PERFORMANCE OF POLYMER TREATED RECYCLED CONCRETE AGGREGATE UNDER DIFFERENT CURING CONDITION OF CONCRETE

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ABSTRACT. The use of recycled aggregates from construction and demolition wastes is showing prospective application in construction as alternative to natural aggregates. To realize the beneficial use of RCA, this study has been conducted to evaluate its applications in structural concrete. Study has been carried out to enhance the performance of recycled aggregate by improving its water absorption by treatment with polymer. Hardened concrete properties of recycled concrete aggregates for M30 and M40 grade under different types of curing i.e. Normal curing, Open-air curing and Polythene curing has been done. Experimental investigation has been carried out at various replacements (i.e. 100% natural coarse aggregate, 100% recycled concrete coarse aggregate, and 100% Polymer treated recycled concrete coarse aggregate). Also, the durability studies such as water absorption and water permeability of the recycled concrete aggregate specimens has been carried out. Water absorption of recycled concrete aggregate has been reduced by 40% with 7% polymer treatment. Compressive strength of normal curing specimens of natural aggregate, recycled concrete aggregate and treated recycled concrete aggregate concrete are higher as compared to polythene curing and open-air curing at 28 days. By reducing the water absorption of recycled concrete aggregates, the compressive strength is very near to concrete with normal aggregate concrete.The study concludes that the hardened concrete properties, water absorption and water permeability improves after the treatment of RCA which makes the TRCA concrete more durable and also improve the strength as compared to RCA concrete.

Keywords: Treated Recycled concrete aggregate (TRCA), Recycled concrete aggregate (RCA), open-air curing, polythene curing, polymer

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INTRODUCTION

Concrete is the single most widely used material in the world in every engineering works including low and high rise buildings and other local or domestic development. Concrete is a manufactured product, essentially consisting of cement, aggregates, water and admixture, amongst these aggregates forms the major part. Traditionally aggregates were available in sufficient quantity and at reliable cost but in recent years the wisdom of our continued wholesale extraction and use of aggregates from natural resources has been questioned.

Indian construction industry today is amongst the five largest in the world and at the current rate of growth, it is slated to be amongst the top two in the next century. Aggregates supply has emerged as a problem in some of the metropolis in India. With the shortage as likely seen today, the future seems to be in dark for the construction sector. The requirements of natural aggregates are not only required to fulfill the demand for the upcoming projects, but also are the needs of the extensive repairs or replacements required for the existing infrastructure and dilapidated buildings built few decades back. For this purpose, concrete recycling has gained importance because it not only protects natural resources but also eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete or other applications. The use of recycled concrete aggregates in new construction applications is still a relatively new technique. In fact many governments throughout the world have now introduced various measures aimed at reducing the use of natural aggregates and increasing reuse and recycling, where it is technically, economically, or environmentally acceptable. For example, the UK government has introduced a number of policies to encourage wider use of recycled aggregates as an alternative to natural aggregates.

There are a variety of benefits in recycling concrete rather than dumping it or burying it in landfill i.e. keeping concrete debris out of landfill saves landfill space, using recycled material as gravel reduces the need for gravel mining, sing recycled concrete as the base material for roadways reduces the pollution involved in trucking material.

While accepting the need to promote the use of RCA in wider applications, it must be remembered that the aggregate for concrete applications must meet the requirements set in relevant specifications for its particular use. Considerable attention is required to the control of water processing and subsequent sorting, separating and grading the aggregate for use of the concrete construction industry. Work on recycled concrete has been carried out at few places in India.

Recycling has the potential to reduce the amount of waste materials disposed of inland fills and to preserve natural resources [2,14,1518,19].The 28-day compressive strengths of RAC were found similar to the natural aggregate concrete when exposed under the standard curing condition while the compressive strength of RAC decrease up to the 20% when they were exposure in open-air conditions [12]. The compressive strength and modulus elasticity of RAC seem to exhibit increase in early stage of steam curing period which is not the case with standard water curing. The steam curing method was also observed to improve the drying shrinkage and the resistance to chloride-ion penetration. However, the effect of this curing method is significantly influenced and affected by the increase of RCA content (Poon et al., 2006).Polydiorganosiloxanes (also called PDMS) and alkylalkoxysilanes (also called silane) have become a very important class of materials used for water-repellent post-treatment of masonry or concrete[16]. The use of polymer based treatments was applied and then the performance achieved was characterized in order to show the relevance of such polymer treatment. Beneficial effects of appropriated polymer based treatments applied on RCA have obtained especially lower water absorption and better fragmentation resistance [17]. The physical and mechanical properties of concrete made of recycled aggregates, were found to suffer as compared to natural aggregate concrete [1,3,4,10,11,19].

