Performance of pervious concrete with recycled concrete aggregate

P. Pal, S. Shukla and A.K. Ranjan

This paper presents the characteristics of pervious concrete with optimum quantity of recycled concrete aggregate (RCA). Six different types of pervious concrete mix equivalent to M-15 grade of concrete containing 0%, 20%, 25%, 30%, 35% and 40% of RCA are prepared to estimate the compressive strength, the flexural strength and the permeability. The compressive strength of the pervious concrete with optimum replacement of primary coarse aggregate (PCA) by 35% of RCA is achieved up to 100% characteristics strength of the M-15 grade of concrete. The findings of this study may help the designers in the design of pervious concrete.

1. INTRODUCTION

Pervious concrete pavements acts as a storm water management tool. In recent times, several cities around the world have encountered frequent flooding due to the combined results of increased rainfall and high impermeable surface areas. As a result, the drainage system gets choked leading to flash flooding, thus causing severe problems to the functioning and maintenance of road transport and flooding of basement parking of shopping centres. In order to avoid frequent flooding and manage storm water runoff, an engineered solution is needed. Pervious concrete pavement with little or no-fines aggregate and a high void content is a better option than the conventional concrete pavement. Pervious concrete can be used for the construction of parking lots, secondary roads, walkways, driveways and sidewalks. The pervious concrete pavements also serve the purpose of reducing noise pollution to some extent and because of their ability to reduce noise they are sometimes referred to as low-noise road surfaces. Worldwide, sustainability is the desperate need whenever there is an inclusion of construction industry. Investigators believe that the use of construction and demolished waste support the cause of sustainable development in the field of highway and transportation industry. With regard to the sustainable development, use of recycled aggregates is being increasing rapidly. In a developing country like India, the primary requirement of any project after performance criteria is its economic feasibility and serviceability criteria. Use of RCA in pervious concrete is one such alternative to meet the economy of the project.

Pervious Concrete is a composite material consisting of coarse aggregate, Portland cement, and water. It is different from traditional concrete in a way that it contains very less or no amount of fine aggregate. The most important property of the pervious concrete is its high water permeability which helps water to pass through existing interconnected voids. The aggregate used in pervious concrete is somewhat of similar size and bonded together by cement water paste at its point of contact. Due to the use of uniformly graded aggregates in the formation of concrete, it leads to the formation of large amount of interconnected voids in the concrete and when performs well finally results in percolation of water through it.

To form a pervious concrete with desired compressive strength and optimum permeability, the amount of water, cement, type of aggregate, size of aggregate, and compaction must be kept in mind. Even a slight variation in compaction may lead to the failure of pervious concrete mix. ACI committee [1-2] reported that the pervious concrete is a special type of concrete with a high proportion of large sized pores, typically 2-8 mm. The typical porosity of pervious concrete ranged from 15 to 30% and the presence of interconnected large pores system allows the water to flow easily through the pervious concrete. ACI committee [2] suggested that minimum vertical force required for compaction is about 0.07 MPa. The strength parameters and structural performance [3] varies too much for the pervious concrete as compared to conventional concrete, and it mainly depends on porosity. Greater porosity leads to higher permeability values but tends to decrease compressive strength too much. The good quality RCA may have similar properties like good quality virgin aggregate [4]. Since recycled aggregates are composed of original aggregates and cement paste, which is typically weaker than the original aggregate, hence it is desired to remove as much hardened cement paste as possible. The part replacement of natural aggregate with recycled concrete aggregate [5] in mid strength concrete reduces compressive strength, tensile strength and modulus of elasticity and increases the dry shrinkage of concrete. The changes [6] in mix composition and supplementary cementitious additives like fly ash and silica fumes can easily be used in order to increase the compressive strength of pervious concrete. The 15% RCA has strength parameters [7] similar to control mix and suggested that up to 30% replacement of natural aggregates with recycled aggregates is feasible without compromising strength and permeability too much. The pervious concrete mixes should meet the specification requirements [8] for permeable concrete pavements. Typical pervious concrete mix consists of 180-355 kg/m^3 of binder material, 1420-1600 kg/m^3 of coarse aggregate and water to cement ratio ranged from 0.27 to 0.43. The typical 28-days compressive strength ranges from 5.6 to 21 MPa, with void ratios ranging from 14% to 31%, and permeability coefficient varies from 0.25 to 6.1 mm/sec. The porosity for pervious concrete lies in the range of 15% to 25% and is dependent on water cement ratio and compaction effort [9]. The density of pervious concrete lies in the range of 1600 kg/m^3 to 2000 kg/m^3 which lies in the upper range of light weight concretes. The compressive strength of pervious concrete can vary from 3.5 to 28 MPa which is applicable for wide range of applications. Compressive strength mainly depends on the material properties, its proportioning, porosity and obviously the compaction techniques.

