EVALUATION OF STRENGTH AND INFILTRATION CHARACTERISTICS OF POROUS CONCRETE MADE USING RECYCLED CONCRETE AGGREGATE

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Abstract: Porous concrete for low impact development has long been studied for the improvement of urban stormwater management. However, the porous concrete made using Recycled Concrete Aggregate (RCA) is still lacking, particularly in relation to its strength and infiltration rates. Therefore, this paper aimed to design porous concrete using RCA with optimum infiltration rate without compromising the strength. To fulfill this aim, a laboratory study evaluating the strength and infiltration characteristics of a porous concrete mix is presented. From the mixed design 1: 0.4: 3.6 (Portland Pozzolana Cement (PPC): natural sand: natural coarse aggregate), Natural Coarse Aggregate (NCA) is partially replaced by RCA in the interval of 0%, 15%, 30% and 45% to find the optimum infiltration without compromising the strength. The 10 mm aggregate is used as it was recorded for the highest compressive strength after curing for 28 days. With the increase in the addition of RCA, the compressive strength decreases whereas the infiltration rate increases. From the comparative study of infiltration rate and compressive strength, 30% replacement of RCA gives the most satisfactory result with infiltration rate and compressive strength of 9737 mm/hr and 8.67 MPa respectively. The water quality test is conducted to evaluate whether the porous concrete detention system can reduce the pollutants from the surface run-off. The pH and acidity parameters are considered to check the quality of stormwater. Stormwater after infiltrating through the prototype becomes basic in nature.

Keywords: recycled concrete aggregate, porous concrete, compressive strength, infiltration.

I. INTRODUCTION

Porous concrete is an innovative paving material that gained popularity mostly in Europe and America mainly due to its function of reducing the amount of stormwater flowing over the surface of urban areas in the early 20th century. Due to the functions and importance, it plays, the big cities around the world have invested in fundamental research into permeable pavement [1]. **Error! Reference source not found.**It mainly allows the infiltration of stormwater through its voids into the stone reservoir and the ground, recharging the groundwater or directly to the drainage system. This innovative and sustainable technique has shown not only its capacity to reduce surface stormwater runoff but also to keep solid and harmful pollutants away from flowing into the drainage system or into the ground. It also reduces noise pollution and maintains the temperature of the environment [2]/

With urbanization, runoff is the major problem. Surface runoff over impervious surfaces is one of the issues that should be considered. The surface runoff causes blockage or overflow of the drain and degradation of the pedestrian or the road by eroding surface gravel along with it. "With no proper drainage and footpaths, stormwater has washed debris and gravel along the road and eaten away sections of road [3]" "In absence of proper drainage, it could wipe off the entire town [4]." Runoff over impervious surfaces is one of the largest contributors to the pollution of water. The eroded materials are washed away and deposited into the sources of water. Thus, stormwater runoff pollutes the source of water contaminating the drinking water and harming the aquatic life

Construction and demolition waste is produced in huge amounts in medium and large cities. A total of about 16,000 tons of solid waste were produced from different civil construction sites every day in São

Paulo, the prime city in Brazil, constituting 50% of the total solid waste [5]. Moreover, around one-third of this solid waste was transported to the municipal landfills, whereas the rest was disposed of illegitimately [6]. By replacing a certain portion of natural aggregate with recycled aggregates, it can not only reduce the construction and demolition waste generation but also conserve the extraction of natural resources. The increasing cost of landfills coupled with the increase in aggregate production requirement for construction has made the use of recycled aggregate to partially replace the natural aggregate more economical and environmentally advantageous [7].

Therefore, due to the problem associated with the generation of construction and demolition waste and filling of the landfill, this paper aims to evaluate the strength and infiltration rate of porous concrete made using recycled concrete aggregate. The specific objectives are:

i. To find the optimum mixed design with respect to the different proportions of fine aggregate,
ii. To determine the optimum infiltration by partial replacement of NCA with RCA, and
iii. To evaluate the water quality infiltrated through a porous concrete prototype.

