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Research Article

Effect of compression casting technique on the water absorption properties of concrete made using 100% recycled aggregates

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Abstract: Effect of compression casting technique on the water absorption characteristics of low grade 100% Recycled Aggregate Concrete (RAC) of target strength range 11 to 15 MPa to be used in the manufacturing of masonry units is investigated. Water absorption characteristics were determined by performing sorptivity test. Recycled aggregates were produced by crushing laboratory-tested concrete samples of strength ranging from 21 MPa to 28 MPa. Two different ratios of recycled coarse aggregate and recycled fine aggregates were investigated using two different cement contents. For comparison, natural aggregate concrete mixes were also tested. The study parameter included effect of aggregates type, casting pressure, casting technique and cement content on the water absorption properties of RAC. Further, depth of penetration of salt was observed using silver nitrate solution after 3-month immersion in 10% NaCl solution. The results of sorptivity test showed positive impact of compression casting technique on water absorption properties of low grade 100% RAC. Further, results showed that RAC mixes exhibited inferior water absorption properties compared to natural aggregates concrete mixes. Various equations were proposed to predict water absorption of 100% RAC under different conditions of casting pressure and cement content based on initial and secondary rate of water absorption.

Keywords: Concrete, recycled aggregates, casting technique, sorptivity, durability.

1. Introduction

Concrete is one of the most widely used construction materials by the construction industry all over the world. The global annual production of concrete is around 33 billion tons (ISO, 2016). At the same time, waste concrete is also being produced in a large volume in the construction industry globally from several sources such as the structures dismantled because of inadequate design or expired design life, structures damaged by natural disasters such as earthquakes, floods or typhoons, and the structures damaged by blast or fire events. Further, defective members in the precast concrete industry, concrete samples tested in material testing laboratories, leftover concrete from concrete batching plants and dismantled road infrastructure are some of the other major sources of waste concrete. Serious environmental threats are posed by this waste concrete because of its deposition in open or in landfills and also because of the need of fresh natural aggregates to replace this old concrete. The decreasing landfill spaces as well as the increasing need of saving natural resources for the future encourage the reuse of this waste concrete.

One of the ways being employed these days to reuse waste concrete in the construction industry is by extracting aggregates from the waste concrete by crushing it. Both the coarse and fine aggregates are separated and then used to partly or fully replace the fresh natural aggregates (NA) to make new concrete termed as Recycled Aggregate Concrete (RAC) for different applications. Research studies have been carried out in the past to determine the properties of RAC from different viewpoints related to the source and quality of the recycled aggregates and the findings of such studies have highlighted the impact of the type and properties of recycled aggregate on the mechanical properties and durability of recycled aggregate concrete (Nedeljkovic et al., 2021, Upshaw & Cai, 2020, Tam et al., 2018, Guo et al., 2018, Xiao et al., 2012, Jagan et al., 2021). In general, a decrease in mechanical and durability properties of RAC has been reported by most of these studies, which is due to the presence of mortar particles and the attached mortar with the recycled aggregate particles.

Owing to this reduction in properties, conventionally researchers have generally replaced only a portion of NA with recycled aggregates (RA) to gain an acceptable level of performance from the resulting concrete. However, there are some major issues with this conventional recycling practice that hinder its general acceptability and use in high-grade structural applications. Firstly, most of the research studies have recommended the use of only coarse fraction of the recycled concrete, however, use of fine fraction of the recycled aggregate is not recommended due to its significant negative impact on the properties of the resulting recycled concrete (Claudio & Angel, 2011, Pedro et al., 2018, Guo et al., 2018). Secondly, replacement of only a percentage of coarse aggregates (10-40%) by recycled aggregates is recommended to get acceptable properties of concrete. Both these reasons negatively affect the feasibility of concrete recycling especially when a large quantity of concrete is to be recycled. The third major issue with conventional recycled aggregate concrete is the higher porosity of RAC, which results in high shrinkage potential, more water absorption and increased susceptibility to chemical attack (Guo et al., 2018). One of the ways to cater these issues of RAC is by the application of pressure during concrete casting, which can reduce the porosity and increase the durability of the resulting concrete while giving required strength. With the application of pressure, the porous recycled fine aggregates (RFA) can also be effectively incorporated into RAC. This approach has been investigated in the past with and without the addition of binding material and has shown positive results with the addition of binding material (Sakai et al., 2016).

Cracks and voids in cement-based matrix allow water to pass through and make the concrete permeable (Kubissa & Jaskulski 2013). The service life of a reinforced concrete structure is determined by the transmission of water in a hardened cement concrete through cracks and capillary action owing to voids, which may be evaluated by measuring the sorptivity of concrete which is water absorption using the gravimetric method (Paktiawal et al., 2021). Sorptivity is a measure of the capacity of concrete to absorb water under capillary forces. It is being tested by many methods and is often considered as a constant value for a given concrete, thus its material feature (Kubissa, 2016).

While previous research suggests the benefits of the compression casting technique on the mechanical properties of concrete (Sakai et al., 2016, Xinyi et al., 2019, Wei & Sakai 2021, Kazmi et al., 2021) and the possibility of 100% recycling of concrete (Corinaldesi & Moriconi 2009, Yehia et al., 2015, Tahar et al., 2017, Tayeh et al., 2020), there is still a paucity of research on the durability characteristics of concrete containing 100% recycled aggregates and prepared using compression casting technique. Hence, the research study reported in this paper aims at investigating the effect of the compression casting technique on water absorption properties of RAC made using 100% RAs in order to promote the 100% recycling of waste concrete. Water absorption of concrete mixes which is a direct indication of the durability of the concrete, was determined by performing sorptivity test following guidelines of ASTM standard C1585 (ASTM C1585, 2020). The RAC containing variable contents of recycled coarse aggregate (RCA) and recycled fine aggregate (RFA) and prepared under compression were immersed in 10% sodium chloride solution for a period of 8 days. The increase in weight was recorded at various time intervals. The sorptivity of concrete was then evaluated using the procedure specified in ASTM C1585 (ASTM C1585, 2020).

Furthermore, the results were compared with 100% natural aggregate concrete (NAC) prepared under compression and RAC prepared using conventional casting technique [i.e., vibration] as well.

2. Materials and methods

2.1. *Materials*

For this study, locally available Ordinary Portland Cement (OPC) was used to prepare all kind of concrete mixes. Chemical and physical properties of cement are given in Table 1 and Table 2, respectively. To produce both Recycled Fine Aggregates (RFA) and Recycled Coarse Aggregates (RCA), laboratory tested concrete specimens (cylinders and cubes) as shown in Figure 1 having compressive strength of 21 MPa to 28 MPa were collected and processed through hammer, jaw and roller crushers to get their required sizes (maximum 12mm). Finally, fine and coarse aggregates were separated by sieving. The complete process of RA production is shown in Figure 2. For Natural Coarse Aggregates (NCA), crushed stones were used while locally available river sand was used as Natural Fine Aggregate (NFA). The properties of RAs and NAs were determined and presented in Table 3. Further, their gradation curves are shown in Figure 3 to Figure 6, where it is obvious that they meet the gradation criteria described in ASTM C33 (ASTM C33, 2018). For all concrete mixes, portable water was used

Figure 1. Tested samples of concrete.

