Use of Thermostone Waste Aggregates for Internal Curing of Reactive Powder Concrete

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Abstract. The concrete need curing for cement hydration that is a chemical reaction in each step require water supply throughout the time period. The traditional concrete cured by external method that prevents the concrete surface dry so that keeping the concrete mixture wet and warm. The internal curing was adopted in normal and high strength concrete such as reactive powder concrete. In present paper, experimental approach is to study the mechanical properties of reactive powder concrete cured internally with thermostone material. The materials that adopted to evaluate and find out the influences of the internal curing on the mechanical properties of reactive powder concrete is focused with different curing methods such as in water, air and combined water and air. Thermostone aggregate are used as partial sand replacement by volume with different percentages to explore the percentage that effects of the concrete mechanical properties. Test results showed that the best partial replacement by thermostone is 5% gave enhancement and increase in compressive strength and flexural resistance strength (modulus of rupture) and concrete density. Highest increasing of compressive strength is 10.07% in case of 5% partial replacement at 90 days. In case of cured the specimens up to 90 days, the increase in modulus of rupture is 4.53%

Keywords: Internal curing, Reactive powder concrete, Mechanical concrete properties, Partial replacement, Waste material, Thermostone.

1. Introduction

Different methodology of concrete curing was adapted to reach the concrete to the required strength. The curing of concrete was classified as internal and external curing based on the curing methodology and procedure. In general, the internal curing (IC) was defined as providing water in every part of a freshly placed cementitious mixture using continuous water source so that the concrete become pre-wetted that lead to complete the processes of hydration. The mechanical properties that produced from IC differ that in magnitude than in case of traditional curing. In case of IC in which this methodology required a lot of sources of water that store and easy to supply that pass through the cement paste during the cementitious reactions. The best materials that can be adopting are cells and gels. A cell membrane provides a boundary to water. Such containers allow water to be stored as an entity. The internal curing of concrete was adapted during recent years because of gave benefits to the concrete before and after casting. The internal curing gave in practical more supporting and additional water to the concrete

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mixture. The internal curing adapted since 1950s and some researchers applied this technic in pre– stresses concrete in 1967s and this methodology can be adopted for all structural concrete elements. Reactive powder concrete has higher mechanical properties as compared with normal concrete. Rami J.,2014 [1], investigated the influenced of thermostone as waste material that added to the concrete mixture as partial replacements in presence of Nano. Different ratio of waste thermostone by weight replacements were considered such as (5, 10, 15 and 20%) and applied destructive and non-destructive tests to investigated the compressive strength and tensile strength of all specimens. Test results showed that the (15%) of partial replacement gave good results while the quality of concrete as mechanical properties that contented normal weight concrete was decreased. J. Justs et al.,2015 [2], investigated the impact of internal curing on the absorption capacity and mechanical properties of high performance concrete. Low water to cement ratio was adapted as (0.25) with and without superabsorbent polymers. Test results showed that the mechanical properties are influenced by superabsorbent polymers addition. Jianhui Liu et al.,2017 [3] reviewed the concrete mechanical properties cured by internal curing method. The materials classified into two parts according to water absorbing mechanism. Concluded that the addition of internal curing materials releases internal curing water that lead to increase the later hydration of cement. Kevern and Nowasell, 2018 [4], improved the mechanical properties of concrete by replaced fine aggregates and followed the internal curing for all specimens. Test results pointed out increased in compressive strength at different test ages as compared with the control mixture without replacements due to the additional water supplied by internal curing which promotes a higher degree of hydration and leads to filling the pores with hydration products and increases the strength of cement paste. D. Pytlik et al.,2018 [5], studied the effects of internal curing of high-performance concrete that mixed with hydrogel on the concrete properties. Different percentages of hydrogel were adapted such as (0, 2.5, 5, 7.5 and 10%) in which the specimens were casted based on selected percentages. Test results indicated that the percentages of hydrogel were more effective than the internal curing on the concrete properties. Dale P. et al.,2018 [6], studied the effects of internal curing on the mechanical properties of higher performance concrete. The micro structural specimens with water to cement ratio 0.3was casted and treatments with and without internal curing. The concrete mixer contained slag, silica fume and fly ash. The specimens that cured by used internal curing gave more strength after cured time (120 days). Xuan Chen et al.,2019 [7] studied and analysed the microstructure behaviour of reactive powder concrete. Different parameters that affects on the performance of reactive powder concrete were adopted curing, the analysis gradations of fine aggregate and steel fiber type by used the technic of scanning electron microscope in addition to the mechanical tests. Based on the test and analysis results an optimal mix proportion of reactive powder concrete was developed by considered the economic benefits. Also, it was found that the gradation of reactive powder concrete fine aggregate achieved the densest stacking state gradation after the optimization of mix proportion. Doha M. et al, 2019 [8], reviewed the behaviour of higher performance concrete with different parameters such as density, mechanical properties and microstructure of hydrated cement paste. Concluded from researchers results that the internal curing was more effective at a later age on flexural strength than on compressive strength. Internal curing has enabled the interfacial transition zone increasingly compact and dense that lead to enhancing strength. Shatha D. Mohammed et al.,2020 [9], looked out on the behaviour of the reactive powder concrete compressive strength by adopted different materials as partial replacements of fine aggregate. Three different materials were used as partial replacements as fine aggregate such as porcelain aggregate, glass waste and granular activated carbon with different percentages of (0, 10, 15 and 20%). The specimens were tested at different ages as (7, 28, 60 and 90 days). Test results showed that the glass waste causes an increase in the overall values of the compressive strength.

