The Sustainable Characteristic of Reinforcement Concrete Slabs Internally Cured with Waste Ceramics

Abdulrasool T Abdulrasool1,*, Laith Sh Rasheed1

1 Civil Engineering Department, College of Engineering, University of Kerbala, Karbala, Iraq.

*Corresponding author, email: abdulrasool.th@s.uokerbala.edu.iq

Abstract. The concrete durability is a fundamental factor in the investigation of concrete elements which require to long service lives, especially the elements which used in infrastructure systems such as bridges and roads, that have a high construction cost. Internal curing has been becoming extensively used for reducing the external factors of aggressive effect and for improving the behavior of the structural element and increased durability of the structural element. The present research work studies the efficiency of internal curing agent that provided by using a local ceramic waste as a fine aggregate on the high-performance concrete (HPC). Two different high-performance concrete slabs without and with the ceramic fine aggregates with two different replacement percentages (10 and 20) % from the volume at three ages (60, 120, and 180) days have been examined to show the structural properties development. The results of tests have shown high effectiveness of the local fine ceramic waste aggregates as internal curing purposes. It has been shown that the incorporation of 10% of the local fine ceramic waste leads to a noticeable significant increase in the ultimate load by 1.26% while the incorporation of 20% increase in the ultimate load by 6.31% at later age compared with reference mix.

Keywords: Sustainability; Internal Curing (IC); High-Performance Concrete (HPC); Ceramic Waste Fine Aggregates; Durability; Flexural Behaviour.

1. Introduction

Through the past decades, high-performance concrete with a low w/b has been become vastly used, and working study on this field has increased profoundly. The high strength and high durability performance of concrete have been considered as an essential issue for structural that used under severe states. Nevertheless, from the laboratory works investigations, it has been proven which high-performance concrete has a very sensitive for the early-age cracking risk unless particular precautions have been taken. One of the particular curing process requirements [1]. Because of autogenous shrinkage is the predominant changing in volume for high-performance concrete, it is well known that the heightened risk of early-age cracking of the high-performance concrete has attributed to the enormous size of early-age autogenous shrinkage happened because of the drying inside the concrete during reactions of binder hydration. On the other side, as autogenous shrinkage is very connected to the self-desiccation phenomenon and the consumption of water by the hydration of cement, the menisci formation in the pore solution will result in the stresses and strains during the autogenous development within the solid.
hydrating of cement [2]. Over time, several processes had been proposed to reduce the effect of autogenous shrinkage and the internal stress it could happen. Expansive additives based on free lime or calcium sulfoaluminate, drying shrinkage-reducing admixtures, such as superabsorbent polymer particles, including high belite or low heat Portland cement, have been extensively and successfully used in effect alleviation of the shrinkage [3]. In general, the use of aggregates containing internal water with a high-performance concrete mix has a very beneficial effect on the structural elements of special use. The internal curing process used in the concrete elements can reduce the appearance of the initial cracks that occur during hardening, as it increases the life of the structural elements by about 10 years, as it is shown that by some studies [4]. Also, another practical study showed by testing some of the mechanical properties of concrete that the process of internal curing can be increased the life of the structural elements by 23 years [5]. The external curing method is one of the most important traditional methods for reducing autogenous shrinkage, especially for thin concrete elements. However, despite the importance of external curing, this method is considered to have a low effect on the non-thin concrete elements due to the inability of the capillary pores to transfer external water to the inside of concrete, for this reason, reinforces the need to use the internal curing process [6]. All conventional external curing methods are unable to prevent drying inside the concrete due to the continuous hydration processes that lead to the consumption of water in the capillary pores and thus will lead to the phenomenon of self-desiccation in the hardening concrete. And as previously mentioned, the use of internal curing is more practical in supplying the concrete need for water during the hydration period and thus reducing the self-shrinkage of concrete. Thus, the internal curing granules can be small reservoirs that supply concrete with water from the inside and thus reduce the self-desiccation. Several studies were conducted on the use of lightweight aggregates, which is in a saturated dry-surface condition, and which showed the effectiveness of this type of technology to improve the behavior of high-performance concrete by working as reservoirs providing and water for concrete to instead of the water consumed during the reaction of cement and thus successfully preventing the occurrence of autogenous shrinkage [7]. It has been suggested that the use of internal curing applications could be very beneficial for the concrete mix containing cement and to which silica fume or fly ash is added and that keeps the water supplied for a late time to complete the hydration of cement and others mineral additives [6]. The internal curing process efficiency is mightily related to both the content and the properties of LWA used, such as pore structure, water absorption, and grain distribution, the ratio of open to closed porosity, in addition to the mechanical characteristics. The paste-aggregate proximity is a key factor determining the distance in which the water of internal curing have to readily penetrate. Some researchers have shown that through practical studies, the fine lightweight aggregates are more effective in terms of distributing moisture in concrete when compared with coarse lightweight aggregates [8]. In contrast, other researchers believe that the pore size of the internal curing granules has a very important role in distributing moisture more than the size of the granules used [2]. In this time, the use of by-products aggregate in concrete has become a widespread practice, and considerable researches study has been done. Nevertheless, most of these researches focused fundamentally on the use of recycled normal aggregates, by-products as mineral admixtures, or waste fibres as reinforcement. This study was conducted on the use of ceramic waste after prepared it as a saturated surface dry fine aggregate and then used it as internal curing materials to study its effect on the structural behaviour of high-performance reinforced concrete slabs.

