The use of ceramics as an internal curing agent in high performance concrete with variable temperature curing to improve mechanical characteristics

Abdulrasool Thamer Abdulrasool¹ *, Noor R. Kadhimi¹, Safaa S. Mohammed¹, Ahmed Abdulmueen Alher²

¹Civil Engineering Department, Faculty of Engineering, University of Warith Al-Anbiyaa, Karbala, Iraq.
²Midland Refineries Company, Ministry of Oil, Iraq.

*Corresponding author, email: abdulrasool.th@g.uowa.edu.iq

Abstract. Concrete curing is one of the most significant factors in the development of compressive strength, and a high temperature difference during curing may reduce strength. The microcracks created in the concrete as a result of the constant temperature change cause this exudation. Internal curing has become popular for decreasing the risk of early-age cracking in high-performance concrete by limiting autogenous shrinkage (HPC). This study looks at the effectiveness of internal wet curing offered by a new kind of aggregate called "recycled waste porous ceramic fine aggregates". The evolution of measured mechanical characteristics is examined on three distinct HPCs, both with and without internal curing materials. Ceramic fine aggregates were used to replace two different quantities of regular weight fine aggregate. Ceramic fine aggregates were shown to be quite beneficial for internal cure. It has been discovered that incorporating 20% ceramic fine aggregates into HPC improves the properties of the material, resulting in low internal stress and a large improvement in compressive strength. It should be emphasized that, unlike some traditional lightweight aggregates, no loss in compressive strength has been seen for the various quantities of ceramic fine aggregates introduced at either early or later ages.

Keywords: High-performance concrete, internal curing agent, ceramic, curing temperature, fine aggregate replacement.

1. Introduction
The addition of silica fume to high-performance concrete (HPC) mixes and a low water/binder (w/b) ratio cause a significant decrease in relative humidity during hydration. The cement paste shrinks as a result of the self-desiccation process. Autogenous shrinkage produces tensile stresses in the cement paste and bulk deformation of the concrete because the aggregates' Young's modulus is greater than the hardening paste's.
Both of these events should be avoided to the greatest extent feasible since they may induce micro- or macrocracking, reducing the concrete's quality[1]. Microcracking may occur as a consequence of internal restriction induced by aggregates in the mixture. Many writers have used analytical methods to forecast the occurrence of these cracks[2] or numerical methods[3]. Real identification of shrinkage microcracks through microscopy observations is more challenging due to sample preparation problems[4]. In different structural members, self-shrinkage results in deformations, especially from high temperatures. Likewise in externally treated concrete, self-shrinkage causes deformation and thus leads to cracks in concrete[5][6][7] possibly compromising the durability. Autogenous deformation measurements are usually carried out at room temperature. So far, only a few researchers have investigated the impact of various curing temperatures on autogenous shrinkage. Cement pastes are the focus of the majority of these tests[8][9][10].

The temperature dependence of autogenous deformation comes from these investigations in an unsystematic manner[1]. According to Ref.[6], at various curing temperatures, only a maturity function can predict autogenous deformation. Results in Ref.[11], they do, however, have a more regular behavior, and the authors conclude that if a temperature-correcting element is included, autogenous deformation may be recreated using the maturity concept. The majority of autogenous shrinkage experimentation has focused on Portland cement mixes. For almost a century, blast-furnace slag (BFS) cement has been used in different European nations. BFS cement (which contains up to 70% slag) has been used extensively and successfully in the Netherlands, particularly in maritime buildings[12]. This kind of cement has many benefits, including environmental friendliness (due to the reuse of a waste material), reduced hydration heat, and a finer pore structure that improves water tightness[13]. Because the cement's chemical composition influences both self-desiccation and autogenous deformation[14] as well as the concrete paste's pore size distribution[15], the shrinkage behavior of BFS cement blends is anticipated to vary from that of Portland cement mixes. Other writers have discovered higher shrinkage values for BFS mixtures[16][17][18].

