Acoustic properties of concrete modified with an asphalt/styrene butadiene emulsion

R A Cruz¹, C R Correa², G A Díaz-Ramírez¹³

¹ INME, Escuela de Ingeniería Civil, Universidad Industrial de Santander, Ciudad Universitaria, Bucaramanga, Colombia.
² Escuela de Ingeniería Electrónica, Electrónica y Telecomunicaciones, Universidad Industrial de Santander, Ciudad Universitaria, Bucaramanga, Colombia.
³ Escuela de Ingeniería Metalúrgica y Ciencias de los Materiales, Universidad Industrial de Santander, Ciudad Universitaria, Bucaramanga, Colombia.

*E-mail: racruz@uis.edu.co

Abstract. This work describes the acoustic properties, such as absorption and reflection acoustic coefficients and noise reduction coefficient (NRC), and the mechanical strengthening of a modified asphaltic emulsion concrete. The asphalt emulsion has emulsifying agents, water and 62% asphalt, and has been mixed with styrene butadiene (SB) to 5% in asphalt weight. The concrete was made with high strength cement. Additionally, the concrete was modified with the SB emulsion at 5, 15 and 20% (CM5, CM15, CM20) of the cement weight. The results showed different coefficients depending on the wave frequency. CM20 shows the higher absorption coefficient. On lower frequencies, the concrete pattern (CP) and CM5 have higher reflection coefficients. CM20 indicated one hundred percent increase on the NRC related to CP. At the same time, the compressive strength decreases proportionally to the amount of emulsion between 13 and 43% compared to the concrete pattern.

1. Introduction
One of the main tasks of the building physics is the acoustic insulation [1]. The construction industry uses a large amount of concrete for fabrication of building elements and requires the implementation of alternative products that improve their properties of durability, acoustic and thermal insulation, among others, without detracting from their mechanical properties [2]. Room acoustic correction and its isolation are achieved by properly using absorbing and isolating materials (acoustic materials) [3–5]. Noise Reduction Coefficient (NRC) indicates the average sound percentage that is absorbed by a given material. This coefficient is the average value of absorption measurements at 250, 500, 1000, and 2000 Hz, rounded to the closest 0.05 multiple [6]. Building materials in general have low NRC values, mainly derived from their stiffness. These values range from 0.05 and up to 0 [7–9]. With an impedance tube could be determined experimentally acoustic properties such as the reflection...
coefficient, specific acoustic resistance, specific acoustic admittance relation, and the absorption coefficient of perpendicularly incident sound, among others [7–12].

Felts made of glass fiber with random and layered cross-sectional structure have been used successfully as sound insulation. Polymeric samples have acoustic properties, like polyester fiber materials, reported recently by Pelegrinis et al. [13]. Polymers are used as components in systems for reducing or eliminating aerial noise, because of its components exhibit long carbonated chains, asphalt for instance, is considered a material with polymeric characteristics [14–22]. This work searches to improve the concrete acoustic absorption property by asphalt emulsion addition to forming a pore matrix structure.

2. Experimental procedure

2.1 Materials

Materials used in this study consist of high initial resistance cement (ARI), 3/4” coarse aggregate, river sand, water and asphalt emulsion type CRL-1L modified with a styrene-butadiene copolymer. Specific gravity s.s.d. (2.63), absorption (8.0%) and fineness modulus (2.34) was obtained for sand. The coarse aggregate used in this work has a specific gravity s.s.d. of 2.63 and an absorption of 0.86%. Tests related to simple compressive strength (ASTM C39), ultrasonic pulses, specific weight, humidity, density, and organic matter were also carried out. To improve the asphalt quality (and thus emulsion quality) was used oil-soluble polymers, such as combinations of isobutene or butadiene-styrene copolymers. The amount of additive used in this work was a 5% weight butadiene-styrene copolymer, related to asphalt, and it was included in all emulsions for this research. Emulsion dosage for this purpose was initially set with respect to the cement weight, at rates of 5 (CM5), 15 (CM15), and 20% (CM20). Compressive Strength test was made to concrete with and without (CP) modification at ages of 3, 7, and 28 days.