2. The objective of the research
The present research aims for studying the potential advantages to use a local ceramic waste (recycled local waste porous ceramic fine aggregates) as an internal curing material for improving the mechanical and structural characteristics of high-performance concrete, in addition for studying the effect of the local ceramic waste over time by testing the samples at three ages (60, 120, and 180) days. This research had been used a local ceramic waste as an internal curing material because of its high ability for absorbing water, that provides additional water as internal curing water. The pores inside the crushed ceramic particles acting as small internal water reservoirs in the concrete.
3. Materials and experimental work
The following section discusses the stages of the experimental program, including preparation of materials, design of the concrete mix, design of the structural slab, and experimental tests.

3.1. Materials
Ordinary Portland cement (OPC) equivalent to Iraqi standards No. 5/1984 Type I [9] in combination with 11% of silica fume (SF) [10]. Natural fine aggregate (NFA) with a fineness modulus 2.92 and 5mm a maximum nominal size had been used, and natural coarse aggregate (NCA) having a maximum nominal size of 12 mm had been employed as normal coarse aggregate also had been used. A single type of recycled crushed ceramic as a fine aggregate recovered from the local ceramic waste has been used as an internal water agent. This explains briefly the main properties of this type of fine aggregate compared with the NFA that is most readily available to use for internal wet curing purposes. Recycled crushed porous ceramic fine aggregate (PCFA) had been used in saturated surface-dry (SSD) state. A superplasticizer of polycarboxylate-based (SP) with a specific gravity of 1.095 [11] had been used to obtain the required slump. The steel bars used as reinforcement were of (8) mm diameters with a yield stress of 373.5 (MPa).

3.2. Concrete mixtures
Two different high-performance concrete mixes were had been used in the present study with adding a single low w/b. The proportion of HPC mixes without and with internal curing agents were illustrated in table 1. One control mix was made without using internal curing and one mix containing the PCFA for internal curing. A (10 and 20) % of PCFA has been used as a partial replacement by volume of the fine aggregate. All concrete mixes had been prepared by using the same procedure for mixing.

| Types of Mix | Cementitious Material Content (kg/m³) | Fine Aggregate (kg/m³) | Gravel (kg/m³) | Superplasticizer (L/100 Kg) | W/B |
|--------------|--------------------------------------|-----------------------|----------------|-----------------------------|-----|
|              | Cement (kg/m³)  | Silica Fume (kg/m³)  | Sand (kg/m³)  | Ceramic (kg/m³)            |     |
| RM-0%        | 450                     | 50                    | 700            | 0                          | 950 | 1 | 0.3 |
| CM-10%       | 450                     | 50                    | 630            | 55                         | 950 | 1 | 0.3 |
| CM-20%       | 450                     | 50                    | 560            | 110                        | 950 | 1 | 0.3 |

3.3. Specimen Preparation
For the two concrete mixes, all concrete samples had been prepared from the same concrete mix. After concrete casting immediately, all samples had been covered with a plastic waterproof sheet and wet fabrics for avoiding in early time water evaporation through the first hours of casting. The tested samples were 1050 mm× 1050 mm× 70 mm used to measure the ultimate load capacity. After the test, from load-deflection curves, four-parameter studied (ultimate load, ductility index, toughness, and liner elastic slop). Two meshes were used for reinforcing the plate, upper and lower with spacing 100 mm in two-way, figure 1 illustrated the details of reinforced slabs.
3.4. Testing methods
For all concrete slabs, they were tested in the same way by a uniform distributing load in the center of the slab by a rigid piece of steel with dimensions (450 * 450 * 40) mm. The load was applied by an electrical hydraulic device connected to a computer to collect the data. The deflection of the concrete slab was measured by three LVDT, one in the middle and the other two diagonally, as shown in figure 2. The testing of the samples was carried out at three ages (60, 120, and 180) days for all concrete slabs. To differentiate among the different slabs, each slab was given a certain designated symbol. The reference slabs were given the symbol (R); the crushed Ceramic slabs were given the symbol (C). To indicate the percentage of replacement in every mix, the symbols (10% and 20%) were used. Additionally, the age of testing specimens is added to the end of the name like (60, 120, and 180) to represent (1, 2, and 3), respectively.

