Construction and Building Materials 73 (2014) 195–204

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement

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HIGHLIGHTS

- Crumb rubber concrete (CRC) has been found to be effective in absorbing sound.
- It performed well as an insulator and comparable to plain concrete.
- Workability was decreased with increasing grades and proportions.
- Compressive strengths also decreased particularly for the higher rubber replacements.
- Density was lower due to higher air contents and reduced relative densities.

ARTICLE INFO

Article history:
Received 30 May 2014
Received in revised form 17 September 2014
Accepted 25 September 2014

Keywords:
Crumb rubber concrete
Acoustics
Absorption
Reflection
Frequency

ABSTRACT

This paper presents the acoustic performance of small scale crumb rubber concrete (CRC) panels in terms of the sound absorbance and insulation at low (63, 125, 250 and 500 Hz) and high (1000, 2000, 4000 and 5000 Hz) frequencies. Acoustic tests were conducted with differing levels of fine aggregate replacement with crumb rubber (7.5% and 15%) with four different grades following freezing and heating. Analysis of the workability, compressive strength and density are also presented.

The results found that CRC performed well in terms of sound absorbance particularly with higher proportions (15% here) and grades of crumb rubber. As an insulator, the CRC was comparable with plain concrete with only marginal differences observed. Effects of freezing and heating were shown to have no significant influence on the insulation properties. The insulation performance for all concretes was found to improve at high frequencies.

The results demonstrate that CRC has potential as an external building cladding to absorb sound around high-rise urban structures but requires full-scale testing on site. This approach offers an environmental friendly solution to the ongoing problem of used tyres.

1. Introduction

Noise pollution is an ongoing issue for inhabitants of urban and industrial areas but is often not adequately addressed by Building Regulations or Planning Authorities. Dense materials like concrete are often used as external cladding as a means to prevent the passage of sound transmission into the property by reflection. However, when sound waves strike concrete cladding panels for example, they are reflected away but are not reduced in magnitude and become problematic in enclosed spaces such as apartment complexes, factories and narrow streets (Fig. 1). This can lead to a variety of problems such as masking warning signals, increasing the possibility of hearing loss and can be a factor in work-related stress [1,2]. The city of Vancouver has published a noise control manual which outlines the issues with this challenge [3]. In it they outline the origins of urban noise, its problematic nature (like reflected sound between buildings) and what can be done to reduce it, including the use of sound absorbing and damping materials and vibration isolation. A study commissioned by the city showed the average noise levels for residences along a busy street ranged from 67 to 70 dB over a 24-hour period.

Lightweight materials such as foam or fabric are often too porous to reflect sound which passes through and its energy converted to heat with a reduction in magnitude. This approach is often used in cinemas and recording studios to reduce the reverberation time of the room. While effective internally, lightweight materials are not suitable externally so concrete is still the preferred material.

Each year 2–3 billion tyres are scrapped in the US with similar quantities in Europe. It is estimated that approximately 40 million

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http://dx.doi.org/10.1016/j.conbuildmat.2014.09.107
0950-0618/

tyres are discarded per year in the UK [4]. Ireland produces over 35,000 tonnes of waste tyres which are banned from many landfill sites and may not be burned [5]. With decreasing disposal options and increasing production, the volume of used tyres is becoming a major waste management issue. Stockpiled tyres lead to many health, environmental and economic risks through air, water and soil pollution, littering the landscape and represent a serious fire hazards as once set alight they emit harmful chemicals [4,5].

The use of crumb rubber concrete (CRC) produced from different sizes including fine (1–6 mm) and course (6–19 mm), of broken down waste tyres to replace a portion of natural aggregates in concrete mixes has been the subject of much research [4,6–13]. However, the literature shows that the use of CRC is impractical in many structural applications due to significant reductions in strength [10,13–15]. Despite the limited mechanical properties of CRC, there is a market for non-structural concrete products with medium to low strength requirements. Sound absorbing substances and barriers are frequently used as a way to mitigate ambient noise and make use of a recyclable waste product. CRC is a durable composite material capable of absorbing and reflecting sound [16] and if used on the exterior of a structure can shield the occupants from ambient street noise. High rise apartment occupiers for example are often overlooking busy streets with high noise levels, often uncomfortably high, passing into dwelling spaces.

This paper investigates the potential of CRC to improve the acoustic performance of small scale slabs. These findings have the potential to be incorporated into larger exterior building cladding systems (in the form of exterior panels as an absorbent material) to decrease noise transmission in urban or built up environments.

