The influence of incorporating recycled brick on concrete properties

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Abstract. One of the major problems in modern construction is the accumulation of construction and demolition waste; this study thus examines the consumption of waste brick in concrete based on the use of blended nano brick powder as replacement for cement and as a fine aggregate. Seven concrete mixes were developed according to ACI 211.1 using recycled waste brick. Nano powder brick at 0, 5, and 10% was used as a replacement by cement weight, with other mixes featuring 10, 20, and 30% partial replacement by volume of river sand with brick. The experimental results for replacement of cement with nano brick powder showed an enhancement in mechanical properties (compressive, flexural, and tensile strength) at 7, 28, 90, and 180 days for the 10% replacement level, while the mixes with 20% brick sand replacement also showed an improvement in mechanical properties.

1. Introduction
New products can be obtained by recycling waste, making it possible to reduce problems with the storage of construction waste and the exhaustion of natural materials. Reusing or recycling waste is also more environmentally friendly [1-7]. Using brick as recycled aggregate in concrete can also give better performance than the normal aggregate at elevated temperatures, as the compressive strength of concrete can otherwise be reduced when the temperature is raised due to the physical or chemical breakdown of aggregates heated to high temperatures. Concretes with siliceous aggregates perform better at elevated temperatures, however, exhibiting less loss of strength [8].

Uddin et al [9] investigated the addition of recycled brick as 0%, 50%, and 100% replacement for natural sand, identifying a reduction in concrete compressive strength as the replacement ratio increased. Kasi and Malasani [10] and David et al [11] replaced granite aggregate with crushed clay bricks by volume, with results that confirmed the possibility of producing recycled brick concrete with 25% replacement of aggregate. Rani [12], Irfan et al [13], and Vaithheki et al [14] investigated the suitability of brick used as crushed aggregate in concrete at different levels of replacement.

The compressive strength of concrete mixes containing crushed brick showed increases for replacement up to 20%. Shruthi et al [15] used five replacement levels, 10%, 20%, 30%, 40%, and 50%, and noted that the compressive strength at the 10% and 20% replacement levels was not increased; the optimum result was obtained for the 40% replacement of fine aggregate with brick powder. Partial replacement at 0%, 22%, 25%, 28% and 31% was performed by Kumar [16], with results that suggested that the 28% replacement gave the maximum tensile strength.

A new approach was developed using nano material to enhance mechanical concrete properties [17-22], and Gopinath et al [23] investigated the effects of three types of nano-silica additions, at 1.5% and 3% for each type, on the strength of concrete. The results showed increases in compressive strength and decreases in split tensile and flexural strength. Naji et al [24] studied the effect of substituting nano-metakaolin (NMF) at 3%, 5%, and 10% by weight into cement on compressive and splitting tensile strength, with replacement by NMF offering higher compressive and splitting tensile strength than that of the reference.
The effect of nano-materials on various mechanical properties in mixtures with nano-silica (N.S.), nano-clay (N.C.) and both N.S. and N.C. inclusions were studied by Mohamed [25]. The results showed that nano-silica is more effective than nano-clay in enhancing mechanical properties. The 3% (25% N.S.+75% N.C.) mix appeared to offer highest compressive and flexure strength as compared same percentage of either type of nano-particles.

Bertolini et al [26] investigated the effects of the addition of nano-silica at 0.5%, 1%, and 1.5% dosages on the compressive strength of concrete with different water/binder ratios (0.65, 0.55, and 0.5). The results showed that N.S. addition had beneficial effects on compressive strength. Raouf et al [27] used Nano-Silica (N.S.) at 1, 1.5, 2, 2.5, and 3% ratios in their studies, with results that showed that 2.5% NS gave the highest compressive strength.

Hassan et al [28] studied the influence of three proportions of nano-silica (0.5, 5, and 10%) and three of micro silica (5, 10 and 15%) on concrete compressive strength, determining that nano-silica had more impact on the compressive strength of concrete than micro silica for all tested ages.

Rezaniaa et al [29] were studied nano-carbon black and nano-silica incorporation in terms of concrete mechanical properties. Their experimental results revealed that the compressive and flexural strength was increased by the addition of nano-silica yet decreased by the addition of nano carbon black initially. At higher densities of these nano particles, higher compressive and flexural strengths were obtained for both, however. Behzadian and Shahrajabian [30] added various proportions of nano-silica to concrete containing 10% waste polyethylene terephthalate (PET) aggregates to investigate the resulting mechanical properties (flexural, tensile and compressive strength). These mechanical properties were significantly improved by incorporating 3% nano-silica as compared to those seen in neat concrete.

The main goal of the current research was to determine the best ways to use waste brick as recycled material in concrete construction. After crushing, particles smaller than 0.15 mm were used to produce nano power for use as partial replacement by weight in cement, with the coarser portion reserved for use as a volume replacement of sand.