The aim of present works is to investigate the internal curing impacts on the mechanical properties of reactive powder concrete with and without partial replacement of fine aggregate by using sustainable material to maintain environment that become health and reducing cost. Different specimens are prepared and specified for each tests types. All specimens with different parameters are considered such as curing type, replacements percentages of sustainable materials and the test methodology for each
specimen. The sand was replaced in different percentage volume with sustainable materials such as thermostone, the sustainable material used is absorbent and pre-soaked fine thermostone aggregate in water for suitable period as an internal curing.

2. Experimental Program

The materials investigations that adopted to make all specimens to explore the mechanical properties of reactive powder concrete for all curing conditions such as in water, in air and combined curing as water and air are presented here. The mechanical properties of the reactive powder concrete with and without partial replacement of fine aggregate consists of cube and prism for compressive strength, modulus of rupture and density for each percentage ratios of partial replacement. All selected materials such as cement, fine aggregate, silica fume, micro steel fiber and thermostone as waste material are tested to specify the chemical and physical properties for each. The specimens are tested at ages of 7, 28 and 90 days after curing under different conditions (water, air and combined). The curing method that adopted is placed all specimens in water tank with up to required time, in case of air curing all specimens placed in laboratory environments up to specified curing ages, also in compound curing (water and air) the specimens placed in water 7 days and the remaining period in air. Fig. 1 shows the schematic representation of test specimens,

![Concrete Tests with replacement as partial from fine aggregate 0, 5, 10 and 15%](image)

Figure 1. Schematic representation of test specimens

2.1. Materials

The materials that adopted in present study are summarized and discuss below as chemical and physical properties. All mortar components mixed with water matching the requirements of the Iraqi Specification, No. 1703, 1992 [10].

2.1.1 Cement

The brand of the cement that popular used in Iraq is Ordinary Portland Cement (OPC) as Tasluja factory was adopted in present study and used to cast all the specimens such as cubes and prisms. The cement package was kept in good conditions to minimize the effect of humidity. Test results indicate that the adopted cement conforms to the Iraqi Specifications No. 5, 2019 [11].
2.1.2 Fine Aggregate for Reactive Powder Concrete

The local natural sand Al-Ekhaider has been used in concrete mix for all tested specimen. It was tested to determine the grading and other physical and chemical properties. Test result shows after is within the requirements of the Iraqi Specification No.45,1984. Fig. 2 shows the sieve analysis with lower and upper limits based on the adopted specification matching the requirements of the Iraqi Specification No.45,1984[12].

![Figure 2. Sieve analysis - fine aggregate.](image)

2.1.3 Micro Silica Fume (SF)

Densified micro silica fume from SIKA company Iraq branch under commercial name (Mega Add MSD) has been used as a mineral admixture. Many trails were applied to reach the best and optimize percentage of the quantity of silica fume as additive material. The replacement of 25% by weight of cement was considered as the best percent. The chemical requirements and physical composition of silica fume is conforming to the requirements of ASTM C 1240-05,2005[13].

2.1.4 Micro Steel Fibers (Vf)

A straight steel fiber manufactured by Ganzhou Daye Metallic Fibers Co., Ltd, China was adopted in all concrete mixtures.

2.1.5 High Range Water Reducing Admixture (HRWRA)

High Range Water Reducing Admixture (HRWRA) was adopted to produce mix with minimum water content. SikaViscocrete-5930 high performance as super plasticizer is used as high range water reducing admixture for concrete, flow ability, very high-water reduction, with high workability retention and high strength development. It is free from chlorides and matching with ASTM C494- type F&G,2005 [14].

