extent than short, louder noises (such as a single car horn), traffic noise analyses typically consider average noise levels over a one-hour period.

Traffic noise can be potentially reduced by modifying either the source of the noise (speed, volume or type of vehicles), the location of the receiver (the person who hears the noise), or the path by which the noise reaches the receiver. Because it is impractical to reduce the speed, volume or type of vehicles on a highway, or to relocate residences solely due to noise impacts, the most common approach to mitigating noise is the construction of noise barriers (INDOT, 2018).

A sound barrier is a solid structure that intercepts the direct sound path from a sound source to a receiver. They are solid obstructions built between the highway and homes or residences along a highway. Noise barriers reduce the sound from a busy highway by either absorbing the sound, transmitting it, reflecting it back across the highway, or forcing it to take a longer path to receivers. A noise barrier must be tall enough and long enough to block traffic noise from the area that is to be protected. Noise barriers provide very little benefit for homes on a hillside overlooking a highway or for buildings, which rise above the barrier. A noise barrier can achieve a 5 dB noise level reduction when it is tall enough to break the line-of-sight from the highway to the home or receiver. Effective noise barriers typically reduce noise levels by 5 to 10 dB, which reduces the loudness of traffic noise by as much as one-half. Noise barriers do not completely eliminate noise, but rather reduce overall noise levels (INDOT, 2018). After it breaks the line-of-sight, it can achieve approximately 1.5 dB of additional noise level reduction for each meter of barrier height. To effectively reduce the noise coming around its ends, a barrier should be at least eight times as long as the distance from the receiver to the barrier (INDOT, 2018).

It reduces the sound pressure level within its shadow zone. A sound-reducing barrier wall with a porous surface material and sound-dampening content material is said to be absorptive. This means little or no noise is reflected back towards the source or elsewhere. Hard surfaces such as masonry or concrete are considered to be reflective. This means much of the noise is reflected back towards the noise source and beyond. A noise barrier without any added absorptive treatment is by default reflective. In highway applications for example, a reflective noise barrier on one side of the roadway can result in some sound energy being reflected back across the roadway to receivers on the opposite side. In this situation, it is a common phenomenon for one to perceive a difference in sound after a noise barrier is installed on the opposite side of a roadway. Individuals on the opposite side of the roadway may perceive a change in the quality of the sound; the signature of the reflected sound may differ from that of the source due to a change in frequency content upon reflection (Sound Figter Systems, 2018).

While reflective products like concrete have been the traditional material for outdoor noise barrier walls & enclosures, the advanced sound-absorptive materials found in Cement-bonded particle board products present a much more effective abatement option. Products like concrete or brick simply bounce sound waves off their surface in different directions. Cement-bonded particle board products actually absorb or completely eliminate the sound waves that hit them, significantly reducing overall noise.

Noise Reduction Coefficient of Cement-Bonded Particle Boards

When evaluating the sound absorption characteristics of noise barriers in general, the frequency values in which the human ear is most sensitive are taken into consideration instead of values in each frequency range. These values are taken at 250 Hz, 500 Hz, 100 Hz and 2000 Hz, the arithmetic mean of the sound absorption coefficient values of these materials are taken and the result is rounded to the nearest 0.05 dB and the sound absorption coefficient of the material is converted into a single expression. In ASTM C 423 Standard, this value is called the Noise Reduction Coefficient. The Noise Reduction Coefficient (commonly abbreviated NRC) is a scalar representation of the amount of sound energy absorbed upon striking a particular surface. In other words, a Noise Reduction Coefficient is an average rating of how much sound an acoustic product can absorb. NRC is a single number rating defined by the ASTM standard C423, the laboratory method for determining sound absorption in a diffuse field reverberation chamber (ASTM, 2017). It is a common misconception that NRC is calculated from octave band sound absorption coefficients. However, ASTM C423 does not define octave band sound absorption coefficients, only 1/3 octave band values. Therefore, sound absorption coefficients in the 1/3 octave bands centered around 250, 500, 1000, and 2000 Hz are used. This is further clarified by the terminology standard ASTM 634 (ASTM, 2013).