3.5. Structural testing of reinforcement concrete slabs
All specimens were examined by fixed support from the four-sided of the plate. The fixed support of the tested concrete plate was applied by two solid and rigid bases from the top and bottom of the concrete slabs, bound together by 16 iron screws, tightly attached for the purpose of distributing the load regularly and evenly on all parts of the two bases and screws together as shown in figure 3. The test was conducted in the concrete laboratory of the civil engineering department – University of Kerbela. A universal testing machine with (2000 kN) loading capacity designed and manufactured for the structural loading...
test was used during the experimental testing program. The machine is equipped with electronically controlled gages (linear variable differential transformer -LVDT) and loading cells, which collects load, deflection data using a computerized system programmed by (LABVIEW) software.

![Figure 3. A sample of the tested concrete plates.](image)

4. Results and Discussion

This part of the study presents the results obtained from the concrete slabs structural testing, including the ultimate load, ductility index, toughness, and liner elastic slop.

4.1. Structural Test Results

The method of testing the concrete slabs by Applying the load to the point of failure and recording the resulting deflection with the increase in the load then draw the curve of the load-deflection and calculating the factors studied in this research. Table 2 and table 3 shows the results of the ultimate load, ultimate deflection, ductility index, toughness, liner elastic slop for each testing slab.

**Table 2. Results of the tested slabs.**

| Plate Groups | Slab Symbol | Age (Days) | Ultimate Load (kN) | Deflection (mm) | Ductility Index | Toughness (kN.mm) | Linear Elastic Slop |
|--------------|-------------|------------|-------------------|----------------|----------------|-------------------|-------------------|
| Reference    | RS-1        | 60         | 88.3              | 22.76          | 1.31           | 1138.67           | 4.18              |
|              | RS-2        | 120        | 131               | 14.3           | 1.35           | 938.46            | 8.99              |
|              | RS-3        | 180        | 158.6             | 24.5           | 1.4            | 2169.49           | 7.45              |
| Ceramic (10 %) | CS10-1      | 60         | 74.3              | 28.45          | 1.35           | 1351.28           | 3.52              |
|              | CS10-2      | 120        | 149.3             | 21.3           | 1.51           | 1726.04           | 7.28              |
|              | CS10-3      | 180        | 160.6             | 17.8           | 1.61           | 2298.78           | 7.83              |
| Ceramic (20 %) | CS20-1      | 60         | 80.9              | 23.83          | 1.48           | 1065.09           | 4.19              |
|              | CS20-2      | 120        | 150.5             | 19             | 1.38           | 1606.84           | 8.42              |
|              | CS20-3      | 180        | 168.6             | 24.4           | 1.36           | 2362.06           | 8.36              |

**Table 3. Percentage of difference in details for the tested slabs compared with the reference slabs.**

| Plate Groups | Plate Symbol | Age (Days) | $\Delta P_d = \frac{P_{UL} - P_{UR}}{P_{UR}}$ | $\Delta_D I = \frac{D I - D I_R}{D I_R}$ | $\Delta_T = \frac{T - T_R}{T_R}$ | $\Delta_L E S = \frac{L E S - L E S_R}{L E S_R}$ |
|--------------|--------------|------------|-----------------------------------------------|----------------------------------------|-----------------------------------|----------------------------------------------|
| Ceramic (10 %) | CS10-1      | 60         | -15.85                                           | 2.42                                  | 18.67                            | -15.81                                        |
|              | CS10-2      | 120        | 13.97                                            | 11.39                                 | 83.92                            | -19.04                                        |
|              | CS10-3      | 180        | 1.26                                             | 14.03                                 | 5.96                             | 5.1                                           |
| Ceramic (20 %) | CS20-1      | 60         | -8.38                                            | 12.66                                 | -6.46                            | 0.14                                          |
|              | CS20-2      | 120        | 14.88                                            | 1.79                                  | 71.22                            | -6.29                                        |
|              | CS20-3      | 180        | 6.31                                             | -3.46                                 | 8.87                             | 12.26                                        |
4.2. Effect of percentage of replacement on reinforcing concrete slabs

Figures 4, 5 and 6 show the load-deflection curves for the LVDT at the center of the slab for all slabs according to the percentage of fine aggregate replacement. The results of the tested slabs showed that the results of the slabs with a percentage of 20% are higher than the results of the slabs with a percentage of 10%, especially in late ages. At the age of 60 days, results showed that slab CS20-1 had a higher ultimate load than slab CS10-1 with a value of 80.9 and 74.3, respectively. This increase is not only in the values of the ultimate load, as the ductility index and the linear elastic slope showed an increase with the increase in the percentage of replacement 20%, in contrast to the toughness that suffered from a clear decrease with the increase in the percentage of replacement, according to the results shown in table 2 and table 3 compared to the results of reference slabs.

