Effect of internal curing on concrete properties

Waleed A.Waryosh[1] **Imtethal H. Jaber**[2]

[1,2]Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

*Corresponding Author: **Waleed A.Waryosh**
waleedwaryosh@uomustansiriyah.edu.iq

https://doi.org/10.31972/iceit2024.062

ABSTRACT

Internal curing has improved the strength and performance of concrete buildings. Insufficient curing of concrete has been shown to result in a considerable loss in its strength, leading to the deterioration of the building's structural performance. This study aimed to investigate the effect of internal curing on concrete properties. Therefore, in this research, two types of internal curing materials were employed: water-absorbent polymer balls with two ratios of 5% and 10% from the weight of cement and crushed Thermostone aggregates with a ratio of replacement of 50% and 100% from coarse aggregates. Under two types of curing conditions (water and air), was studies and compares the efficiency of the polymer balls and crushed Thermostone aggregates through several tests conducted on (cubes, cylinders, and prisms)from where compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity. The findings demonstrated the efficacy of using water-absorbent polymer balls as internal curing material, and the optimum percentage was 5% for the P5A specimen compared to the reference specimen curing in water. Also, the findings show that raising the dosages of internal curing materials can reduce the mechanical properties of concrete. Therefore, carefully choosing suitable materials and controlling their quantity may be guaranteed internal water curing.

Keywords: internal curing, polymer balls, Thermostone, Mechanical properties

1. INTRODUCTION

Internal curing according to ACI is defined as the process of cement hydration persists as a result of the presence of internal water that is not part of the water used for blending [1]. Additional internal water is ordinarily provided using reservoirs that gradually release water into the concrete using pre-saturated lightweight aggregates (LWA). [2][3][4][5][6][7][8][9]. The properties that facilitate the internal curing process of LWA are a high porosity and an open, coarse pore structure, enabling water absorption when submerged in water, and the release of water in concrete under high internal relative humidity [10]. A system of internal pores in LWA lowers its specific gravity compared to ordinary weight aggregates. LWA's capacity to cure concrete internally comes from the coarse porous network, which retains water inside the aggregate grains and has a favorable role in cement hydration. LWA can absorb a substantial amount of water in relation to its initial volume. It can absorb from 5% to 25% of its total volume, with a minimum pore size of 100 nanometers for water absorption [11][12]. Saturated LWA is characterized by water release preceding the apertures of the smaller pores due to the reduced intermolecular forces in the large pores [13]. The variation in the adsorption capacity of LWA is due to the distinct pore size distribution exhibited by each LWA [14]. Preferred are lightweight aggregate systems with a discharge rate of at least 90 percent for absorbed water. If the chosen LWA cannot release most of the absorbed water, increasing the amount of LWA in the mixture is advisable. Where the cement particles will undergo the requisite hydration due to the elevated LWA content [15], generally, elevated levels of LWA content might give rise to detrimental consequences and decrease mechanical properties because of its inferior characteristics. Nevertheless, internal curing improves many properties, such as freeze-thaw resistance, dynamic modulus of elasticity, and crack delay [16]. Another method for internally curing concrete is using superabsorbent polymers (SAP). [17][18][19]. A polymeric materials can absorb substantial amounts quantities of water and hold the water within without dissolution [20]. Polymers are covalently linked to dual functional molecules. Due to their ionic composition and interconnected structure, these substances can absorb significant amounts of water without dissolution [21]. This fact invented the water-absorbent polymer balls, which are small spherical balls. When adding to concrete enhances many features, including workability, augmenting compressive and flexural strengths, diminishing water absorption, and penetration of carbonation and chloride ions [22]. The effectiveness of all preceding enhancements is contingent upon the specific polymers that are introduced and amounts [23]. Absorbent polymers have recently been studied and are expected to serve as internal water sources [24]. It can absorb water between 100 and 400 g/g dry and can be made in any shape or size. Used in concrete, it has been classified as an intelligent material [25]. Their properties change significantly: Exposure to water results in swelling, while subsequent drying results in reversible shrinkage. These essential characteristics may be efficiently used in relation to concrete. They have several properties, including low density, excellent surface finishing, low tensile strength, low mechanical properties, low coefficient of friction, economical, low-temperature resistance, and various colors [26].