2.2. Mix proportions

Total 28 concrete mixes were prepared and tested in this research study. These concrete mixes differed with respect to aggregate type (RA and NA), casting techniques (Compression Casting Technique (CCT) and vibration), casting pressure (25, 35 & 45 MPa) based on density achieved, fine to coarse aggregates ratio (30% RFA+70%RCA & 40%RFA+60%RCA) and cement content (10% and 15%). For all mixes of RAC, 100% RAs were used. To prepare samples by CCT (described in section 2.3), initially extra water equivalent to water absorption of RCA (i.e. 7.97%) was used in addition to water added to achieve w/c = 0.3. It was observed that 28% to 33% of extra added water was expelled under applied pressure value of 25MPa to 45MPa, respectively which resulted in lower effective w/c ratio (even lesser than required for hydration) and hence lower compressive strength. Based on this experimental observation, it was decided finally to use RCAs in SSD condition. Accordingly, new test matrix was designed in which 28 concrete mixes were prepared. Detail of all 28 concrete mixes is given in Table 4.

Table 1. Chemical composition of cement.

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3
Chemical Composition	62.6%	20.8%	5.06%	3.27%	2.56%	1.57%

Table 2. Physical properties of cement.

	Fineness	Soundness	Initial & final setting	Standard consistency
Physical properties	8%	9 mm	105-215	30%

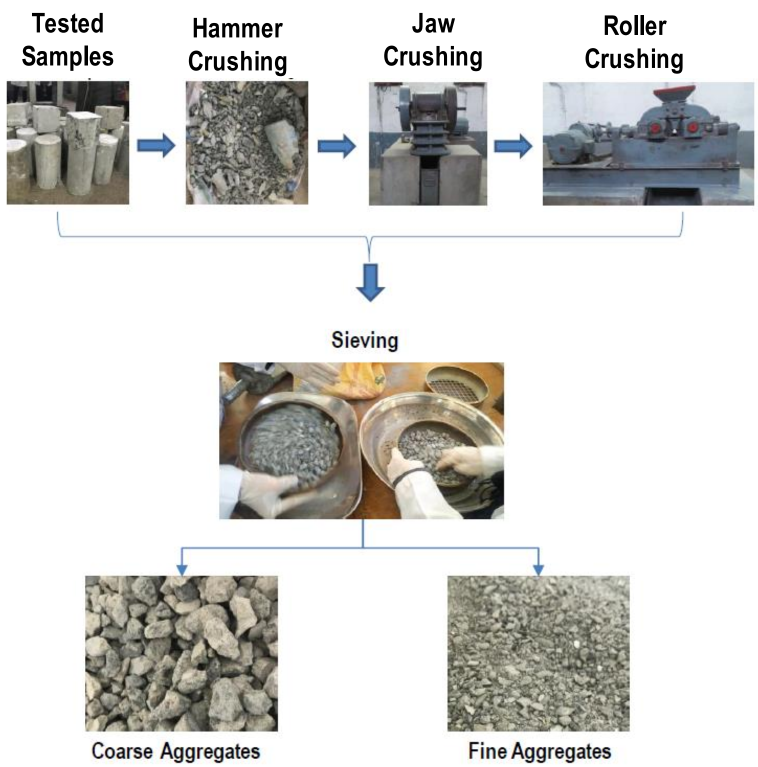


Figure 2. Production process of recycled aggregates.

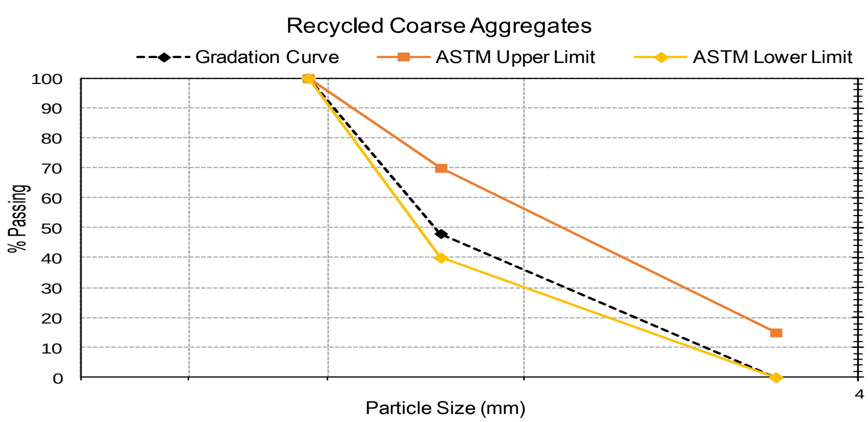


Figure 3. Gradation curve of RCA

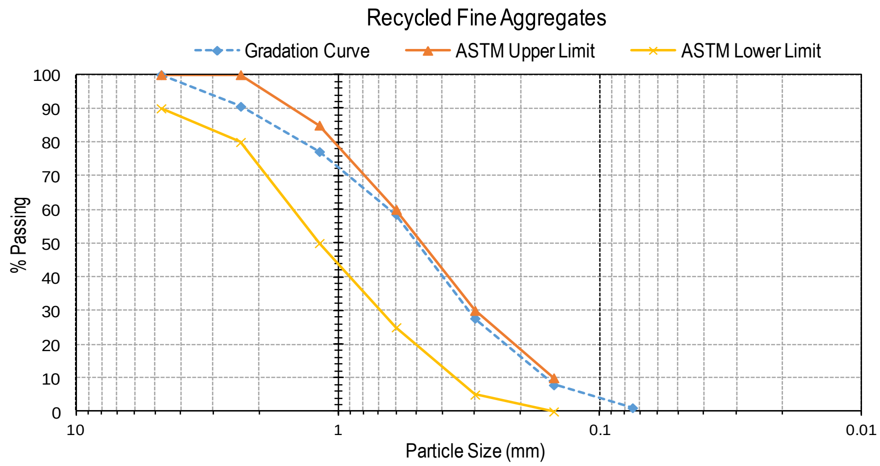


Figure 4. Gradation curve of RFA.

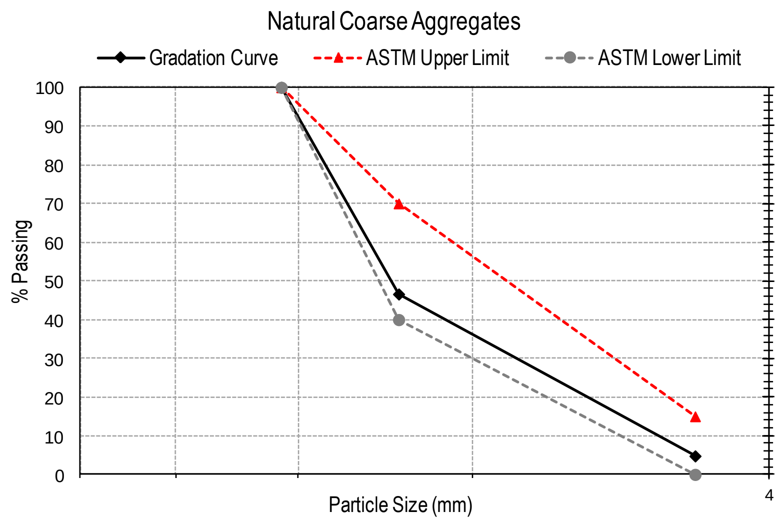


Figure 5. Gradation curve of NCA.

