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*Research Article*

# Water absorbing polymer balls as internal water curing agent in concrete to support hydration reaction

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**Abstract:** polymer balls can supply water to the mortar or concrete mixture when added during the initial stage of mixing the concrete ingredients. It supplies the absorbed water during the hydration process of concrete as an internal water source. Water Absorption polymers (WAP) can absorb water up to hundred times of their own weight. Using this idea, the concrete mixture has been prepared with WAP and without WAP (Control) and subjected to air curing and water curing respectively. In this work WAP has been added in two different percentages i.e., 2.5% and 5% of the weight of cement, and the hardened concrete has been subjected to compression load. The mechanical strength and the volumetric change of these mixes were compared with the water cured control mix (Concrete without WAP). From the result, it was concluded that the air-cured specimen showed strength of 30.37 MPa and 28.74 MPa for 2.5% and 5% of addition of WAP balls respectively. This strength is about 99% and 94.2% of the strength of control water-cured specimen. Results also showed that specimens in air behave for expansion while samples in the water acted for shrinkage. Experiment results also showed that air-cured concrete specimens with WAP balls show significant strength gain over a period of 84 days compared to water-cured normal concrete mix samples.

**Keywords:** polymers; air-curing, internal curing, hydration, recycled aggregate.

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## 1. Introduction

According to American Concrete Institute (ACI), internal curing (IC) can be defined as “a process by which the hydration of cement continues because of the availability of internal water provided by some additives in the concrete, other than the mixing water. When compared to conventional water curing (WC), IC is an effective method of curing in many cases like concrete mix with lower water-cement (w/c) ratio and concreting in hot climate regions (Duxson et al., 2007). In the case of low W/C ratio mix, the hydration process will continue for a long period, but due to the lack of water availability internally within the concrete, the hydration process which continues creates partially filled pores inside the concrete (Ma et al., 2017). These pores result in the formation of weak zones in the concrete and also leads to shrinkage (Meyst et al., 2021). The concept behind the IC is that, it provides continuous supply of water internally to the concrete and supports the hydration to take place. Because of this IC, the pores in the concrete are completely filled with hydration products which reduces the shrinkage, cracking and also increases the strength in concrete for a long period of time (Olawuyi et al. 2021). The pores in the concrete are completely filled with cement products, thereby reducing the permeability and increasing the resistance to chloride penetration and acid attack (HoonKang et al. 2017; Lyu et al., 2020). Internal curing work well for concrete with supplementary cement materials such as fly ash, which has high water demand compared to ordinary portland cement (OPC) during the hydration reaction, which will be provided by the internal curing agent (Olivier et al. 2018; Tu et al. 2019). Another case where IC work well is the place where, weather condition is less than ideal level and in situations where poor convention water curing is adopted. IC cannot completely replace WC but work along with it to improve the strength and properties of concrete. Xie et al., (2021) studied the mechanical property of internally cured concrete with SAP through four-point bending loading subjected to monotonic and cyclic load.

Water absorbent polymers (WAP) can be used as an effective internal water curing agent in mortars and concrete. The addition of WAP to cement mortar and concrete, enhances many properties such as workability, increased flexural and compressive strengths, reduced water absorption, carbonation and chloride ions penetration and improved performance in humid and industrial environments (Riyazi et al., 2017). Many research works have been carried out using this polymer for internal curing. Using Super Absorbent Polymers (SAP) for internal curing, lowers shrinkage of alkali activated slag, mortar and alkali activated fly ash slag paste (Li et al., 2020; Oh & Choi, 2018; Tu et al., 2019). Yang et al., (2019) studied the influence of SAP on the property of drying shrinkage and humidity distribution in concrete pavements strain analysis in the inner wall region of concrete pavement showed that, internal curing with SAP could reduce the shrinkage strain at the center and corners of the pavement slab.