II. METHODOLOGY

The following sequence of methods shown in Fig. 1 was implemented for the achievement of the aim and objectives set for this research.

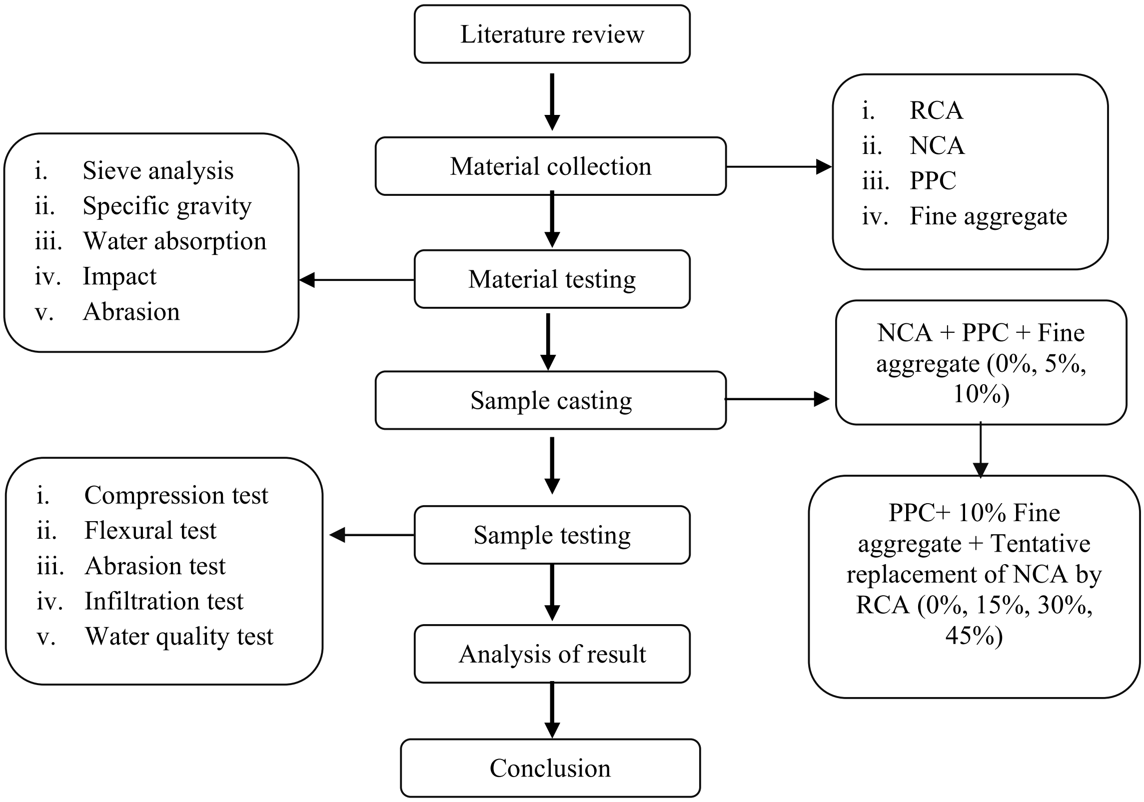

Fig. 1. Methodology chart

2.1 Material Used

The following materials were used for the preparation of samples:

2.1.1 Cement
We used Portland Pozzolana Cement (PPC) of grade 33 conforming to IS: 8112-1989 with the specific gravity of 3. A small amount of fly ash is added to RCA to increase its infiltration. The fly ash provides a significant lubricating effect that drastically decreases the water demand (2% to 10%) [8].

2.1.2 Fine Aggregate
We used the natural sand locally extracted from river bed which is graded as uniformly distributed under zone III conforming to IS: 383-1970. The addition of fine aggregate is limited to 20% for porous concrete since it behaves like the conventional concrete if it is more [8]. Porous concrete is much lighter than conventional concrete as fine aggregate is not used. When compared with conventional concrete, porous concrete was found to be much cheaper as it uses a much lesser amount of cement and has low density. Compressive strength was found to increase with the increment of fine aggregate [9].