2.1.6 Thermostone Aggregate – Partial Replacements

Thermostone aggregate is adopted as partial replacements from fine aggregate that collected from industrial process as waste material (Karbala Thermostone Factory). The main processes on the thermostone is broken into smaller pieces until become same as sand in size by using iron hammer in
order to facilitate the insertion of thermostone through the opening of the standard set of sieves of sand. The crushed thermostone is washed and cleaned with water so that no dust resulting from crushing and then dried by spread in air. Sieve analysis for the thermostone crushed particles and then each thermostone aggregate size is replaced by volume with the same size of sand with a certain percentage to have the same grading as original aggregate based on Iraqi Specification No.45,1984 [12]. After all processes complete, the thermostone aggregate is soaked in water for (24) hours to bring the aggregate particles to saturated condition. Fig. 3 shows the prepared processes of thermostone as crushed, sieved, washed and saturated (from left to right).

![Figure 3](image)

**Figure 3.** Prepared processes of thermostone as crushed, sieved, washed and saturated

2.2. Concrete Mixing

Many trails are tested to reach the required mixes proportions that gave maximum strength and good flow based on ASTM C109/C109M,2016[15] and ASTM C-1437,2005[16]. Table 1 lists the mix proportion materials.

| W/Cm ratio | Sand [kg/m³] | %Silica fume* | Cement content [kg/m³] | %Micro steel fiber** | %Super stabilizer*** |
|------------|--------------|---------------|------------------------|---------------------|---------------------|
| 0.172      | 960          | 25            | 880                    | 0.75                | 1.50                |

*by weight of cement, **by volume of mix, ***by weight of binder(cement and silica fume)

Four groups marked as Group A, B, C and D of RPC mixes are adopted. Each group covers certain recognized parameters to investigate the effects of each other in which the average of three specimens for each test is considered. Group A represent the reference specimens that is mean the specimen casted without partial replacement of fine aggregate by thermostone as waste material. Group B represent the specimens that caste with 5% of sand partial replacement while group C and D same as group B but the partial replacement is 10 and 15% respectively. Each group, the specimens are tested under different curing conditions such as water, air and combine curing (water and air). Compressive strength, modulus of rupture and densityare investigating for each group. The specimen groups are lists in Table 2 and Table 3 lists the mix proportions of the concrete, Fig. 4 shows the casted of specimens as cubes with dimensions of 50x50x50 mm and prisms with dimensions of 300x50x50 mm.

**Table 2.** Details of all the series and its curing conditions.
| Specimen mark | Curing method | Group mark | Curing type | % Thermostone replacement |
|---------------|---------------|------------|-------------|--------------------------|
| A             | 1             | A          | water       | 0                        |
|               | 2             | A1         | Air         | 0                        |
|               | 3             | A2         | Water + Air | 0                        |
| B             | 1             | B          | water       | 5                        |
|               | 2             | B1         | Air         | 5                        |
|               | 3             | B2         | Water + Air | 5                        |
| C             | 1             | C          | water       | 10                       |
|               | 2             | C1         | Air         | 10                       |
|               | 3             | C2         | Water + Air | 10                       |
| D             | 1             | D          | water       | 15                       |
|               | 2             | D1         | Air         | 15                       |
|               | 3             | D2         | Water + Air | 15                       |

Table 3. Mix proportions of RPC mixes

| Materials          | (A) | (B)  | (C)  | (D)   |
|--------------------|-----|------|------|-------|
| Cement(kg/m³)      | 880 | 880  | 880  | 880   |
| Sand(kg/m³)        | 960 | 912  | 864  | 816   |
| Water(kg/m³)       | 189.2 | 189.2 | 189.2 | 189.2 |
| Silica Fume(kg/m³) | 220 | 220  | 220  | 220   |
| SP(kg/m³)          | 16.5 | 16.5 | 16.5 | 16.5  |
| % Steel fibres     | 0.75 | 0.75 | 0.75 | 0.75  |
| Thermostone(kg/m³) | --- | 20.9 | 41.8 | 62.8  |

(a) Cubes and prism molds  
(b) Cubes and prism casted specimens withinmold
3. Test Results

To evaluate the mechanical properties of hardened concrete, different tests are applied such as compressive strength, modulus of rupture and density under different curing conditions. Followings are test results and discussions for each experimental investigation.