The composition of the concrete mix for a water cement ratio w/c of 0.45, a target slump of 7.5 cm and compressive strength of 31.5 MPa, is: 350 kg/m³ cement, 820 kg/m³ sand, 1072 kg/m³ coarse aggregate. Table 1 shows the composition for each concrete sample.

| Table 1. Composition of the designed concrete mix |
| CONCRETE (Kg) | SAND (Kg) | COARSE AGGREGATE (Kg) | EMULSION (Kg) |
|----------------|------------|-----------------------|---------------|
| CP             | 350        | 820                   | 1072          | 0             |
| CM 5           | 350        | 820                   | 1072          | 17.5          |
| CM 15          | 350        | 820                   | 1072          | 57.5          |
| CM 20          | 350        | 820                   | 1072          | 70            |
| Ratio Water/Cement: 0.45 | Target Slump: 7.5 cm |

2.2 Equipment: Impedance tube (ISO10534-1)

The impedance tube (figure 1) was designed and built based on three main components: resonance tube, sound source, and measurement system [8,10,12]. The method consists of a plane wave traveling in one direction within a tube that is reflected backward by the test subject. This generates a standing wave that can be captured by the test microphone. Normal absorption coefficient can be measured by the permanent wave relation, usually in decibels. An additional measurement to determine the impedance relation at any frequency is the permanent wave position referred to the front of the test tube or material. Taking in account that absorption coefficients and impedance relations are functions of frequency, measurements are carried out at pure tones by selecting an adequate number of frequencies. Absorption coefficient calculation is shown in equation (3). In figure 2, the standing wave ratio (SWR) represents the relation between the peaks of the standing wave, measured as shown.
Measurements were carried out at the positions where the maximum and minimum amplitudes of the reflected wave appeared. With these values can determine the reflection and absorption coefficient of the sample at each frequency, and thus in calculating the NRC of the material. These values were calculated using the equations (1), (2) and (3).

![Figure 1. Impedance tube (ISO 10534-1 standards)](image)

\[ SWR = \frac{A + B}{A - B} = \frac{V_{\text{max}}}{V_{\text{min}}} \]  
\[ r = \frac{SWR - 1}{SWR + 1} \]  
\[ \alpha = 1 - r^2 \]

where SWR is the standing wave ratio (dimensionless), \( V_{\text{max}} \) is the first maximum tension (Volts), \( V_{\text{min}} \) is the minimum tension (Volts), \( r \) is the reflection coefficient (dimensionless), \( \alpha \) is normal absorption coefficient (dimensionless) and \( A \) and \( B \) are constants defined in figure 2.

3. Experimental results

3.1 Compressive strength

Compressive tests were made to CP and CM modified at rates of 5, 10, and 15% of emulsion respect cement weight at ages of 3, 7, and 28 days. The maximum resistance diminishing was of 43%, falling from 31.2 to 17.9 MPa for concrete plus emulsion at 15% in cement weight.
Table 2. Concrete compressive strength for CP and age at 3, 7 and 28 days

| AGE/DAYS | CP  | CM 5 | CM 15 | CM 20 |
|----------|-----|------|-------|-------|
| 3        | 20.17 | 16.64 | 15.84 | 12.84 |
| 7        | 28.28 | 21.60 | 17.00 | 15.80 |
| 28       | 31.22 | 27.15 | 24.54 | 17.84 |

3.2 Fluidity and workability.
Cement paste fluidity was evaluated through the consistency test to non-modify and modify mixes showing its significant increases proportional to the emulsion percentage. Setting time test of cement paste showed that the setting times were considerably delayed, but no negative change was made in the emulsion hardened paste. The asphalt emulsion content has a greater influence on fluidity and workability of the concrete making CM20 difficult to handling, because of the flow of aggregates is reduced and showing clumping.

3.3 Bulk density
The test results show (figure 3) that the bulk density of concrete mixed with asphalt emulsion was found to decrease gradually with the emulsion content compared to normal concrete. The average bulk density of CM concrete was in the range of 2121-2252 kg/m³, while the bulk density of normal concrete was about 2291 kg/m³.