2.1.3 Natural Coarse Aggregate (NCA)
We used an aggregate of size 10 mm. Experimentally it was found that the aggregate size of 10mm was recorded for the highest compressive strength test after curing for 28 days [10]. Similarly, the rate of water absorption for 10 mm aggregate was the least compared to the larger size of aggregate used that's 14 mm and 20 mm aggregates [10]. In porous concrete, the size of the coarse aggregate should be between 9.5 mm to 19 mm. Aggregate sizes which do not fall between the above-mentioned ranges should be avoided as it affects the void content. Any variation in void content changes the infiltration and the strength of porous concrete [11].

2.1.4 Recycled Concrete Aggregate (RCA)
We crushed the demolished concrete waste and sieved it confirming to 10 mm size. It was used as a partial replacement for NCA. The properties of the RCA highly depend on the source of the parent material, loading and exposure conditions [12]. The RCA from medium or high strength concrete has slight influences on the concrete properties whereas the lab-sourced RCA has greater influences on the concrete properties [13]. The tested samples with more than 30% of RCA showed a drastic increase in void content and infiltration whereas significantly decreased the strength but 15% of RCA did not significantly affect any of the parameters when compared to the control mix of porous concrete [14]. The greater absorption capacity of RCA can also result in a reduction in workability by effectively reducing the water-cement ratio [15]. The fresh concrete mixtures incorporating RCA commonly experience reduced workability due to the increased absorption capacity of RCA. Therefore, water reducer or the fly ash Pozzolana should be used to improve the workability [16].

Fig. 2. Sample preparation

Fig. 4. Sample casting

2.2 Preparation of Specimen

Firstly, we proceeded with the collection of RCA. RCA was then subjected to various tests and the results were analyzed. As per the mix design ACI 211.3 the material proportion of 4:1(coarse aggregate: cement) is chosen. Throughout the test, the water-cement ratio of 0.38 is maintained. The different cubes' dimensions of 150 x 150 x 150 mm to check the compressive strength and slabs of dimension 304.8 mm x 304.8 mm were cast to carry out the infiltration test by adding 0%, 5% and 10% fine aggregate replacing the NCA. For 0% addition of fine aggregate, 6 cubes were cast to check the strength after 7 and 28 days of curing and 2 slabs were cast to check infiltration after 28 days of curing. Similarly, for 5% and 10% addition of fine aggregate, 6 cubes and 2 slabs were cast. In total, 18 cubes and 6 slabs were cast for the test. After obtaining the proportion of fine aggregate to be added, samples were cast by tentatively replacing NCA with RCA in the percentage of 0%, 15%, 30% and 45% for beams of dimension 100 x 100 x 500 mm in addition to the above two specimens to do the flexural strength test. Samples were then tested and the results were analyzed. After obtaining the optimum mix design, the durability of porous concrete was tested to check its feasibility.

2.3 Mix Proportion

The study was done with the reference to concrete mix proportion of 0.27 to 0.3:1(water: cement), 4 to 4.5:1(aggregate: cement) and 0 to 1:1(fine: coarse aggregate) by mass as per ACI 211.3 [17]. For porous concrete, the mix proportion of cement to coarse aggregate is in a ratio of 1:4.5 which is equivalent to 380 kg/m^3 to 1420 kg/m^3 by weight [18].

III. MATERIAL TESTING

3.1 Specific Gravity Test

The specific gravity test was conducted as per IS:2386-1963 PART 3. The specific gravity obtained for NCA was 2.37 and RCA from demolished concrete waste was 2.4 as shown in Fig. 4. Specific gravity obtained for RCA is more than NCA which signifies RCA is heavier than NCA.

