Utilisation of Dune Sand and Clay Brick Waste in the Production of Sustainable Concrete

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Abstract: The massive growth of the construction sector has increased demand for sustainable concrete that meets the requirements of modern eco-friendly policies; this in turn has made it necessary to reuse abundant and recycled materials to achieve this end. In this study, crushed clay brick (CCB) as a coarse aggregate and dune sand (DS) as a fine aggregate were used to produce a sustainable concrete. An experimental programme was accomplished by performing partial replacement by DS of conventional sand (CS) at various percentages (25%, 35%, and 50%), with a similar procedure used for crushed clay brick (CCB) and conventional coarse aggregate (CA). The impact of this dual aggregate replacement on workability, density, tensile splitting, and compressive strength was then studied, and the experimental results showed that the density decreased by 12.3% as the dual replacement of aggregates increased to 50%. The workability of the sustainable concrete was within the standard limits, while the results of the slump tests ranged between 120 mm for control concrete and 80 mm as the dual replacement of aggregates increased to 50%. Both the splitting and compressive strengths of the produced concretes were systematically decreased as the dual replacement of aggregates increased under 7- and 28-days curing. The produced concrete was thus deemed to be generally affordable though suitable only for general small works or non-structural uses.

1. Introduction

Concrete is a heterogeneous material made of a paste (cement, water, and potentially other additives) and fine and coarse aggregates. This heterogeneity is often considered a drawback due to the diversity of material hardness it engenders, which prevents the equalisation of load distribution [1]. Moreover, the heterogeneity of concrete can cause microcracks within a concrete skeleton due to thermal expansion or chemical shrinkage of paste versus the solidity of aggregate [2]. Replacing some of the aggregates (fine or coarse) could offer a way to enhance concrete homogeneity.

Globally, and particularly in the Middle East, clay brick is the dominant construction material for medium-size building and residential houses. Clay brick, as with many construction materials, generates
huge amounts of waste during its production and on demolition due to end of design lifetime [3]. In addition, further waste is also generated during the manufacturing and transportation of clay bricks [4]. As the scarcity of landfill increases, such waste disposal has become a real challenge, particularly in relation to environmental policies which require sustainable solutions. In order to adopt an integrated approach to managing solid waste materials, the hierarchy of management of solid waste suggests several solutions, particularly reuse in further construction activities [5]. The first use of crushed clay brick in concrete was recorded in Germany in the reconstruction activities undertaken after the Second World War [6]. In general, the use of crushed clay brick aggregates derived from waste and demolished sources is limited by impurities, however, so many studies prefer clean clay brick [7]. However, it remains clear that the preservation of natural coarse aggregates could be achieved by replacing them with crushed clay brick to create affordable concrete without any significant change in strength and durability [8].

Previous studies have investigated the effect of adding clay brick waste as coarse aggregate to fabricate a versatile concrete material with advantageous properties such as reduced density and to mitigate the expensive use of conventional aggregates [9]. In this context, Aliabdo et al [10] investigated the effect of using crushed clay brick to produce load-bearing concrete masonry units. The crushed clay brick, derived from waste rubble, was classified after crushing as coarse, fine, and powdery, and the experimental evidence ensued suggested that it produced a concrete with 25% less density than conventional concrete.

In order to access concrete phase changing, there have also been suggestions of replacing natural sand (NS) with the more abundant dune sand (DS) which covers large areas in Iraq such as the Al Tib region, as shown in figure 3. The expansion of dune sand areas in the last four decades in Iraq has become a real problem as a direct and major source of wind-blown sands [11], and the movement of those sands requires permanent solutions and can be expensive [12]. Such sands can, however, be included in construction activities as a source of natural material. In this context, studies have been conducted to investigate the feasibility of using dune sand in concrete or mortar production, and even with high plastic clayey soils, mixing dune sand to a certain level offers soil plasticity improvement [13]. Dune sand also has been used as a mineral addition in the production of self-compacted concrete [14]. Al-Harthy et al [12] investigated the effect of adding dune sand to concrete mixtures, with results that indicated that the addition of dune sand improves concrete workability at up to 50% replacement for natural sand. However, the compressive strength decreases proportionally with dune sand increments due to the increase of the surface area of aggregates, which necessitates extra grout to coat the surface.