MATERIALS AND EXPERIMENTAL PROGRAM

Introductory Remark

The main aim of this research work is to utilize the recycled concrete coarse aggregate for the production of concrete. It is required to verify whether the recycled concrete aggregate is acceptable or not. A polymer treatment has been done on RCA to reduce the water absorption. Three types of aggregates of size 10mm and 20mm have been used in this research work which includes natural coarse aggregate, RCA and polymer treated RCA. Fine aggregates are used from the source Ghagar river sand. The physical properties test such as specific gravity, water absorption and sieve analysis are carried out. Then concrete cube prepared of grade M30 and M40 for different replacement of coarse aggregates i.e. 100% natural aggregates, 100% RCA and 100% polymer treated RCA and same has been cured for 7 and 28 days in different three curing conditions i.e. normal curing, open- air curing and polythene curing. After 7 and 28 days curing, the compressive strength has been determined and after 28 days of curing, water absorption and water permeability test has been determined. The engineering properties of the RCA concrete are then compared to natural aggregate concrete and polymer treated RCA concrete.

Sources of Fine & Coarse Aggregates

The natural aggregates used are from the source Nagal. Natural fine aggregate used are from the source Ghagar river sand. RCA used from the construction and demolition waste are from the source IL & FS plant, Jhangirpuri, New Delhi. The cement used is OPC 53 grade of UltraTech.

POLYMER TREATMENT PROCESS FOR RCA

To improve the water absorption of RCA, Peterseal Concentrate Polymer has been used for treating the RCA to reduce the water absorption. Peterseal Concentrate is superior performance Nano silica based porosity reducer for sand and aggregates used in construction industry.

Usage

Required quantity of water as per lab trials in drum or in concrete mixer was added along with the Peterseal Concentrate. Aggregates were added in the mixer till all the particles are uniformly coated up to SSD conditions. The treated material was dried in the oven and under natural conditions. Considering the variation in aggregate to be treated, prior lab trials were necessary to find the suitable dilution ratio to achieve required porosity reduction.

Physical Properties of Polymer

Table 1 Physical properties of polymer

CHEMICAL	TYPE	COLOR	SUBSTRATE
Nano Silica Fluid	Porosity Reducer	Slightly yellowish	Aggregates, Sand

PROPERTIES OF NA, RCA AND TREATED RCA (TRCA)

To compare the physical properties of RCA and TRCA with NA, various tests were done on aggregates and Table 2.3 shows the comparison between NA, RCA and TRCA.

Physical Properties of Aggregates

Table 2 Physical Properties of Aggregates

PHYSICAL PROPERTY	NA		RCA		TRCA	
	10mm	20mm	10mm	20mm	10mm	20mm
Specific gravity	2.63	2.63	2.45	2.27	2.47	2.33
Water Absorption	0.6	0.6	3.1	2.9	1.9	1.8

Mechanical Properties of Aggregates

Table 3 Mechanical Properties of Aggregates

MECHANICAL PROPERTY	NA		RCA	
	10mm	20mm	10mm	20mm
Impact value (%)	19.40	19.20	23.06	23.30
Bulk density (Kg/lit)	1510	1520	1310	1298
Crushing value (%)	22.90	23.40	26.60	26.60
Flakiness &Elongation(%)	24.58	23.47	31.93	25.85

MIX DESIGN

According to the IS mix design numerous trial mixes are conducted to obtain the optimum mix and then concrete mixes of grade M30 and M40 using different replacements of aggregates i.e. 100% recycled concrete coarse aggregates (RCA), 100% natural coarse aggregate (NA), 100% treated recycled concrete coarse aggregate (TRCA) of maximum size 20mm and 10mm was prepared. Concrete mixes of M40 grade using recycled aggregate were designed as per the suggested guidelines of IS: 10262-2009.