3.2 Water Absorption Test

The water absorption test was conducted as per IS:2386-1963 PART 3. The water absorption obtained for NCA was 0.3 and RCA from demolished concrete waste was found to be 3.56 as shown in Fig. 5. Water absorption obtained for RCA is more than NCA which signify RCA is more porous than NCA.

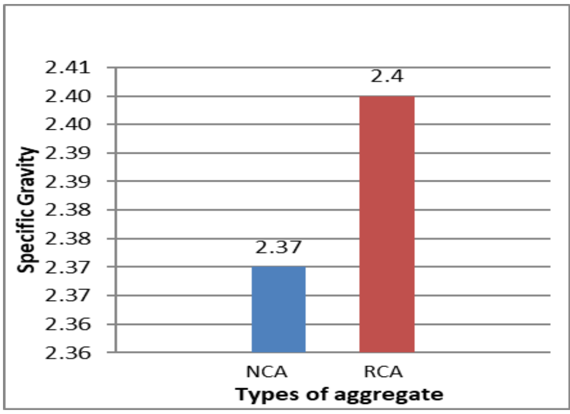

Fig. 3. Specific gravity test results

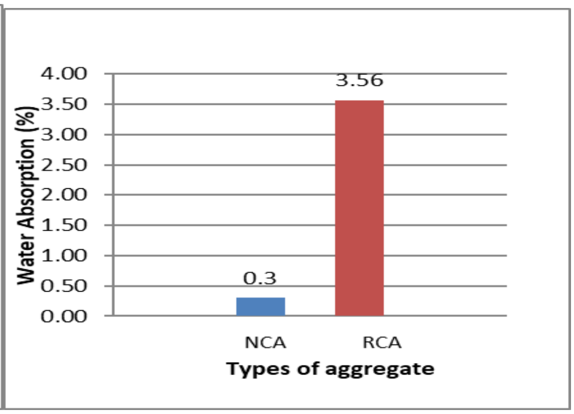

Fig. 4. Water absorption test results

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3.3 Abrasion Test

The abrasion test was conducted as per IS:2386-1963 PART 4. It was conducted using a Los Angeles machine. The abrasion value for NCA was 9.54 and RCA sized from demolished concrete waste was found to be 26.97 as shown in Fig. 6. The abrasion value obtained for RCA is more than NCA which signifies RCA is less resistant to wear than NCA.

3.4 Impact Value Test

The abrasion test was conducted as per IS:2386-1963 PART 4. It was conducted using an impact testing machine. The obtained impact value for NCA was 9.56 and RCA from demolished concrete waste was found to be 8.57 as shown in Fig. 7. The impact value obtained for NCA is more than RCA which signifies RCA is tougher than NCA.