Concrete and mortar's strength and microstructure are known to be affected by the drying process. When large amounts of water are removed from cement paste before maturation, insufficient curing conditions result in poorer characteristics and performance. Furthermore, the moisture level of a cement-based material determines its mechanical characteristics at any age. Drying has a significant impact on the degree of shrinkage and stress state of the system[19]. Drying shrinkage affects the microstructure in a number of ways, with two major impacts on mechanical properties. It tends to increase surface energy and bonding between calcium silicate hydrate particles, which boosts strength in one manner (C-S-H). Microcrack formation, on the other hand, lowers the material's strength since it is a quasi-brittle material. The pace and severity of drying, as well as the sample form, all influence cracking[20]. According to conventional thinking, concrete cast and cured at low temperatures builds strength far more slowly than concrete poured at ambient temperature. For example, Price (1951)[21] and Klieger (1958)[22] according to conventional thinking, concrete cast and cured at low temperatures builds strength far more slowly than equivalent concrete poured at ambient temperature[23]. Gardner et al. (1988)[24] and Ho et al. (1989)[20] cold-cast and cured concretes did not exhibit the expected gradual strength development at low temperatures, according to the findings. The cement, on the other hand, will continue to hydrate in the core of the concrete as long as sufficient pore water is present. The hydration process will eat some of the pore water, while the drying surface will lose some. Powers (1947)[25] claims that when the relative water vapor pressure in capillaries falls below around 0.8, cement hydration nearly stops. Spears (1983)[26] asserts that continuing to cure below 80% relative humidity does not result in an increase in cement hydration, which is required for further concrete quality improvement. In actuality, site concrete is subjected to daily humidity cycles that are compounded by seasonal fluctuations, and active curing may be interrupted before the cement has
entirely hydrated[23]. Curing is necessary for improving the quality of the concrete cover and preventing the infiltration of aggressive substances into the concrete structure from a durability standpoint. Corrosion of reinforcing steel caused by chloride ions is a major issue[27].

The aim of this study is to use wet lightweight aggregate as an internal water supply to avoid self-desiccation and strain formation in constrained environments. It's essential to bear in mind while developing this idea and evaluating its impact because the reverse effect, namely internal shrinkage due to water absorption from matrix holes into aggregate pores, may occur[28]. This was noticed by Merikallio et al[29] for a particular type of normal concrete. When looking at the effectiveness of lightweight aggregates used as internal ripening materials, it is necessary to first know the difference between the amount of water contained in the granule compared to the water around it in the concrete.

This research looked at the effects of using ceramic as an internal curing material on high-performance concrete with different percentages and ages in a variable curing media. Two percentages of 10% and 15% were used as a partial substitute for fine aggregate and were evaluated at three ages: 60, 120, and 180 days.

2. Materials and methods

The next part covers the phases of the experimental program, including material preparation, concrete mix design, and experimental testing.

2.1. Materials

Ordinary Portland cement (OPC) having a silica fume content of 11%, as per Iraqi Regulation No. 5/1984 Type I. (SF). Normal coarse aggregate was made up of natural fine aggregate (NFA) with a fineness modulus of 2.92 and a maximum nominal size of 5 mm, as well as natural coarse aggregate (NCA) with a maximum nominal size of 12 mm. After completing the preparation of the ceramic aggregate collected from the local waste, it was partially added to the concrete by partial volumetric substitution in two different proportions, the first 10% and the second 20%, where it was added to the mixture as a saturated dry-surface aggregate. A superplasticizer with a density of 1.095 was used to obtain the slump required for fresh concrete.