The influence of SAP in mortar and concrete with high fines, low water cement ratio (0.35), high performance concrete (HPC) and ultra-high-performance concrete (UHPC) were investigated. SAP when added to such high-performance mortar and concrete act as internal curing agents and reduce the autogenous shrinkage. Addition of polymer balls beyond 5% of weight of cement results in the reduction of strength due to the pores created by the balls (Li et al., 2020). Mechanical property of HPC decreases slightly as SAP content increases for both the early-age and long-term. Statistical results also showed that water binder ratio and SAP contents significantly influences the strength development of HPC (Justs et al., 2015; Olawuyi et al., 2021; Shen et al., 2020). Afridi et al., (2019) investigated the durability properties of geopolymer based mortar. Internal curing by polymers results in the reduction of pores diameter and reduces the porosity of concrete, lower the calcium silicate ratio thereby, improving the crack resistance behavior of concrete (Lyu et al., 2020). Faxiang et al., (2021) & Tanyildizi, (2021) studied the mechanical property of internally cured concrete.

The performance of HSC reinforced with barchip fiber internally cured with SAP showed reduction in autogenous shrinkage (Shen et al., 2020). Esteves. (2011) studied the compressive strength of SAP mortar under different humidity environments and pointed out that a low curing humidity resulted in the minimal influence of SAP on the reduction of compressive strength. Yao et al., (2012) revealed that SAP could significantly improve the tensile strength and ductility of engineered cementitious composite (ECC), but reduce its compressive strength. From the literature study it can be concluded that hand full of work has been done using SAP balls in concrete. But application of polymer balls in recycled aggregate concrete subjected to air curing and water curing has not been studied and compared so far. The effect of water absorbed by polymers on the volumetric behavior of RAC also need to be studied for air and water cured specimen. Therefore, the main aim of this research work is to study the strength and shrinkage property of normal and recycled aggregate concrete mix with different percentage of polymer balls. The investigation is to be carried out for three periods of curing i.e., 28days, 56 days and 84 days and compare the mechanical and shrinkage property of both normal aggregate concrete (NAC) mix and recycled aggregate concrete (RAC) mix with and without polymer balls.

## 2. Experimental study

The experimental program involves the preparation of OPC concrete that have water absorption polymer balls and study the mechanical strength and volumetric change of the specimens. WAP have excellent water absorption characteristics and this makes them interesting in relation to concrete. This research deals with the use of WAP at 2.5% and 5% of weight of cement. The casted specimens were tested for three different curing period, i.e., 28 days, 56 days and 84 days.

### 2.1. *Materials*

Ordinary Portland cement of grade 53 confirming to IS 12269: 1987 was used. The coarse aggregate has a maximum size of 20 mm and confirm to IS: 383 1970 along with this, well-graded natural sand was used as fine aggregate in all concrete mixes. Another set of specimens were prepared with Recycled Aggregate (RA) as coarse aggregate. The dry water absorption polymer balls were immersed in water for one day and then it was used in concrete. Concrete mixes were prepared with 2.5% and 5% polymer balls by weight of cement as a typical percentage. The WAP balls is shown in Figure 1.


(a) (b)

**Figure 1.** Water absorption polymer balls: (a) dry polymer balls (b) water absorbed polymer balls.

### 2.2 *Mix details*

Five set of concrete mixes were prepared in this research work in which the strength of control mix was equal to 30MPa. Totally six different mixes were prepared, the mix proportion and specimen ID are listed in Table 1. First mix is the control specimen, without any polymer balls. Second and third mix were prepared with WAP balls of weight equal to 2.5% and 5 % of cement weight. Fourth mix was prepared by replacing the regular gravel aggregate with recycled aggregate without WAP balls. Fifth and sixth mix were prepared using recycled concrete aggregate with 2.5% and 5% of WAP balls. The concrete specimen was named in such a way that it indicates the percentage of WAP balls and whether air cured or water cured. For example, M-2.5-WAP-WC indicates Mix with 2.5 % WAP balls subjected to water curing. CM represent Control Mix and RAC represent Recycled Aggregate Concrete.

### 2.3 *Casting of specimens*

Cube mold of size 150×150×150 mm and cylinder mold of size 150×300 mm was used for casting the specimen. All the ingredients of the concrete were added to the concrete mixture and thoroughly mixed for 5 minutes. WAP balls were added to the mixture only at the end and mixed for 30 seconds and stopped, because continuous mixing may damage the polymer balls and it will lead to increase in water content of the mix. In the first mix 18 cubes and 18 cylinders were casted, out of which nine cubes and nine cylinders were subject to air curing and remaining specimens were subjected to water curing. similarly, for mix 2 to mix 6, 18 cubes and 18 cylinders were casted for each mix, so that three specimens can be tested for each case and average reading can be calculated. The process of preparation of specimen is shown in figure 2. The specimens were subjected to three different curing periods i.e., 28 days, 56 days and 84 days and subjected to air and water curing separately.