This study has been further divided into three phases. In first phase, NA concrete was designed of grade M30 and M40, then in second phase, NA has been replaced by RCA and in third phase, NA has been replaced by TRCA i.e. NA30, NA40 and RCA30, RCA40 and TRCA30, TRCA40 concrete.

The mix proportions of M30 grade of NA, RCA and TRCA concrete is1:1.98:3.30,1:1.98:2.89 and1:1.98:2.93respectively at 0.45 water cement ratio and the mix proportion of M40 grade of NA, RCA and TRCA concrete is 1:1.492:2.597, 1:1.492:2.275and1:1.492:2.303respectively at 0.4 water cement ratio.

Curing Methods

The concrete specimens were cured using three different techniques until when their compressive strength were determined at ages 7 and 28days. The curing techniques that were applied are:

a) **Normal Curing (NC):** This involved the submersion of the concrete cube specimens in water.

b) **Open-air Curing (OAC):** This served as the control by active curing of the specimens exposed to ambient air in the Laboratory.

c) **Polythene Curing (PC):** These specimens were covered with at least two layers of polythene membrane to prevent moisture movement from the concrete specimens.

All curing methods were carried out in the laboratory under the same environmental conditions of 27^{o}C temperature and 75% relative humidity.

Test Performed on Concrete

Slump cone test

Slump Cone Test is performed to determine the workability of concrete as per IS:1199-1959.

Unit weight of concrete

The unit weight of the concrete specimens of size 150mm x 150mm x 150mm has been recorded after 28 days of three different curing.

Compressive strength test

The purpose of compression test is to determine the crushing strength of hardened concrete. Compression test has been carried out on cube size 150mm x 150mm x 150mm. In this study the compressive strength of the concrete were determined after 7days and 28days of normal curing, open-air curing and polythene curing of concrete specimens. The average reading of three specimens was recorded as the strength at respective age of concrete. The test was conducted in accordance with the IS: 516-1959. The compressive strength test was carried out in compression testing machine (CTM) of 2000KN capacity and the rate of loading was 5.25 KN/sec. Compressive strength test was done in concrete laboratory of Ultratech Concrete Plant located at Surajpur, GreaterNoida.

Water absorption of concrete

Water absorption of concrete specimens was carried out at 28 days of normal curing specimens.

Water permeability of concrete

The specimens were tested for permeability test according to German standard DIN 1048 part-5. It was carried out at 28 days of normal curing specimens and water pressure was applied to the middle portion of the cube by which water can penetrate inside the concrete.

The water pressure was maintained such that 1 bar for initial 48 hours, 3 bar for next 24 hours and 7 bar for next 24 hours.
After this, the water pressure was released and the cubes were removed from the sets.Split tensile test was done using compression testing machine to split the cubes into two halves. Measure the depth of penetration of water. Average of 3 maximum values of penetration has been considered.

RESULTS AND DISCUSSION

Polymer Treatment on RCA

RCA has been treated by siloxane polymer. After treatment, specific gravity and water absorption of RCA become lesser as compared to non-treated RCA.A parametric study has been done at different percentage of polymer concentration i.e., 5%, 7%, 10% and 12%. The highest reduction in water absorption has been obtained equal to 1.8% of RCA after treatment with 7% of polymer concentration.

Table 4 Water Absorption after Treatment at different Concentration of Polymer

5% Polymer	Water Absorption	10% Polymer	Water Absorption
10mm	2.45%	10mm	1.9%
20mm	2.15%	20mm	1.7%
7% Polymer	**Water Absorption**	**12% Polymer**	**Water Absorption**
10mm	1.9%	10mm	2.0%
20mm	1.8%	20mm	1.6%

From Table 4, it is observed that water absorption of RCA is minimum for 7% concentration of polymer. So the entire work has been done at 7% polymer concentration.