There is, however, a lack of previous work on concrete made by changing the full aggregate phase (coarse and fine). This study thus aimed to experimentally investigate concrete by partially replacing the full aggregate phase (coarse and fine) with crushed clay brick for coarse aggregate and dune sand for fine aggregate. The percentages of replacement examined were 25, 35 and 50% by weight. Replacing the total aggregate phase offers additional conservation of natural resources and provides a sustainable solution to demolition waste. To overcome the impurity of CCB aggregates, the clay brick was directly obtained from the manufacturing source, utilising units damaged during transport or burring. Throughout this study, the engineering properties of the novel sustainable concrete such as compressive strength, splitting
tensile strength, density, and workability were thus examined with respect to various design mixtures, and all results were compared with those for a standard conventional mix design.

2. Materials

This investigation used commercially available materials as listed below:

2.1 Cement

Ordinary Portland cement, as confirmed by the Iraqi Organization of Standards IOS5_84 [21], was used throughout.

2.2 Aggregate

2.2.1 Coarse aggregate

In this study, two types of coarse aggregate were used. The first was natural coarse aggregate (NCA) that conformed to the Iraqi Standard Specifications [22], while the other was crushed clay brick (CCB) prepared by manually crushing clay brick waste, as shown in figure 1. The particle size of both aggregates ranged from 5 mm to 20 mm, as shown in table 1.

Figure 1. Manually crushed clay brick.
Table 1: Sieve analysis of coarse aggregates

| Sieve size (mm) | Cumulative passing % | Result | Requirements of I.O.S.45-80 |
|-----------------|-----------------------|--------|----------------------------|
|                 |                       | NCA    | CCB                        |
| 20              | 100                   | 100    | 95–100                     |
| 14              | 64.26                 | 60.7   | ----                       |
| 10              | 51.34                 | 48.3   | 30–60                      |
| 5               | 2.29                  | 3.1    | 0–10                       |

2.2.2 Fine aggregate

Two types of fine aggregate were used, natural fine aggregate and dune sands (DS) from AL-Tib in Maisan, as shown in figure 3. The results of the sieve analysis for natural sand (NS) and DS are shown in table 2.

Table 2: Sieve analysis of fine aggregate

| Sieve size (mm) | Cumulative passing % | Result | Requirements of I.O.S.45-80 |
|-----------------|-----------------------|--------|----------------------------|
|                 |                       | NS     | DS                         |
| 4.75            | 100                   | 100    | 100                        |
| 2.36            | 100                   | 100    | 90-100                     |
| 1.18            | 92.2                  | 99.8   | 75-100                     |
| 0.6             | 68.7                  | 89.5   | 55-90                      |
Figure 2. Al-Tib region, Maysan, in the south of Iraq.
2.3 Superplasticizer

A superplasticizer was used to enable the production of free-flowing concrete and as a substantial water-reducing agent to enhance the early and ultimate strength of concrete. Sika visocrete 5930 was used as a high-range water reducer at a 0.20% proportion of cement weight, as recommended by the manufacturer for casting concrete.

2.4 Water

Throughout this work, ordinary tap water was used for washing aggregates and for mixing and curing the concrete.

3. Mix proportions and test programme

Several tests on the properties of NCA, as well as the concrete made with this aggregate, were conducted to study the effect of substituting NCA with CCB and NS by DS on concrete properties. In this study, the percentages of NCA replaced with CBA and NS by DS were 0%, 25%, 35%, and 50% (by weight), to clarify the effect at various levels of the replacements on the concrete properties and to generate more useful comparisons; all other aspects were thus kept identical to facilitate such comparison.
The CBA was held at saturated surface dry condition before mixing with other components, and a mixing ratio of 1:1.5:3 was used, based on the dry weight of each component. The water-to-cement ratio was 42%. The test specimens were divided into four groups based on the corresponding concrete mixes, identified as M1, M2, M3, and M4, as shown in Table 3. Mix M1 was thus the control mix (Reference Mix), being made entirely with NS and NCA to allow proper comparison of the results.

| Mix No. | NCA (%) | CCB (%) | NS (%) | DS (%) |
|---------|---------|---------|--------|--------|
| M1      | 100     | 0       | 100    | 0      |
| M2      | 75      | 25      | 75     | 25     |
| M3      | 65      | 35      | 65     | 35     |
| M4      | 50      | 50      | 50     | 50     |

The workability of the fresh concrete was measured immediately after mixing with a standard slump cone test. Two types of steel moulds were used in this study. The first was a 150 × 150 × 150 mm cube-shaped steel mould, as shown in Figure 4, with these samples used for compressive strength and density testing. The second was a 100 × 200 mm cylindrical steel mould, as shown in Figure 5, which produced samples used to examine the splitting tensile strength. All strength tests were calculated both at 7- and 28-days curing.
4. Results and discussion

4.1. Workability test

The slump of all concrete mixes was measured using standard slump test apparatus[15]. Workability refers to the practical effect of several properties, such as consistency, plasticity, and cohesion. The slump test indicates the water content and hardened strength of concrete [16], and Figure 8 shows the workability (slump test in mm) results.
Figure 6. Slump test in mm.