**Table 1.** Mix proportions and specimen details.

| Mix details | Specimen ID | Mix proportions (1: 1.9: 3.1: 0.50) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cement (Kg/m$^3$) | Sand (Kg/m$^3$) | Gravel (Kg/m$^3$) | RA (Kg/m$^3$) | Water (Kg/m$^3$) | WAP balls (Kg/m$^3$) |
| Mix 1 | CM | 380 | 717 | 1170 | - | 190 | - |
| Mix 2 | M-2.5-WAP-AC | 380 | 717 | 1170 | - | 190 | 9.5 |
| | M-2.5-WAP-WC | 380 | 717 | 1170 | - | 190 | 9.5 |
| Mix 3 | M-5-WAP-AC | 380 | 717 | 1170 | - | 190 | 19 |
| | M-5-WAP-WC | 380 | 717 | 1170 | - | 190 | 19 |
| Mix 4 | RAC | 380 | 717 | - | 1170 | 190 | - |
| Mix 5 | RAC-2.5-WAP-AC | 380 | 717 | - | 1170 | 190 | 9.5 |
| | RAC-2.5-WAP-WC | 380 | 717 | - | 1170 | 190 | 9.5 |
| Mix 6 | RAC -5-WAP-AC | 380 | 717 | - | 1170 | 190 | 19 |
| | RAC -5-WAP-WC | 380 | 717 | - | 1170 | 190 | 19 |

**Figure 2.** Preparation of concrete specimen (a) mixing of constituents (b) placing in mold (c) water absorption polymer balls in concrete (d) water cured specimen (e) air cured Specimen (f) recycled aggregate.

### 2.4 *Testing of water and air cured concrete specimen with and without WAP balls*

Three cubes and three cylinders were tested for each mix. The load was applied on the specimen using compression testing machine at a uniform rate and the testing was continued until a major cracking plane appeared on the specimen. The compressive strength was calculated for all the three specimen and the average value was taken as the mean compressive strength for that mix. One set of readings was taken after 28 days and the next set after 56 days and the last set of readings was taken after 84 days of curing. The same procedure was repeated for RAC cube specimens with 0 %, 2.5% and 5% polymer balls. To study the volumetric behavior of the concrete mix with and without polymer balls, cylindrical specimen was tested in Universal Testing Machine (UTM) with the extensometer fixed in the middle portion of the cylinder. The dial gauge reading was set to zero and the entire setup was placed in the UTM and loading was applied at a uniform rate and continued till the specimen fails. The strain reading was noted at every 5KN load till the specimen breaks. The loading arrangement of cube and cylinder specimen is shown in Figure 3. The volumetric change in the cylinder specimen is tabulated in Table 2 and the compressive strength values of different mix is tabulated in Table 3.

**Table 2.** Volumetric change in cylinder specimen with and without WAP balls.

| MIX details | Specimen ID | Volumetric change (micro strain, με) | | |
|---|---|---|---|---|
| | | 28 days of curing | 56 days of curing | 84 days of curing |
| Mix 1 | CM-WC | 600 | 800 | 900 |
| | CM-AC | -500 | -900 | -1200 |
| Mix 2 | M-2.5-WAP-WC | 500 | 600 | 700 |
| | M-2.5-WAP-AC | -700 | -1100 | -1400 |
| Mix 3 | M-5-WAP-WC | 500 | 700 | 800 |
| | M-5-WAP-AC | -1000 | -1400 | -1600 |
| Mix 4 | RAC-WC | 700 | 800 | 1000 |
| | RAC-AC | -600 | -1000 | -1300 |
| Mix 5 | RAC-2.5-WAP-WC | 600 | 700 | 900 |
| | RAC-2.5-WAP-AC | -800 | -1200 | -1500 |
| Mix 6 | RAC -5-WAP-WC | 500 | 700 | 800 |
| | RAC -5-WAP-AC | -1000 | -1400 | -1600 |