Nomenclature is included if necessary

A	air curing
P	polymer ball
R	reference
T	Thermostone
W	water curing

2. RESEARCH SIGNIFICANCE

The objective of this research was to fill knowledge gaps about the effect of Internal Curing on the properties of concrete and how various parameters of Internal Curing, such as the type and quantity of curing agents, influence the properties of concrete. Implementing a self-governing and highly effective concrete curing method will significantly enhance concrete buildings' caliber and prolong their operational lifespans. This study is expected to contribute substantially from scientific, industrial, and economic perspectives.

3. EXPERIMENTAL PROGRAM

To achieve the objectives of this work, 27 concrete specimens (cubes, cylinders, and prisms) were cast and tested, and two materials were used in this work as internal curing agents: polymer balls with ratio of 5% and 10% by the weight of cement and crushed Thermostone aggregates at a ratio of 50% and 100% a replacement of weight of the natural coarse aggregate. Materials of internal curing agents they were placed in water for a day to soak up the water, after which they were included in the mixtures in varying proportions. Two curing conditions were used: air curing and water curing and all details of the specimens are in Table 1.

Table1. **Details of specimens**

No.	labels	Cement (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	Thermostone (Kg/m^3)	Water (L/m^3)	Polymer balls (Kg/m^3)
1	R W	400	600	1200	-	180	-
2	R A	400	600	1200	-	180	-
3	P5W	400	600	1200	-	180	20
4	P5A	400	600	1200	-	180	20
5	P10W	400	600	1200	-	180	40
6	P10A	400	600	1200	-	180	40
7	PT100W	400	600	-	1200	180	-
8	PT100A	400	600	-	1200	180	-
9	BT50A	400	600	-	600	180	-

4. MATERIAL

4.1. CEMENT

Ordinary Portland cement was used in this research. Chemical tests were conducted on it, and the results are illustrated in tables 2. The tests show that cement complies with Iraqi Specifications (IQS) No. 5/1984 [27].

Table2. Cement Chemicals Analysis

Oxide	Content by Weight (%)	Limit of IQS 5/1984[27]
SiO_2	21.6	-
CaO	63.18	-
$Al2O_3$	4.16	-
Fe_2O_3	3.36	-
MgO	2.72	< 5.0 %
SO_3	2.59	< 2.80 %
Loss on ignition	3.73	< 4.00 %
Insoluble residue	0.75	<1.5 %
Lime saturation factor	0.95	(0.66-1.02) %

4.2. FINE AGGREGATE

The natural sand utilized is a fine aggregate with a maximum particle size of 4.75mm. tables 3 and 4. Detail the gradation of the sand and its physical and chemical characteristics. The test findings show the gradation of the fine aggregate according to IQS, No.45/1984 zone (2) [28]. and its physical and chemical qualities according to ASTM C128-15 [29].

Table3. Fine aggregate grading

Size Sieve (mm)	Passing cumulatively%	Limits of IQS No.45/1984[28]
4.75	91.2	90-100
2.36	76.3	75-100
1.18	58.7	55-90
0.60	39.4	35-59
0.30	12.1	8-30
0.15	1.8	0-10

Table4. Physical and chemical characteristics of sand

Property	Results of the test	SpecificationNo.45/1984[28] and ASTMC128-15[29]
Fineness modulus	3.20	-
Specific gravity	2.66	-
SO3%	0.17%	≤ 0.5 %

Absorption%	2.5%	-
Dry loose unit weight, (kg/m³)	1492	-

4.3. COARSE AGGREGATE

The coarse aggregate utilised is natural crushed gravel with a maximum particle size of 12.5 mm. The gradation of the gravel and its physical attributes are detailed in Tables 5. and 6.The test results show that the gradation of the coarse aggregate and its physical qualities meet the specifications outlined in Iraqi Specifications No. 45/1984 [28].