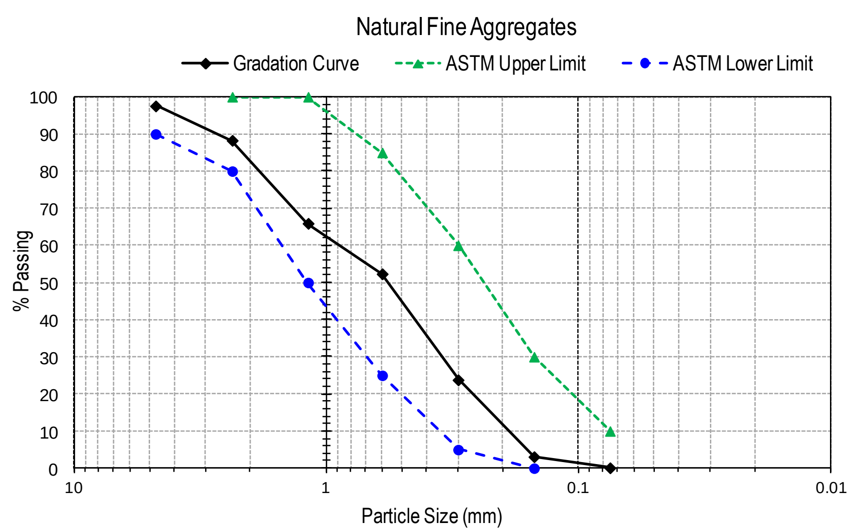


Figure 6. Gradation curve of NFA.

Table 3. Properties of recycled and natural aggregates.

Property	Testing standard	Recycled aggregates		Natural aggregates	
		Coarse	Fine	Coarse	Fine
Bulk oven dry specific gravity	ASTM C127 & ASTM C128	2.26	2.05	2.84	2.70
Bulk SSD specific gravity		2.44	2.28	2.86	2.75
Bulk apparent specific gravity		2.76	2.66	2.87	2.84
Water absorption (%)		7.97	11.15	0.9	1.79
Moisture content (%)	ASTM C566	2.37	5.32	0.9	1.2
Flakiness index (%)	BS 812-105.1	14.1	-	19.6	-
Elongation index (%)	BS 812-105.2	21.25	-	44.1	-
Bulk density (kg/m³)	ASTM C29	1267	1335	1441	1722
Los Angeles abrasion value, %	ASTM C131	37.57	-	25.20	-
Aggregate crushing value, ACV (%)	BS 812-110	20.80	-	22.55	-
10% Fine value, TFV (kN)	BS 812-111	184.36	-	199.57	-
Aggregate impact value, AIV (%)	BS 812-112	15.36	-	17.70	-

2.3. Specimen preparation

For this study, cylindrical specimens of 150mm height and 75mm diameter were prepared using CCT and the conventional casting method (compaction through vibration). For CCT, a special metallic mold was prepared as shown in Figure 7 where it can be observed that this mold consisted of three major parts. Part 1 is a hollow cylindrical tube having internal diameter equal to 75mm and height 275 mm. Part 2 is the end block fixed on one end. This part had small holes at three locations in order to release the extruded/expelled water due to pressure application. This was required to avoid development of pore water pressure during casting. Part 3 is a plunger that is used to apply the pressure on the material filled in part 1 of this mold. After preparing concrete mixes, the concrete was poured into the metallic mold in two layers by imparting 25 blows of a steel rod as shown in Figure 8(a) and Figure 8(b). Force was then applied at the top of the metallic mold through plunger to obtain the desired pressure as presented in Figure 8(c). This casting pressure was maintained on the specimen for a short duration of 15 seconds. The sample was then extruded and typical extruded samples are displayed in Figure 8(d). As mentioned earlier, the sample height was required to be 150mm. The extruded sample of larger height was cut with the help of a concrete cutter to the required height (i.e., 150mm) before testing. Samples were also casted by the conventional casting method (vibration). After 24 hours, the samples were extruded and cured following the same method and duration as for CCT samples.

Table 4. Concrete mix proportions.

Sr. No.	Mix designation	Cement contents	Water content	Pressure applied, MPa	Compressive strength, MPa
1	RAC-30F70C	10%	w/c ratio = 0.5 (Coarse recycled aggregates used in SSD condition)	25	9.0
2				35	11.5
3				45	12.6
4		15%		25	20.8
5				35	27.0
6				45	16.7
7	RAC-40F60C	10%		25	13.7
8				35	16.0
9				45	19.0
10		15%		25	18.7
11				35	19.2
12				45	22.3
13	NAC-30F70C	10%	w/c ratio = 0.5	25	12.8
14				35	13.5
15				45	16.7
16		15%		25	25.4
17				35	27.7
18				45	30.4
19	NAC-40F60C	10%		25	14.5
20				35	16.7
21				45	20.8
22		15%		25	22.4
23				35	24.5
24				45	26.0
25	RAC-30F70C-V	10%	w/c ratio = 0.5 (Coarse recycled aggregates used in SSD condition)	Compaction by Vibration (Conventional method)	8.5
26		15%			15.2
27	RAC-40F60C-V	10%			13.5
28		15%			17.4

2.4. Testing method

Sorptivity test was conducted on all the prepared specimens to evaluate their water absorption properties. The test was carried out as per ASTM C1585. However, the size of the sample was different from that mentioned in this standard. The surfaces of the specimens were sealed with the help of epoxy and the top surfaces were covered with polythene sheet. The prepared specimens are shown in Figure 9 and the test setup is shown in Figure 10. The immersion depth of the specimen was kept as 3mm in 10% NaCl solution and the change in mass of the specimen (m_t) from 0 seconds up to the 8-day time was recorded with the help of a digital weighing balance. At each of the time intervals, the water absorbed through capillary action (I) was calculated by using the following relationship given in ASTM C1585.

$$\boldsymbol{I} = \frac{m_t}{a \times d} \quad (1)$$

where,
I = Water absorbed in mm
m_t = change in mass of the specimen in grams, at time t.
a = exposed surface area of the specimen in mm^2

d = density of water in g/mm^3

After completion of 8-day observations, all testing samples were kept immersed in 10% NaCl solution for 3 months and then weighed. Finally, these specimens were split into two pieces after 3 months of immersion in 10% NaCl solution and their internal surfaces were sprayed with 0.1M silver nitrate (AgNO3) solution to observe the depth of salt penetration.

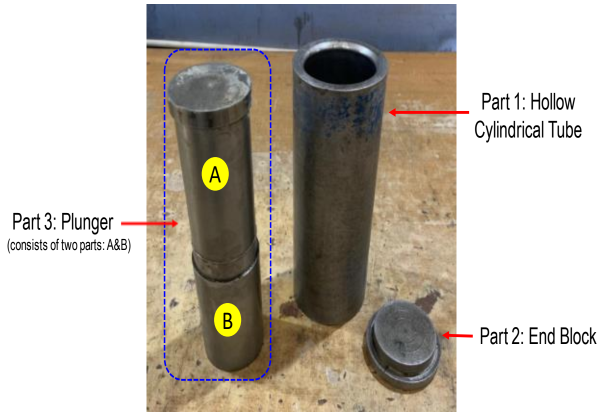


Figure 7. Metallic mold prepared for compression casting.

3. Experimental results and discussions

3.1. Water absorption of concrete

In the following section, the effect of parameters such as cement content, casting technique, casting pressure and aggregate type on the water absorption characteristics of 100% RAC have been discussed.