3.1 Compressive Strength

Compressive strength was classified as the basic parameter to evaluate the strength capacity of concrete. Compressive strength test based on ASTM C109/C109M,2016 [15]. In general, the tested specimens show that increase in compressive strength due to internal curing with increasing of curing age. The enhancement in compressive strength due to continue cement hydration with the progress of curing age that is match with other concluded by Lam ,2005 [17], Bentz, 2007 [18] and Sato et al. ,2011 [19], Amar and Nada [20]. The increase in compressive strength percentage in case of 5% as compared with that 10 and 15%. Also, the increase in percentages of compressive strength of specimens decrease as increased in partial thermostone replacement as waste material. A Fig. 5 to 7 shows the variations of compressive strength against the cured method that symbols mentioned above. The compressive strength in case of cured the specimens in the water more than that cured the specimens in air and combined curing. This is due to in water curing the hydration process complete without discrete that lead to increase in the compressive strength. The presences of thermostone as partial replacement from fine aggregate in case of 5% gave more strength of specimen than the control and other percentages specimens. The partial replacements of fine aggregates by 10 and 15% also gave higher compressive strength than the control specimens. The reasons that caused increased in compressive strength because of increase the degree of hydration that lead to increase in the hydration products which fill the voids of concrete, in additions to the decrease the concrete porosity and reduced in the developed stresses.
3.2 Modulus of rupture

Modulus of rupture of concrete tests under a 3-point load based on ASTM C293-02, 2002 [21]. The modulus of rupture measures the bond strength of the specimens (cement matrix). Increase in concrete compressive strength lead to increase in modulus of rupture because of the concrete resistance to the applied load. Higher compressive strength of reactive powder makes the concrete more resistance to
applied load that cause tension stress due to bending that is mean increase in modulus of rupture of concrete. The increase in modulus of rupture percentage in case of 5% as compared with that 10 and 15%. Also, the increase in percentages of modulus of rupture of specimens decrease as increased in partial thermostone replacement as waste material. Increase in modulus of rupture related to increase in compressive strength of specimen that make the concrete more resistance to flexural under the effect of applied load. Fig. 8 to 10 shows the modulus of rupture variations with ages for different percentages of thermostone partial replacements percentages. In all ages, the modulus of rupture with partial replacement 5% more than the other specimens and all specimens with partial replacements by thermostone are greater than the control specimens.
Figure 10. Relationship between modulus of rupture and curing ages externally cured with water and air.

3.3 Density

Concrete density is the mass per unit volume in which the throughout the adopted test found out the actual concrete density for all adopted specimens with the considered parameters based on Iraqi Guidelines No. 274, 1992 [22]. The density of concrete differs from concrete to others, it is vastly relying on the mix design and other characteristics such as specific gravity of the aggregates. The increase in the concrete density percentage in case of 5% as compared with that 10 and 15%. Also, the increase in percentages of the concrete density of specimens decrease as increased in partial thermostone replacement as waste material. Increase in the concrete density due to increase in compressive strength of specimen. Figs. 11 to 13 shows the concrete density variations with ages for different percentages of thermostone partial replacements percentages. In all ages, the concrete density with partial replacement 5% more than the other specimens and all specimens with partial replacements by thermostone are greater than the control specimens.

Figure 11. Relationship between density and curing ages externally cured with water.
4. Discussions
Test results pointed out the mixes are internally cured gave mechanical properties of reactive powder concrete with thermostat as waste material partially replacements more than reference specimens with all partial replacements percentages. These improvements in concrete because of increase degree of cement hydration from internal curing water that make increase the hydration products.
Based on the test results the best partial replacement by thermostat is 5% gave enhancement and increase in compressive strength and modulus of rupture and concrete density due to this percentage is the best for this compositions of RPC with internal curing method that gave improvements in RPC mechanical properties. The increased in the quantity of thermostat aggregate as partial sand replacement causes the formation of large pores in the concrete matrix and in turn leads to decrease the density and other RPC properties as compared with 5% but still more than reference specimens for all cured ages. IC that the water supplied internally that cured the mixture (thermostat aggregate) promote high degree of hydration which leads to fill the pores with hydration product and increase the density of cement paste.
In case of cured the specimens up to 90 days, the increase in compressive strength and modulus of rupture when the specimens cured in water rather than when the specimens cured in air.