NRC ratings range from 0 to 1. An NRC of 0 indicates perfect reflection which means that the product absorbs no sound; an NRC of 1 indicates perfect absorption which means that the product absorbs all sound. The higher the NRC, the better the product is at soaking up sound. In a general sense, if the NRC value is less than 0.3, these types of materials are called as reflection materials. The thickness and density of a product are two factors in calculating a Noise Reduction Coefficient. An acoustic product with a .95 NRC rating means that 95% of sound in the space is absorbed, while the other 5% is reflected.

In this research work, Noise Reduction Coefficient values of surface textured Cement-Bonded Particle Boards and flat surface Cement-Bonded Particle Boards in different thicknesses were examined. According to the findings, NRC value of flat surface Cement-Bonded Particle Boards is defines as 0.025 with 10 mm board thickness. For 12 mm board thickness, NRC values was determined as 0.030 and 0.035 for 18 mm board thickness. On the other hand, NRC value of surface textured Cement-Bonded Particle Boards is defines as 0.035 with 10 mm board thickness. For 12 mm board thickness, NRC values was determined as 0.040 and 0.045 for 14 mm board thickness. Due to the wood chip within the structure of the boards, it was observed that the NRC value of the material was slightly higher than the other fibercement boards. According to these definitions, it is understood that these board types are all reflective.

Sound Absorption of Cement-Bonded Particle Board Panels

All building materials have some acoustical properties in that they will all absorb, reflect or transmit sound striking them. Conventionally speaking, acoustical materials are those materials designed and used for the purpose of absorbing sound that might otherwise be reflected. When a sound wave strikes an acoustical material the sound wave causes the fibers or particle makeup of the absorbing material to vibrate. This vibration causes tiny amounts of heat due to the friction and thus sound absorption is accomplished by way of energy to heat conversion. The more fibrous a material is the better the absorption; conversely denser materials are less absorptive (URL1, 2018). The sound absorbing characteristics of acoustical materials vary significantly with frequency. In general low frequency sounds are very difficult to absorb because of their long wavelength. On the other hand, people are less susceptible to low frequency sounds, which can be to human’s benefit in many cases. For the vast majority of conventional acoustical materials, the material thickness has the greatest impact on the material's sound absorbing qualities. While the inherent composition of the acoustical material determines the material’s acoustical performance, other factors can be brought to bear to improve or influence the acoustical performance (URL1, 2018). Incorporating an air space or sound absorber layer in a composite panel often serves to improve low frequency performance.

In this research work, sound absorption characteristics of Cement-Bonded Particle Board panels in composite form with incorporating a sound absorber material layer were investigated. Figure 1 shows the general form of a composite sound barrier panel in which the design is easy to apply, the durability is high and practically repairing and/or renewing can also be performed. Dimension of cement-bonded particle boards are 3000 mm length and 1250 mm width. Metal capping was used as a top panel capping and also base channel at the bottom of the models. Thickness of the cement-bonded particle boards were chosen according to model design.

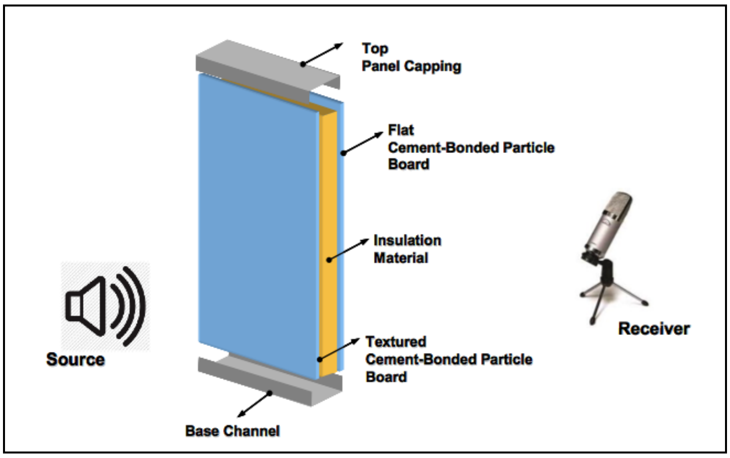

Figure 1. A simplified sketch of composite panel analysis model

Two different composite panels were modelled in different panel cross section components. These models are symbolised in Figure 2 and Figure 3. In these models, mineral wool was used 10 mm to 90 mm thickness changes as an insulation material component with dry unit density of 50 kg/m^3. All these models, the thickness values of cement-bonded particle board panels were kept as constant as shown in the figures.