2. Investigational work

2.1 Materials and methods

Portland cement type I (OPC) was used in this investigation; the main properties of the cement are presented in Table 1. The grading and properties for river sand and crushed gravel with nominal maximum size =20mm are presented in Tables 2 and 3, respectively. The specific gravity for both river sand and crushed gravel are 2.6 and 2.62, respectively. All tests were carried out in the material construction lab of the civil engineering department at the University of Baghdad.

| Table 1. Properties of cement (chemical and physical). |
|---------------------------------|------------------|-----------------|------------------|
| Abbreviation | Results | Limit of IQS NO. 5 [31] | Limit of ASTM C150 [32] |
|-----------------|------------------|-----------------|------------------|
| Chemical properties (%) | | | |
| CaO | 61.5 | - | - |
| SiO₂ | 20.5 | - | - |
| Al₂O₃ | 5.1 | - | - |
| Fe₂O₃ | 4.1 | - | - |
| SO₃ | 2.25 | ≤ 2.8 C₃A ≥ 5 | ≤3.0 C₃A≤8 |
| MgO | 1.8 | ≤ 5.0 | ≤ 6.0 |
| L.O.I. | 2.5 | ≤ 4.0 | ≤ 3.0 |
| L.R. | 0.6 | ≤ 1.5 | ≤ 0.75 |
| C₃S | 47.96 | - | - |
### Table 2. Sieve analysis of sand (river and brick) and crushed gravel.

| Tests            | Sieve size (mm) | Passing (%) - river sand | Passing (%) - Brick sand | IQS specifications No.45/1984 [33] | ASTM specification C33 [34] |
|------------------|-----------------|---------------------------|--------------------------|-----------------------------------|-----------------------------|
| River sand (Zone 2) | 10              | 100                       | 100                      | 100                               | 100                         |
|                  | 4.75            | 97                        | 95                       | 90-100                            | 95 - 100                   |
|                  | 2.36            | 85                        | 80                       | 75-100                            | 80 – 100                   |
|                  | 1.18            | 68                        | 65                       | 55-90                             | 50 – 85                    |
|                  | 0.6             | 50                        | 45                       | 35-59                             | 25 – 60                    |
|                  | 0.3             | 18                        | 20                       | 8-30                              | 5 – 30                     |
|                  | 0.15            | 4                         | 5                        | 0-10                              | 0 – 10                     |
| Crushed gravel   | 37.5            | 100                       | -                        | 100                               | -                           |
|                  | 20              | 96                        | -                        | 95-100                            | 90-100                     |
|                  | 10              | 42                        | -                        | 30-60                             | 20-55                      |
|                  | 5               | 5                         | -                        | 0-10                              | 0-10                       |

### Table 3. Properties of sand (river and brick) and crushed gravel.

| Material                  | Tests                  | Passing (%) - river sand | Passing (%) - brick sand | IQS specifications No.45/1984 [33] | ASTM specification C33 [34] |
|---------------------------|------------------------|--------------------------|--------------------------|-----------------------------------|-----------------------------|
| River sand                | Material Finer Than 75-μm (sieve No. 200) | 2.5                      | 3.1                      | ≤ 5                               | ≤ 5                         |
|                           | SO₃ content (%)        | 0.24                     | 0.1                      | ≤ 0.5                             | -                           |
|                           | Absorption (%)         | 1.19                     | 20                       | -                                 | -                           |
|                           | Fineness modulus       | 2.78                     | 2.90                     | -                                 | -                           |
| Crushed gravel            | Material Finer Than 75-μm (sieve No. 200) | 1.0                      | -                        | ≤ 3.0                             | ≤ 1.0                       |
|                           | Sulphate content (%)   | 0.02                     | -                        | ≤ 0.1                             | -                           |
|                           | Absorption %           | 1.05                     | -                        | -                                 | -                           |

2.2 Preparation of brick sand and ground brick powder
The raw material, waste brick, was crushed to fine particle size to create “brick sand” (sieve size 4.75-0.15 mm) that conformed to Iraqi and American sieve analysis limits and was well-matched to river sand, as presented in Table 2 and 3, with a specific gravity of 2.25. The waste brick finer than 0.15 mm was placed in a storming machine in order to prepare nano-brick powder.

The chemical analysis of the brick powder (BP) is presented in Table 4; the strength activity index of 80% conform to ASTM C618 [35] (min. =75%).

### Table 4. Properties of nano-brick powder (BP).
**Tests**

| Tests                              | Brick Powder | ASTM C 618 [35] |
|------------------------------------|--------------|-----------------|
| Chemical test - oxides (%)         |              |                 |
| SiO<sub>2</sub>                    | 68.8         | (SiO<sub>2</sub>+ Al<sub>2</sub>O<sub>3</sub>+ Fe<sub>2</sub>O<sub>3</sub>) ≥ 70% |
| Al<sub>2</sub>O<sub>3</sub>         | 8.4          |                 |
| Fe<sub>2</sub>O<sub>3</sub>         | 2.65         |                 |
| CaO                                | 7.5          |                 |
| MgO                                | 4.2          |                 |
| SO<sub>3</sub>                      | 1.56         | ≤ 4%            |
| L.O.I                             | 2.82         | ≤ 10 %          |
| Physical test                      |              |                 |
| Strength activity index            | 80           | 75%             |
| Percentage retained of wet-sieved on 45 μm (max.) | 0            | 34%             |

2.3 Concrete mixes

The reference concrete mix was designed according to ACI 211.1 [36] at 28-days curing to reach a specified compressive strength equal to 25MPa and slump range 75 and 100 mm as per ASTM C143 [37].