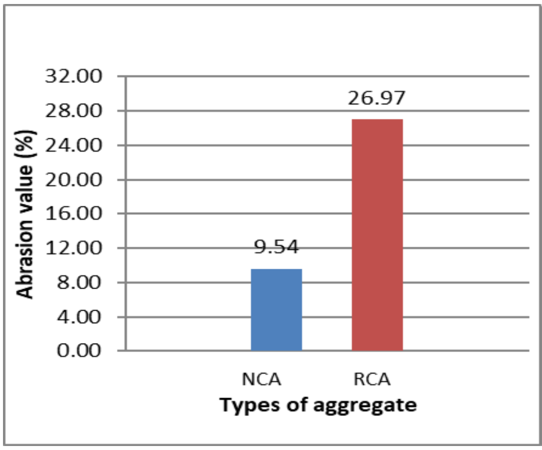

Fig. 5. Abrasion test result

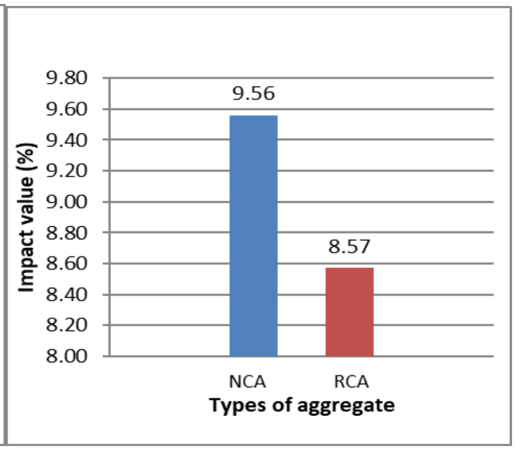

Fig. 6. Impact value test result

IV. RESULT AND DISCUSSION

4.1 Compression Test

A compression test is conducted on a concrete cube prepared from a mix proportion of 4:1(coarse aggregate: cement) with a water-cement ratio of 0.38 for 0%, 5%, and 10% replacement of NCA with fine aggregate as shown in Fig. 10. From the comparative compressive strength shown in Fig. 8, 10% replacement of NCA by fine aggregate gives the maximum strength. It is due to the increase in fine aggregate filling the void of NCA. Therefore, the mix proportion of $1:\frac{2}{5}:3\frac{3}{5}$ (cement: fine aggregate: NCA) is chosen as the optimum mix proportion without RCA. Once the amount of fine aggregate to be added is decided, NCA is partially replaced RCA in the percentage of 0%, 15%, 30% and 45% and compressive strength is determined as shown in Fig. 9.

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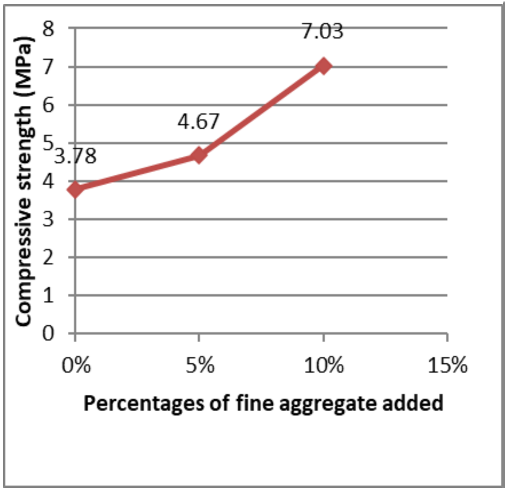

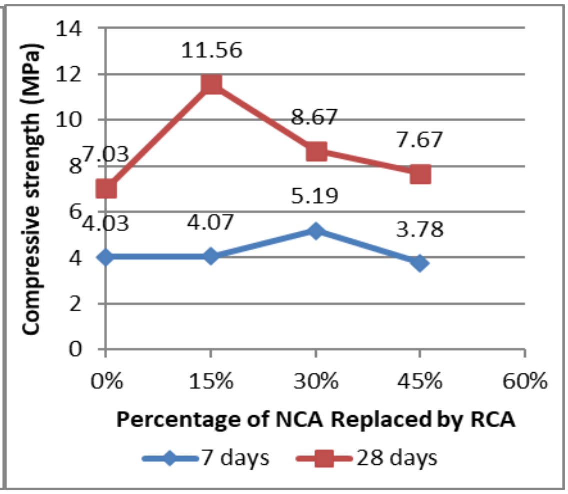

Fig. 7. Compressive test result for partial replacement of NCA by fine aggregate

Fig. 8. Compressive test result for partial replacement of NCA by RCA

Fig. 9. Compression test setup

As the percentage of partial replacement of NCA by RCA increases from 0% to 15%, strength increases but it gets decreases from 30% to 45% replacement of NCA by RCA. From the test result analysis, 30% replacement gives the required strength to be used for pavement. Therefore, the mix proportion of $1: \frac{2}{5} : 1\frac{2}{25} : 2\frac{2}{25}$ (cement: fine aggregate: RCA: NCA) is chosen as the optimum mix design.

4.2 Flexure Test

Flexural or bending test is determined by standard test method of third-point loading or center-point loading done on concrete beam for mix proportion of $1: \frac{2}{5} : 3\frac{3}{5}$ (cement: fine aggregate: NCA) with partial replacement of NCA by RCA in the percentage of 0%, 15%, 30% and 45% as shown in Fig. 11.