The aim of the present investigation is to find out the optimum percentage of recycled aggregate for producing low density pervious concrete. Six different types of concrete mix containing different percentage of RCA are prepared to estimate the compressive strength, the flexural strength and the permeability of pervious concrete at the age of 7 and 28 days. The methodology for preparing the pervious concrete is described below as there is no specific technique for the construction of pervious concrete.

2. METHODOLOGY

Recycled concrete aggregates are generally more porous in nature than the primary coarse aggregates. The main property of pervious concrete is its permeability, so the part of fine aggregate can be reduced and the part of natural aggregate can be replaced with recycled concrete aggregate to enhance the permeability without much affecting the strength of the concrete. The materials used for making pervious concrete are cement, primary coarse aggregates, recycled coarse aggregate and water. With a purpose to carry out the investigation sequentially, the work has been divided into the following phases:

- Phase-I: Preparation of RCA.
- Phase-II: Determination of physical properties of PCA and RCA.
- Phase-III: Partial replacement of PCA by RCA.
- Phase–IV: Establishing the mix proportion of pervious concrete.
- Phase V: Determination of properties of pervious concrete

In this study, the physical properties of RCA carried out are specific gravity, water absorption, abrasion value and impact value. The properties of pervious concrete estimated are the compressive strength, the flexural strength and the permeability. Primary coarse aggregates are replaced by recycled concrete aggregates in different

percentages so as to make the pervious concrete. The different mixes are then compared with referral mix and an optimum percentage of recycled concrete aggregate is determined on the basis of test results.

3. RESULTS AND DISCUSSION

3.1 Preparation of RCA

Stepwise procedure for the preparation of RCA is stated below.

- Rejected/demolished concrete samples are collected from the testing laboratory.
- Collected concrete samples are broken into small pieces with the help of hammer.
- The broken pieces are further broken with the help of hammer.
- Crushed materials are then sieved through 19.5 mm and 22 mm sieve to get an average size of 20 mm aggregate.
- Materials retained on 22 mm sieve are again broken into the small pieces so as to get 20 mm size of aggregate.
- Materials passing through 19.5 mm sieve are again sieved through 12.5 mm sieve and 9.6 mm sieve to obtain an average size of 10 mm aggregate.
- Materials retained on 12.5 mm sieve are broken again and then sieved so as to get 10 mm size of aggregate.
- Material passing 9.6 mm sieve can be used to prepare 6 mm size of aggregates.

Table 1. Specific gravity and water absorption of aggregates

No.	Aggregate	Specific gravity	Water absorption
1	10 mm PCA	2.63	0.537 %
2	10 mm RCA	2.40	2.367 %
3	20 mm PCA	2.58	1.260 %
4	20 mm RCA	2.32	4.59 %

3.2 Properties of aggregates

Required properties of the recycled concrete aggregates are determined as per IS standards [10-11] so as to compare them with the properties of primary aggregates and also to estimate their suitability for the partial replacement of primary aggregate in pervious concrete. Table 1 presents the specific gravity and water absorption of both PCA and RCA. Specific gravity is found more for PCA as compared to the RCA. Water absorption is found less for PCA as compared to the RCA. It is because the RCA contain hydrated cement paste and hence reduces the specific gravity and increases the water absorption capacity. This increased water absorption values depicts porous nature of recycled concrete aggregate. Table 2 presents the abrasion and impact values of both PCA and RCA. Abrasion value comes out to be 21% and impact value comes out to be 19% for recycled aggregates which is below the maximum specified limit of 30% for high quality pavement material.

Lower specific gravity and higher water absorption values of recycled concrete aggregate refers to that fact that recycled aggregates are more porous than primary aggregates. Basically specific gravity is an indicator of strength of the aggregates and hence it implicates that the recycled aggregates have lesser strength as compared to primary aggregate. The impact value of recycled aggregate is lower than that of primary aggregate. The possible reason for this may be the difference in the composition of aggregates. Higher abrasion value of recycled aggregate can be understood from the fact that it contains higher percentage of cement mortar which is removed in the process of abrasion.