**Table 3.** Compressive strength of normal aggregate and recycled concrete with and without polymer balls.

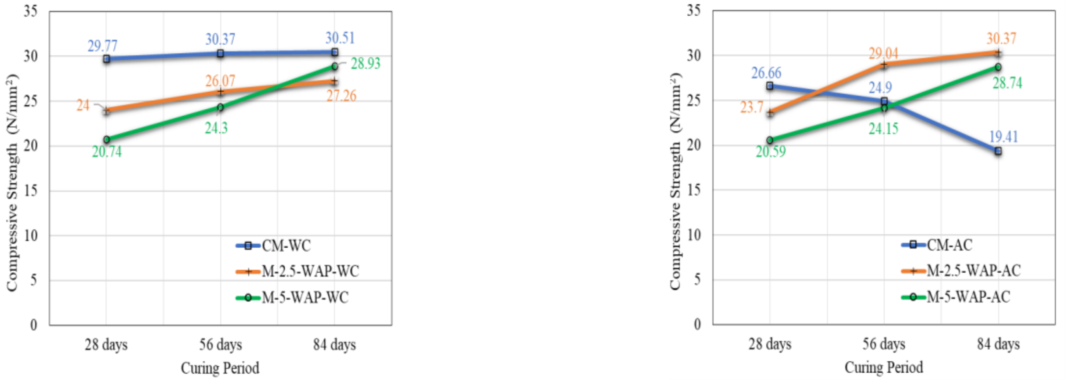
| Specimen ID | Compressive strength after 28 days of curing (MPa) | Compressive strength after 56 days of curing (MPa) | Compressive strength after 84 days of curing (MPa) |
|---|---|---|---|
| | (N/mm$^2$) | (N/mm$^2$) | (N/mm$^2$) |
| CM-WC | 29.77 | 30.37 | 30.51 |
| CM-AC | 26.66 | 24.89 | 19.41 |
| M-2.5-WAP-WC | 24 | 26.07 | 27.26 |
| M-2.5-WAP-AC | 23.7 | 29.04 | 30.37 |
| M-5-WAP-WC | 20.74 | 24.3 | 29.93 |
| M-5-WAP-AC | 20.59 | 24.15 | 28.74 |
| RAC-WC | 26.37 | 28.44 | 30.26 |
| RAC-AC | 25.18 | 22.22 | 20.89 |
| RAC-2.5-WAP-WC | 25.04 | 24.89 | 24.15 |
| RAC-2.5-WAP-AC | 22.82 | 23.11 | 27.26 |
| RAC -5-WAP-WC | 20.44 | 20.29 | 27.26 |
| RAC -5-WAP-AC | 20.89 | 22.81 | 24.29 |

CM- Control mix; WAP- water absorption polymer; AC- air curing; WC- water curing; RAC-recycled aggregate concrete.

## 3 Results and discussion

### 3.2 *Compressive strength of normal aggregate concrete with and without WAP balls*

The compressive strength of normal aggregate concrete (NAC) with and without WAP balls are shown in Figure 4. The control mix without WAP balls (control) subjected to water curing reached a maximum strength of 29.77 MPa after 28 days of curing and reached up to 30.5 MPa after 84 days curing period. But the strength value decreases for the control specimen subjected to air curing. The strength which was 26 MPa reduces to 19 MPa after 84 days. Drastic decrease in the strength was observed which was mainly due to the absence of water for the hydration process. For mix with 2.5 % WAP balls, the water cured specimen showed gradual increase in strength from 24 MPa to 27.26 MPa. In case of air cured specimen, the compressive strength showed a drastic increase from 23 MPa to 29.04 MPa after 56 days curing and reached maximum of 30.37 MPa after 84 days curing.