Table5. Coarse Aggregate Grading

Size Sieve (mm)	Passing Cumulative (%)	Limits of IQSNo.45/1984[28]
19.5	100	100
12.5	93.8	90-100
9.5	51.1	40-70
4.75	10.12	0-15
2.36	0.08	0-5

Table6. Physical Properties of the Coarse Aggregate

property	Results	Limit of IQS No.45/1984[28]
Specific gravity	2.65	-
SO3%	0.02%	0.1% (max)
Absorption%	0.63%	-
Dry loose unit weight kg/m³	1590	

4.3. CRUSHED THERMOSTONE

Thermostone was used as coarse aggregate with the same gradation zone as the original aggregate, which was crushed manually with a hammer and then with a jaw crusher machine; the jaw crusher produced a crushed stone with a 20 mm maximum size aggregate. The crushed Thermostone was screened on a standard sieve series to obtain a gradation identical to the gradation coarse aggregates12.5. Table 7 detail the gradation of the crushed Thermostone. After that, it was put in water until saturated to examine its water absorption capability which was (55%) of weight.

Table7. Gradation of the Crushed Thermostone

Size Sieve (mm)	Passing Cumulative (%)	Coarse aggregate grading

19.5	100	100
12.5	93.8	90-100
9.5	51.1	40-70
4.75	10.12	0-15
2.36	0.08	0-5

4.4. POLYMER BALLS

Polymers with small spherical morphologies were incorporated into the mixture with ratio of 5% and 10% from the weight of the cement after submerged in water for 24 hours.

4.5. WATER

The specimens were cast and cured using tap water.

5. MIXING AND CASTING

The mixing process was performed using a 0.19 m3 horizontal rotary mixer in the structural laboratory of the College of Engineering, Mustansiriya University, First, coarse and fine aggregates were mixed. In refractory stone mixes, the two types of coarse aggregate (natural coarse aggregate and crushed refractory stone) are mixed before sand is added. Then add cement and mix the dry ingredients until a homogeneous dry mixture is obtained. Then, water is supplied, and mixing continues until a homogeneous mixture is obtained the addition of polymer balls in two strata. All samples were disassembled after 24 h and treated under different conditions (water or air) until tested after 28 days.

6. TESTING AND RESULTS

6.1. COMPRESSIVE STRENGTH

Testing is conducted on three cubes measuring (150x150x150) mm the test was According to B.S1881 [30]. for each mixture after 28 days.

The values of the mixtures presented in Figure 4 are demonstrated. There is a high degree of agreement among the three cubic specimen compressive strength readings. The reference mix, when cured in water, exhibited superior strength compared to other mixes incorporating the internal curing ingredient, reaching a peak strength of 39.5 MPa following a 28-day curing period. Nevertheless, the strength of the control specimen fell by approximately 14% due to air curing. The loss in strength primarily resulted from the lack of water required for the hydration process. Specimen p5A had the highest values of compressive strength. This may be attributed to the internal cure facilitated by the water-absorbent polymer balls, which provide a continuous water supply to the concrete. This helps in the development of hydration products and increases the strength of the concrete. Crushed thermostone samples exhibit a decline in their ability to withstand compression, as depicted in Figure 1. The decrease in bonding between the paste and aggregate may be attributed to variations in strength, particularly because the crushed thermostone aggregate is not as robust as the normal weight aggregate.