3.1.1. Effect of cement content and casting technique

Variation of water absorption with time for concrete mixes prepared by using 100% RAs are graphically presented in Figure 11, where it may be observed that for all mixes CCT showed a positive impact on the water absorption properties of the concrete mixes as the sorptivity of concrete mixes casted by pressure was found to be significantly lesser than that of concrete mixes casted by conventional vibration method. Similar impact of compression casting technique on the porosity of concrete was also observed by Liang et al., 2022. For mix 40F60C at 15% cement content and 45 MPa casting pressure, the water absorption after 8 days was observed to be 48% lesser than that of its corresponding vibrated concrete. It can be seen in Figure 11 that with increasing cement content from 10% to 15%, the sorptivity of compacted concrete was decreased at all casting pressure values, which resulted in a higher difference in the value of absorbed water by RAC samples, casted by CCT when compared to sorptivity of vibrated concrete samples. Improvement in the durability properties of RAC with the increase in cement content due to improvement in the quality of hydrated cement paste and its density, has also been highlighted in the past by Thomas et al., 2018.

(a) (b) (c) (d)

Figure 8. (a) Pouring of concrete, (b) manual compaction, (c) compression casting, (d) prepared specimens.

Figure 9. Samples for sorptivity test.

Figure 10. Test setup for sorptivity test.

3.1.2. Effect of casting pressure

In Figure 11, it can also be noticed that with the increase of casting pressure, the sorptivity of the resulting concrete was decreased. However, the effect of casting pressure at 10% cement content was less than at 15% cement. This may be attributed to the fact that at greater cement content, resulting in more hydration product and hence denser microstructure, better compaction was achieved due to the presence of more water as compared to RAC with 10% cement to keep the w/c ratio same

3.1.3. Effect of aggregate ratio

It may be noted in Figure 11 that with the decrease of the coarse contents from 70% to 60%, the sorptivity of the resulting concrete was also decreased. This may be attributed to the fact that coarse aggregates are more porous. Moreover, with increasing fine contents in the mix better compaction was achieved under pressure. At 15% cement, the water absorption of 40F60C was found to be 13% lesser than 30F70C at 45 MPa pressure.

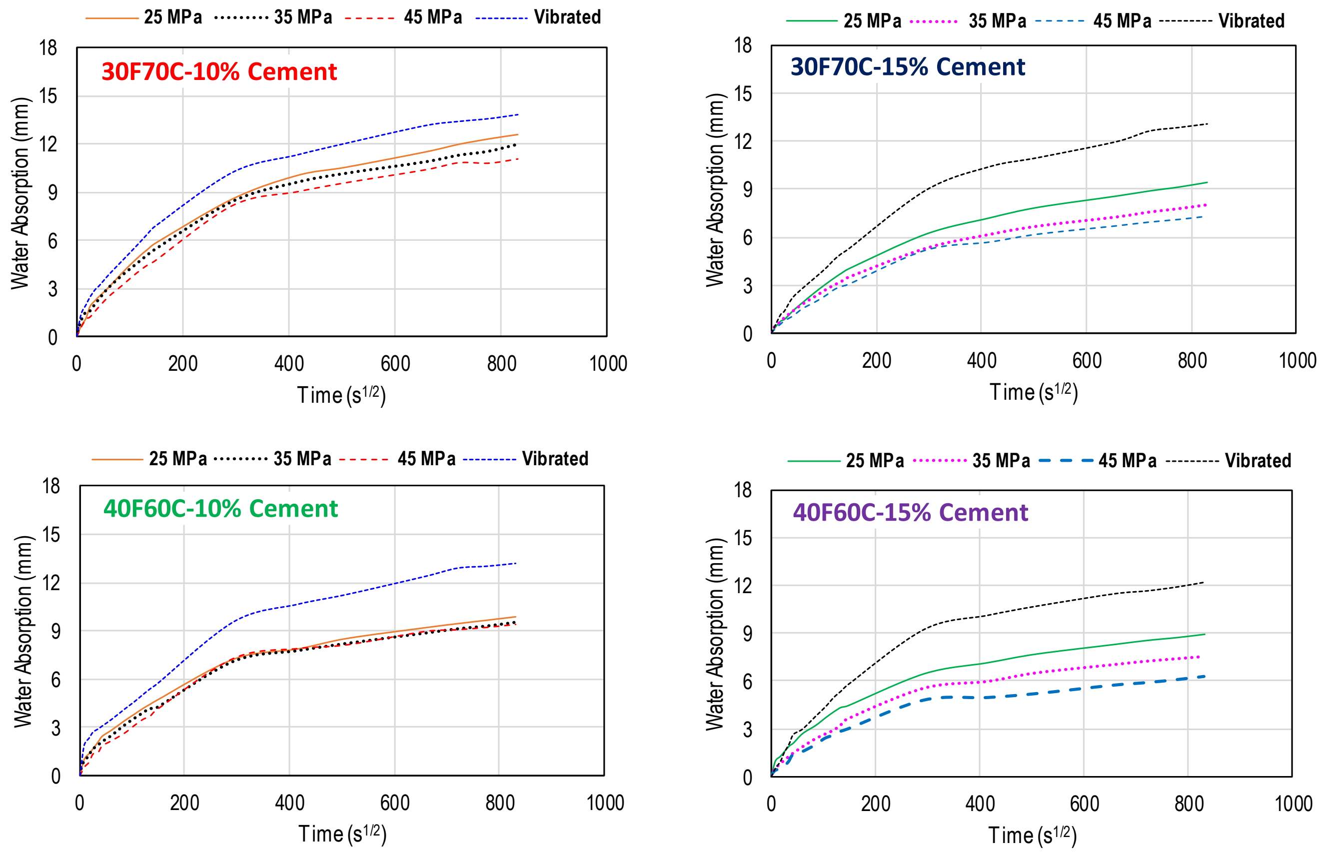


Figure 11. Effect of casting technique on water absorption.

3.1.4. Effect of aggregate type

The water absorption of compressed concrete mixes containing 100% RAs was compared with compressed concrete mixes containing 100% NAs and the results are presented in Figure 12. It can be observed in this figure that under same conditions, the sorptivity of compressed concrete mixes containing 100% RAs is significantly greater than compressed concrete mixes containing 100% NAs. This is due to the porous nature of RAs as compared to NAs as evident from the water absorption value of RAs and NAs given in Table 3. Similar observation regarding higher water absorption of RAs due to porosity was made by Eckert and Oliveira, 2017. With the decrease in coarse aggregate content in concrete mixes, the difference between water absorption of RAC and NAC was reduced. Under same conditions, the water absorption of RAC mix 30F70C was 86.5% higher than corresponding NAC mix, whereas for 40F60C it was 68% greater than the corresponding NAC mix. The higher water absorption and porosity of RAC is mainly due to higher amount of adhered mortar of recycled aggregates which leads to poorer durability of RAC compared to NAC (Guo et al., 2018).

