Acoustic and thermal insulation properties of recycled aggregate mortar

W Gh Abdul Hussein¹, A A Al-Sultan¹ *, F H Al-Ani¹
¹,2 Assistant Professor, Ph.D., Civil Engineering Department, University of Technology, Baghdad, Iraq
² Lecturer, M.Sc., Civil Engineering Department, University of Technology, Baghdad, Iraq
*Corresponding Author: 40321@uotechnology.edu.iq ; +964 770 170 6779

Abstract. This study focuses on the design of a lightweight cement mortar with recycled fine aggregates of wood, plastic, and glass. The normal fine aggregate (sand) was replaced with 20%, 40%, and 60% by weight of sand of recycled aggregates, prepared by cleaning wood sawdust, broken plastic, and broken glass with mechanical milling and then using a mill to obtain a similar gradation to that of the sand. The main goal of this paper was to study the effects of using these recycled aggregates on acoustic and thermal properties as compared with those of the reference cement mortar. Acoustic insulation tests were thus carried out on samples with dimensions of 23 × 23 × 0.8 cm prepared for this purpose at the age of 28 days, with three models for each replacement ratio. The acoustic isolation results showed that cement mortar with sawdust at replacement ratios 20%, 40%, and 60% showed better acoustic isolation properties than cement mortar with plastic and glass with the same replacement percentages or ordinary cement mortar. The thermal insulation of the samples was tested in samples with dimensions of 10 × 5 × 2 cm at 28 days. The results for thermal conductivity coefficients were 0.2353 W.m⁻¹K⁻¹, 0.1981 W.m⁻¹K⁻¹, and 0.1609 W.m⁻¹K⁻¹ for the replacement ratios 20%, 40%, and 60%, respectively. These results show that the cement mortar with sawdust offered less thermal insulation than cement mortar with plastic debris, while cement mortar with crushed glass was even less thermally isolated.

1. Introduction

The absence of successful engineering management has led to the spread of municipal solid waste, which includes many items that might offer important sources of materials if recycled and reused to achieve engineering sustainability, in addition to validating the cost of extracting these materials from their sources and preventing waste of primary materials. Wood sawdust and tree waste, glass, and plastic form large proportions of current waste solids, and these can and should be exploited, re-routed, and reused in several areas, including the construction sector.

It is important to recognise that the sustained growth in reuse efforts, as well as sustained interest in the reuse industry, derives in large measure from the solid waste reduction hierarchy: Reduce, Reuse, Recycle [1, 13]. It is best to reduce use first, reusing materials as a second option, and only then to resort to recycling. Reuse is recognized as being distinct from recycling, both in doctrine, and in the handling of the materials, as it diverts items from the waste stream [1, 14]. Recyclers successfully keep waste materials out of landfill by collecting, segregating, processing, and manufacturing goods into new products, yet reuse requires little or no processing and keeps materials out the waste stream entirely by...
moving goods into new functions. There are also some other forms of managing materials that are not quite simple reuse and not yet full recycling, however [1, 15, 16].

2. Materials and Methods

2.1. Mix Design

Mortar mixes containing fine aggregate (sand) and recycled fine aggregates made of Sawdust (SD), Plastic (P), and Glass (G) were used to produce structural lightweight mortars. An acoustic insulation test device was manufactured locally in the Materials Engineering Department at the University of Technology, and as the test moulds for this work were not standard, the standard specification ASTM C109/C109M-07 was adopted to calculate the equivalent weights for different percentages of replaced fine aggregate materials for the experiments [2].

Table 1 shows the mix designs in terms of content by weight according to the American Method used for the acoustic isolation tests, which were set in moulds of dimensions 23 × 23 × 0.08 cm, to meet the needs of the acoustic isolation test device.

| Replacement Ratio (%) | Mixing content by Weight (g) | Cement | Sand | SD | P | G | Water |
|-----------------------|-------------------------------|--------|------|----|---|---|------|
| 20                    |                               | 282    | 621  | 27 | 76 | 134| 137  |
| 40                    |                               | 282    | 466  | 53 | 151| 267| 137  |
| 60                    |                               | 282    | 311  | 79 | 266| 400| 137  |
| S.G.                  |                               | 1.40   | 2.65 | 0.65 |1.19 | 2.20 | 1.00 |

