Effect of partial replacement of fine aggregate by internal curing materials on mechanical properties of concrete

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Abstract. Internal curing has long been utilized to decrease self-shrinkage and consequently the increased danger of concrete cracking prematurely. The measured mechanical characteristics of concrete were studied in five mixes, both with and without internal curing. Two of these mixtures have a 10% replacement rate, with one using ceramic and the other Attapulgite, while the other two have a 20% replacement, with one using ceramic and the other using Attapulgite, and the fifth is a reference mixture with no replacement for comparative reasons. With an increase of 27.93%, the ceramic combination with a 20% replacement rate is judged to have the highest compressive resistance, followed by the Attapulgite mixture with a 20% replacement rate with an increase of 34.2%. The results showed that the ceramic and Attapulgite internal curing purposes were highly effective, especially with a 20% replacement. The use of crushed ceramics and attapulgite as internal curing materials improves the characteristics of concrete.

Keywords: Sustainability; Internal Curing (IC); Concrete; Partial Replacement; Ceramic; Attapulgite.

1. Introduction and Literature Review

In recent decades, HPC with a low w/b has become increasingly popular, and research on the area has flourished. Their extraordinary strength and longevity were considered crucial for structural applications in hostile conditions. However, practical experience and laboratory research have shown that HPC is particularly susceptible to early age cracking unless extra safeguards are taken. One of the unique requirements is the technique of curing(1). Curing concrete properly is crucial to its performance and should be considered a major factor in achieving long-term HPC. The amount of water in this form of concrete with a low w/b is insufficient to keep the capillary pores filled with water (saturation state of capillary pores); however, keeping the cement hydrated and the pozzolanic process running, as well as preventing self-desiccation, is critical(2). The volume change in high performance concrete due to self-shrinkage is one of the main problems. As the low water in the concrete results in the risk of early cracks(3). Several therapies have been proposed to minimize autogenous shrinkage and the resulting internal stress throughout the years. Calcium sulfo-aluminate or free lime-based additives are examples of expansive additives.
admixtures that prevent drying shrinkage (SRA)(4)(6)(7), inclusion of polymer particles that are very absorbent(8), portland cement with a high level of belite or a low degree of heat(4)(5) have been proven to be effective and widely used in the prevention of shrinking. Sulfo-aluminate-based expansive additives, on the other hand, may have a negative impact on the likelihood of delayed ettringite production when used in large concrete elements (DEF). The increase in the temperature of the mass concrete during the reaction is one of the factors that help reduce the amount of internal water and thus reduce the formation of hydration products that can compensate for shrinkage, especially when the temperature of the concrete during the reaction increases to more than 70 degrees Celsius. Where the temperature in the center of the concrete may reach more than 65 degrees Celsius, depending on the type and size of the concrete block(9). Temperatures as high as 90 degrees Celsius were recorded in the Shanghai Jinmao building in China(10). Many writers believe that such a high temperature in a large concrete containing a sulfo-aluminate-type expansion agent could result in DEF(11)(12). As a result, the use of EXA sulfo-aluminate-type in concrete is restricted, and precautions must be taken to avoid any adverse effects. Yan et al. [13] confirmed the presence of DEF in shrinkage compensating concrete at temperatures over 70°C.

Internal water curing, commonly known as "autogenous curing," has also been proved to be the safest and most successful means of removing autogenous shrinkage in concrete when compared to the use of expanding chemicals. Many previous studies have confirmed that replacing a specific part of ordinary aggregate with another dry aggregate with high porosity can significantly reduce the phenomenon of self-cracking(8)(13). HPC should be healed for at least 7 days with external water, according to Atcin(14). Since it is difficult to conduct water through capillary pores into the concrete, internal curing is one of the best methods of curing as it helps to supply water to the concrete from the inside and thus reduces shrinkage(15). The traditional treatment methods are not sufficient to prevent a decrease in moisture inside the concrete during the consumption of water in the capillary pores, which is consumed as a result of the progression of hydration processes, which results in self-drying. Internal water curing is thus seen to be the most efficient way for decreasing autogenous shrinkage and generated capillary strains. Internal wet curing relies on internal reservoirs to provide a constant supply of curing for the cement paste and avoid self-desiccation. The lightweight aggregate used is small tanks inside the concrete that help provide the water needed for the gradual hydration process. The use of lightweight aggregate is a common process in use. Through previous studies, it was concluded that the use of lightweight aggregate reduces self-shrinkage in high-performance concrete with a low w/c ratio(16)(17)(18). Internal wet curing has been suggested as being particularly effective in cements mix containing silica fume, where the water outfit may not be sufficient to sustain the pozzolanic reaction(15).