Slump Cone Test

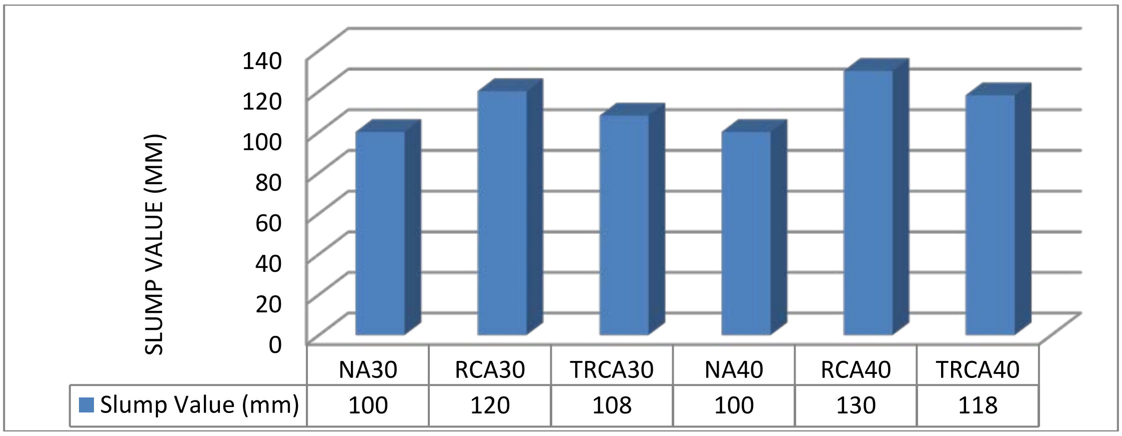


Figure 1 Slump Values of Different Mix

Figure 1shows that the RCA30 and RCA40 concrete have higher workability 120mm and 130mm respectively. NA30, NA40 and TRCA30, TRCA40 concrete have lower workability as compared to RCA. The reason is water content in RCA concrete is higher than NA and

TRCA concrete.

Unit Weight of Concrete

Table 5 Unit Weight of Concrete

Mix/Curing	NORMAL	OPEN-AIR	POLYTHENE
NA30	2452.94	2370.58	2427.45
RCA30	2329.41	2274.50	2290.00
TRCA30	2378.43	2323.50	2350.68
NA40	2458.82	2389.21	2427.45
RCA40	2343.53	2278.53	2285.00
TRCA40	2384.31	2267.16	2341.18

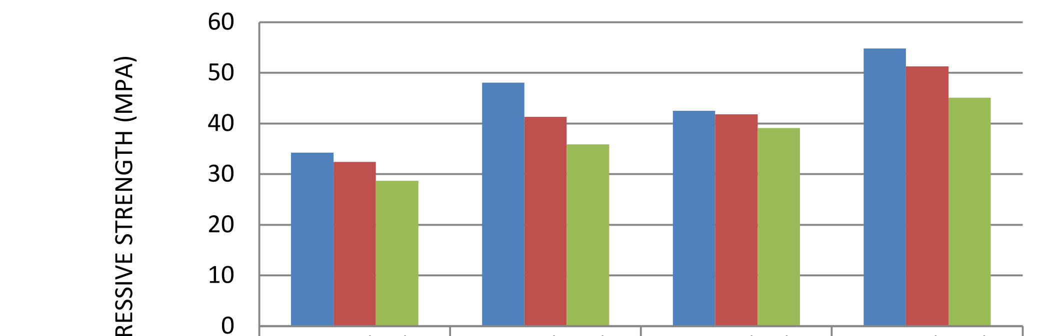
From the Table 5, it is observed that RCA concrete have lower unit weight as compared to TRCA and NA concrete. This reduction in unit weight is comes due to the specific gravity of RCA is low as compared to NA and TRCA, which will affect the unit weight of concrete. Results shows there is no much change in unit weight of concrete of grade M30 and M40 by different curing methods. This reduction in unit weight is comes due to the specific gravity of RCA is low as compared to NA and TRCA, which will affect the unit weight of concrete.

Compressive Strength Test

Table 6 shows the results of the 7 days and 28 days compressive strength of NA, RCA and TRCA concrete of grade M30 and M40. It can be seen that all the concrete mix of NA and TRCA concrete achieves their target mean strength at 28 days. While the RCA concrete has not achieved the target mean strength in 28 days in open-air curing.