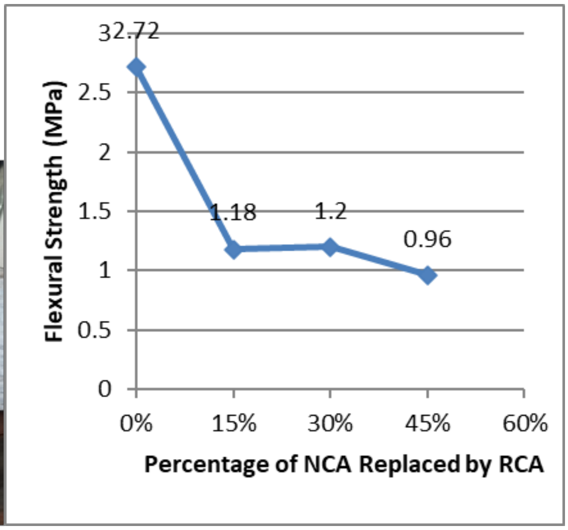

Fig. 10. Flexure test setup

Fig. 11. Flexure test result

The flexural strength of porous concrete decreases gradually with the increase in the percentage of the RCA replacing NCA as shown in Fig. 12. It can also be observed from the graph that at 30% replacement, there is a peak in the strength.

4.3 Abrasion Test

The abrasion test is conducted for conventional pavement and porous concrete (30% NCA is replaced by RCA) to ascertain the resistance of pavement for wearing as shown in Fig. 13. The obtained abrasion value for conventional paver block and porous concrete is 13.82 and 17.54 respectively as shown in Fig. 14. The higher abrasion value for porous concrete signified its less resistance to wear.

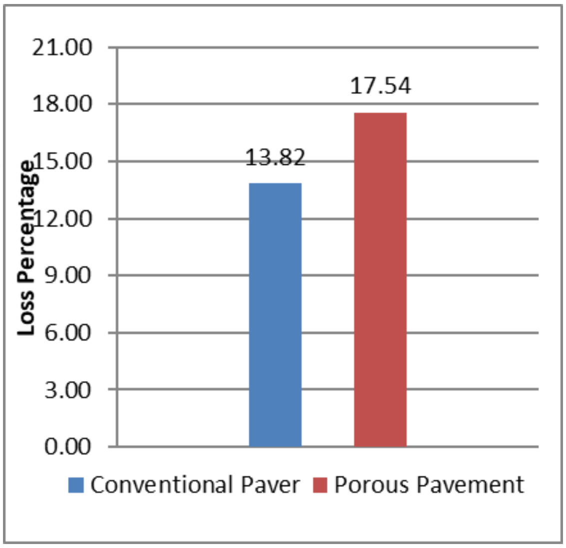

Fig. 12. Abrasion test setup

Fig. 13. Abrasion test result

4.4 Infiltration Test

The infiltration test is carried out using the Single Ring Infiltration Test (SRIT) method (ASTM C1701) on a concrete slab of 304.8 mm x 304.8 mm size with a thickness of 127mm shown in Fig. 17. The slab is made using a mix proportion of 4:1(coarse aggregate: cement) with a water-cement ratio of 0.38 for 0%, 5%, 10% replacement of NCA with fine aggregate and checks its infiltration rate as shown in Fig. 15. Similarly, like a compressive test, 10% replacement of NCA by fine aggregate gives the optimum infiltration rate. From the mix proportion of $1:\frac{2}{5}:3\frac{3}{5}$ (cement: fine aggregate: NCA), NCA is partially replaced by RCA in the percentage of 0%, 15%, 30% and 45% and its infiltration rate is determined as shown in Fig. 16.