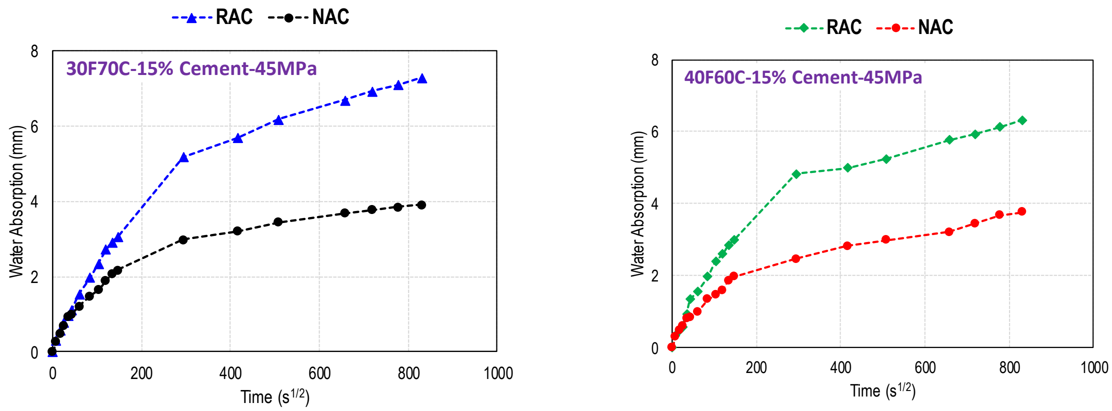
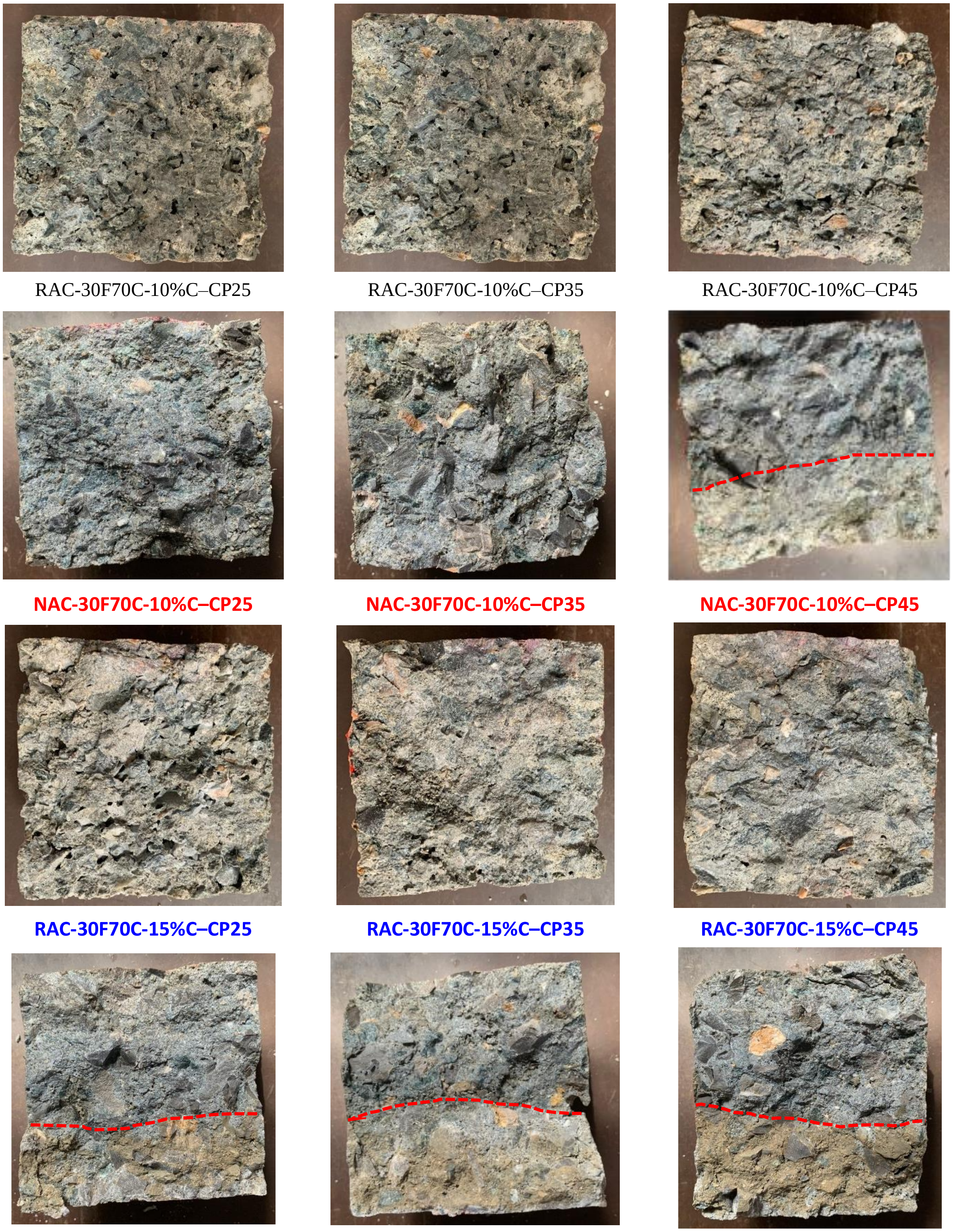


Figure 12. Effect of aggregate type on water absorption.

3.2. Water absorption after 3 months

As mentioned earlier, after completion of sorptivity test at day-8, the RAC and NAC samples were kept immersed in 10% NaCl solution to determine their long-term response with respect to water absorption through capillary action and the results showed similar trends as observed for up to 8-days immersion i.e., with the increase in casting pressure and cement content, the water absorption of the concrete samples was decreased. Moreover, vibrated RAC concrete samples exhibited higher water absorption in all cases, which showed a positive impact of CCT on the water absorption characteristics of RAC. Finally, these specimens were split into two pieces after 3-month immersion in 10% NaCl solution and their internal surfaces were sprayed with 0.1M Silver Nitrate (AgNO3) solution to observe the depth of salt penetration and the results are presented in Figure 13 to Figure 15.

From Figures 13 to 15, it is clear that the Cl- ions penetrated throughout the depth of the samples for all the mixes containing recycled aggregates [i.e., RAC casted using CCT and compression by vibration]. However, the concrete mixes containing natural aggregates [i.e., NAC casted using CCT] showed improved resistance to the Cl- ions penetration, which is visible in the Figure 13 and Figure 14 in the form of brown-colored areas where there was no penetration of Cl- ions. The increased Cl- ion penetration for the case of RAC mixes is due to the higher porosity of the aggregates, which is also evident from the water absorption values. Further, the resistance of compressed NAC was more for the case of 15% cement than for the mixes containing 10% cement. Furthermore, it can be observed that there is a slight increase in the resistance of compressed NAC with the increase in casting pressure, which shows the effectiveness of CCT for the case of compressed NAC. Although the Cl- ions penetration of the developed RAC mixes is more than the compressed NAC mixes, however, the intended and feasible use of the compressed low grade 100% RAC is for the production of unreinforced concrete masonry units where Cl- penetration doesn't pose a major durability issues unlike for the reinforced concrete.



RAC-30F70C-10%C–CP25 RAC-30F70C-10%C–CP35 RAC-30F70C-10%C–CP45

NAC-30F70C-10%C–CP25 NAC-30F70C-10%C–CP35 NAC-30F70C-10%C–CP45

RAC-30F70C-15%C–CP25 RAC-30F70C-15%C–CP35 RAC-30F70C-15%C–CP45

NAC-30F70C-15%C–CP25 NAC-30F70C-15%C–CP35 NAC-30F70C-15%C–CP45

Figure 13. Depth of water absorption after 3 months [Mixes 30F70C].