Table 6 Results of Compressive Strength Test at 7 and 28 days in different Curing Condition

MIX NOTATION /CURING	NORMAL CURING (MPA)		OPEN-AIR CURING (MPA)		POLYTHENE CURING (MPA)	
	7days	28days	7days	28days	7days	28days
			M30			
NA30	34.22	48.05	28.70	35.85	32.39	41.28
RCA30	24.79	41.16	26.79	31.63	26.58	40.29
TRCA30	31.53	43.90	27.35	32.97	29.99	40.78
			M40			
NA40	42.49	54.81	39.10	45.07	41.82	51.28
RCA40	29.90	46.99	31.15	38.64	30.60	42.53
TRCA40	35.50	49.48	32.90	40.94	33.59	45.87

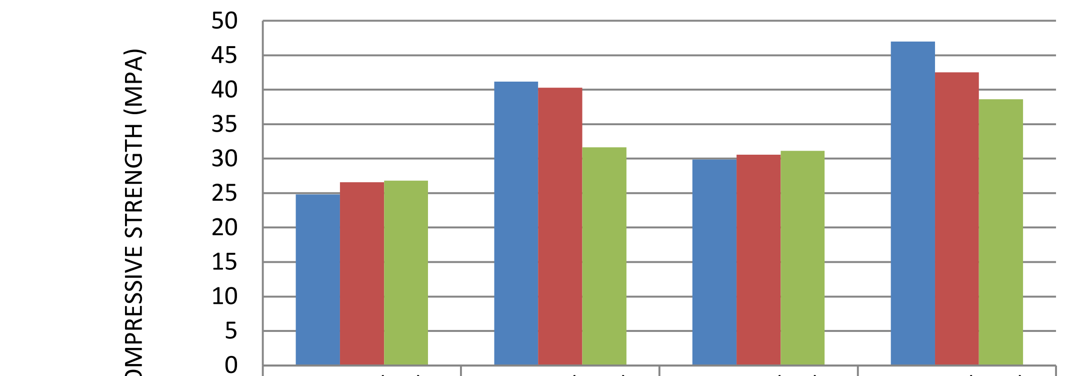


	NA30 (7D)	NA30 (28D)	NA40 (7D)	NA40 (28D)
Normal Curing	34.22	48.05	42.49	54.81
Polythene Curing	32.39	41.28	41.82	51.28
Open air Curing	28.7	35.85	39.1	45.07

Figure 2 Comparison of Compressive Strength Result of NA Concrete of Grade M30 and M40

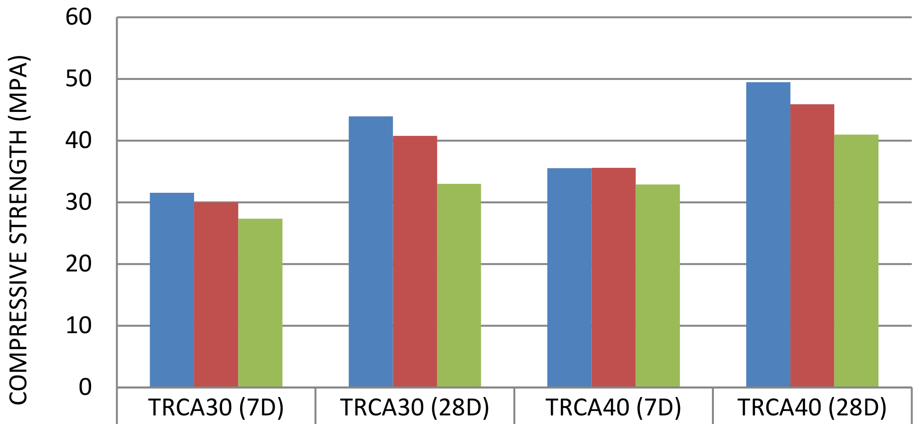
Figure 2 shows that the compressive strength results, for NA30 and NA40 at 7 and 28 days, normal curing concrete specimen's strength is higher as compared to polythene and open-air curing.

Figure3 shows that the compressive strength results, for RCA30 and RCA40 at 7 and 28 days. At 7 days, open air curing concrete specimens strength is higher as compared to polythene and normal curing. At 28 days normal curing concrete specimens strength is higher as compared to polythene curing and open air curing.