Test results indicated that internal curing methodology form the water slowly consumed over time for hydration of concrete matrix. Internal curing allows more effects and improvement concrete modulus of rupture when cured in water than in air for all mixes. Reactive powder concrete mechanical properties and density at age of 90 days with 5% of thermostone aggregate cured in water show increase compare with cured in air and combine curried specimens (water and air) due to increase of cement hydration degree. The combine curried specimens (water and air) gave modulus of rupture greater than the specimens when cured in air only and less than that cured in water due to increase in the hydration cement degree in presence of water so that the concrete strength increase as compare with specimens cured only in air.

The enhancements of compressive strengths, modulus of ruptures and densities for all casted specimens showed and mentioned above with respect to cured methodologies and tested ages with partial replacements percentages by thermostone.

5. Conclusions

The important conclusions based on the test results points as follow:

1. Using of local thermostone waste material that partially replacement from fine aggregate as internal curing materials to internal curing purpose gave improvements in reactive powder concrete mechanical properties.
2. Test results indicated that internal curing methodology from the water slowly consumed over time for hydration of adopted concrete.
3. The internal curing by adopting thermostone aggregate as partial sand replacement is significant enhancing the compressive strength of concrete at all ages of curing as compared with the reference specimens. Results show that there are improvements in the compressive strength with partially replacements as compared with the control specimens for each group and for all cured conditions.
4. There are increase in compressive strength based on test results when percentage of 5% as compared with that 10 and 15%. Also, the increase in percentages of compressive strength of specimens decrease as increased in partial thermostone replacement as waste material. Compressive strength of reactive powder concrete in cases of 10 and 15% gave more than reference but less than 5% replacement.
5. Reactive powder concrete compressive strength cured in water was improved because internal curing with thermostone waste material with different percentages as compared with reference concrete. Highest increasing of compressive strength is 10.07% in case of 5% partial replacement at 90 days. In case of cured the specimens up to 90 days, the increase in compressive strength 10.07, 6.04 and 4.70% for B, C and D respectively when the specimens cured in water. When the specimens cured in air the increase percentages as compare with the reference within same group are 7.69, 5.38 and 3.08% for B1, C1 and D1 respectively, also 9.63, 5.93 and 4.44% for B2, C2 and D2 respectively when the specimens cured in water and air.
6. Higher compressive strength of reactive powder makes the concrete more resistance to applied load that cause tension stress due to bending that is mean increase in modulus of rupture of concrete.
7. The presence of super-stabilizer in the concrete mixture and absence of micro steel fiber that lead to increase the concrete workability even the less of water to cement ratio that adopted.

8. Modulus of rupture of reactive powder concrete with partial replacement by thermostone as waste material shows higher values as compared with the reference concrete at all ages and all cured methodologies. Test results indicated that the progress of cured age, the reactive powder concrete specimens show a continuous gain in modulus of rupture that lead to enhancing in the modulus of rupture that make improving the properties of concrete by the additional internal curing water supplied by internal curing materials.

9. The increase in modulus of rupture percentage in case of 5% as compared with that 10 and 15%. Increase in modulus of rupture related to increase in compressive strength of specimen that make the concrete more resistance in tension. In case of cured the specimens up to 90 days, the increase in modulus of rupture 4.53, 2.48 and 1.63% for B, C and D respectively when the specimens cured in water. When the specimens cured in air the increase percentages as compare with the reference within same group are 2.87, 2.33 and 1.43% for B1, C1 and D1 respectively, also 4.32, 2.42 and 1.55% for B2, C2 and D2 respectively when the specimens cured in water and air.

10. Internal curing allows more effects and improvement concrete modulus of rupture when cured in water than in air for all mixes. The combine curried specimens (water and air) gave modulus of rupture greater than the specimens when cured in air only and less than that cured in water. In case of curing initially by water then the specimen's transferee to cured in air make the specimens to reduce in modulus of rupture as compare with the specimen cured total 90 days in water.

11. Increased in the percentage of replacement concrete more or equal to 10% make the density of reactive powder concrete decreased, and at the percentage of replacement of 15% concrete showed lower density but still more than the reference specimen. Increasing reactive powder concrete density of internally cured concrete with replacement of sand by 5% by 0.86% in water.

12. The internal curing method can be used in the construction field because of its ease of inclusive in the concrete mixture.

6. Summary

Three different methodologies with different ages (7, 28 and 90 days) and three percentages of sand aggregate by thermostone as waste material partially (5, 10 and 15%) of reactive powder concrete specimens are investigated. Hardened concrete specimens are tested such as cube and prismatic to find out the reactive powder concrete properties. Density, compressive strength and modulus of rupture are the main test are investigating. Internal curing of tested specimens leading to increase of reactive powder concrete properties due to continue cement hydration with the progress of internal curing age.

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