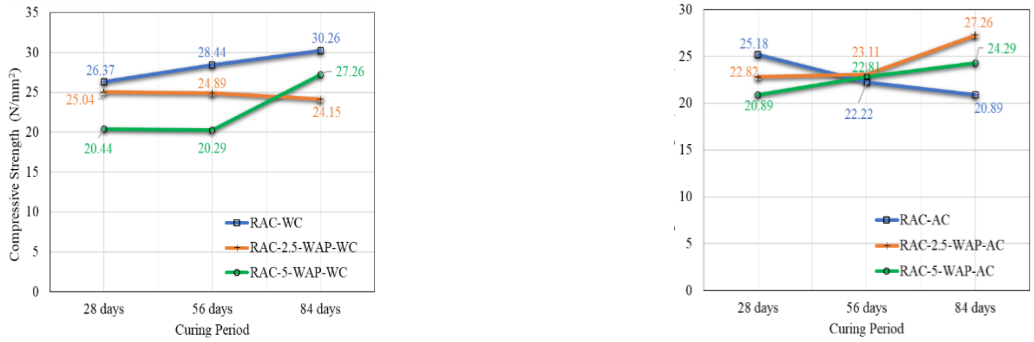
(a) (b)

**Figure 4.** Compressive strength of normal aggregate concrete with and without WAP balls, (a) water cured specimens (b) air cured specimens.

When comparing to air cured and water cured specimen, air cured specimen showed a much better performance which is mainly due to the internal curing provided by the WAP balls. The water absorbed by the polymer balls is continuously suppled to the concrete, for a long period and result in long term strength gain. If the percentage of WAP balls is increased, the performance of both air and water cured specimen are more or less the same. The strength of specimen increases from 20 MPa to 28 MPa after 84 days of curing. WAP balls continuously supply water to the concrete and support in the formation of hydration products and strength gain. On comparing the performance of NAC mix without WAP balls and with WAP balls, the air cured specimen with 2.5% WAP balls showed a better strength gain which is same as the Control mix. Therefore 2.5 % WAP balls may be considered as the optimum amount for internal curing, which supports the long-term hydration reaction and strength gain.

### 3.3 *Compressive strength of recycled aggregate concrete with and without WAP balls*

To reduce the accumulation of construction and demolition waste, recycled concrete aggregate are used as a substitute for regular gravel aggregate. Even though the RAC results in the minor reduction in the compressive strength of concrete specimen after 28 days water curing, the maximum strength is reached after 84 days. The compressive strength plot is shown in Figure 5. But in the case of air cured RAC, the strength decreases with the curing period mainly due to the lack of water and there by affecting the hydration reaction and strength. The strength reduces from 25MPa to 20 MPa for RAC-AC specimens. Surprisingly, the RAC with 2.5 % WAP balls subjected to water curing showed less compressive strength (24.15Mpa), when compared to air cured specimen. In RAC-2.5-WAP-AC specimen the 28 days' strength was less and it gradually increases with the curing period and reached a maximum value of 27.8 MPa. The reason for reduction in strength for water cured specimen with WAP balls, may be due to the voids created by the polymer balls or increase in the water content (Riyazi et al., 2017).



(a) (b)

**Figure 5.** Compressive strength of recycled aggregate concrete with and without WAP balls (a) water cured specimen (b) air cured specimen.

On comparing the specimen with 5% WAP balls the initial strength was low for both air curing and water curing. After 84 days curing period the strength gain was observed for both air cured and water cured RAC specimen with 5% WAP balls. The maximum strength of 27.26 MPa was achieved by water cured specimen. The reason for such increase in strength may be due to the filling up of void which are created by the dry WAP balls, with the hydration product, and thereby resulting in strength gain (Olivier et al., 2018). The video measuring system was used to capture the magnified images of inner surface of concrete, which showed the presence of hydration product in the WAP balls region (figure 6). On comparing all the result for specimen with RAC, the specimen with 5% WAP balls subjected to, water curing showed a maximum strength after 84 days curing period.