3.3 Partial replacement of PCA with RCA

In the study, 20%, 25%, 30%, 35% and 40% of the primary coarse aggregates are replaced with recycled concrete aggregates to prepare the different mixes of pervious concrete.

Table 2. Abrasion values of aggregates

No.	Aggregate	Abrasion value	Impact value
1	PCA	15 %	16%
2	RCA	21%	19%

Table 3. Details of the various mixes having different percentages of RCA

Mix	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	20 mm PCA (kg/m^3)	20 mm RCA (kg/m^3)	10 mm PCA (kg/m^3)	10 mm RCA (kg/m^3)	Density of green concrete (kg/m^3)
RC	340	116	187	828	0	552	0	2023
RC20	340	116	187	662.4	165.6	441.6	110.4	
RC25	340	116	187	621.0	207.0	414.0	138.0	
RC30	340	116	187	579.6	248.4	386.4	165.6	
RC35	340	116	187	538.2	289.8	358.8	193.2	
RC40	340	116	187	496.8	331.2	331.2	220.8	

Table 3 presents the details of the various mixes containing different percentages of RCA. The mix containing 20% replaced recycled aggregate is termed as RC20. Similarly, the term RC25, RC30, RC35, and RC40 are assigned. Referral concrete with only PCA is termed as RC. The different mixes are prepared to investigate the potentiality of RCA and the effect of replacement of PCA by RCA.

3.4 Pervious concrete mix design

There is no such standard code of practices for the mix design of pervious concrete. So, it is imperative to establish the trial mixes in accordance with the literature study on pervious concrete design. The testing of pervious concrete is carried out as per IS standards [12-14]. Strength and permeability characteristics of the prepared mixes are carried out from the laboratory tests. The mix design is finalised when the strengths and permeability of the mixes fulfil the minimum stipulated criteria. The quantity of materials, presented in Table 4, are finalized for preparing pervious concrete, decided in accordance with literature study and on the basis of trial mixes. The adopted water-cement ratio (by weight) is 0.341, slump value is within the range of 25-50 mm and the ratio of cement, sand and coarse aggregate (by weight) is 1:0.55:4.059 for the preparation of low density pervious concrete mix.

Table 4. Materials for mix design

No.	Material	Quantity (kg/m^3)
1	Cement (PPC)	340
2	Fine aggregate (Zone-III)	187
3	20 mm PCA	828
4	10 mm PCA	552
5	Water	116
6	Density of green concrete	2023

3.5 Properties of pervious concrete

Concrete containing no recycled aggregates is considered as the reference and this referral concrete is then compared with the one having recycled aggregates. Based on the test results, an optimum percentage of recycled concrete aggregate is recommended. Figure 1 shows the samples of pervious concrete prepared in the laboratory for the

(a) Cube sample (b) Beam sample (c) Cylindrical sample

Figure 1. Prepared samples of pervious concrete

Table 5. Characteristics of different pervious concrete at seven days

Mix	Compressive strength (MPa)	Flexural strength (MPa)	Permeability (mm/sec)
RC	16.67	3.29	1.11
RC20	16.44	3.20	1.13
RC25	15.78	3.11	1.18
RC30	12.44	2.93	1.22
RC35	12.22	2.84	1.24
RC40	8.22	2.31	1.37

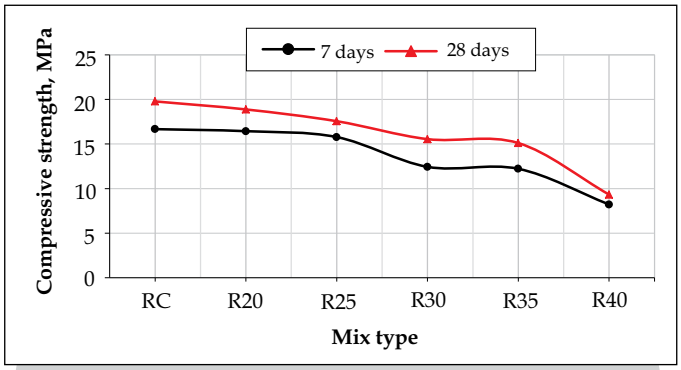

Figure 2. Compressive strength of pervious concrete

determination of the compressive strength (Figure 1a), the flexural strength (Figure 1b) and the permeability (Figure 1c). The characteristics of different mixes of pervious concrete at the age of seven days and twenty eight days are presented in Tables 5 and 6, respectively. Replacement of primary coarse aggregates by recycled coarse aggregates leads to decrease in strength of the pervious concrete.