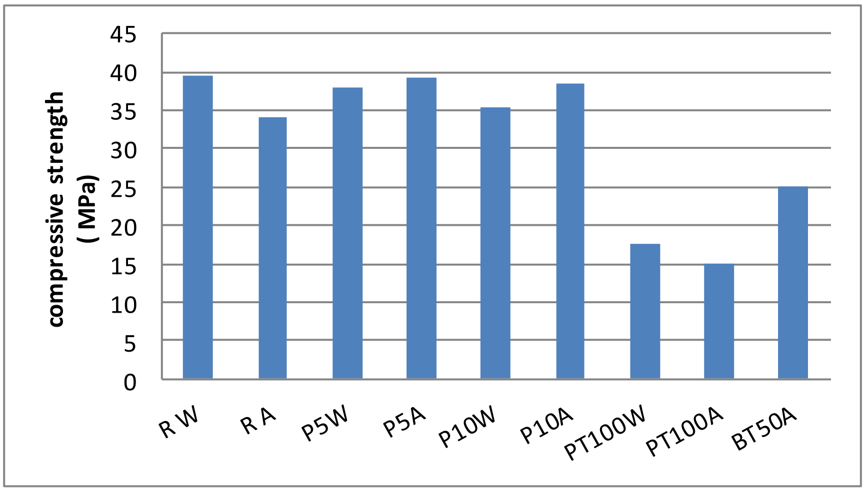

FIGURE1. Test results for the compressive strength

6.2. SPLITTING TENSILE STRENGTH (FT)

The test was performed according to ASTM C496-2004[31]. Which used Cylindrical concrete specimens of 150×300 mm at the age of (28) days. For each mixture, the average of three specimens is calculated. Figure 2 explains Splitting Tensile Strength values. It was observed that the mixes of water-absorbent polymer balls cured in air showed better performance than the reference mixes and water-curing mixes due to continuous hydration resulting from internal curing facilitated by polymer balls, which improved the interfacial transition zone. Specimens of crushed Thermostone aggregates showed a decrease in tensile strength for all mixes; This conforms to compressive strength reduction because the crushed Thermostone aggregates have lower stiffness than the normal weight aggregates and also due to the increase in the void system linked to moisture within the concrete. The presence of a significant moisture gradient from the center to the surface of the cylinder thereby impacts the tensile strength of the concrete.

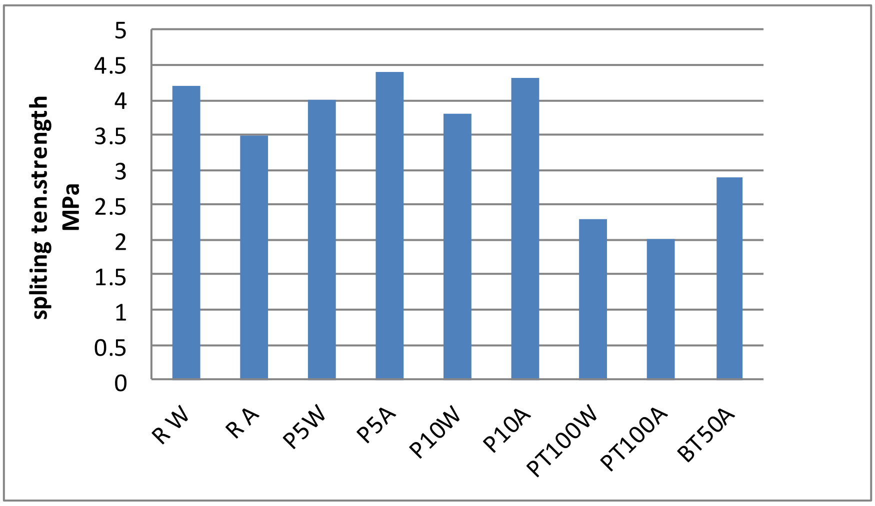

FIGURE2. Test results for the Splitting Tensile strength

6.3. FLEXURAL STRENGTH TEST (FR)

The concrete's flexural strength was estimated using (100x100x500mm) prism specimens according to ASTM 293-79 [32]. Prisms were put through the 2-point load, and an average was taken to 3 specimens.

The values of results of the mixtures presented in Figure 3 All mixes of polymer balls cured in the air have higher strength (or equal) than the reference mix, showing that the internal curing by polymer balls is significantly adequate in continuous hydration. Specimens of crushed thermostone aggregates showed lower strength than the reference mix. That conforms to lowering compressive strength and splitting tensile strength compared to the reference mix. They are attributed to the crushed thermostone aggregates' lower stiffness than the normal weight aggregates.