The efficiency of lightweight aggregates used in internal processing is affected by a number of factors such as their internal porous structure, mechanical properties, the ratio of open pores to closed pores inside the granule, in addition to the distribution of aggregate particles within the concrete. Fine lightweight aggregate was found to be more successful than coarse lightweight aggregate in dispersing accessible moisture for internal curing, according to certain writers(18)(19). Other authors(20) believe that pore size, rather than grain size, is more important in the internal curing process. The dose of LWA is determined by the amount of internal curing water that may be injected into the cement matrix. It has been suggested that a low LWA ratio of roughly 6% of cement weight could completely eliminate HPC autogenous shrinkage(21)(20)(18). In contrast, Bentur et al. (22) predicted that all autogenous shrinkage in HPC could be successfully removed by substituting 25% of fine LWA with NWA.
In fact, as previously stated, both normal LWA and anti-shrinkage chemicals have practical limitations when it comes to shrinkage compensating concrete. On the one hand, it has been demonstrated that a large percentage of normal LWA may be necessary to entirely prevent autogenous shrinkage, resulting in a significant reduction in compressive strength, decreasing the performance of such concrete and perhaps offsetting its benefits. According to the Center of Excellence for Airport Technology, using SRA in a significant amount (CEAT)[24], may result in a 16 percent increase in the final cost. The cost increases while employing EXA in HPC are projected to be similar. As a result, the high cost of anti-shrinkage agents (SRA and EXA), the increased risk of DEF in case of massive concrete elements or EXA overdosing, and the potential loss of compressive strength caused by the use of conventional LWA in HPC structural elements may limit their use, driving up demand for alternative materials. By-products are becoming more prevalent in cement-based materials, and there has been a lot of research into it. However, the majority of these studies concentrated on using by-products as mineral admixtures, regenerated normal aggregates, or waste fibers as reinforcement(23)(24)(25).

In the current study, a recovered waste ceramic aggregate and Attapulgite aggregate are employed as a partial replacement for fine aggregate as a water-entraining agent for internal wet curing to show the effect of these materials on the mechanical properties.

2. Materials and Experimental Work
Crushed ceramic and crushed Attapulgite clay were employed as internal curing agents in this project. To evaluate the fresh concrete characteristics, compressive strength, and hardened properties, 15 concrete cubes (100*100*100 mm) were cast. 15 cylinders (100*200 mm) were also manufactured to assess splitting tensile strength. All specimens were cured in water at a temperature of 24 degrees Celsius.

2.1. Materials
In general, specific aggregates and admixtures can be added to ordinary concrete to make high-performance concrete. Unusual aggregates, mineral admixtures, chemical admixtures, and various fibers, for example, can all be utilized to make high-performance concrete.

2.1.1. Cement
The current project utilizes Iraqi ordinary Portland cement (type I) produced by the Karbala cement plant. This kind is compliant with IQS 5-1984.

2.1.2. Coarse aggregate
The studies employed black crushed aggregate from the Niba'ai region as coarse aggregate. The grading and property tests were carried out in accordance with Iraqi specification No. 45/1984.

2.1.3. Fine aggregate
The sand utilized in this project came from the AL-Akhaidir region. Iraqi standards No. 45/1984 was used for the tests.

2.1.4. Water
The mixtures were made with tap water from the water-supply network system.
2.1.5. Super-Plasticizer
Sika ViscoCrete®-5930, a third-generation superplasticizer for concrete and mortar, was used as a high-range water reduction additive. It complies with the ASTM-C-494 types G and F and BS EN 934 part 2: 2001 specifications for superplasticizer (Sika ViscoCrete®, 2015).

