Research Article

Rawa Shakir Abdulradha Mawashee*, Muaid Adnan Abid Shhatha and Qusay Abdulhameed Jabal Alatiya

Waste ceramic as partial replacement for sand in integral waterproof concrete: The durability against sulfate attack of certain properties

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Abstract: Nowadays, the use of waste materials in concrete production is crucial for a clean environment and less concrete cost. This study aimed to enhance some mechanical properties of concrete utilizing integral waterproof (IWP) admixture and using waste ceramics as fine aggregate with finer particles to improve compressive strength and modulus of elasticity and absorption studied. Studies indicate increase in compressive strength and modulus of elasticity by using IWP only and also a reduction in absorption and by using ceramic powder as a replacement with normal sand, more advantages were achieved, i.e., the compressive strength increased from 41.7 to 47.8 MPa by replacing sand with some ceramic waste, and the modulus of elasticity increased from 25.22 to 29.61 GPa. The absorption lowered to only 1% while it was 1.96% for concrete without ceramic waste. Durability against sulfate attack was also studied in this research.

Keywords: concrete, ceramic waste, waterproof, compressive strength, elastic modulus

1 Introduction

Waste materials widely used in concrete, such as plastic wastes, bricks, iron filings and chips, copper slag, ceramics, tile wastes, and others, give several advantages to humans and nature, such as less concrete cost, higher mechanical property values, and more clean environment. Many researchers studied the influences of using wastes. Key concerns in material engineering for the twenty-first century include the creation and adoption of “green” technologies in the building industry that guarantee the preservation of natural resources, lower hazardous emissions, and provide the exploitation of industrial waste. These problems have been the subject of much investigation, including studies in the field of concrete science [1,2].

For widespread use of nonmetallic extraction wastes from the Sangalyk quarry (Mansurovo village, Russia), as well as for economical resource use and the production of long-lasting, high-quality concretes, it is advised to use the developed compositions of fine-grained concrete using quarry fines of the 0–5 mm fraction [1]. Additionally, applying concrete waste aggregate (replacing 50% of the aggregate) improves concrete’s resilience to environments containing magnesium sulfate. Only clean, cleaned quartz sands with a dust and clay percentage of <1% should be used to create concretes with high durability [1]. With no appreciable loss of the necessary service qualities, using polycarboxylate-based chemical additives in concretes utilizing local raw materials results in cement reductions between 10 and 20% and a two-fold reduction in thermostatic treatment [1]. In order to meet human needs and enable unrestricted progress, sustainable development tries to stop the environment’s deterioration from getting worse [3].

Marwah [4] used waste iron filings as a replacement for fine aggregate in concrete and achieved improvements in mechanical properties of concrete such as compressive and tensile strength. In order to mitigate its detrimental effect on the performance of concrete, Ahmad et al. [5] used waste glass (WG) as a filler material to cover the spaces between recycled concrete aggregate (RCA). The substitution ratios for RCA and WG, respectively, were 20, 40, and 60% by weight of coarse aggregate. According to test results, concrete’s workability deteriorated when WG
and RCA percentages rose. WG did not significantly increase strength in the first 7 days since the pozzolanic reactions took so long to complete. However, at 28 and 56 days of cure, a significant increase in strength was seen. The highest strength was attained with a 20% WG replacement. After 28 days of curing, the concrete’s punching strength and compressive strength were both 29 and 27% higher than the reference concrete, respectively. According to the statistical analysis, which demonstrated compressive strength almost similar to that of the reference concrete, the ideal doses of WG and RCA (20% WG and 30% RCA) were projected. Additionally, identical WG and RCA doses (20% WG and 30% RCA) were cast and put to the test experimentally.