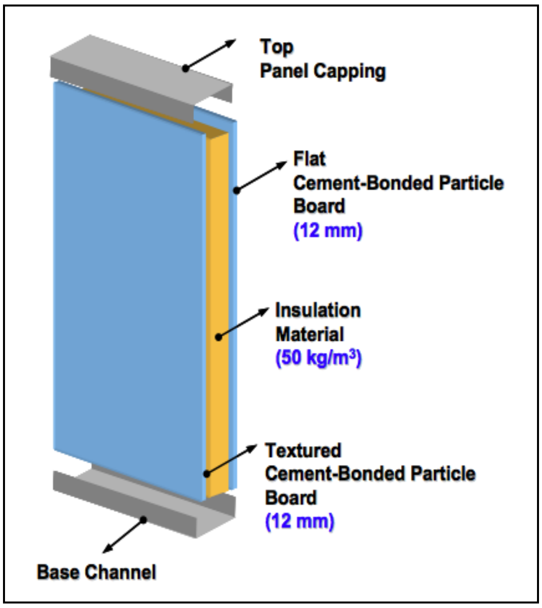

Figure 2. Components of composite panel-Model 1

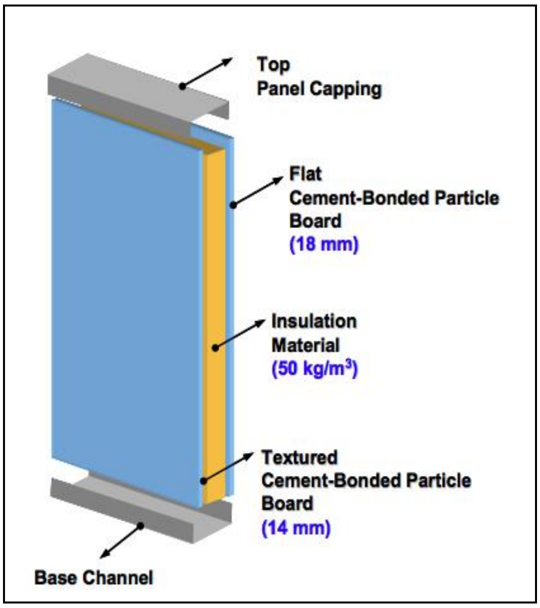

Figure 3. Components of composite panel-Model 2

In the research study, according to the component values applied in these model analyses, the general technical findings obtained in the models are summarized in Table 1 and Table 2.

Table 1. Some technical dimensions of Model 1 cross-section components.

Insulation Layer (mm)	Model Cross Section (mm)	Insulation Layer Ratio By Thickness (%)	Insulation Layer Ratio By Weight (%)	Areal Density (kg/m^2)
10	34	29,41	1,44	34,7
20	44	45,45	2,84	35,2
30	54	55,56	4,20	35,7
50	74	67,57	6,81	36,7
60	84	71,43	8,06	37,2
70	94	74,47	9,28	37,7
80	104	76,92	10,47	38,2
90	114	78,95	11,63	38,7

Table 2. Some technical dimensions of Model 2 cross-section components.