2.1.6. Mineral Admixture (Silica Fume (SF))
MegaAdd MS (D) densified micro silica fume was utilized in the mixes. MegaAdd MS (D) is a pozzolanic mineral addition for use in concrete that is very fine and ready to use. Its physical property optimizes particle packing in concrete or mortar mixes, and it also functions chemically as a highly reactive pozzolan.

2.1.7. Crushed Ceramic (CC)
Crushed ceramic was a construction waste that was crushed to the requisite fine aggregate size and then sieved to meet the needed grain size distribution table 1 and figure 1.

| Property          | Value       |
|-------------------|-------------|
| Absorption        | 24.85%      |
| Specific gravity  | 2.28        |
| Fineness modulus  | 2.91        |
| Bulk density      | 1439 Kg/m³  |
| Color             | Brown       |

Figure 1. Crushed ceramic prepared in the laboratory.

2.1.8. Crushed Attapulgite (CA)
After crushing and burning procedures figure 2, natural Attapulgite clay from the western part of Iraq was used as fine aggregate, with the same gradation zone as the original fine aggregate. Before burning in a kiln to incipient fusion (temperatures of 1000°C to 1100°C), the raw material was crushed to the necessary size. The raw material was laid out in loose layers that were around 100–150 mm thick. This porous structure was preserved during cooling, resulting in a substantially lower apparent specific gravity of the expanded material than before heating (26), table 2. The Attapulgite sand was submerged in water until it reached full saturation.
### Table 2. Physical properties of Attapulgite clay.

| Property          | Before burning | After burning |
|-------------------|----------------|---------------|
| Absorption        | 22.5 %         | 35.8 %        |
| Specific gravity  | 1.67           | 1.35          |
| Fineness modulus  | /              | 2.91          |
| Bulk density      | /              | 1198.9 Kg/m³  |
| Color             | Greenish Yellow| Reddish orange|

### Table 3. Mixes design used details.

| Types of mix | Fine aggregate (Kg/m³) | Cementitious material |
|--------------|-------------------------|-----------------------|
|              | The replaced aggregates| Sand                  |
|              | Cement (Kg/m³)          | Silica fume (Kg/m³)   |
|              | Gravel (Kg/m³)          | Superplasticizer (L/100 Kg) |
|              | Water/binder (w/b)      |                       |
| RM-0%        | 0                       | 700                   |
| AM-10%       | 46                      | 630                   |
| AM-20%       | 92                      | 560                   |
| CM-10%       | 55                      | 630                   |
| CM-20%       | 110                     | 560                   |

2.2. Concrete mixtures

Five concrete combinations were used in this study as shown in table 3. The first mixture serves as a baseline against which the effects of other chemicals can be measured. The second mixture had the same proportions as the first, but the Attapulgite was used to replace 10% of the fine aggregate in the fine aggregate. The third mixture was the same as the first, except that 20% of the fine aggregate was replaced with Attapulgite. The fourth combination had the same proportions as the first, but with ceramics replacing 10% of the fine aggregate. The fifth mixture was the same as the first, except that ceramics were used to replace 20% of the fine aggregate.
2.3. Specimen Preparation

The concrete components (cement, sand, silica fume, etc.) were prepared and weighed according to the mix design's prescribed ratios. Two processes were used to prepare the interior curing materials (crushed ceramic and Attapulgite): Before batching, it was 1) soaked in water for 24 hours and 2) rubbed with clean clothes to eliminate surface moisture. In the concrete laboratory of the civil engineering department at the University of Kerbala, the mixing was done with a (0.185 m³) rotary batching machine. The elements (gravel, sand, cement, silica fume, internal curing materials, super-plasticizer, and water) were combined in a batching machine for 3 to 5 minutes at a steady rotation rate before being put onto a clean steel handcart for casting. A steel vibration rod was used to vibrate each sample to ensure that the concrete was suitably condensed and that no segregation would occur. The concrete samples were submerged in water for 28 days to maintain the degree of cure.