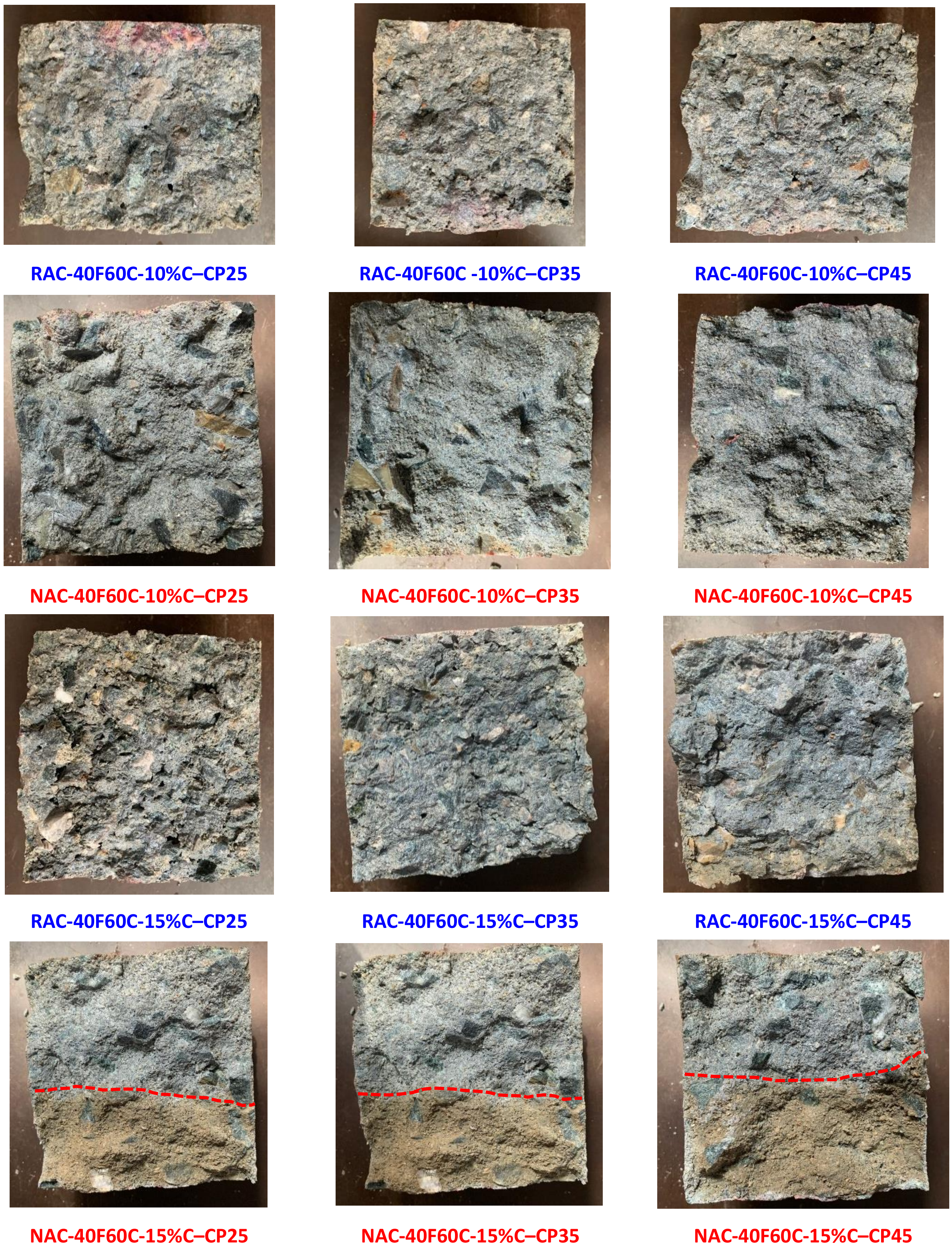


Figure 14. Depth of water absorption after 3 months [Mixes 40F60C].

RAC-30F70C-10%C–Vibrated

RAC-40F60C-10%C–Vibrated

RAC-30F70C-15%C–Vibrated

RAC-40F60C-15%C–Vibrated

Figure 15. Depth of water absorption after 3 months [vibrated concrete].

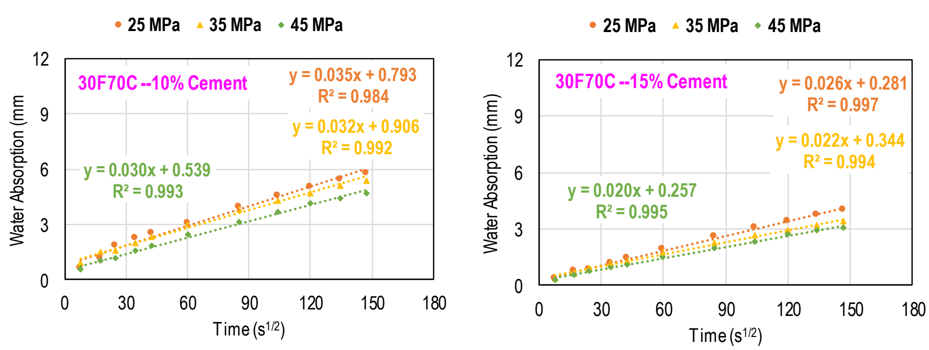


Figure 16. Effect of casting pressure on initial rate of absorption.

3.3. Initial rate of water absorption

To calculate the initial rate of absorption, the water absorbed up to 6 hours was plotted against square root of time. Linear regression analysis was performed and the slope of the resulting plot was the initial rate of water absorption. From the results presented in Figure 16 regarding the mix 30F70C containing 10% cement, it is noted that with the increase of casting pressure, the initial rate of water absorption was reduced and it was found to be true based on the results presented in Figure 16 and Figure 17 for all other mixes. The initial rate of water absorption of the 30F70C mix containing 10% cement was 0.035, 0.032 and 0.030 mm/$t^{1/2}$ at casting pressure of 25, 35 and 45MPa, respectively. Similarly, for 30F70C mix containing 15% cement, initial rate of water absorption was 0.026, 0.022 and 0.020 mm/$t^{1/2}$ at casting pressure of 25, 35 and 45MPa, respectively. The values of initial rate of water absorption of mixes 40F60C at 10% and 15 % cement may be noted from Figure 17.

Linear regression analysis of the values of water absorption versus square root of time made it possible to propose the following equations [from Eq. 2 to Eq.13 provided in Table 5] to predict water absorption of RAC mixes prepared by CCT up to 6 hours [time of immersion in 10% NaCl solution]:

Table 5. Proposed equations for initial rate of water absorption.