Insulation Layer (mm)	Model Cross Section (mm)	Insulation Layer Ratio By Thickness (%)	Insulation Layer Ratio By Weight (%)	Areal Density (kg/m^2)
10	42	23,81	1,09	46,0
20	52	38,46	2,15	46,5
30	62	48,39	3,19	47,0
50	82	60,98	5,21	48,0
60	92	65,22	6,19	48,5
70	102	68,63	7,14	49,0
80	112	71,43	8,08	49,5
90	122	73,77	9,00	50,0

As the table values are examined, as the insulation layer value increases, the areal density of the composite panel form also tends to increase with a parabolic trend. This evaluation was analyzed graphically by correlating the areal density value of the model section with the thickness ratio of the insulation layer in the total cross-section composition. Analysis findings are presented in Figure 4 and Figure 5 for each model.

As an evaluation situation, the key criterion for noise-sensitive areas and the noise shielding barriers to be applied in the world is considered to be 35 dB(A). In other words, it is desirable for a material to be used as a noise barrier to provide the weighted sound reduction index, Rw = 35 dBA value to be taken into account by considering the application conditions. Materials with a areal density greater than 20 kg/m^2 are considered to cause at least 20 dB(A) sound transmission loss. It is accepted in the literature that such a material provides a sound reduction of at least 10 dB(A) due to diffraction. According to these general evaluations, it can be foreseen in the context of preliminary findings that the areal density changes of both models are greater than 20 kg/m^2 and that they can be used in the form of sound barrier in sound-noise barrier applications.

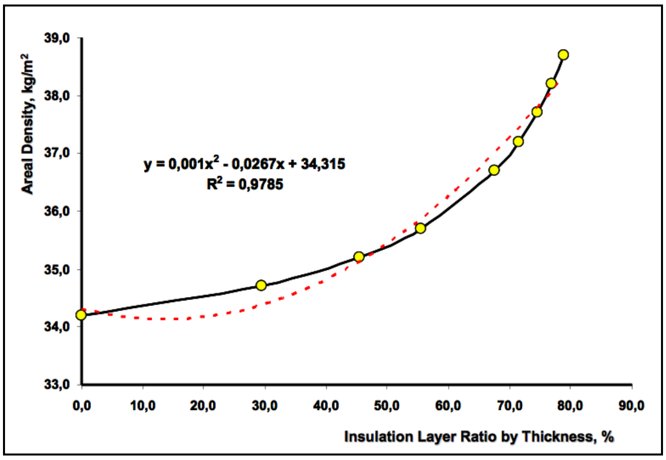

Figure 4. Insulation layer ratio by thickness versus areal density for Model 1

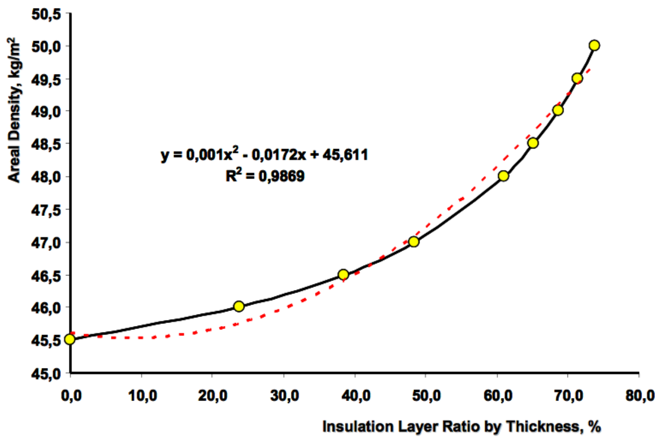

Figure 5. Insulation layer ratio by thickness versus areal density for Model 2

However, in order to be able to examine the sound transmission loss characteristics of cement-bonded particle board composite panels, the sound transition loss values of the model designs at each frequency in the range of 50 Hz - 5000 Hz were determined in 1/3 octave band frequency values. Composite sound barrier panel models using the mass law approach, 50 kg/m^3 dry density insulation layer in the range of 10 - 90 mm thickness changes are applied in the case of sound transmission loss values are determined based on 1/3 octave band frequency values. As an example of the analysis findings, the sound transmission loss values obtained for the models with 50 mm insulation layer thickness are given in Figure 6 and Figure 7. In addition, the weighted sound reduction index value Rw and the spectrum values (C; Ctr) of each evaluation were determined according to the principles stipulated by the standard.