Table 2 shows the mix designs in terms of content by weight according to the American Method for the thermal isolation test. The mould dimension in this case was 10.0 × 5.0 × 2.0 cm, to match the thermal isolation test device. The test was conducted based on ASTM C1113/C1113M - 09 [3].

| Replacement Ratio (%) | Mixing content by Weight (g) | Cement | Sand | SD | P | G | Water |
|-----------------------|-------------------------------|--------|------|----|---|---|------|
| 20                    |                               | 141    | 310  | 13 | 38 | 67 | 68   |
| 40                    |                               | 141    | 233  | 26 | 75 | 133| 68   |
| 60                    |                               | 141    | 155  | 39 | 113| 200| 68   |
| S.G.                  |                               | 1.40   | 2.65 | 0.65 |1.19 | 2.20 | 1.00 |

2.2. Mortar Mixing

The mixing of mortar ingredients was performed using a 0.1 m³ horizontal pan type mixer. The dry constituents of each mortar were placed in the mixer pan and mixed for two minutes to ensure
homogeneity and to split any agglomerations of cement particles. The mixing sequence was as follows: sand and half of the mixing water were loaded into the mixer and mixed for 1 minute; then, the required quantities of dry cement and water were added, and the mixing was continued for a further 3 minutes.

2.3. Acoustic Isolation Test’s Device

An acoustic isolation test device of local manufacture was used in this project according to ASTM E413-10 [4]. All the tests were conducted in the Materials Engineering Department of the University of Technology, Baghdad. Plate 1 shows the acoustic isolation test device.

![Plate 1: Acoustic isolation test device](image1)

2.4. Thermal Isolation Test Device

The thermal isolation tests were conducted in the National Centre of the Construction Lab., Ministry of Construction and Housing, Iraq according to ASTM C1113/C1113M-09 [3]. Plate 2 shows the thermal isolation test device.

![Plate 2: Thermal isolation test device](image2)
2.5. Flow Test

The workability of all mortar mixes was measured immediately after mixing using a flow test, according to the procedure described in ASTM C1437-15 [5]. The w/c was adjusted to maintain an equal workability of 260 mm for all mixes [2, 5].

3. Results

3.1. Acoustic Isolation

The most striking results to emerge from the data derived from this experimental work are shown in Table 3. Figures 1, 2, and 3 represent the percentages of acoustic isolation for sawdust, plastic, and glass for the percentage ratios 20%, 40%, and 60%, respectively, at the age of 28 days. From the figures, sawdust offers better isolation than plastic and glass, while the acoustic isolation of plastic is better than that of glass.

The figures also show the variation of the percentage of acoustic insulation with increased sound wave frequency (Hz) [4]. The results show the superiority of the cement mortar with sawdust in terms of acoustic insulation as compared to its plastic and glass counterparts for all percentage ratios. Moreover, the results for acoustic insulation in cement mortar with any recycled aggregates were better than those of conventional cement mortar for all mixing ratios.

These results may be attributed to different specific weights of materials, as sawdust has the lowest weight, followed by plastics and glass, a pattern reflected in the variation of the results of acoustic insulation; the transmission speed of the acoustic wave is thus lower in materials with low densities or low weights [6], a finding is consistent with those of Akçaözoğlu and Ganiron [7, 8].