Figure 1. Crushed ceramic made in the lab.
2.2. Concrete mixtures
Table 1 shows the proportions of concrete mixtures that were approved for pouring in this research. Three mixtures, one without internal ripening and two with fine ceramic aggregate, were poured as internal ripening materials. The first mixture was without internal ripening materials, the second mixture with internal ripening materials at a rate of 10% was replaced by fine aggregates, and the third mixture only was with 20% replacement of fine aggregates. Where the volumetric fine aggregates were replaced by concrete mixtures.

| Types of Mix | Cementitious Material Content (kg/m³) | Fine Aggregate (kg/m³) | Gravel (kg/m³) | Superplasticizer (L/100 Kg) | W/B |
|--------------|--------------------------------------|------------------------|----------------|-----------------------------|-----|
| 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 |

2.3. Specimen Preparation
Immediately after casting, the newly cast samples were covered with a plastic cover to prevent water loss during the concrete hardening stages. The technique of leaching was immersion in water for the first 60 days with temperature fluctuations between maximum and lowest, which reached about 16 degrees Celsius on certain days, particularly at young ages. Three factors were examined in the research (compressive strength, splitting tensile strength, dry density).

2.4. Testing methods
Compressive strength tests were conducted using concrete cubes with dimensions of (100 * 100 * 100 mm) (BS 1881 part 116). There were 27 cubes in total, all of which were curried for 60 days in water. The splitting tensile strength was tested in accordance with the manufacturer's instructions (ASTM C496-04). (100 * 200 mm) cylinders were employed. There were 27 cylinders total in the collection. The density was calculated with 100*100*100 mm cubes. The experiment included a total of 27 cubes. After baking the samples for 24 hours at (100-110 C°), the dry mass of the samples was measured. The test was carried out according to the ASTM C 138-01. Each test used an average of three cubes. At 60, 120, and 180 days old, tests were performed.

3. Results and Discussion
The test data, such as compressive strength, splitting tensile strength, and dry density, are presented in this section of the study.

3.1. Compressive Strength
The results showed a significant decrease in the compressive strength, as shown in Figure 2. Where the percentage of decrease at the age of 120 days was 10.29 %, as well as a decrease at the age of 180 days by 27.33 %. On the contrary, mixtures containing internal curing materials showed a good increase in compressive strength. Where the mixture containing 10 % of ceramic aggregate showed an increase in the age of 120 days by 24.72 %, while at the age of 180 days only showed an increase of 30.17 %. Also, the mixture containing 20 % ceramic aggregate showed an increase at the age of 120 days by 11.21 %, while
at the age of 180 days only showed an increase of 27.02 %. Through the study, it was found that the concrete mixture with a replacement rate of 20 % is the best among the mixtures and the best in terms of results. This behavior has been demonstrated by other researchers[1].

Figure 2. Compressive strength for all mixes.

3.2. Splitting tensile strength
The performance of concrete mixtures in terms of splitting tensile strength was not different from their performance in compressive strength, it is somewhat similar. Where the percentage of decrease at the age of 120 days was 5.14 %, as well as a decrease at the age of 180 days by 13.33 %. On the contrary, mixtures containing internal curing materials showed a good increase in splitting tensile strength. Where the mixture containing 10 % of ceramic aggregate showed an increase in the age of 120 days by 25.32 %, while the age of 180 days only showed an increase of 27.88 %. Also, the mixture containing 20 % ceramic aggregate showed an increase at the age of 120 days by 15.83 %, while at the age of 180 days only showed an increase of 38.07 %. Through the study, it was found that the concrete mixture with a replacement rate of 20 % is the best among the mixtures and the best in terms of results. This behavior has been demonstrated by other researchers[1].
3.3. **Dry density**

Figure 4 shows that the density of concrete without internal curing materials has a slight increase with age, which is almost equal. As for the mixtures with internal curing, the low density compared to the density of concrete without internal curing is normal because the replaced materials are of a lower density than fine aggregates. Figure 4 also showed that the results of the mixture with 20% replacement had a slight increase in density with time. This behavior has been demonstrated by other researchers[1].