Frequency (Hz)	Sound Transmission Loss R (dB)
50	20,8
63	19,7
80	17,1
100	21,3
125	25,6
160	30,7
200	35,8
250	39,8
315	42,7
400	44,5
500	47,6
630	49,7
800	51,9
1000	53,1
1250	54,8
1600	55,5
2000	55,8
2500	52,5
3150	47,7
4000	51,8
5000	55,8

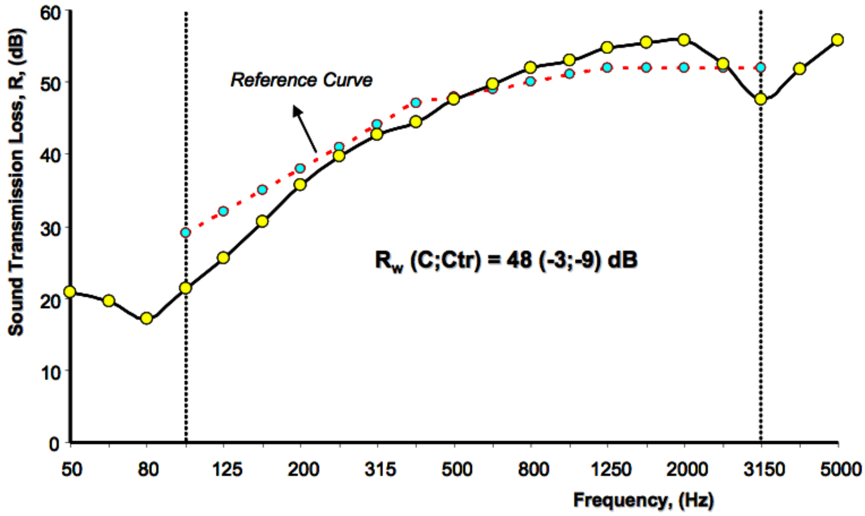

Figure 6. Sound transmission loss verses frequency for Model 1 with 50 mm insulation layer

Frequency (Hz)	Sound Transmission Loss R (dB)
50	23,2
63	22,0
80	19,4
100	23,6
125	27,9
160	33,0
200	38,1
250	42,1
315	45,0
400	46,8
500	49,9
630	52,1
800	54,3
1000	55,4
1250	57,2
1600	57,9
2000	58,1
2500	54,9
3150	50,0
4000	54,1
5000	58,1

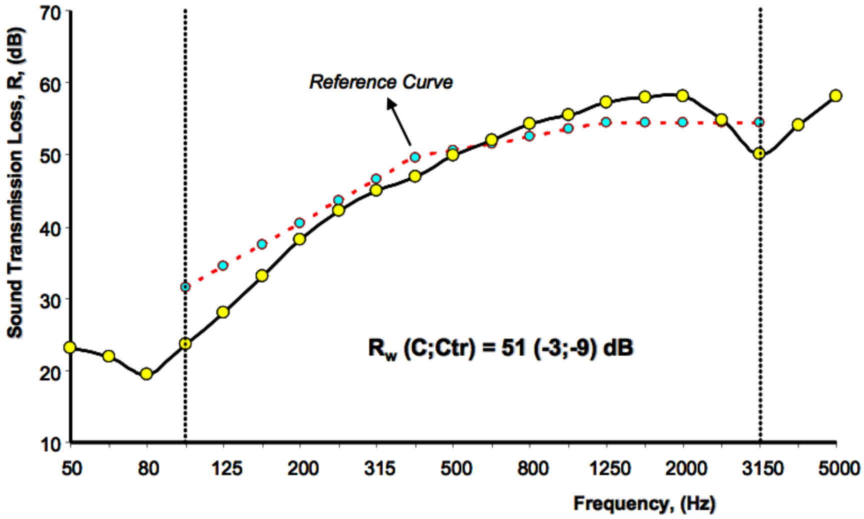

Figure 7. Sound transmission loss verses frequency for Model 2 with 50 mm insulation layer

As seen in the model 1, the weighted sound reduction index Rw value for the cement-bonded particle board composite sound barrier panel designed with a thickness of 50 mm is 48 dB, while in the Model 2 version the Rw value with the equivalent insulation layer thickness is obtained as 51 dB with 3 dB increment. This change is seen as a function of the change of cement particle board thicknesses used in equal beads.