3.4 Acoustic test
Tests were carried out in three different series, each one containing four test plates (CP, CM5, CM15, CM20). Each series was subject to testing at six different frequency levels (630, 800, 1000, 1250, 1600 and 2000 Hz), measuring the amplitude at the position of the maxima and minima. Then were determined absorption and reflection coefficients and the NRC. Test temperature was 25°C and plate thickness 20 mm. Table 3 shows the voltage data measured at microphone different distances to the sample and the reflection and absorption coefficients calculated with equations (1), (2) and (3). Only values at 800 Hz are shown as an example, but the evaluation was done for all samples, including CP. For other frequencies was observed that the coefficients vary slightly across the samples.
| Distance (10^-2 m) | Pattern concrete | Emulsion at 5% | Emulsion at 15% | Emulsion at 20% |
|-------------------|------------------|----------------|----------------|----------------|
| 2.0               | 1.667            | 1.613          | 1.467          | 1.333          |
| 10.6              | 0.044            | 0.093          | 0.160          | 0.253          |
| 22.5              | 1.753            | 1.673          | 1.553          | 1.453          |
| 33.0              | 0.044            | 0.093          | 0.160          | 0.253          |
| 43.7              | 1.723            | 1.643          | 1.523          | 1.423          |
| 54.5              | 0.044            | 0.093          | 0.160          | 0.253          |
| 66.0              | 1.783            | 1.703          | 1.587          | 1.483          |
| 76.5              | 0.074            | 0.123          | 0.187          | 0.283          |
| 88.2              | 1.753            | 1.673          | 1.553          | 1.453          |
| 98.3              | 0.044            | 0.093          | 0.160          | 0.253          |

Vmax = 1.753
Vmin = 0.044
SWR = 39.85
r^a = 0.95
α^b = 0.10

Testing frequency is 800 Hz.

^a Reflection coefficient
^b Acoustic absorption coefficient.

Figure 4. Average data after four measurements of the reflective behaviour of the concrete, mixed at different composition levels with a modified asphalt emulsion. Test frequency: 1000 Hz. A stands for the amplitude (in Volts).

In figure 4, experimental data from the oscilloscope is shown. The data shows the reflective behaviour of the CP concrete and of CM (concrete modified with asphalt emulsion) at a frequency of
1000 Hz. It can be observed that a standing wave is generated, as required for measuring the coefficients.

Table 4 shows the averaged normal reflection and absorption coefficients after six repetitions and the NRC values. Data shown are a sample run of the experiments.

| Frequency (Hz) | CP   | CM5  | CM15 | CM20 |
|----------------|------|------|------|------|
| 630            | 0.15 | 0.31 | 0.18 | 0.28 |
| 800            | 0.09 | 0.20 | 0.30 | 0.45 |
| 1000           | 0.01 | 0.06 | 0.12 | 0.31 |
| 1250           | 0.12 | 0.12 | 0.11 | 0.15 |
| 1600           | 0.10 | 0.10 | 0.10 | 0.19 |
| 2000           | 0.27 | 0.28 | 0.28 | 0.29 |

| Frequency (Hz) | CP   | CM5  | CM15 | CM20 |
|----------------|------|------|------|------|
| 630            | 0.92 | 0.83 | 0.90 | 0.85 |
| 800            | 0.95 | 0.89 | 0.84 | 0.74 |
| 1000           | 0.99 | 0.97 | 0.94 | 0.83 |
| 1250           | 0.94 | 0.94 | 0.94 | 0.92 |
| 1600           | 0.95 | 0.95 | 0.95 | 0.90 |
| 2000           | 0.85 | 0.85 | 0.85 | 0.84 |

| Frequency (Hz) | CP   | CM5  | CM15 | CM20 |
|----------------|------|------|------|------|
| 630            | 0.13 | 0.18 | 0.18 | 0.28 |
| 800            | 0.15 | 0.20 | 0.20 | 0.30 |

3.5 Analysis of acoustic results.

Beginning at 630 Hz the mixed concrete begins showing its absorption features. Proportions of 5% and 20% exhibited the best conditions for absorption, whilst the pattern concrete is the most reflective. Modified concrete at 15% sits at intermediate values. At this frequency, however, no clear tendency is evident.

At 800 Hz a sharp difference in the reflective behaviour of each material appears. All mixed materials improve the absorption capacity. A direct relation is detected between the amount of emulsion and the material absorption. At 1000 Hz the difference in reflective behaviour diminishes. Nonetheless the previously observe tendency remains. Pattern concrete is the most reflective material whilst the concrete with 20% emulsion is the one with the best absorption features.