From these results, increasing the replacement percentage of NCA with CCB aggregate and NS by DS reduced slump. The decrease in slump (up to 33%) was due to the fineness of DS and the increased water requirement. The resulting high specific surface area decreased the flowability of concrete made of DS and reduced its slump. The angular shape and roughness of CCB was also an additional factor decreasing the high percentage replacement mixtures’ workability.

4.2. Density test

Figure 7 illustrates the densities of normal and replaced aggregate concrete for the four mixes at 28 days. The density of concrete cubes was determined in accordance with ASTM C138 [17]. The density of normal concrete was 2,320 kg/m$^3$, and this decreased with increasing replacement ratios. At a 25%, 35%, and 50% replacement ratios, the density decreased by 4.6, 10.3, and 12.3%, respectively. This decrease in density was caused by CCB aggregates having a density less than the density of natural aggregates.
Figure 7. Effect of DS and CCB substitution on density of concrete

4.3 Compressive strength test

In accordance with BS 1881-116 1983 [18], compressive strength was measured by breaking 150 mm cube specimens in a compressive testing machine at 7 and 28 days of curing, as shown in Figure 8.

Figure 9. Compressive strength test.

The results indicated that the strength of concrete generally decreased with increases in the replacement ratio. At a 50% replacement ratio, the compressive strength was decreased by approximately 38.3% and 32.5% at 7 and 28 days, respectively, as shown in Figure 9. This decrease in strength can be attributed to the increase in surface area of the fine aggregates, which thus requires more grout to coat the surface of the aggregates. Given the high porosity of CCB, the resistance to mechanical action in crushed brick aggregates is less than that in natural aggregates due to microcracks developed during the crushing of
The results indicate that the compressive strength of concrete increases with concrete age for both natural and replacement aggregates, however, although the compressive strength of concrete produced with replaced aggregates is consistently lower than the compressive strength of natural aggregate concrete at the same age.

![Figure 9. Effect of DS and CCB on concrete compressive strength](image)

### 4.4 Splitting Tensile Strength

In accordance with ASTM c496-11[20], the splitting tensile strength was measured by breaking 100 × 200 mm cylindrical specimens at 7 and 28 days, as shown in Figures 10 and 11.
Figure 10. Splitting tensile test.

Figure 11. Concrete cylinder specimens after testing.
The results of the test, as shown in Figure 12, indicated that the splitting tensile strength of concrete decreased with increasing replacement ratios at both 7 and 28 days. This decrease reached 22.9% at a 50% replacement ratio at 28 days. The splitting tensile strength of all concrete produced with replaced and natural aggregates increased with concrete age, however. From the results, the amount of reduction in the value of splitting tensile for concrete produced with replaced aggregates was lower than that of the compressive strength value of concrete produced with replacement aggregates at the same replacement ratios. This reduction in strength may, nevertheless, also be due to microcracks within the structure of the crushed bricks and the higher surface area of dune sand, which requires more grout to coat the sand particles.

![Figure 12](image)

**Figure 12.** Effects of DS and CCB on splitting tensile strength of concrete.

5. Conclusions

1. DS and CCB can be used satisfactorily as fine and coarse aggregates to produce concrete with acceptable strength characteristics. From a sustainability perspective, the strength ratio (fc/density) was reduced only slightly with the increments of replacement ratio, and thus the 50% replacement level may be considered the best choice due to it consuming more waste material. From a structural perspective, however, the 25% replacement level showed the best strength characteristics as compared with other percentages.
2. The use of DS and CCB as fine and coarse aggregate respectively decreases the compressive strength of concrete by approximately 22.3 to 32.5% at 28 days, varying according to the exact ratio of replaced aggregates used.

3. The splitting tensile strength of concretes with replacement aggregates is lower than that of normal concrete. The decreases in splitting tensile strength of concretes ranged from 17.8 to 22.9% at 28 days.

4. The workability of concrete with replaced aggregates is lower than that of normal concrete.

5. The density of concrete decreases with the increasing replacement ratio of aggregates. The decrease rate was 12.3% of the density of the reference mix at a 50% replacement ratio of aggregates. The decrease in density was directly proportional to the percentage of replacement throughout.

6. The compressive and splitting tensile strengths of the concrete increased with concrete age for both natural and replacement aggregates. The strength of concrete produced with replacement aggregates was consistently lower than the strength of natural aggregate concrete at any given age, however.

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