2.4. Testing methods

Three experiments were performed at the age of 28 days to investigate the effect of partial replacement of fine aggregates with internal curing materials: compressive strength, splitting tensile strength, and density.

2.4.1. Compressive Strength

For the compression strength test, 15 cubes measuring 10 x 10 x 10 cm were cast and sealed with a plastic bag to prevent water loss for 24 hours after casting, the molds were opened and transferred to a basin for external treatment, which lasted for 60 days. The test was carried out on an ELE digital hydraulic compression machine with a capacity of (2000 kN). At each test, the average value of three cubes was used. The tests began when the animals were 28 days old.

2.4.2. Splitting Tensile Strength

For the splitting tensile strength test, 15 cylinders (100 x 200 mm) were cast. Between the sample and the upper and lower bearing blocks of the testing machine, two thin plywood strips were put. For this test, a hydraulic compression machine with a force of (2000 kN) was used. At each test, the average value of three cubes was used. The tests began when the animals were 28 days old.

2.4.3. Density

A density test was carried out using 15 cubes of size 10 * 10 * 10 cm by placing them in an oven at a temperature of 100-110 °C for 24 hours, after which the weight of the samples was calculated. At each test, the average value of three cubes was used. The tests began when the concrete were 28 days old.

3. Results

Compressive strength, tensile strength, and density are the mechanical parameters of the tested concrete mixes. All of the tests were done at the age of 28 days, and the average of three readings was used.

3.1 Compressive Strength

Figure 3 shows that the partial replacement of these materials leads to a significant improvement in the compressive strength. There is an increase in the compressive strength with an increase in the replacement ratio. As the mixtures with a replacement 20% have a higher compressive strength. The percentages increase were 16.72%, 27.93%, 4.95% and 34.2% for the mixes RM, AM10, AM20, CM10 and CM20 respectively. It is clear that the increase in the porosity with the percentage of replacement played an important role in the development of the building by providing the internal curing water for the concrete to complete the hydration processes.
3.2 Splitting Tensile Strength
As it is clear that from Figure 4, there was an improvement in the splitting tensile strength, as the materials with the 20% replacement have the highest values of splitting tensile strength. The percentages increase were 7.81%, 9.14%, 7.62% and 9.71% for the mixes RM, AM10, AM20, CM10 and CM20 respectively.

3.3 Density
Since the replaced materials have a density less than the density of the sand used in the concrete mix, it is normal for the density to decrease with the increase in the proportion of replacement. The lower density than the density of the reference mixture is a good indicator because the density of concrete increases with
the increase in the targeted compressive strength in general. On the other hand, the low density of the concrete mix has financial consequences on the design of the structural design of the buildings. Figure 5 shows that the decrease in density depends on the percentage of replacement, as well as the density of the material used for internal curing. The percentages decrease was 2.9%, 4.74%, 2.86% and 3.75% for the mixes RM, AM10, AM20, CM10 and CM20 respectively.

Figure 5. Density of the studied mixes at the age of 28 days.

4 Conclusions
Using crushed ceramic and Attapulgite as internal curing materials is useful in improving the concrete properties. The use of waste and local materials to improve the properties of the concrete mixture is an aspect of sustainability. The results showed that the improvement in the mechanical properties of the concrete mix improves with the increase in the percentage of replacement, as from the above results it is clear that the concrete mix with the replacement rate of 20% has higher results than the mixture with the replacement rate of 10%. The ceramic mixture with a 20% replacement rate is considered to have the highest compressive resistance with an increase of 27.93%, after which the Attapulgite mixture with a 20% replacement rate with an increase of 34.2%. The splitting tensile strength also had a noticeable improvement, that of 20% ceramic had an increase by 9.14%, and the mixture of 20% Attapulgite had an increase of 9.71%. Density results had a noticeable decrease with the increase in the percentage of replacement, as the concrete mix with 20% Attapulgite has a decrease rate of 4.74%, while the concrete mix with 20% ceramic has a decrease rate of 3.75%.

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