At the age of 120 days, results showed that slab CS20-2 had a higher ultimate load than slab CS10-2 with a value of 150.5 and 149.3, respectively. This increase is not only in the values of the ultimate load, as the linear elastic slope showed an increase with the increase in the percentage of replacement 20%, in contrast to the ductility index and the toughness that suffered from a clear decrease with the increase in the percentage of replacement, according to the results shown in table 2 and table 3 compared to the results of reference slabs.

At the age of 180 days, results showed that slab CS20-3 had a higher ultimate load than slab CS10-3 with a value of 168.6 and 160.6, respectively. This increase is not only in the values of the ultimate load, as the toughness and the linear elastic slope showed an increase with the increase in the percentage of replacement 20%, in contrast to the ductility index that suffered from a clear decrease with the increase in the percentage of replacement, according to the results shown in table 2 and table 3 compared to the results of reference slabs.

It is clear that the results showed an increase in slabs containing ceramics 20% higher than slabs containing ceramics 10% and, in all ages, which shows an enhancement in slab behavior with an increase in the percentage of internal curing agents. This shows the effectiveness of using ceramics as an internal curing agent on the structural behavior of concrete slabs, especially in later ages.

Figure 4. Load-deflection curves for ceramic plates with a different percentage at age 60 days.
Figure 5. Load-deflection curves for ceramic plates with a different percentage at age 120 days.

Figure 6. Load-deflection curves for ceramic plates with a different percentage at age 180 days.
4.3. Effect of Ages on Internally Cured of Reinforcing Concrete Slabs

Figure 7, 8, and 9 show the load-deflection curves for the LVDT at the center of the slab for all slabs according to the age of samples test. The ultimate load of reference concrete slab at the age of 60 days showed higher than the ultimate load of slabs containing ceramic materials as internal curing agents, but it is possible to notice the increase in the ductility index. The results showed a notable enhancement in all slabs with age, as it is possible to notice this enhancement, especially in slabs that contain ceramics as internal curing agents. It can also be noted that slabs that contain a 20% ceramic have the highest ultimate load than slabs that have a 10% ceramic. However, the enhancement was not limited to the ultimate load, but this enhancement included another structural behavior of the concrete slabs, such as the ductility index and the linear elastic slope, in addition to the toughness, as shown in the table 2 and table 3.

Figure 7. Load-deflection curve for reference concrete plates at 60, 120, 180 days.

Figure 8. Load-deflection curve for 10% ceramic plates at 60, 120, 180 days.
4.4. Crack Patterns

It is noticeable that the cracks of the concrete slabs began to increase with the increase of the load, as the first crack in line form extends through the loading area of the concrete slabs. As the load increased, the numbers, lengths, and widths of the cracks increased, and then at the end of the loading, cracks were concentrated below the loading area. Figure 10 is the crack pattern of all the slabs. It is possible to note that the number of cracks, their lengths, and width was increased in slabs that contain ceramics as internal curing agents, especially in slabs that contain 20% of ceramics, which indicates an enhancement in the ductility index and good ability to adapt under external loads.

Figure 9. Load-deflection curve for 20% ceramic plates at 60, 120, 180 days.
Figure 10. Cracks patterns at failure for slabs.
5. Conclusions

1. This study has focused on using the waste material "local fine ceramic waste aggregates" in high-performance concrete mixes as a saturated surface dry fine aggregate for enhancing the hydration reaction of the cement for improving the structural slab behavior.

2. The sample testing results indicate that the local fine waste ceramic aggregate has a great possibility for internal curing uses and it successfully can be used in high-performance concrete mixes for obtaining a significant enhancing of the structural slab behavior.

3. The adding of different percentages of the pre-saturated local fine waste ceramic aggregate in high-performance concrete for supplying the internal curing water which has shown high effectiveness to substantial enhancement in the structural behavior, particularly at a later age.

4. Where the increase in the ultimate load of concrete slabs at the age of 180 days and that have a 10% replacement percentage had an increase of 1.26%, while tiles with a percentage of 20% have an increase of 6.31% compared with the reference slab results.

5. The volumetric partial replacement of fine aggregate by different percentages of the local fine waste aggregate resulted in an essential reduction in the ultimate load at 60 days.

6. The use of ceramics as internal curing agents in concrete slabs has led to a significant improvement in the ductility index of concrete slabs, at the age of 180 days, concrete slabs that had 10% of replacement showed that the ductility index had an increase of 14.03%, while concrete slabs that had 20% of replacement showed an increase in the ductility index at the age of 60 days 12.66%, reversed the behavior of slabs that had 20% replacement at later ages which showed a decrease in the age of 180 days.

7. Increasing the amount of local fine ceramic waste has led to a significant enhancement of structural behavior.

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