	RCA30 (7D)	RCA30 (28D)	RCA40 (7D)	RCA40 (28D)
Normal Curing	24.79	41.16	29.9	46.99
Polythene Curing	26.58	40.29	30.6	42.53
Open air Curing	26.79	31.63	31.15	38.64

Figure 3 Comparison of Compressive Strength Result of RCA Concrete of Grade M30 and M40



	TRCA30 (7D)	TRCA30 (28D)	TRCA40 (7D)	TRCA40 (28D)
Normal Curing	31.53	43.9	35.5	49.48
Polythene Curing	29.99	40.78	35.59	45.87
Open air Curing	27.35	32.97	32.9	40.94

Figure 4 Comparison of Compressive Strength Result of TRCA Concrete of Grade M30 and M40

Figure 4 shows that the compressive strength results, for TRCA30 and TRCA40 at 7 and 28 days, normal curing concrete specimen's strength is higher as compared to polythene and open-air curing.

Water Absorption Test

Figure 5 shows the water absorption test results; RCA concrete specimens have higher water absorption as compared to NA and TRCA concrete. It is because the porosity of recycled concrete aggregate is higher as compared to natural and treated recycled concrete aggregates.

Water Permeability Test

Figure.6 shows the water absorption test results; RCA concrete specimens have higher water absorption as compared to NA and TRCA concrete. Water permeability increases due to the water-cement ratio, as shown in results for M30 grade w/c is 0.45 and for M40 grade w/c is 0.4 due to which water penetration depth in M30 grade concrete is higher than M40 grade concrete.

But in case of RCA concrete, no such effect is dominating i.e., the values for RCA concrete of M30 and M40 are approximately same. The size of RCA is greater than NA which makes RCA concrete more permeable and the porosity of the RCA concrete is more than NA concrete. The main factors of the increased water permeability of RCA concrete are cracks and pores.

After treatment of RCA, the porosity of RCA decreases due to which TRCA concrete has less water penetration depth than RCA concrete because polymer made a layer on the RCA which act as a fillers in reinforcing cementitious materials to produce high packing density that is able to refine the capillary void in concrete structures, thus decreasing the water permeability.