At 1250 Hz, there is a sharp reduction in the difference between behaviours. Pattern concrete shows a slight increase in absorption performance, barely outperforming the mixtures with 5% and 15%. Concrete at 20% is still the one that best absorbs the sound wave.

At 1600 Hz there is a new increase in behaviour difference. Pattern concrete shows a slight increase in absorption performance, barely matching the pattern concrete under some conditions. At 2000 Hz the behaviours become similar once again, though tendencies are preserved. This implies that
concrete at 20% is the one with best absorption, vastly outperforming the remaining ones at most frequencies.

Pattern concrete shows its best absorption at 2000 Hz, whilst the mixture at 5% does it at 630 Hz. Mixtures at 15% and 20% performed best at 800 Hz. Pattern concrete and the mixture at 5% exhibited their best reflection coefficient at 1000 Hz, whilst the mixtures at 15% and 20% did so at 1600 Hz and 1250 Hz, respectively.

Analysing NRC values for each series it can be concluded that the tendency in reflective behaviour of each material is preserved. Difference between series is due to no uniformities within the mixture that create discs with different behaviour. A good behaviour of the emulsion was observed, especially after adding it in 20%, since it improved the NRC of the pattern concrete in 100%. By adding the emulsion in a 5% and in a 15%, the NRC improved in 33%. A material was developed with fairly superior absorbing capacities than traditional materials such as wood, glass, brick and the pattern concrete itself. Comparing NRC results for the concrete modified with asphalt emulsion against the values shown in Table 5, it can be concluded that this material has, at least, acceptable absorption features of acoustic energy. But, it also exhibits additional advantages such as low cost and the fast production rate that can be achieved.

The cost of the new acoustic material is far lower than those of commercially available ceilings. The response of the modified asphalt emulsion for noise absorption is quite significant since using it at 20% doubles the absorption rate of the pattern concrete. After carrying out four runs with different microphone gains and volume of the emitted wave, it was concluded that these two factors do not have an effect on the NRC values of the tested materials.

**Table 5.** NRC values for common construction materials used as aerial noise absorbers; the three mixtures are included for comparison purposes.

| Material                                | NRC  |
|-----------------------------------------|------|
| Vinyl-faced fiberglass ceilings         | 0.70 |
| Minetone                                | 0.55 |
| Second look IV                          | 0.45 |
| Brick                                   | 0.35 |
| Concrete + 20% emulsion                 | 0.30 |
| Plaster                                 | 0.30 |
| Concrete + 15% emulsion                 | 0.20 |
| Concrete + 5% emulsion                  | 0.20 |
| Pattern concrete                        | 0.15 |
| Wood                                    | 0.10 |
| Glass (ordinary window crystal)         | 0.10 |
| Concrete block                          | 0.05 |

4. **Conclusions**

- The emulsion addition has a negative effect on concrete compressive strength depending its content. With the use of plasticizer could be better the fluidity and concrete mechanical behaviour.
- The modified concrete bulk density decreases proportionally to emulsion addition percentage. Probably, it was formed a porosity making the modified concrete more appropriate as noise absorbing material.
- Depending on the test frequency vary the acoustic coefficients of the modified concrete. A direct relation is detected between the amount of emulsion and the material absorption. PC shows its best absorption at 2000 Hz, whilst CM5 does it at 630 Hz. CM15 and CM20 performed best at 800 Hz. PC and CM5 exhibited their best reflection coefficient at 1000 Hz, whilst CM 15 and CM20 did so at 1600 Hz and 1250 Hz, respectively.
- NRC values for each series have preserved the tendency as in the reflective behavior of each material. The NRC value of CM20 was 100% higher than of CP. By adding the emulsion in 5% and 15%, the NRC improved by 33%.
Noise reduction coefficients were obtained for materials traditionally used in civil projects with a precision of 95%.

Further studies are required to increase the absorption coefficient by varying the percentage of dissolved copolymer and by using emulsions with a higher asphalt content.

Noise reduction coefficients were obtained for materials traditionally used in civil projects with a precision of 95%. Further studies are required to increase the absorption coefficient by varying the percentage of dissolved copolymer and by using emulsions with a higher asphalt content.