### 3.4 *Volumetric behavior of cylinder specimens with and without WAP balls*

The failure of the cylinder specimen subjected to compression loading is shown in Figure 7. As the loading increases the lateral expansion of the specimen increased and the failure of the specimen occurred. From the failed specimen WAP balls were picked, and examined. The water present in the WAP balls were completely used for the hydration reaction and the spaces were filled by the hydration product (Figure 8). The volumetric strain for all the specimen were noted, and the graphs were plotted for all three-curing period and shown in figure 9 ((a-f). On comparing the volumetric strain of NAC and RAC the expansion behavior is same for water cured specimen. For the air cured specimen, the expansion behavior was slightly more compared to water cured specimen. When comparing the specimen with 2.5% WAP balls, the water cured specimen showed shrinkage behavior. This may be due to the fact that in water cured specimen the WAP balls would have cracked leaving void in the concrete and mitigates the shrinkage behavior (Xie et al., 2021). But the specimen with 2.5%WAP subjected to air curing showed expansion behavior. This may be due to the filling up of voids in air cured specimen with hydration product. The same pattern was repeated for specimen with 5% WAP balls. The shrinkage was more for water cured specimen and expansion was more for air cured specimen (Yao et al., 2012).

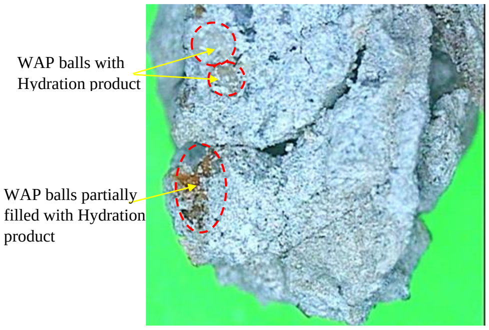
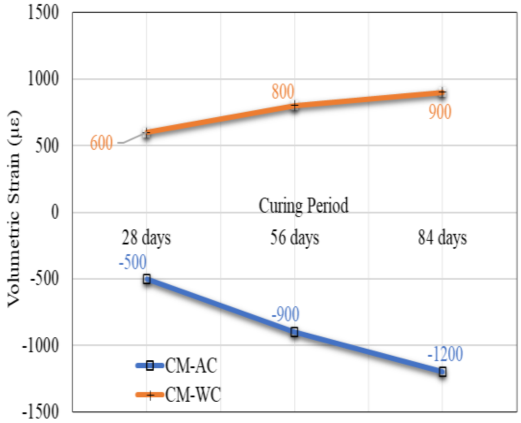


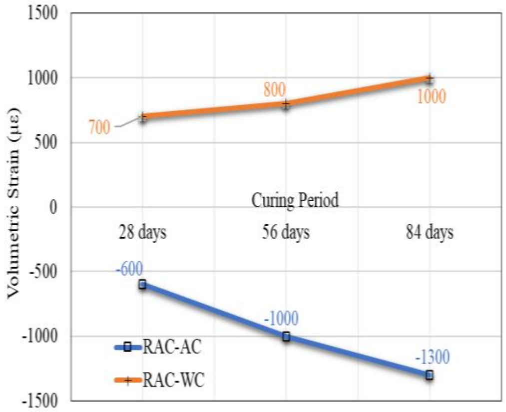
**Figure 6.** VMS (Video Measuring System) image of failed specimen showing the presence of hydration product in the WAP balls.

**Figure 7.** Crushing of cylinder specimen.

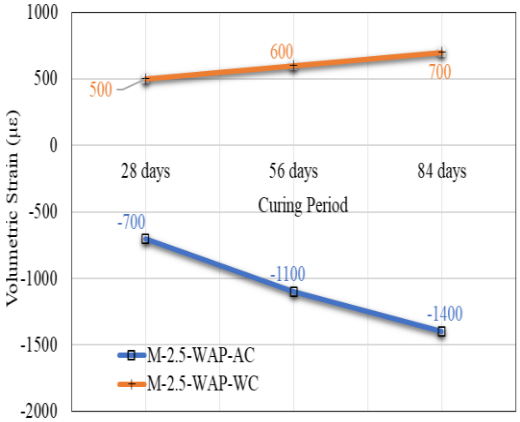
**Figure 8.** WAP balls shrinks and forms a hard cement product.