Ahmad et al. [6] examined a number of qualities, including the mechanical and durability performance of fresh concrete, physical and chemical composition of waste foundry sand (WFS), and fresh properties. The results showed that the substitution of WFS decreased the flowability of concrete. WFS substitution up to 30% showed good workability, but over 50%, a larger dose of admixture (plasticizer) was required. WFS may replace natural river sand up to 30% of the time without affecting the strength of concrete. This is due to the fact that the micro infill makes the concrete more dense, increasing load resistance. However, with larger doses of WFS (over 50%), a loss in strength was noted. Its mechanical strength typically decreases when WFS is added. Concrete developed porosity due to the lack of workability, and there was less paste available for binding, which decreased the strength. Results at a 20% replacement level of WFS can be compared to the control concrete. In several research studies, a 30% replacement of WFS has been proposed.

For instance, it is strategically important to use polymeric and metallic construction debris to lessen the environmental impact of the product families that make up the Technological and Environmental Park portfolio. The viability of the concept with the suggested product families based simply on construction and demolition waste in this initial stage, however, may be guaranteed by the current need for construction systems [7]. Horňáková and Lehner [8] studied the relationships between destructive testing methods and non-destructive testing method in the period after 28 days of concrete cure. They discovered that the splitting tensile strength and static modulus of elasticity have a linear correlation with the dynamic modulus of elasticity defined by the ultrasonic velocity. The authors discovered that the dynamic modulus of elasticity has a high quadratic regression with a compressive strength, proportionality limit, and shear strength. The surface resistivity was also discovered to have increased fluctuation and, consequently, worsened agreement for some metrics. Finally, there is no adequate correlation at any level for compressive strength or static modulus of elasticity; however, for splitting tensile strength and shear strength, the electrical resistance exhibits strong linear regression values.

Using fly ash and calcium carbide waste (CCW) as supplementary cementitious materials improved the resistance of self-compacting concrete (SCC) to salt medium and acid attack, as measured by immersion in H₂SO₄ and MgSO₄, respectively, according to the findings of Kelechi et al. [9]. In addition, the resistance of SCC mixes to attacks from acids and salts was dramatically decreased when fine aggregate was partially substituted with crump rubber (CR). The SCC mixes without fly ash and CCW had a worsening of this adverse effect. Additionally, after temperatures above 200°C, the tolerance of SCC mixes to heat made it less effective to replace 40% of the cement with fly ash.

CERAMICS wastes are used as aggregate in concrete to achieve higher mechanical properties such as compressive and tensile strength [10,11]. Safaa [12] used ceramic waste powder as a replacement for cement weight in concrete to improve the fire resistance of concrete. Azmi [13] achieved an increment in compressive strength of concrete by using waste ceramic as fine aggregate until 45% replacement. Khalid [14] concluded that 35% of waste ceramic as a coarse aggregate replacement shows higher compressive strength than reference or control concrete mix. According to Najm et al. [15], concrete that contains natural material plain concrete loses up to 11.61, 18.91, and 36.01% of its compressive strength when subjected to temperatures of 100, 200, and 300°C, respectively. On the other hand, the specimens containing waste ceramic material showed a reduction of about 8.48, 16.72, and 34.25%. Because concrete made with ceramic tiles has lower thermal conductivity than concrete made with natural aggregates, it was inferred that ceramic material helped make concrete more heat resistant than concrete made with natural materials. Concrete containing hybrid fibers (PVA + CR) demonstrated a good effect on concrete compressive strength under high temperatures because of the increase in the transport capabilities of heated material. When subjected to 100, 200, and 300°C, respectively, hybrid fiber specimens lose compressive strength by around 7.15, 14.55, and 19.51% [15].

This study uses wasted ceramic as fine aggregate and integral waterproof (IWP) additive to enhance the mechanical properties of concrete, reduce absorption, and increase durability.
2 Experimental program

This section is focused on the materials used in this study in addition to the experimental program as in the following points:

- **Materials and mixes:** sulfate-resisting cement was used in all mixes. The sand used was red sand with grading shown in Table 1, and it confirms that Zone 2 is according to Indian standards I-S 383 [16]. Gravel with 20 mm maximum size aggregate with grading as indicated in Table 2 was used. Waste ceramic was used as a replacement for sand and it was crushed to Zone 4 (fine particles).