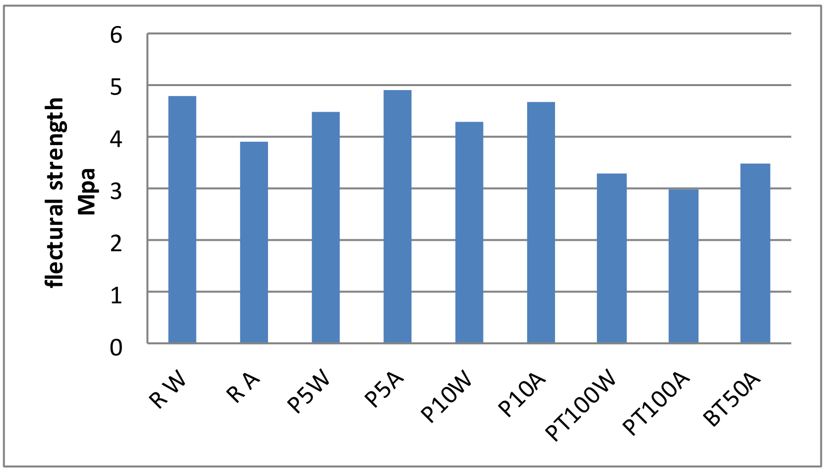

FIGURE3. Test results for the Flexural Strength

6.4. MODULUS OF ELASTICITY TEST (EC)

The elastic modulus was determined by conducting a uniaxial compression test using the modulus technique specified in the ASTM C469-02 [33] standard. The test was performed when the specimens were 28 days old using cylindrical specimens measuring 150×300mm. The chord modulus measures the slope of a stress-strain diagram line that connects two fixed points. The lower point is established to eliminate the influence of the crack on the early section of the stress-strain curve, namely at a strain of 0.00005 mm/mm. Meanwhile, the upper point is set as a stress level equivalent to 40% of the ultimate stress the values of the mixtures depicted in Figure 4 exhibited. The strength of all water-absorbent polymer ball mixes cured in the air is either higher or equal to that of the reference mix. This is because of the improvement in the interfacial transition zone, enhanced hydration resulting from internal curing, and the absence of micro cracking caused by shrinkage. The crushed thermostone aggregate specimens exhibited lower values than the reference mix. This adheres to decreased compressive, splitting tensile and flexural strength. One possible factor contributing to the decrease in elastic modulus could be the Increase in moisture-related void systems within concrete. The low value shows that the crushed thermostone aggregate concrete exhibited reduced stiffness compared to the reference mix.

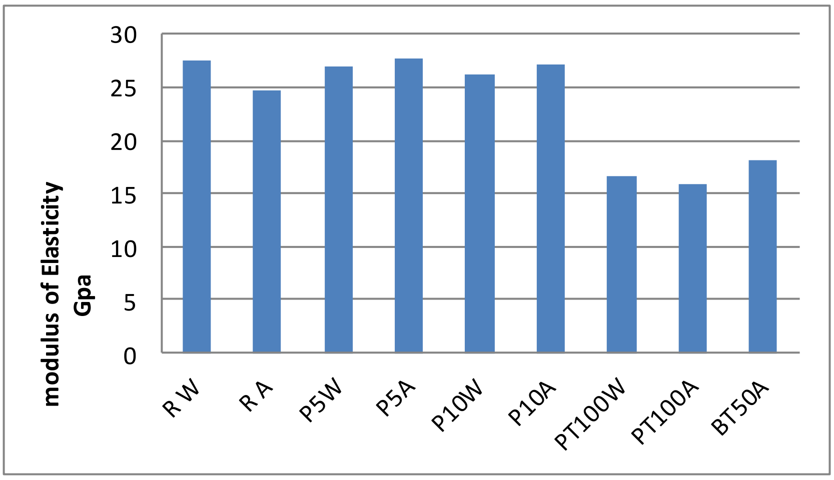

FIGURE4. **Test results for the Modulus of Elasticity**

7. CONCLUSION

In summary, these are the major conclusions:

1. Mixes of water-absorbent polymer balls with a ratio of 5% cured in the air was the optimum dosage within the limits of this study to have a reasonable strength, the same strength as that of traditionally cured concrete, hence suitable where water is insufficient
2. Increasing the dosages of polymer balls and crushed Thermostone aggregates decreased mechanical properties. The reduction was greatest for crushed Thermostone aggregate mixes. This highlights the importance of adjusting replacement doses to meet target characteristics.
3. Water-absorbent Polymer ball mixes showed better enhancement in all properties than the crushed Thermostone aggregate mixes

FUNDING

No funding received for this work

ACKNOWLEDGEMENT

The authors would like to thank the anonymous reviewers for their efforts.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

1. Akers, D.J., Gruber, R.D., Ramme, B.W., Boyle, M.J., Grygar, J.G., Rowe, S.K., Bremner, T.W., Kluckowski, E.S., Sheetz, S.R., Burg, R.G. and Kowalsky, M.J., 2003. Guide for structural lightweight-aggregate concrete. ACI 213R-03. American Concrete Institute (ACI), Michigan.
2. Akcay, B. and Tasdemir, M.A., 2010. Effects of distribution of lightweight aggregates on internal curing of concrete. Cement and Concrete Composites, 32(8), pp.611-616.
3. D. P. Bentz, "ACI Webinar Introducing ACI (308-213) R-13: Report on Internally Cured Concrete."
4. Bandara, M.M.H.W., Mampearachchi, W.K. and Anojan, T., 2019. Enhance the properties of concrete using pre-developed burnt clay chips as internally curing concrete aggregate. Case Studies in Construction Materials, 11, p.e00284.
5. Bentz, D.P., Lura, P. and Roberts, J.W., 2005. Mixture proportioning for internal curing. Concrete international, 27(2), pp.35-40.
6. Kevern, J.T. and Nowasell, Q.C., 2018. Internal curing of pervious concrete using lightweight aggregates. Construction and Building Materials, 161, pp.229-235.

7. Espinoza-Hijazin, G. and Lopez, M., 2011. Extending internal curing to concrete mixtures with W/C higher than 0.42. Construction and Building Materials, 25(3), pp.1236-1242.
8. Ma, X., Liu, J. and Shi, C., 2019. A review on the use of LWA as an internal curing agent of high performance cement-based materials. Construction and Building Materials, 218, pp.385-393.
9. Liu, B., Jiang, J., Shen, S., Zhou, F., Shi, J. and He, Z., 2020. Effects of curing methods of concrete after steam curing on mechanical strength and permeability. Construction and Building Materials, 256, p.119441.
10. Paul, A., Murgadas, S., Delpiano, J., Moreno-Casas, P.A., Walczak, M. and Lopez, M., 2021. The role of moisture transport mechanisms on the performance of lightweight aggregates in internal curing. Construction and Building Materials, 268, p.121191.
11. Balapour, M., Zhao, W., Garboczi, E.J., Oo, N.Y., Spatari, S., Hsuan, Y.G., Billen, P. and Farnam, Y., 2020. Potential use of lightweight aggregate (LWA) produced from bottom coal ash for internal curing of concrete systems. Cement and Concrete Composites, 105, p.103428.
12. Karakurt, C. and Özen, U., 2017. Influence of natural lightweight aggregates on the properties of concrete. Journal of the Turkish Chemical Society Section B: Chemical Engineering, 1(Sp. is. 2), pp.9-16.
13. Ghiasvand, H., Bastami, M. and Farokhzad, R., 2022. Enhancing the internal curing process of self-compacting concrete containing lightweight aggregate and chemical additives. European Journal of Environmental and Civil Engineering, 26(16), pp.8414-8432.
14. Guo, K.Z., Zhang, G.Z., Li, Y., Yang, J. and Ding, Q.J., 2024. The mechanism of curing regimes on the macroscopic properties and microstructure of ultra-high performance concrete with lightweight aggregates. Journal of Building Engineering, 82, p.108236.
15. Akhnoukh, A.K., 2018. Internal curing of concrete using lightweight aggregates. Particulate Science and Technology, 36(3), pp.362-367.
16. El-Hawary, M. and Al-Sulily, A., 2020. Internal curing of recycled aggregates concrete. Journal of Cleaner Production, 275, p.122911.
17. Zhong, P., Wyrzykowski, M., Toropovs, N., Li, L., Liu, J. and Lura, P., 2019. Internal curing with superabsorbent polymers of different chemical structures. Cement and Concrete Research, 123, p.105789.
18. Ma, X., Liu, J., Wu, Z. and Shi, C., 2017. Effects of SAP on the properties and pore structure of high performance cement-based materials. Construction and Building Materials, 131, pp.476-484.
19. Hong, G., Kim, J., Song, C., Yeon, J.H. and Choi, S., 2024. Effect of internal curing by superabsorbent polymers on the densification and microstructural development of cementitious materials exposed to different environmental conditions. Construction and Building Materials, 411, p.134778.