The mix proportion by weight was approximately equal to ratio 1 (cement): 2.1 (river sand): 3 (crushed gravel). Two mixes with nano brick powder replacement by weight of cement at 5 and 10% were created, with other mixes featuring 10, 20, and 30% replacement by volume of river sand with approximately the same grading size of brick.

The details of the mixes used in this investigation are given in Table 5. The mixing process was performed according to ASTM C192 [38] and the replacement with powder by weight of cement at 10, 20, and 30% in each concrete mix was undertaken.

| Mix's                                | Cement (kg/m³) | Powder of brick (BP)-(kg/m³) | River sand (kg/m³) | Brick sand (BS)-(kg/m³) |
|--------------------------------------|----------------|------------------------------|--------------------|------------------------|
| MR-Reference mix                     | 340            | -                            | 715                | -                      |
| MC5- 5% replacement of cement with BP| 323            | 17                           | 715                | -                      |
| MC10- 10% replacement of cement with BP| 306           | 34                           | 715                | -                      |
| MS10- 10% replacement of sand with BS| 340            | -                            | 644                | 62                     |
| MS20- 20% replacement of sand with BS| 340            | -                            | 572                | 125                    |
| MS30- 30% replacement of sand with BS| 340            | -                            | 500                | 188                    |

[Crushed gravel=1020 and water=205] (kg/m³)

2.4 Testing

For each concrete mix, a cylinder of 150 x 300 mm and a prism of 100 x 100 x 300 mm were cast for the determination of compressive and splitting tensile and flexural strength, respectively. These tests were performed according to ASTM C39 [39], ASTM C496 [40], and ASTM C293 [41], respectively, on specimens de-moulded after 24 hours and stored in water until testing commenced.

3. Results and discussion
Based on the experimental work, the compressive strength results were as presented in Table 6 and Figure 1. a. The 7-day compressive strength was not affected by the replacement of either powder or sand, which may be attributed to the mechanical behaviour of the natural pozzolana [23, 24, 28].

For the nano-brick powder mixes, an improvement in compressive strength was observed at all ages. The mix with a 10% replacement of BP showed the maximum increase of up to 10.1% at 180 days. The effective silica in the brick powder with high fineness reacts with the calcium hydroxide formed by the hydration of silicates in cement to produce essential cementitious materials that enhance the microstructure of cement paste [17-19, 22].

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The tensile and flexural strength results are presented in Table 6 and Figure 1(b) and (c):

The mix with 10% replacement of cement by BP showed an improvement of up to 8.9% and 9.0% for tensile and flexural strength, respectively, at 180 days, with an improvement of up to 5.5% for both tensile and flexural strength at 180 days for 20% replacement of sand, which was compatible with the compressive test results.

A slight reduction in both tensile and flexural strength began at the 30% replacement level, in agreement with previous researchers. The results for tensile and flexural strength were compatible with those for compressive strength with only slight variances. The relationship is presented in Figure 2.

A statistical equation of the relationship between tensile and flexural strength is presented in Figure 3, showing the strength of this statistical link at up to 0.999.

**Table 6. Compressive, tensile, and flexural strength outcomes for nano brick and brick sand**

| Test          | Age (days) | Mixes |
|---------------|------------|-------|
| **Compressive** |            |       |
| strength (MPa) | 7          | 25.8  |
|               | 28         | 32.5  |
|               | 90         | 34.5  |
|               | 180        | 36.8  |
| **Tensile**   |            |       |
| strength (MPa) | 7          | 2.844 |
|               | 28         | 3.192 |
|               | 90         | 3.289 |
|               | 180        | 3.397 |
| **Flexural**  |            |       |
| strength (MPa) | 7          | 3.149 |
|               | 28         | 3.535 |
|               | 90         | 3.642 |
|               | 180        | 3.761 |
Figure 1. Changes in mechanical properties: (a) Compressive strength, (b) Tensile strength, and (c) Flexural strength.
4. Conclusions

- The possibility of using waste brick as volumetric partial replacement of river sand up to 20%, while we can replace the cement by weight of nano-brick powder up to 10% to produce good quality concrete.
- Cumulative enhancements of mechanical properties (compressive, tensile, and flexural strength) up to 12.5, 11.1, and 12.6%, respectively, were seen for 20% replacement of sand with brick sand.
- The development of compressive, tensile and flexural strength continues with increasing replacement of cement from 5 to 10% at all ages, with optimum cumulative increases of up to 27.9, 24.3, and 24.8%.
- There are high correlations between compressive strength and tensile and flexural strength of up to 0.9857 and 0.9842, respectively.
- The tensile and flexural strength show high correlations of up to 0.9992.

Figure 2. The relationship between tensile and flexural strength and compressive strength

Figure 3. The relationship between tensile and flexural strength.
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