- **Testing procedure:** 100 mm × 200 mm cylinders were used for compressive strength test as shown in Figure 1, and all specimens were tested in 28 days. The elastic

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### Table 1: Sieve analysis of sand confirmed with Zone 2 (IS-383)

<table>
<thead>
<tr>
<th>Sieve dimension (mm or µm)</th>
<th>% Passing by weight</th>
<th>% Passing Indian specification IS-383</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>92.3</td>
<td>90–100</td>
</tr>
<tr>
<td>2.36</td>
<td>78.5</td>
<td>75–100</td>
</tr>
<tr>
<td>1.18</td>
<td>63.1</td>
<td>55–90</td>
</tr>
<tr>
<td>600 µm</td>
<td>43.6</td>
<td>35–59</td>
</tr>
<tr>
<td>300</td>
<td>18.5</td>
<td>8–30</td>
</tr>
<tr>
<td>150</td>
<td>4.9</td>
<td>0–10</td>
</tr>
</tbody>
</table>

### Table 2: Sieve analysis of gravel used in the study

<table>
<thead>
<tr>
<th>Sieve dimension (mm)</th>
<th>% Passing by weight</th>
<th>% Passing, limits of Indian specification IS-383</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>20.0</td>
<td>96.1</td>
<td>95–100</td>
</tr>
<tr>
<td>10.0</td>
<td>29.4</td>
<td>25–55</td>
</tr>
<tr>
<td>4.75</td>
<td>4.3</td>
<td>0–10</td>
</tr>
</tbody>
</table>

### Table 3: Mix proportions of concrete with different ingredients

<table>
<thead>
<tr>
<th>Ingredient, kilograms for each one cubic meter concrete</th>
<th>Cement</th>
<th>Sand</th>
<th>Gravel</th>
<th>Water</th>
<th>IWP (l)</th>
<th>Waste ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>500</td>
<td>700</td>
<td>1,000</td>
<td>200</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M1</td>
<td>500</td>
<td>700</td>
<td>1,000</td>
<td>175</td>
<td>5</td>
<td>0.00</td>
</tr>
<tr>
<td>M2</td>
<td>500</td>
<td>700</td>
<td>1,000</td>
<td>160</td>
<td>7.5</td>
<td>0.00</td>
</tr>
<tr>
<td>M3</td>
<td>500</td>
<td>700</td>
<td>1,000</td>
<td>150</td>
<td>10</td>
<td>0.00</td>
</tr>
<tr>
<td>M4</td>
<td>500</td>
<td>630</td>
<td>1,000</td>
<td>150</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>M5</td>
<td>500</td>
<td>560</td>
<td>1,000</td>
<td>150</td>
<td>10</td>
<td>140</td>
</tr>
<tr>
<td>M6</td>
<td>500</td>
<td>490</td>
<td>1,000</td>
<td>150</td>
<td>10</td>
<td>210</td>
</tr>
<tr>
<td>M7</td>
<td>500</td>
<td>420</td>
<td>1,000</td>
<td>150</td>
<td>10</td>
<td>280</td>
</tr>
</tbody>
</table>

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Figure 1: Concrete specimens used for compressive strength and elastic modulus tests.

Figure 2: Cylinder concrete specimen during modulus of elasticity test.
modulus tests were carried out using 150 mm × 300 mm samples and the test was carried out using machine type Impact with 2,000 kN maximum capacity.

A mechanical strain gauge (as shown in Figure 2) was fixed on the concrete specimen, and then the specimen was placed in the compression testing machine and loaded with a constant stress rate in line with the ASTM C-469 specification [17]. The elasticity modulus value was obtained from the readings of stress and strain values during the test in the straight portion of the stress–strain curve. All specimens were tested after 28 days from cast concrete.

- The absorption was carried out by using cylinders with 100 mm × 200 mm, and the specimens were dried in an oven for 1 day, after which the dry weight readings were taken, and then the samples were submerged in water for 1 day and taking the saturated weight then the value of the absorption can be determined from the following equation (1)

\[
\text{Absorption} \, (\%) = \left[ \frac{(W_2 - W_1)}{W_1} \right] \times 100, \tag{1}
\]

where \(W_1\) is the dried weight of sample for 1 day, and \(W_2\) is the weight of submerged sample for 1 day.