Equations for 30F70C having 10% cement		
$WA = 0.035 \times t + 0.79$	for casting pressure of 25 MPa	(2)
$WA = 0.032 \times t + 0.91$	for casting pressure of 35 MPa	(3)
$WA = 0.03 \times t + 0.54$	for casting pressure of 45 MPa	(4)
Equations for 30F70C having 15% cement		
$WA = 0.026 \times t + 0.28$	for casting pressure of 25 MPa	(5)
$WA = 0.022 \times t + 0.34$	for casting pressure of 35 MPa	(6)
$WA = 0.02 \times t + 0.26$	for casting pressure of 45 MPa	(7)
Equations for 40F60C having 10% cement		
$WA = 0.026 \times t + 1.09$	for casting pressure of 25 MPa	(8)
$WA = 0.024 \times t + 0.89$	for casting pressure of 35 MPa	(9)
$WA = 0.023 \times t + 0.67$	for casting pressure of 45 MPa	(10)
Equations for 40F60C having 15% cement		
$WA = 0.025 \times t + 0.97$	for casting pressure of 25 MPa	(11)
$WA = 0.021 \times t + 0.43$	for casting pressure of 35 MPa	(12)
$WA = 0.019 \times t + 0.29$	for casting pressure of 45 MPa	(13)

In all above proposed equations,
WA = water absorption in mm
t = square root of time of reading in second [up to 6-hours immersion in 10% NaCl solution]

The initial rate of water absorption of 100% RAC casted by CCT under 45 MPa casting pressure and by conventional casting method was compared and is graphically presented in Figure 18 for mixes 30F70C-15%C and 40F60C-15%C, respectively. It can be observed from these results that CCT has a significant positive impact on the initial rate of water absorption of RAC mixes. In comparison of 30F70C mix with 15% cement prepared by CCT, the initial rate of absorption was increased by 80% when cast by the conventional method [i.e., vibration]. Similarly, for vibrated 40F60C with 15% cement, it was increased by 74% when compared to its corresponding compressed mix.

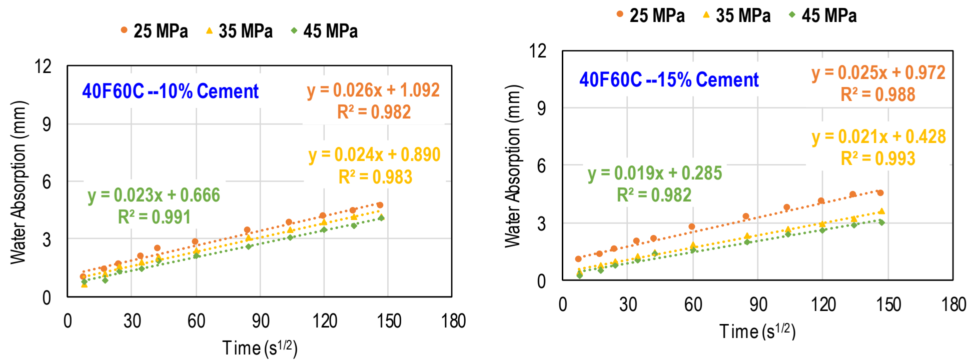


Figure 17: Effect of casting pressure on initial rate of absorption.

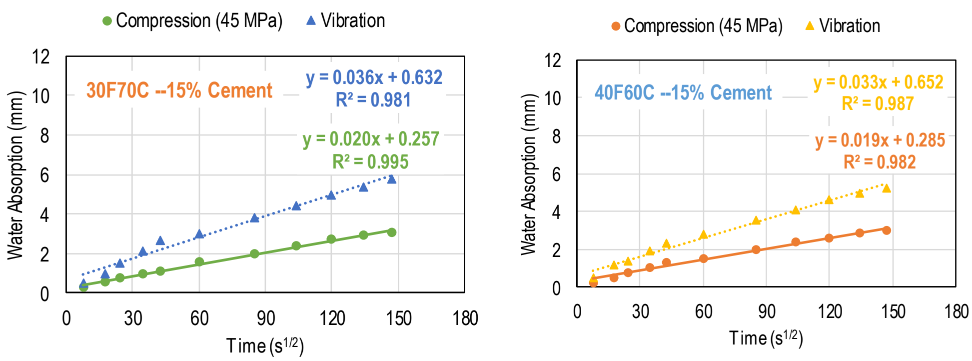


Figure 18: Effect of casting technique on initial rate of absorption.

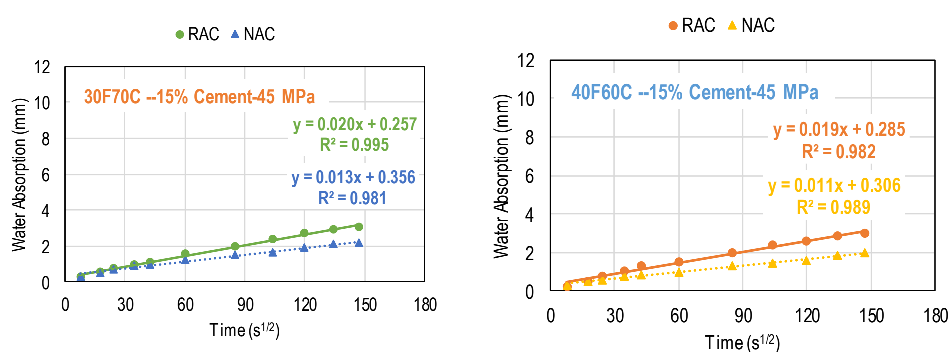


Figure 19. Effect of aggregate type on initial rate of absorption.

The initial rate of water absorption of compressed concrete mixes containing 100% RAs was also compared with compressed concrete mixes containing 100% NAs and is presented in Figure 19 for concrete mixes 30F70C and 40F60C. From these graphs, it is obvious that RAC mix exhibited higher initial rate of absorption than that of the NAC mix. Under the same conditions of casting pressure and cement content, for 30F70C mix, the initial rate of water absorption of RAC was 54% higher than NAC, whereas for 40F60C mix it was 73% greater than NAC.

3.4. Secondary rate of water absorption

Similar to the initial rate of absorption, the water absorption results after day 1 to day 8 were plotted against the square root of time. Linear regression analysis was performed and the slope of the resulting plot was the secondary rate of water absorption. From the results presented in Figure 20 regarding the mix 30F70C containing 10% cement, it is observed that with the increase of casting pressure, the secondary rate of water absorption was decreased and this observation was also true for other mixes [refer to results presented in Figure 20]. The secondary rate of water absorption of the 30F70C mix containing 10% was 0.007, 0.006 and 0.005 mm/$t^{1/2}$ at casting pressure of 25, 35 and 45MPa, respectively. Similarly, for 30F70C mix containing 15%, the secondary rate of water absorption was 0.006, 0.005 and 0.004 mm/$t^{1/2}$ at casting pressure of 25, 35 and 45MPa, respectively. The values of secondary rate of water absorption of mixes 40F60C at 10% and 15 % cement may be noted from Figure 20.

Based on the linear regression analysis of the results of water absorption plotted against the square root of time, it was possible to propose the following equations [from Eq. 14 to Eq.25 provided in Table 6] to predict water absorption of RAC mixes prepared by CCT after day 1 up to day 8 [time of immersion in 10% NaCl solution].

Table 6. Proposed equations for secondary rate of water absorption.