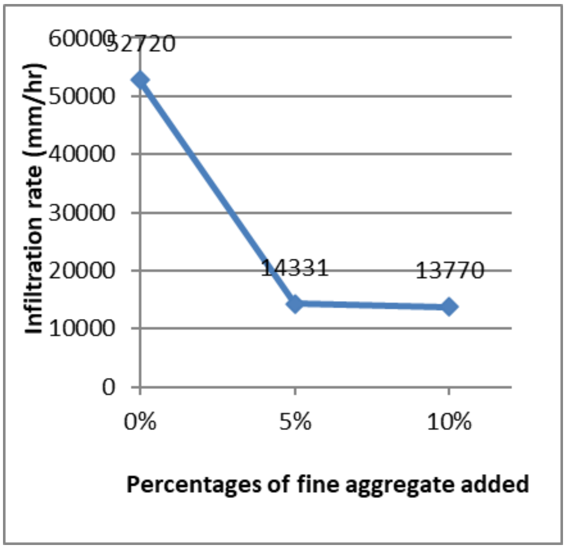

Fig. 14. Infiltration test result for partial replacement of NCA by fine aggregate

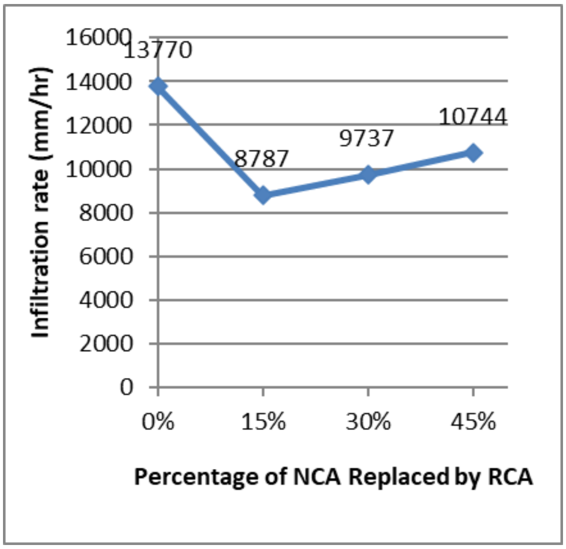

Fig. 15. Infiltration test result for partial replacement of NCA by RCA

Fig. 16. Infiltration test setup

It is observed that when the NCA in a porous concrete cube is partially replaced with RCA, it reduces its infiltration for the first 15% partial replacement but it gets increases when its replacement is more than it.

The peak intensity of rainfall in the southern region of Bhutan is much below 9737 mm/hr from 30% replacement of NCA by RCA. It further supports the mix proportion $1: \frac{2}{5} : 1\frac{2}{25} : 2\frac{2}{25}$ (cement: fine aggregate: RCA: NCA) as the optimum mix design.

4.5 Water Quality Test

The stormwater runoff through the impervious surface is transported into the surface water harming the aquatic habitat and contaminating the drinking water. The water quality check is, therefore, conducted to evaluate whether the porous concrete detention system can reduce the pollutants from the runoff. The prototype was designed as per ASTM C-33. A prototype has an area of 600 mm x 600 mm with a depth of 101.6 mm to 152.4 mm. The slope of the subgrade is maintained at less than 5% and porous concrete is placed over it as shown in Fig. 18.