### Table: Dry density

|       | 60-Days | 120-Days | 180-Days |
|-------|---------|----------|----------|
| RM    | 2474.59 | 2459.34  | 2436.67  |
| CM10  | 2475    | 2456.67  | 2450     |
| CM20  | 2475.67 | 2448.34  | 2457.5   |

**Figure 3.** Splitting tensile strength for all mixes.

**Figure 4.** Dry density for all mixes.

4. **Conclusions**
The main objective of this research is to study the mechanical behavior of high-performance concrete when using ceramic aggregate as an internal treatment material, partially replaced by fine aggregate in concrete. The results obtained from the mechanical tests showed that the ceramic aggregate is highly efficient when used as an internal curing material. The results show that fine ceramic aggregate has a positive effect that leads to improving mechanical properties in high-performance concrete, especially at the later ages of concrete life. The use of different percentages of pre-saturated local fine waste ceramic aggregate for providing internal curing water in high-performance concrete has resulted in a considerable increase in mechanical behavior, especially at a later age. Increased replacement of fine ceramic waste from the local area has resulted in a significant improvement in structural behavior. By increasing the percentage of local fine ceramic waste that is replaced, the structural behavior has been substantially enhanced. Ceramic aggregate as an interior curing medium is regarded as a sustainable choice since it may be obtained from building demolition waste.

References
[1] P. Lura, K. Van Breugel, and I. Maruyama, “Effect of curing temperature and type of cement on early-age shrinkage of high-performance concrete,” Cem. Concr. Res., vol. 31, no. 12, pp. 1867–1872, 2001, doi: 10.1016/S0008-8846(01)00601-9.
[2] P. GOLTERMANN, “MECHANICAL PREDICTIONS ON CONCRETE DETERIORATION. PART 1: EIGENSTRESSES IN CONCRETE,” ACI Mater. J., vol. 91, no. 6, pp. 543–550, 1994, [Online]. Available: https://www.concrete.org/publications/acimaterialsjournal.aspx.
[3] H. Sadouki and F. H. Wittmann, “Shrinkage and internal damage induced by drying and endogenous drying,” Shrinkage Concr., vol. 17, pp. 299–314, 2000.
[4] J. Bisschop, P. Lura, and J. Van Mier, “Shrinkage Microcracking in Cement-Based Materials With Low Water-Cement Ratio,” Concr. Sci. Eng., vol. 3, no. 3, pp. 151–156, 2001.
[5] A. Bentur, “Control of autogenous shrinkage stresses and cracking in high strength concrete,” Proc. 5th Int. Symp. Util. High Strength/High Perform. Concr. Sandefjord, pp. 1017–1026, 1999.
[6] K. Van Breugel, “Mixture optimization of HPC in view of autogenous shrinkage,” Proc. 5th Int. Symp. Util. High Strength/High Perform. Concr. Sandefjord, p. 1999, 1999.
[7] O. Bjontegaard, “Thermal dilation and autogenous deformation as driving forces to self-induced stresses in high performance concrete,” Norges Tek. Naturvitenskapelige Univ., 1999.
[8] A. Radocea, “Autogenous volume change of concrete at very early age,” Mag. Concr. Res., vol. 50, no. 2, pp. 107–113, 1998, doi: 10.1680/macr.1998.50.2.107.
[9] E. Tazawa, Y. Matsuoka, S. Miyazawa, and S. Okamoto, “Effect of autogenous shrinkage on self stress in hardening concrete,” Proc. Int. RILEM Symp. Therm. Crack. Concr. early Ages, Munich, E&FN Spon, London, UK, pp. 221–228, 1995.
[10] O. M. Jensen and P. F. Hansen, “Influence of temperature on autogenous deformation and relative humidity change in hardening cement paste,” Cem. Concr. Res., vol. 29, no. 4, pp. 567–575, 1999, doi: 10.1016/S0008-8846(99)00021-6.
[11] H. Hedlund and J.-E. Jonasson, “Effect on stress development of restrained thermal and moisture deformation,” Int. RILEM Work. Shrinkage Concr., vol. 30, pp. 355–377, 2000.
[12] J. M. J. M. Bijen, “Blast furnace slag cement for durable marine structures,” CIP R. Libr. Den
Haag, Sticht. BetonPrisma, 1996.

[13] R. N. Swamy, “Holistic design of concrete technology the only route to durability and sustainability in construction,” *Cem. Concr. Technol.*, pp. 58–71, 2000.