The sound transmission loss characteristics of the cement-bonded particle board panel for sound barrier purposes is dependent on the change in thickness of the insulation layer used in panel design. In this analysis, the panel's performance change was seen as a function of the rate of change of the insulation layer thickness ratio with a gradual increase or the increase in the insulation layer ratio by weight of the total section. In this context, the findings obtained for both sound barrier model designs are given in Figure 8 - Figure 11 graphically for Rw performance evaluation.

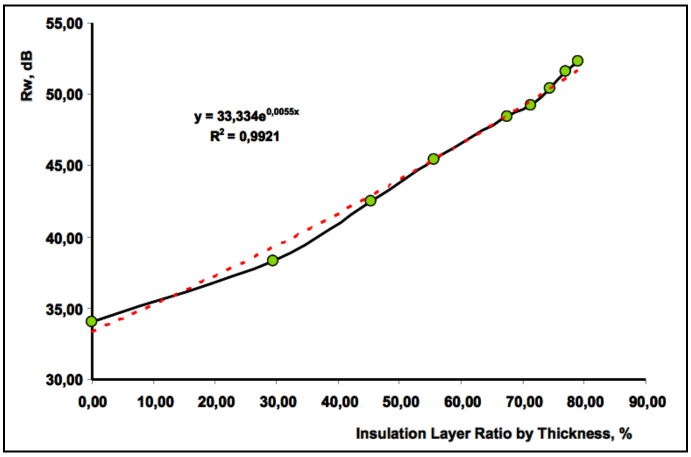

Figure 8. Insulation layer ratio by thickness versus Rw for Model 1

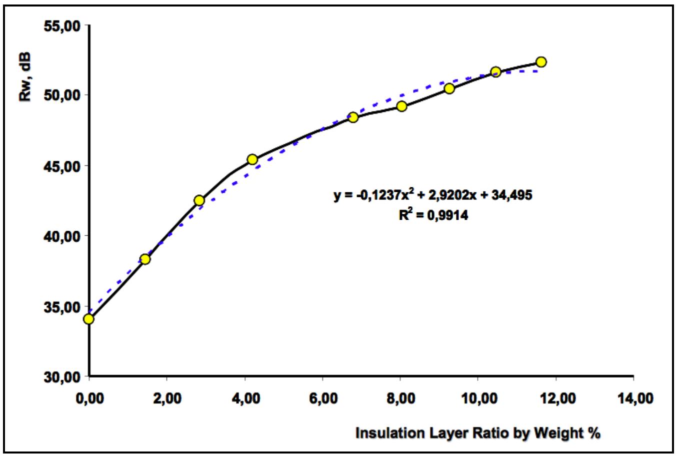

Figure 9. Insulation layer ratio by weight versus Rw for Model 1

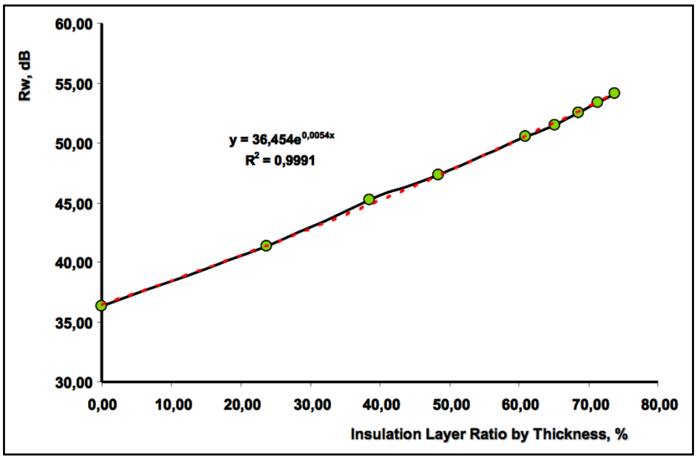

Figure 10. Insulation layer ratio by thickness versus Rw for Model 2

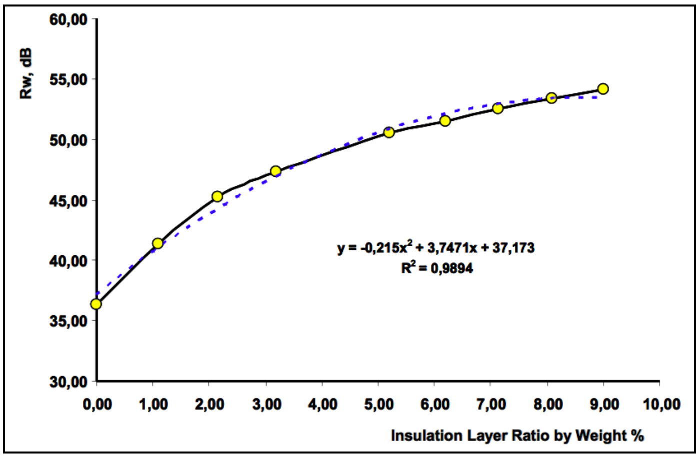

Figure 11. Insulation layer ratio by weight versus Rw for Model 2

Using these curvilinear findings, the optimum insulation thickness and model design components can be optimized in terms of the desired sound barrier performance. As a general phenomenon, the material derivative, density and layer thickness of the insulation layer to be preferred in the sound barrier composite panel application are among the main factors directly affecting the Rw performance of the model design. The analysis results show that when the ratio of the insulation layer reaches a value greater than 4.5% by weight in the total cross-section, the composite panel achieves an increasingly stable value in terms of Rw performance. In other words, the Rw performance improvement rate occurs at increasingly low levels. However, an increase in the thickness ratio of the total layer of the insulating layer improves Rw performance with a linear trend. Another criterion is that the thickness and surface properties of the cement-bonded particle boards used in the composite panel are also an important factor in the improvement of Rw performance due to the increased areal density value. As can be seen from these findings, all model designs can easily provide the sound comfort provided by the sound panel applications in the world. In other words, the findings of all applications provide a value of 35 dB(A) sound transmission loss which can be taken from the literature as reference.