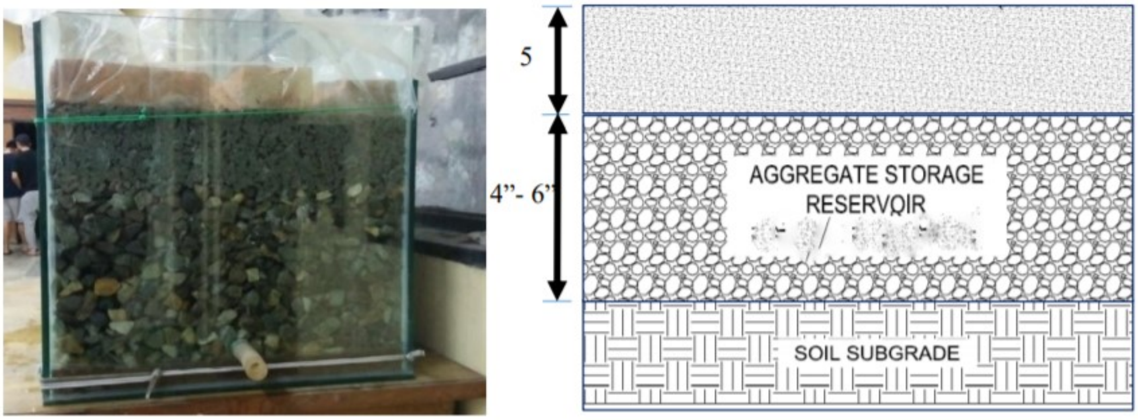

Fig. 17. Infiltration test prototype and layout

The raw rainwater was filtered through the pavement system and checked for water quality. The following water quality parameters are checked for two samples, stormwater before and after filtering through the prototype.

4.5.1 pH test

TABLE 1. Tabulated values of pH

Sample	Temperature ofSample (˚C)	pH
Raw stormwater	25	6.85
Filtered stormwater	25	11.18

From the result, obtained raw stormwater is slightly acidic in nature but infiltrate raw watershows basic in nature

4.5.2 Acidity test

TABLE 2. Tabulated Values of acidity

Sample	Acidity (mg/l as CaCO3)		
	Mineral(pH 4.4)	Total (pH8.3)	Carbon dioxide
Raw stormwater	0	16	16
Filtered stormwater	0	0	0

From the result obtained, raw stormwater shows the presence of acid in rainwater but infiltrating stormwater shows an absence of acid in water.

V. CONCLUSION

Based on the result, observation and discussion following conclusions were drawn:

The obtained specific gravity for NCA was 2.37 and RCA from demolished concrete waste was 2.4. Specific gravity obtained for RCA is more than NCA which signifies RCA is heavier than NCA
The obtained water absorption for NCA was 0.17 and RCA from demolished concrete waste was found to be 3.56. Water absorption obtained for RCA is more than NCA which signifies RCA is more porous than NCA
The obtained abrasion value for NCA was 9.54 and RCA sized from demolished concrete waste was found to be 26.97. The abrasion value obtained for RCA is more than NCA which signifies RCA is less resistant to wear than NCA.
The obtained impact value for NCA was 9.56 and RCA from demolished concrete waste was found to be 8.57. The impact value obtained for NCA is more than RCA which signifies RCA is tougher than NCA.
When the percentage of fine aggregate replacing the NCA increases, infiltration reduces but strength increases. It is found that 10% replacement of NCA by fine aggregate gives the optimum replacement based on strength and infiltration characteristics.
From the different mix proportions, $1: \frac{2}{5} : 1\frac{2}{25} : 2\frac{2}{25}$ (cement: fine aggregate: RCA: NCA) is found as the optimum mix design for porous concrete pavement. It is found that 30% replacement of NCA by RCA gives the optimum percentage replacement with compressive strength of 8.67 MPa, the infiltration rate of 9737 mm/hr and flexural strength of 1.2 MPa.
Stormwater after infiltrating through the prototype becomes basic in nature.

To draw the overall conclusion on this topic, the following further studies were recommended:
The study beyond 10% partial replacement of NCA by natural fine aggregate. Since it was limited to 0% to 10% based on the literature review.
The minimal interval on partial replacement of NCA by RCA is recommended for in-depth analysis. For this study, a 15 % interval was chosen. And also, beyond 45% replacement is suggested.
The bonding behavior of the material within the porous concrete.
The different mix design ratio. In this study, a constant mix design ratio of 1:4 (cement: Aggregate) was tested based on a literature review.
The life cycle cost analysis of RCA is recommended in addition to its strength and infiltration rate.
The water quality test on different parameters other than pH and acidity to ascertain its filtration capacity.

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