Acknowledgments
The authors would like to thank Mr. Carbonell, T. and Gonzalez, I., civil engineers of Universidad Industrial de Santander for their helping in preparation for the experiment.

References
[1] Pérez G, Coma J, Barreneche C, de Gracia A, Urrestarazu M, Burés S and Cabeza L F 2016 Acoustic insulation capacity of Vertical Greenery Systems for buildings Appl. Acoust. 110 218–26
[2] Kim H K and Lee H K 2010 Influence of cement flow and aggregate type on the mechanical and acoustic characteristics of porous concrete Appl. Acoust. 71 607–15
[3] Secchi S, Asdrubali F, Cellai G, Nannipieri E, Rotili A and Vannucchi I 2016 Experimental and environmental analysis of new sound-absorbing and insulating elements in recycled cardboard J. Build. Eng. 5 1–12
[4] Zhang Y B, Bi C X, Chen J and Chen X Z 2008 Acoustic design sensitivity analysis based on wave superposition approach Noise Control Eng. J. 56 203–10
[5] Yang Y, Li B, Chen Z, Saeed M U, Chen Z, Li C, Wu C, Li Y and Fu R 2016 Effect of cross-sectional morphology and composite structure of glass fiber felts on their corresponding acoustic properties Fibers Polym. 17 97–103
[6] Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens J V S 1999 Fundamentals of Acoustics, 4th Edition
[7] Moretti E, Belloni E and Agosti F 2016 Innovative mineral fiber insulation panels for buildings: Thermal and acoustic characterization Appl. Energy 169 421–32
[8] Deckers E, Claeyts C, Atak O, Groby J-P, Dazel O and Desmet W 2016 A wave based method to predict the absorption, reflection and transmission coefficient of two-dimensional rigid frame porous structures with periodic inclusions J. Comput. Phys. 312 115–38
[9] Yahya I, Kusuma J I, Kristiani H R and Hanina R 2016 Laboratory investigation on the role of tubular shaped micro resonators phononic crystal insertion on the absorption coefficient of profiled sound absorber IOP Conf. Ser. Mater. Sci. Eng. 107
[10] Muehleisen R T and Beamer C W 2002 Comparison of errors in the three- and four-microphone methods used in the measurement of the acoustic properties of porous materials Acoust. Res. Lett. Online 3 112–7
[11] Haines J 1989 Standing wave and two-microphone impedance tube round-robin test program
[12] Seybert A F and Ross D F 1977 Experimental determination of acoustic properties using a two microphone random excitation technique J. Acoust. Soc. Am. 61 1362–70
[13] Pelegrinis M T, Horoshenkov K V. and Burnett A 2016 An application of Kozeny–Carman flow resistivity model to predict the acoustical properties of polyester fibre Appl. Acoust. 101 1–4
[14] Kang C, Matsumura J and Oda K 2006 A comparison of the standing wave and two microphone methods in measuring the sound absorption coefficient of wood J. Fac. Agric. Kyushu Univ. 51 1–4
[15] Pitre J 2007 Improving the sound absorbing capacity of Portland cement concrete pavements using recycled materials 1–45
[16] Tiwari V, Shukla A and Bose A 2004 Acoustic properties of cenosphere reinforced cement and asphalt concrete Appl. Acoust. 65 263–75
[17] Park S B, Seo D S and Lee J 2005 Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio Cem. Concr. Res. 35 1846–54

[18] Kim H K and Lee H K 2010 Acoustic absorption modeling of porous concrete considering the gradation and shape of aggregates and void ratio J. Sound Vib. 329 866–79

[19] Pastor J M, García L D, Quintana S and Peña J 2014 Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers Constr. Build. Mater. 54 541–9

[20] Zaetang Y, Wongsa A, Sata V and Chindaprasirt P 2013 Use of lightweight aggregates in pervious concrete Constr. Build. Mater. 48 585–91

[21] Kuo W-T, Liu C-C and Su D-S 2013 Use of washed municipal solid waste incinerator bottom ash in pervious concrete Cem. Concr. Compos. 37 328–35

[22] Park S B, Jang Y Il, Lee J and Lee B J 2009 An experimental study on the hazard assessment and mechanical properties of porous concrete utilizing coal bottom ash coarse aggregate in Korea J. Hazard. Mater. 166 348–55