Conclusion

While reflective products like concrete have been the traditional material for outdoor noise barrier walls & enclosures, the advanced sound-absorptive materials found in Cement-bonded particle board products present a much more effective abatement option. In this paper, sound transmission loss performance of Cement-Bonded Particle Board panels for especially noise barrier applications was discusses in different construction models. In this research work, Noise Reduction Coefficient values of surface textured Cement-Bonded Particle Boards and flat surface Cement-Bonded Particle Boards in different thicknesses were examined. According to the findings, NRC value of flat surface Cement-Bonded Particle Boards is defines as 0.025 with 10 mm board thickness. For 12 mm board thickness, NRC values was determined as 0.030 and 0.035 for 18 mm board thickness. On the other hand, NRC value of surface textured Cement-Bonded Particle Boards is defines as 0.035 with 10 mm board thickness. For 12 mm board thickness, NRC values was determined as 0.040 and 0.045 for 14 mm board thickness. Due to the wood chip within the structure of the boards, it was observed that the NRC value of the material was slightly higher than the other fibercement boards. According to these definitions, it is understood that these board types are all reflective. It is desirable for a material to be used as a noise barrier to provide the weighted sound reduction index, Rw = 35 dBA value to be taken into account by considering the application conditions. As seen in the model 1, the weighted sound reduction index Rw value for the cement-bonded particle board composite sound barrier panel designed with a thickness of 50 mm is 48 dB, while in the Model 2 version the Rw value with the equivalent insulation layer thickness is obtained as 51 dB with 3 dB increment. According to the research results, cement-bonded particle boards with a composite form is an effective application in terms of acoustic outdoor noise barriers.

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