[14] O. M. Jensen, “Influence of cement composition on autogenous deformation and change of the relative humidity,” *Proc. Shrinkage 2000—Int. RILEM Work. Shrinkage Concr. Paris, RILEM Publ. S.A.R.L. Cachan Cedex, Fr.*, pp. 143–153, 2000.

[15] E.A.B. Koenders, “Simulation of volume changes in hardening cementbased materials,” *Delft Univ. Technol. PhD, Delft*, 1997.

[16] S. Hanehara, H. Hirao, and H. Uchikawa, “Relationship between autogenous shrinkage and the microstructure and humidity changes at inner part of hardened cement pastes at early ages,” *Proc. Autoshrink ’98, Int. Work. Autogenous Shrinkage Concr. Hiroshima, E&FN Spon, London, UK*, pp. 89–100, 1998.

[17] E. Tazawa and S. Miyazawa, “Autogenous shrinkage: What is understood and which are the further research needs?,” *Proc. Int. Work. Control Crack. Early Age Concr. Sendai*, 2000.

[18] X. Zhang, Y. Li, and K. Wu, “Study on autogenous shrinkage and AC impedance of paste with additives,” *Proc. Shrinkage 2000—Int. RILEM Work. Shrinkage Concr. Paris, RILEM Publ. S.A.R.L. Cachan Cedex, Fr.*, pp. 547–557, 2000.

[19] V. Kanna, R. . Olson, and H. . Jennings, “Effect of shrinkage and moisture content on the physical characteristics of blended cement mortars,” *Cem. Concr. Res.*, vol. 28, no. 10, pp. 1467–1477, Oct. 1998, doi: 10.1016/S0008-8846(98)00120-3.

[20] D. W. S. Ho, Q. Y. Cui, and D. J. Ritchie, “The influence of humidity and curing time on the quality of concrete,” *Cem. Concr. Res.*, vol. 19, no. 3, pp. 457–464, May 1989, doi: 10.1016/0008-8846(89)90034-3.

[21] Walter H. Price, “Factors Influencing Concrete Strength,” *J. Proc.*, vol. 47, no. 2, pp. 417–432, 1951.

[22] Paul Klieger, “Effect of Mixing and Curing Temperature on Concrete Strength,” *J. Proc.*, vol. 54, no. 6, pp. 1063–1081, 1958.

[23] H. Un and B. Baradan, “The effect of curing temperature and relative humidity on the strength development of Portland cement mortar,” *Sci. Res. Essays*, vol. 6, no. 12, pp. 2504–2511, 2011, doi: 10.5897/SRE11.269.

[24] N. J. Gardner, P. L. Sau, and M. S. Cheung, “Strength Development and Durability of Concretes Cast and Cured at 0 C,” *Mater. J.*, vol. 85, no. 6, pp. 529–536, 1988.

[25] T. C. Powers, “A DISCUSSION OF CEMENT HYDRATION IN RELATION TO THE CURING OF CONCRETE,” *Highw. Res. Board*, vol. 27, pp. 178–188, 1948.

[26] Ralph E. Spears, “The 80 Percent Solution to Inadequate Curing Problems,” *Concr. Int.*, vol. 5, no. 4, pp. 15–18, 1983.

[27] A. M. Neville and J. J. Brooks, *Concrete technology*, vol. 19, no. 4. 1999.

[28] A. Bentur, S. I. Igarashi, and K. Kovler, “Prevention of autogenous shrinkage in high-strength...
concrete by internal curing using wet lightweight aggregates,” *Cem. Concr. Res.*, vol. 31, no. 11, pp. 1587–1591, 2001, doi: 10.1016/S0008-8846(01)00608-1.

[29] T. Merikallio, R. Mannonen, and V. Penttala, “Drying of lightweight concrete produced from crushed expanded clay aggregates,” *Cem. Concr. Res.*, vol. 26, no. 9, pp. 1423–1433, Sep. 1996, doi: 10.1016/0008-8846(96)00116-0.