Figure 2 shows the variation of compressive strength at seven and twenty eight days of curing for different percentage replacement of PCA. It is observed that with the increase of percentage replacement of PCA by RCA the compressive strength decreases. Compressive strength of concrete at twenty eight days is considered as the characteristic strength of concrete and it is assumed that the concrete attains about its 100% of compressive strength in these twenty eight days. For the purpose of selecting the optimum percentage of recycled concrete aggregate, twenty eight days characteristic compressive strength has been chosen as the prime deciding parameter. It is clearly found that the mix containing 25% recycled concrete aggregates has compressive strength comparable to that of the referral mix. Compressive strength of the mix containing 35% RCA is reduced by 23.61 % as compared to referral concrete and hence up to 35% replacement of PCA by RCA may be considered as this mix has the average compressive strength of 15 MPa which is suitable for wide range of applications. Similar observation is found in Figure 3 in the case of flexural strength of pervious concrete.

Table 6. Characteristics of different pervious concrete at twenty eight days

Mix	Compressive strength (MPa)	Flexural strength (MPa)	Permeability (mm/sec)
RC	19.78	3.91	0.93
R20	18.88	3.73	0.95
R25	17.55	3.56	0.99
R30	15.55	3.47	1.01
R35	15.11	3.38	1.03
R40	9.33	2.76	1.17

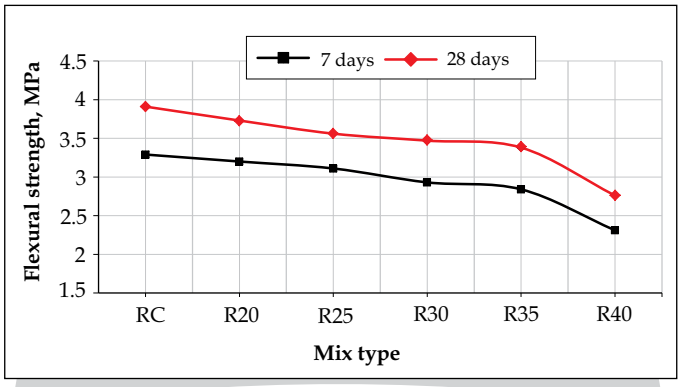

Figure 3. Flexural strength of pervious concrete

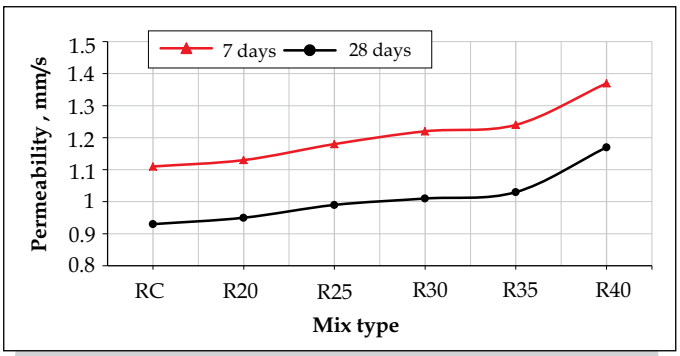

Figure 4. Permeability of pervious concrete

Figure 4 shows that the permeability of pervious concrete increases with the increase of percentage of RCA. The flexural strength and the permeability of pervious concrete with 35% replacement of primary aggregates are giving satisfactory results and hence, 35% replacement of PCA by RCA can be used for making pervious concrete which may be suitable for concrete pavement. However, for producing pervious concrete equivalent to other grades of concrete, more investigation is required for finding the optimum percentage of RCA to be used to replace the PCA. Higher density of green concrete may also affect the characteristics of pervious concrete.

4. CONCLUSIONS

The present study provides evidence that supports the following conclusions.

- The adopted mix proportion may be used for producing pervious concrete as the obtained results are satisfactory.
- Aggregate to cement ratio for pervious concrete is considered to be 4.06:1.
- Compressive strength and flexural strength of pervious concrete decreases with the increase in percentage of recycled aggregates.
- Permeability increases with the increase in percentage of recycled aggregates.
- The strength of the pervious concrete with optimum replacement of 35% of PCA by RCA is achieved about 100% of the characteristics strength of the M-15 grade of concrete.