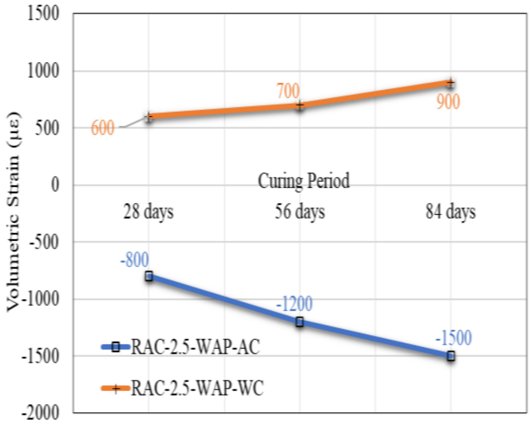
(a) NAC cylinder



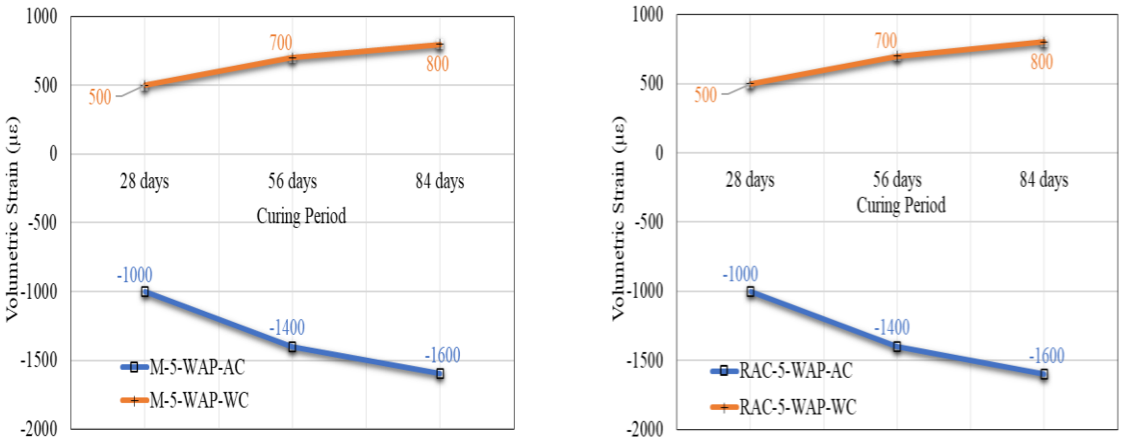
(b) RAC cylinder



(c) NAC cylinder with 2.5% WAP



(d) RAC cylinder with 2.5% WAP



(e) NAC cylinder with 5% WAP. (f) RAC cylinder with 5% WAP.

**Figure 9.** Volumetric change of cylinder specimen with different percentage of WAP balls subjected to air and water curing.

## 4 Conclusions

[From the experimental investigation carried out using normal aggregate and recycled aggregate concrete with and without polymer balls the following conclusions was derived;

1. The addition of polymer balls to the concrete help to provide internal curing to the concrete and this process is mainly suitable for concreting in hot and humid climate regions;
2. Even if the surface water evaporates due to high temperature, the water absorbed by the polymer balls continuously supply water to the concrete and supports the hydration reaction and strength gain;
3. From the compression strength test the Normal aggregate concrete with 2.5% WAP balls showed an excellent strength which is mainly due to the formation of hydration products in the voids created by the WAP balls;
4. The presence of WAP balls results in the strength gain for a long period of time, due to the internal curing provided by polymer balls;
5. The volumetric behavior of normal and recycled aggregate concrete specimen subjected to water curing showed shrinkage behavior and specimens subjected to air curing showed expansion behavior;
6. Internal curing provided by the polymer balls by releasing the absorbed water inside the concrete and improves the durability and reduced the plastic shrinkage cracking and also improves the self-healing and self-sealing of concrete.
7. Water cured specimen have excess water, absorbed by the polymer balls which remains unused and evaporated at the early stage of hydration reaction and results in shrinkage;
8. while the Air cured specimen utilizes, the water absorbed by the polymer balls slowly for a long period of time and result in strength gain at the slow rate which prevents the formation of plastic shrinkage cracks for air cured specimen;
9. In the hot and dry regions, where the availability of water is limited, application of water absorption polymer balls provides a better solution for curing of concrete and strength gain but the availability of such polymers and its application in huge concreting work, may increase the cost of construction to a considerable amount;
10. Addition of polymer balls at an excess amount may result in the strength reduction, an optimum amount of 2 - 4% is advisable for concrete in hot and humid regions.

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