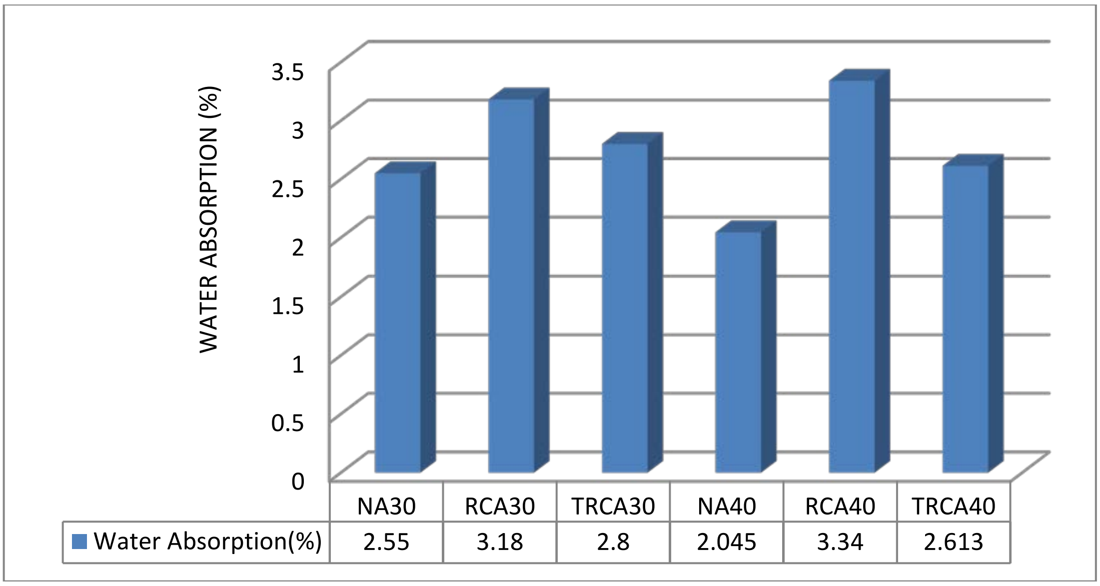


Figure 5 Water Absorption Test Results

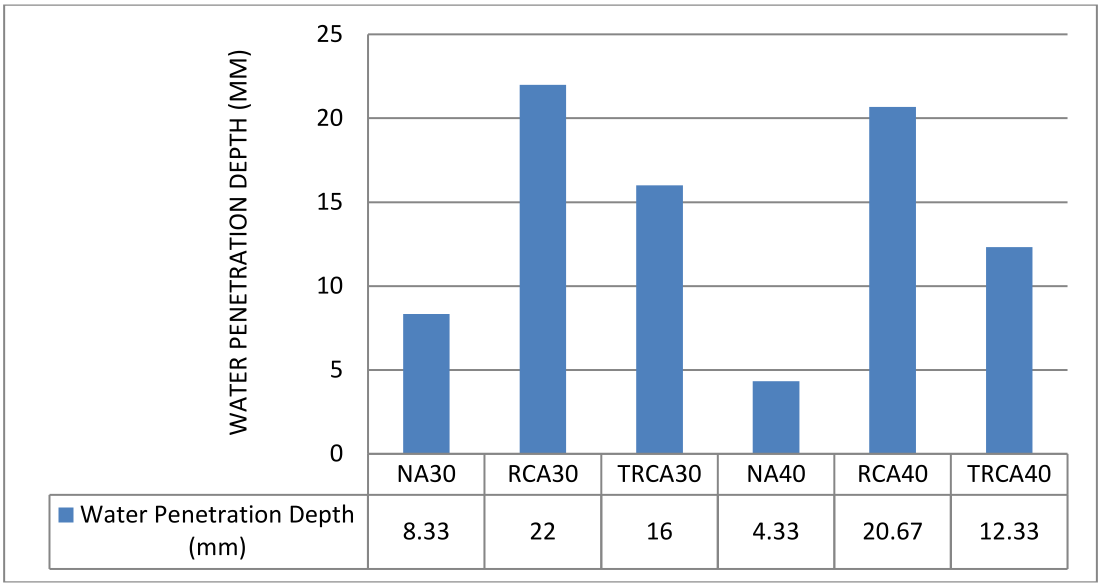


Figure 6 Water Permeability Test Results

CONCLUSIONS

The following conclusions are drawn from the work:

1) Water absorption of RCA concrete is higher than NA concrete and TRCA concrete. The water absorption of Recycled Concrete Aggregate is reduced by the Peterseal Concentrate Polymer. It reduces the porosity of RCA by which the water absorption get reduced. The highest reduction in water absorption has been obtained equal to 1.8% of RCA after treatment with 7% of polymer concentration.
2) The workability of NA, RCA and TRCA Concrete is 100,120 and 108mm respectively of grade M30. And for grade M40, workability of NA, RCA and TRCA is 100, 130 and 118 mm respectively. As workability is directly proportional to the water content and as the water content in RCA concrete is higher as compared to NA and TRCA concrete due to higher water absorption in RCA, the slump is more in RCA concrete.

3) The unit weight of RCA concrete is lower as compared to NA and TRCA concrete. This reduction in unit weight is because the specific gravity of RCA is low as compared to NA and TRCA, which will affect the unit weight of concrete.
4) There is no much effect of different curing methods on unit weight of concrete. By which it is clarify that the unit weight of concrete depends on the specific gravity of aggregates only.
5) At 7 days, the compressive strength of NA and TRCA concrete specimens achieves higher strength 34.22MPa and 31.55MPa respectively in normal curing as compared to polythene and open-air curing. While RCA concrete shows different behavior at 7 days, it achieves higher strength 26.79MPa in open-air curing as compared to normal and polythene curing strength is 24.79 and 26.58MParespectively.
6) At 28 days age the compressive strength of NA, RCA and TRCA concrete specimens achieves higher strength in normal curing 48.05, 38.85 and 41.28MPa as compared to polythene and open-air curing.
7) RCA concrete shows different behavior at 7 days and 28 days. In beginning it achieve high strength in open-air curing. But at 28 days age it achieves high strength in normal curing. While NA and TRCA concrete show same behavior at 7 and 28 days achieves high strength in normal curing and least in open-air curing. It clarifies that the water absorption of RCA is more than the NA and TRCA which affect the compressive strength of RCA concrete.
8) By decreasing the water absorption of RCA by polymer treatment, RCA behaves like NA which is observed from the Compressive strength results at 7 and 28 days under different three curing conditions.
9) Water permeability of RCA concrete is higher than NA concrete and TRCA concrete. For M30 grade, the water penetration depth of RCA concrete is higher than NA concrete and TRCA concrete by 16mm and 7.67mm respectively. For M40 grade, the water penetration depth of RCA concrete is higher than NA concrete and TRCA concrete by 16.34mm and 8mm respectively.