20. Olawuyi, B.J., Babafemi, A.J. and Boshoff, W.P., 2021. Early-age and long-term strength development of high-performance concrete with SAP. Construction and Building Materials, 267, p.121798.
21. Shembade, K.T., Hedgire, P.P. and Chavan, S.V., 2020. Experimental study on effect of internal curing on compressive strength of concrete using super absorbent polymer. Int J Eng Res Technol, 9(9), pp.81-92.
22. Hussen, N.F. and Mohammed, S.D., 2022. Influence of water-absorbent polymer balls on the structural performance of reinforced concrete beam: An experimental investigation. Journal of the Mechanical Behavior of Materials, 31(1), pp.357-368.
23. Ramalingam, V., Ramesh, K., Duraipandi, M., Jayesh, U. and Kuppusamy, S., 2022. Water absorbing polymer balls as internal water curing agent in concrete to support hydration reaction. Revista de la construcción, 21(1), pp.83-92.
24. Ahmed, I.F., 2017. COMPRESSIVE STRENGTH OF CONCRETE CONTAINING WATER ABSORPTION POLYMER BALLS (WAPB). Kufa Journal of Engineering, 8(2), pp.42-52.
25. Zhang, X., Song, Z. and Ding, Y., 2022. Predicting compressive strength of cement-based materials containing water-absorbent polymers considering the internal-curing region. Construction and Building Materials, 360, p.129594.
26. Kearsley, E.P. and Wainwright, P.J., 2001. Porosity and permeability of foamed concrete. Cement and concrete research, 31(5), pp.805-812.
27. Specification, I.S., 1984. No. 5/1984, portland cement. Central Organization for Standardization & Quality Control (COSQC), Baghdad, Iraq.
28. Specification, I.S., 1984. No. 45/1984, Aggregate from Natural Sources for Concrete and Construction. Central Organization for Standardization & Quality Control (COSQC), Baghdad, Iraq.
29. ASTM, A., 2015. Standard test method for relative density (specific gravity) and absorption of coarse aggregate. ASTM West Conshohocken, PA.
30. British, S., 1983. 116: Testing concrete-Part 116: method for determination of compressive strength of concrete cubes. British Standards Institution London, UK.
31. ASTM, C., 2014.Splitting Tensile Strength of Cylindrical Concrete Specimens .ASTM West Conshohocken, PA.
32. ASTM, C., 2014.Flexural Strength of Concrete (Using Simple Beam with Centre – Point Loading. ASTM West Conshohocken, PA.
33. Standard, A.S.T.M., 2014. C469/C469M-14 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. ASTM International: West Conshohocken, PA, USA, pp.1-5.