References

1. American Concrete Institute, Removal and reuse of hardened concrete, ACI 555 committee report, P.O. Box 9094, Farmington Hills, MI 48333-9094, 2001, pp. 1-26.
2. American Concrete Institute, Pervious concrete, ACI 522 committee report, P.O. Box 9094, Farmington Hills, MI, 2006.
3. L. K. Crouch, J. Pitt and R. Hewitt, Aggregate effects on pervious Portland cement concrete static modulus of elasticity. Journal of Materials in Civil Engineering, Vol.19, No.7. ASCE, Reston, VA, 2007, pp 561-568.
4. M. Etxeberria, E. Vazquez, A. Mari and M. Barra, Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete, Cement and Concrete Research, 2007, Vol.37, No.5, pp.735-742.
5. R. S. Ravindrarajah and C.T. Tam, Properties of concrete made with crushed concrete as coarse aggregate, Magazine of Concrete Research, 1985, Vol. 37, No. 130, pp. 29-38.
6. R. S. Ravindrarajah and C.T. Tam, Methods of improving the quality of recycled aggregate concrete, demolition and reuse of concrete and masonry: reuse of demolition waste, Chapman and Hall, London, U.K., 1988, pp.575-584.
7. R. Rizvi, S. Tighe, V. Henderson and J. Norris, Evaluating the use of recycled concrete aggregate in pervious concrete pavement. Journal of the Transportation Research Board, No. 2164, Transportation Research Board of the National Academies, Washington D.C., 2010, pp. 132-140.
8. V. R. Schaefer, K. Wang, M. T. Suleiman and J. T. Kevern, Mix design development for pervious concrete in cold weather climates, Research report, Center for Transportation Research and Education, Iowa State University, Ames, Iowa, 2006.
9. P. D. Tennis, M. L. Leming, and D. J. Akers, Pervious concrete pavements, Special publication by the Portland Cement Association and the National Ready Mixed Concrete Association, 2004.
10. _____ Indian standard methods of test for aggregates for concrete (part- I to part-VIII), IS: 2386-1963 (Reaffirmed 1997). Bureau of Indian Standards, New Delhi.
11. _____ Indian Standard specification for coarse and fine aggregates from natural sources for concrete, IS: 383-1970 (Reaffirmed 1997). Second revision, Bureau of Indian Standards, New Delhi.
12. _____ Indian standard code of practice for splitting tensile strength of concrete - method of test, IS: 5816-1997. Bureau of Indian Standards, New Delhi.
13. _____ Indian Standard methods of tests for strength of concrete, IS: 516-1959 (Reaffirmed 1999). Bureau of Indian Standards, New Delhi.
14. _____Indian standard code of practice for plain and reinforced concrete for general building construction, IS: 456-2000. Bureau of Indian Standards, New Delhi.

Dr. P. Pal holds a Bachelor's Degree in Civil Engineering from IIEST Shibpur, India (Formerly Bengal Engineering and Science University, Shibpur and Erstwhile Bengal Engineering College, Shibpur); M.E. in Structural Engineering from IIEST Shibpur; PhD in Civil Engineering from Indian Institute of Technology, Kharagpur, India. He is an Assistant Professor in the Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad, India. His research areas are composite structures, fluid-structure interaction, concrete technology, finite element method and meshless methods. He has published more than 35 research papers in national and international journals and conferences.

Dr. Shalinee Shukla holds a Bachelor's Degree in Civil Engineering from GEC, Rewa, Madhya Pradesh, India; M.Tech. and PhD in Transportation Engineering from IIT Roorkee, Uttarakhand, India. She is an Assistant professor in the Department of Civil Engineering, MNNIT Allahabad, India. Her areas of research are transportation and pavement engineering. She has published more than 15 research papers in different conferences and journals of national and international repute.

A.K. Ranjan holds Bachelor's Degree in Civil Engineering from University Institute of Technology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India; M.Tech. in Transportation Engineering from MNNIT Allahabad; was a post graduate student in the Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad, India. His areas of research are transportation and pavement engineering.

What is your Opinion?

Do you wish to share your thoughts/views regarding the prevalent construction practices in the construction industry with our readers? If yes, the Indian concrete Journal gives a change to the engineering fratrnity to express their views in its columns.

These shall be reviewed by a panel of experts. Your views could be supplemented with good photographs and neat line drawings. Send them across by e-mail to editor@icjonline.com

ICJ

Write to :

The Editor, The Indian Concrete Journal,
ACC Limited, L.B. Shastri Marg, Thane - 400 604.
e : editor@icjonline.com w: www.icjonline.com