2. Concrete acoustic properties

Sound is a form of energy which travels through solids, liquids or gasses in longitudinal waves by vibrating particles oscillating in a body. These waves expand outwards with the intensity distributed over a larger area as it dissipates. The greater the particles vibrate within the medium, the more energy passes through it. There are two types of audible sounds; airborne and impact. Airborne sounds (speech, loudspeakers, musical instruments, etc.) cause waves to travel through the air but not solids. However, they produce vibrations within the structure which cause particles in the air on the opposite side to vibrate allowing them to be heard.

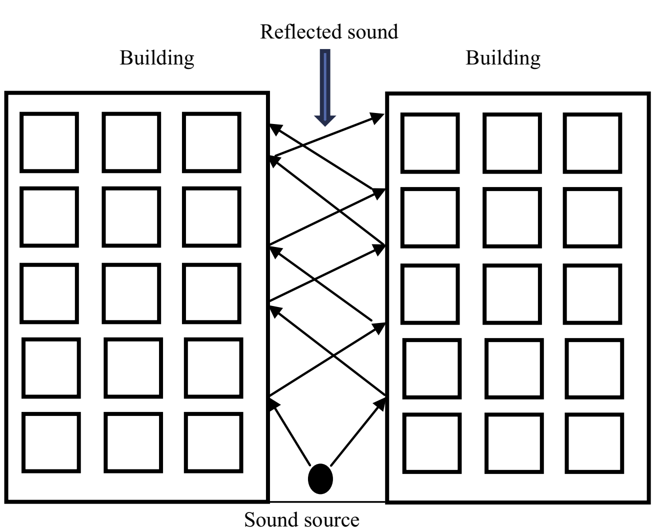

Fig. 1. Reflections of sound waves in an enclosed narrow street.

Impact sounds (footsteps, closing doors, falling objects, etc.) vibrate through walls and floors and lead to airborne noise in adjacent rooms [17]. Noise and sound are often interchanged but are quite different with the former being subjective and dependant on the receptor. This concept of subjectivity is what many designers must take into account when considering noise in a structure, particularly in urban settings. As it is difficult to reduce the volume or production of sound in these environments, noise mitigation measures are often put in place to reduce the level of annoyance. Insulation, reflection or isolation methods along with dense barriers are better able to reflect sound energy where lighter materials can absorb noise and contain it.

The acoustic properties of concrete are defined as its ability to reduce the transmission of sound through it. The density of standard concrete mixes can, in relatively small thicknesses, provide sufficient mass to reflect sound. Previous research [18–20] has defined concrete as a good insulator which, due to its high density, can reflect up to 99% of sound energy [21]. However, plain concrete is a poor sound absorber which can lead to echoes within enclosed spaces.

2.1. CRC acoustic properties

The level of sound absorption is expressed as the absorption coefficient. An extremely dense material, which reflects 100% of sound away, has an absorption coefficient of 0. Typical absorption coefficients for common construction materials are shown in Table 1.

Previous work has shown [22] that absorption coefficients for materials containing crumb rubber range from 0.3 to 0.7 which categorises it as a good absorber. Combining it with concrete has the potential of increasing the absorption qualities while reducing the level of reflected sound. Previous work in this area [19,20,22,23] found sound absorption is improved with the inclusion of crumb rubber.

Crumb rubber as a sound absorber for highways has been used in many parts of Arizona by incorporating it into bituminous mixes to reduce the noise produced by vehicular traffic. It is reported that over 80% of all asphalt in the state contains rubber asphalt accounting for roughly 12 million end-of-life tyres [24]. Research [25] has shown that the sound absorption qualities of asphalt are significantly improved over time with the inclusion of crumb rubber in lightweight pavements due to greater energy absorption despite the well published reductions in compressive and tensile strength. This is supported by other work [26–28] who found the levels of vibration damping were 230% greater in CRC with a 15% replacement of fine aggregate compared to standard concrete.

Crumb rubber has also been added into concrete blocks producing a lighter, more flexible and durable absorbing material with a 20% fine aggregate substitute [29]. Investigations into the performance of CRC in different environments found that the use of air entraining admixtures increases the durability against freeze thaw action [30–33]. A study into the compressive behaviour of CRC subjected to excessive heat [15] (25–600 °C) demonstrated a significant improvement in energy absorption particularly with smaller grades of rubber and lower fine aggregate replacements. Unlike regular aggregates such as sand & gravel, crumb rubber is highly

Table 1
Average absorption coefficients for common construction materials.

Material	Sound absorption co-efficient
Concrete	0.02–0.06
Unpainted blockwork	0.02–0.05
Hardwood	0.3