| Frequency (Hz) | Reference | 20% replacement ratio of recycled aggregate | 40% replacement ratio of recycled aggregate | 60% replacement ratio of recycled aggregate |
|---------------|-----------|--------------------------------------------|--------------------------------------------|--------------------------------------------|
|               | SD        | P              | G              | SD        | P              | G              | SD        | P              | G              |
| 100           | 92.8      | 97             | 94.3           | 93.3      | 98.9           | 95.1           | 94.5      | 99.9           | 98.9           | 98.6           |
| 200           | 92.7      | 96.9           | 94.2           | 93.2      | 98.8           | 95             | 94.4      | 99.8           | 98.8           | 98.5           |
| 300           | 92.6      | 96.9           | 95.1           | 93         | 98.7           | 94.9           | 94.2      | 99.7           | 98.7           | 98.3           |
| 400           | 92.5      | 96.8           | 93.9           | 92.9      | 98.5           | 94.7           | 94.1      | 99.5           | 98.5           | 98.2           |
| 500           | 92.4      | 96.7           | 93.9           | 92.6      | 98.4           | 94.6           | 94        | 99.4           | 98.4           | 98.1           |
| 600           | 92.4      | 96.7           | 93.7           | 92.7      | 98.3           | 94.5           | 93.9      | 99.3           | 98.3           | 98             |
| 700           | 92.3      | 96.6           | 93.6           | 92.9      | 98.2           | 94.4           | 93.8      | 99.2           | 98.2           | 97.9           |
| 800           | 92.2      | 96.5           | 93.5           | 92.5      | 98.2           | 94.4           | 93.6      | 99.2           | 98.2           | 97.7           |
| 900           | 92.1      | 96.5           | 93.6           | 92.6      | 98.2           | 94.4           | 93.5      | 99.2           | 98.2           | 97.6           |
| 1 K           | 92.1      | 96.4           | 93.4           | 93         | 98.1           | 94.3           | 93.4      | 99.1           | 98.1           | 97.5           |
| 2 K           | 92        | 96.3           | 93.4           | 92.4      | 98             | 94.2           | 93.2      | 99             | 98             | 97.3           |
|   | 3K | 92  | 96.4 | 93.5 | 92.4 | 98  | 94.2 | 93.1 | 99  | 98  | 97.2 |
|---|----|-----|------|------|------|-----|------|------|-----|-----|------|
|   | 4K | 91.9| 96.3 | 93.4 | 92.4 | 97.9| 94.1 | 93   | 98.9| 97.9| 97.1 |

**Figure 1.** Acoustic isolation results at 20% replacement ratio

**Figure 2.** Acoustic isolation results at 40% replacement ratio
3.2. Thermal Isolation

The thermal tests were conducted according to ASTM C1113/C1113M - 09 [3]. Tests for the thermal insulation of cement mortar with recycled aggregates at the age of 28 days produced the findings listed in Table 4, showing that the thermal insulation of cement mortar with recycled aggregates is better than that of reference cement mortar, with thermal insulation inversely proportional to the Thermal Conductivity Coefficient (W.m⁻¹K⁻¹) or λ [9, 10]. Figure 4 represents the variation of test results for Thermal Conductivity Coefficient (W.m⁻¹K⁻¹) at replacement ratios of 20%, 40%, and 60%.

These test results show that the cement mortar with recycled plastic offers better thermal insulation than sawdust and glass, with the thermal insulation offered by sawdust ranking second. In general, the thermal insulation of recycled aggregate cement mortar is better than that of the reference cement mortar. This may be due to the fact that the recycled aggregate cement mortar has a lower specific weight than conventional cement mortar, thus offering better thermal insulation. These results are supported by the work of Michael and Adilson [11, 12].

Table 4. Thermal conductivity coefficients (W.m⁻¹K⁻¹) at 20%, 40%, and 60% replacement ratios

| Cement Mortar | Thermal Conductivity Coefficient (W.m⁻¹K⁻¹) |
|---------------|---------------------------------------------|
|               | 20%  | 40%  | 60%  |
| Recycled      |      |      |      |
| G             | 0.5124 | 0.4711 | 0.3701 |
| P             | 0.2353 | 0.1981 | 0.1609 |
| SD            | 0.3530 | 0.2284 | 0.1981 |
| Reference     |      |      | 0.5423* |

*Average results
4. Conclusions
The results showed the superiority of cement mortar with sawdust, which offered better acoustic insulation than its plastic and glass counterparts for all replacement percentage ratios. The best acoustic insulation rate was about 99%, at a replacement rate of 60%, followed by the insulation rate of around 98% at the replacement ratio of 40%; the insulation rate was about 97% at a replacement rate of 20%.

The results for acoustic insulation of all cement mortars with recycled aggregates were better than those of the conventional cement mortar for all mixing ratios, however. Cement mortar with recycled plastic offered a better thermal insulation rate than those with sawdust and glass for all mixing ratios. The 60% replacement rate for plastic achieved the lowest thermal conductivity coefficient at 0.1609 W.m⁻¹K⁻¹, followed by the 40% replacement rate, while the 20% replacement rate showed the highest thermal conductivity coefficient. Cement mortar with sawdust ranked second in terms of thermal isolation. The results also showed that a 20% replacement rate for glass achieved the highest thermal transfer coefficient, with a value of 0.5124 W.m⁻¹K⁻¹. Overall, the acoustic and thermal insulation offered by all recycled aggregate cement mortars was better than that of the reference cement mortar at the age of 28 days, however.
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