Equations for 30F70C having 10% cement		
$WA = 0.007 \times t + 6.77$	for casting pressure of 25 MPa	(14)
$WA = 0.006 \times t + 6.84$	for casting pressure of 35 MPa	(15)
$WA = 0.005 \times t + 6.72$	for casting pressure of 45 MPa	(16)
Equations for 30F70C having 15% cement		
$WA = 0.006 \times t + 4.67$	for casting pressure of 25 MPa	(17)
$WA = 0.005 \times t + 4.0$	for casting pressure of 35 MPa	(18)
$WA = 0.004 \times t + 4.08$	for casting pressure of 45 MPa	(19)
Equations for 40F60C having 10% cement		
$WA = 0.005 \times t + 5.89$	for casting pressure of 25 MPa	(20)
$WA = 0.004 \times t + 5.89$	for casting pressure of 35 MPa	(21)
$WA = 0.004 \times t + 6.17$	for casting pressure of 45 MPa	(22)
Equations for 40F60C having 15% cement		
$WA = 0.005 \times t + 5.27$	for casting pressure of 25 MPa	(23)
$WA = 0.004 \times t + 4.47$	for casting pressure of 35 MPa	(24)
$WA = 0.003 \times t + 3.85$	for casting pressure of 45 MPa	(25)

In all above proposed equations, WA = water absorption in mm
t = square root of time of reading in second [ranging after day 1 up to day 8 of immersion in 10% NaCl solution].

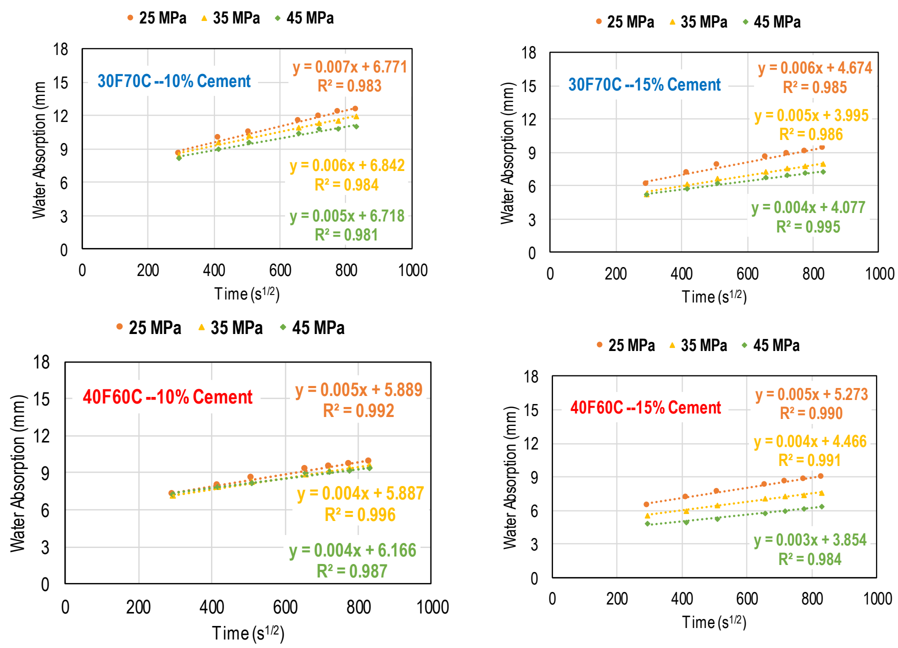


Figure 20: Effect of casting pressure on secondary rate of water absorption.

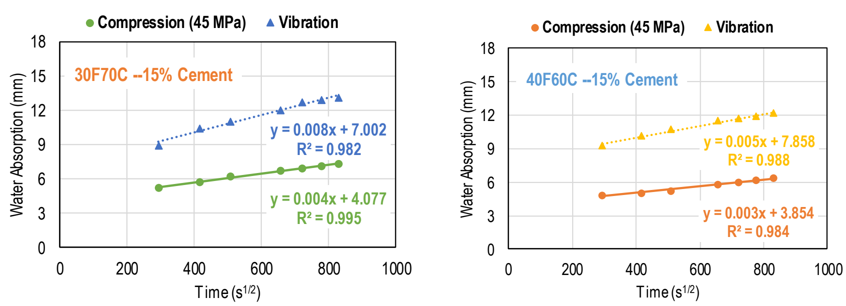


Figure 21: Effect of casting technique on secondary rate of water absorption.

The secondary rate of water absorption of 100% RAC casted by CCT under 45 MPa casting pressure and by conventional casting method was also compared and is graphically presented in Figure 21 for mixes 30F70C-15%C and 40F60C-15%C. It was noticed in these figures that CCT showed a significant positive impact on the secondary rate of water absorption of RAC mixes. In comparison of 30F70C mix with 15% cement prepared by CCT, the initial rate of absorption was increased by 100% when casted by conventional method [i.e., vibration]. Similarly, for vibrated 40F60C with 15% cement, it was increased by 67% when compared to its corresponding compressed mix.

The secondary rate of water absorption of compressed concrete mixes containing 100% RAs has been compared with compressed concrete mixes containing 100% NA and is presented in Figure 22 for concrete mixes 30F70C & 40F60C. From these results, it was obvious that RAC mix exhibited a greater secondary rate of absorption than that of the NAC mix. Under the same conditions of casting pressure and cement content, for 30F70C mix, the secondary rate of water absorption of RAC was 100% more than NAC, whereas for 40F60C mix it was 50% higher than NAC.

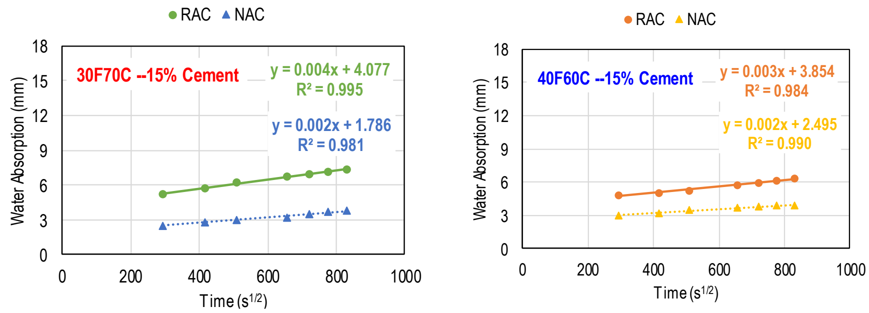


Figure 22. Effect of aggregate type on secondary rate of water absorption.

4. Conclusions

The main objective of this study was to investigate the water absorption characteristics of concrete containing 100% recycled aggregates in order to promote the 100% recycling of waste concrete without leaving any residue. The results of sorptivity test performed on 100% RAC mixes were presented and discussed in terms of three parameters i.e., water absorption, initial rate of water absorption and secondary rate of water absorption and the same were compared with the corresponding values of 100% NAC casted using CCT and RAC casted using conventional vibration casting. Based on the results of the experimental work carried out in this research study, the following conclusions have been drawn:

1. Water absorption and the rate of water absorption (initial and secondary as per ASTM C1585) of compressed 100% RAC is more than compressed NAC but it is found to be lesser than the vibrated 100% RAC which shows the importance of casting technique;
2. With the increase of casting pressure, water absorption, initial rate of absorption and secondary rate of absorption of the RAC concrete mixes is decreased which shows the positive impact of CCT on the sorptivity of the concrete mixes;
3. With the increase of recycled coarse aggregates content in the concrete mix, the sorptivity value is increased due to their high porous nature;
4. Based on the initial and secondary rate of absorption, various relationships have been proposed to predict the water absorption of the compressed RAC concrete mixes prepared using different cement content and casting pressure.
5. Among different 100% RAC mixes investigated in this study, the optimum case for water absorption was RAC mix 40F60C prepared using 15% cement and at 45MPa casting pressure;
6. The developed 100% recycled aggregate concrete mixes having reasonable strength and sorptivity values can be utilized for the manufacturing of eco-friendly masonry units which will be the focus of future research in continuation of this study.

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