From the above conclusions, it is observed that the RCA concrete has less strength and is less durable (water absorption and water penetration depth is high) as compared to NA concrete.
But these properties can be improved after the treatment of RCA which makes the TRCA concrete more durable and also improve the strength as compared to RCA concrete.

REFERENCES

1. ACHTEMICHUK S, HUBBARD J, SLUCE R, SHEHATA M H, The utilization of recycled concrete aggregate to produce controlled low strength materials without using Portland cement. Cement Concrete Comp. Vol 31,2009, 564–569.
2. BRAUNSCHWEIG A, KYTZIA S, BISCHOF S, Recycled concrete: Environmentally beneficial over virgin concrete - life cycle management conference, 2011.
3. CASUCCIO M, TORRIJOS M C, GIACCIO G, ZERBINO R, Failure mechanism of recycled aggregate concrete. Construction and Building Materials. Vol 22,2008, 1500–1506
4. CHAKRADHARA R M, BHATTACHARYYA S, BARAI S, Influence of field recycled coarse aggregate on properties of concrete. Materials and Structures. 2011, pp. 205–220.
5. GERMAN STANDARD FOR DETERMINATION OF PERMEABILITY OF CONCRETE, DIN 1048 (PAT 5)-2006.
6. Indian Standard specification for coarse and fine aggregate from natural source of

concrete, IS 383:1970, Bureau of Indian Standards, New Delhi, India.
7. Indian Standard code of practice for plain and reinforced concrete, IS: 456-2000, Bureau of Indian standard, New Delhi, India.
8. Indian Standard recommended guidelines for concrete mix design, IS: 10262-2009, Bureau of Indian Standards, New Delhi, India.
9. Indian standard code of practice method of test for strength of concrete, IS: 516-1959, Bureau of Indian Standards, New Delhi, India.
10. KOU S, POON C, Enhancing the durability properties of concrete prepared with coarse recycled aggregate. Construction and Building Materials, Vol 35, 2012, pp.69-76.
11. KOU S, POON C, AGRELA F, Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. Cement and Concrete Composites, Vol 33(8), 2011, pp.788-795.
12. LÓPEZ GAYARRE F, LÓPEZ-COLINA PÉREZ C, SERRANO LÓPEZ M, DOMINGO CABO A, The effect of curing conditions on the compressive strength of recycled aggregate concrete. Construction and Building Materials, Vol 53, 2014, pp.260-266.
13. POON C, CHAN D, Paving blocks made with recycled concrete aggregate and crushed clay brick. Construction and Building Materials, 20(8), 2006, pp.569-577.
14. RAO A, JHA K, MISRA S, Use of aggregates from recycled construction and demolition waste in concrete. Resources, Conservation and Recycling, 50(1), 2007,pp.71-81.A-15.
15. SONAWANE TR, PIMPLIKAR S S, Use of Recycled Aggregate Concrete. Journal of Mechanical and Civil Engineering, 2013, pp: 52-59
16. SCHUEREMANS L, VAN GEMERT D, FRIEDEL M, Giessler-Blank, Durability of water repellents in a marine environment, 5th International Conference on Water Repellent Treatment of Building, 2008,pp. 357–367
17. SPAETH V, DJERBI TEGGUER A, Improvement of recycled concrete aggregate properties by polymer treatments. International Journal of Sustainable Built Environment, Vol 2(2), 2013,pp.143-152.
18. TAM V W Y, TAM C M, WANG Y, Optimization on proportion for recycled aggregate in concrete using two-stage mixing approach. Constr. Build. Material, Vol 21, 2007, pp 1928–1939
19. TOPCU I B, SENGEL S, Properties of concretes produced with waste recycled aggregates. Cement and concrete research, 34(2004), pp1307-1312.