- The sulfate attack was made using concrete cylinders in salty water obtained from the well of Kufa University, with salt concentrations as indicated in Table 4. After 28 days of curing, it was submerged in salty water for 3 and 6 months, respectively, and tested for compressive strength to find the residual strength.

- The properties of the liquid admixture IWP used in the study are listed in Table 5. This table indicates all information about IWP such as color, chemical composition, density, and country produced from.

### 3 Results and discussion

Table 6 indicates the different mixes that reflect the effect of IWP admixture and mixes with other replacement of waste ceramic as percentages from sand; the impact of IWP is clear from the table, and the compressive strength increased from 28.4 MPa for reference mix to 41.7 MPa with a maximum dosage of 2% from weight of cement. The elastic modulus also increased from 21,334 to 25,228 MPa using only IWP admixture. The absorption decreased using IWP. It was dropped from 6.8 to 1.9%, which can be attributed to the action of IWP that reduces the voids inside concrete [18]. Using waste ceramic as a replacement for natural sand, the compressive strength and modulus of elasticity also increase, as shown in Table 6. From Table 6, the compressive strength increased by replacing sand with waste ceramic powder, which was added to mixes with only 2.0 l/100 kg cement.
with maximum strength. The compressive strength increased from 41.7 MPa for M3 mixtures (which have no waste ceramic) to 47.8 MPa for M7 (40% ceramic replacement). Also, the modulus of elasticity increased using ceramic wastes from 25.2 to 29.6 GPa. The absorption decreased using ceramic, from 1.96 to 1.08% only using 40% replacement.

Table 7 demonstrates the reduction in strength for concrete specimens subjected to salty water, the less absorption concrete behaves more durable against salted water as shown in the table. Also, the table indicates higher residual compressive strength. Compressive strength decreased from 28.45 for reference mix to 17.2 MPa after 3 months of exposure to sulfate attack by salty water and reduce then to 12.89 MPa after 6 months of exposure.

Using a maximum dosage of IWP, the concrete behaved better; the compressive strength decreased from 41.7 to 35.3 MPa after 3 months of exposure,
then reduced to 31.1 MPa after 6 months of exposure. Using ceramic wastes, compressive strength decreased slightly. The mixes before exposure showed 47.8 MPa compressive strength \((M7)\). After 3 months of exposure, the compressive strength decreased to 43.6 and 40.3 MPa after 6 months of exposure. Figures 3 and 4 display the relationship between % IWP dosage and compressive strength, modulus of elasticity, respectively.

Figure 5 states how IWP dosage and absorption% are related. Figure 6 indicates the relationship between % ceramic replacement and compressive strength, whereas Figure 7 shows the relationship between % ceramic replacement and modulus of elasticity.

Figure 8 illustrates how ceramic replacement and the absorption of concrete are related. Figure 9 reveals that the relationship between exposure to sulfate attack and compressive strength for reference mix and M3 (which contains only IWP [2%]).

Figure 10 represents the relationship between exposure to sulfate attack and compressive strength for M3 (without ceramic) and 40% replacement mixes \((M7)\).

In summary, the minimum reduction in absorption is in both 2% IWP and 40% replacement of ceramic waste as indicated in Figures 5 and 8. However, the highest values of compressive strength and modulus of elasticity are at 2% IWP and 40% replacement of ceramic waste as indicated in Figures 3, 4, 6 and 8. Finally, the higher reduction value at 6 months is observed at 2% IWP and 40% replacement mixes than the value obtained from M3 as indicated in Figures 9 and 10.

### 4 Conclusions

The main conclusions obtained from this study are summarized as follows:
• Using IWP increases compressive strength and modulus of elasticity and decreases absorption of ordinary concrete.
• Using waste ceramic as fine aggregate improves compressive strength and modulus of elasticity of concrete, and there is a slight increment of mechanical properties after 30% replacement.
• There is a slight decrement in concrete containing IWP and waste ceramic after exposure to salty sulfate water compared with ordinary concrete or reference mixes.

Conflict of interest: Authors state no conflict of interest.

References