

# Mechanical Properties of Pavement Quality Concrete Using Recycled Aggregate

K.Poongodi, P.Murthi, R.Gobinath, A.Srinivas, G.Sangeetha

**Abstract:** The mechanical properties of pavement quality concrete using recycled concrete aggregate (RCA) obtained from the concrete debris as coarse aggregate (CA) are experimentally determined and presented in this paper. M40 grade concrete was tested with conventional granite CA before adding RCA and then CA was replaced by RCA at the rate of 10, 20, 30, 40 and 50%. The concrete was tested in fresh state by slump and compaction factor (CF) value to evaluate variations in workability. The compressive strength and flexural strength of concrete were conducted to ascertain performance in hardened state. The water absorption test was conducted as a part of durability test. The gradual reduction of slump value was noticed after adding RCA as aggregate in concrete. The slump value had been maintained by substituting the superplasticizer without varying the w/c ratio. The strength properties were calculated after 3, 7 and 28 days curing. No significant reduction of strength was observed up to the 30% replacement of RCA and the strength was reduced by adding more than 30% of RCA. From the results obtained in this investigation, it was concluded that the RCA could be used up to 40% as CA for pavement quality concrete.

**Key words:** Recycled aggregate, Pavement quality concrete, Mechanical properties, Water absorption

## I. INTRODUCTION

High quality concrete layer lay over top of rigid pavement or cement concrete road is known as Pavement Quality Concrete (PQC). PQC is a special type of Plain Cement Concrete (PCC) and should be hard and strong enough to distribute the wheel load of vehicles to bottom layers without any deformation. PQC is also called as very low workable concrete [1]. Lower slump and higher compaction factor are required for manually prepared PQC. The expected slump and CF of PQC are  $30 \pm 15$  mm and 0.85 respectively for mechanically prepared concrete [2]. PQC is relatively better durable but lesser flexibility and hence rebars are inserted at joints of the concrete

namely tie rod and dowel bars according to the technical requirements of the pavement. Aggregates are inert materials in concrete and considered as volumetric materials in concrete. The aggregates are occupied nearly 70 - 80% of the volume of concrete in which more than 50% is occupied by coarse aggregate (CA) [3]. Coarse aggregates should be clean, hard, strong, non-porous pieces of crushed stone. The maximum size shall not exceed 25 mm. The steps are continuously taken by both central and state governments to improve the performance of existing pavements to meet future necessities and also proposed for new concrete road projects. Hence demand for CA portion is always exist. The researchers are taking steps to find alternate to natural CA by considering industrial byproduct [4-6], agricultural solid waste [3, 7] and building debris [8-9]. The usage of RCA is a century old practice in conventional construction. However the research activities are performed to apply RCA in modern structural concrete. RCA is usually obtained from demolished concrete debris and covered old adhered mortar. The concrete debris are always to be processed for suitability in new concrete for getting superior quality concrete. The expected quality of RCA was obtained by removing unwanted old mortar portions stick in the debris before use as aggregate in new concrete [10]. The water absorption and surface porosity of the RCA is higher than the conventional granite aggregate [11]. Adding RCA in normal concrete is reported that the compressive strength is decreased up to 20% than the conventional CA concrete [12-13]. The reductions in flexural strength and durability of RCA based concrete are noticed in various research findings [14-15]. The reports on increasing the carbonation depth and permeability are also presented by few results [15-16]. The review from the various studies reported that the reduction of mechanical and durability properties of RCA based concrete is attributed to the old mortar stick in the RCA. Various methods are used to eliminate stick mortar portion in RCA for improving the performance of RCA. Thermal treatment [17] and Acid treatment [17-18] are the examples of treatments to remove the old mortar portions in RCA. In this background, the present investigation is intended to evaluate appropriateness of RCA in PQC based on the compressive strength, flexural strength test and absorption test. RCA used in the study were processed in the laboratory by acid treatment.

## II. EXPERIMENTAL INVESTIGATION PROGRAM

### A. Materials considered

#### 1. Cement

Market available cement meeting the requirements to IS: 269-2015 [19] was utilized throughout investigation. Fineness was determined as  $257\text{m}^2/\text{g}$  and the specific gravity was calculated as 3.147. The chemical compositions are presented in Table 1.

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## 2. Aggregates

The sand was selected from the local river bed and screened before use as fine aggregate. As per the laboratory investigation, the FA found fit in to grade zone-II and fineness modulus of 2.67. The specific gravity of FA was determined as 2.62 and silt content was less than 1%. The natural granite CA of maximum size 20mm available from the local market was utilized in this investigation. RCA was collected from local debris and screened by 40 mm sieve to remove unwanted materials and separation of RCA particles of less than 40 mm. The passing RCA through 40 mm size sieve was crushed in to smaller particle in a ball mill and the larger size (more than 40 mm size) are allowed to break into smaller size by mechanical crushing machine. The aggregate content below 40mm was isolated from this process and allowed to treatment for removal of adhered mortal portions. In this process, the selected RCA samples were pre-soaked in 0.1 molar of H<sub>2</sub>SO<sub>4</sub> solution and abrasion process was followed to remove adhered mortar. Before using this processed RCA in concrete, it was allowed to saturate and dried in sun light for 24 hours. Both the natural CA and processed RCA was tested to ascertain the physical properties as per IS 2386 (Part III and IV) [20-21] and the results are shown in Table 2. The samples of natural granite aggregate and RCA used in this investigation are shown in Fig.1.

## 3. Chemical admixtures

Market available superplasticizer (Conplast SP430SRV from Fosroc Chemicals India Pvt Ltd) was utilized in this investigation to maintain desired slump in concrete mixes. The specific gravity of the superplasticizer was evaluated and reported as 1.26 with no chloride content.



(b) Recycled Concrete Aggregate

Figure 1. Aggregate

## 4. Mix proportioning

M40 grade concrete was proposed in this investigation and the mix proportioning was determined as per the guidelines suggested in IRC: 15-2011[22]. After various trials, the final mix proportion of M40 grade concrete was selected and shown in Table 3. The control concrete was designated as RCA0, where '0' represents the percentage of RCA addition in the concrete. The natural CA was replaced by RCA at 10, 20, 30, 40 and 50% by weight of CA. The desired quantity of superplasticizer was added to maintain the workability of RCA added PQC up to the level of control concrete. The water cement ratio was maintained as 0.45.



(a) Granite Aggregate

Table 1. Chemical compositions of cement

Components	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	LoI
Composition (%)	23.27	5.17	3.93	62.37	1.70	1.33

Table 2. Physical properties of Aggregates

Type of CA	Specific Gravity	Fineness modulus	Water absorption	Grade zone
Granite	2.78	7.19	2.07	Zone - II
RCA	2.69	7.33	3.12	Zone - II

**Table 3. Mix proportioning of M40 grade PQC**

Mix Designation	Cement (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	CA (kg/m <sup>3</sup> )	RA		W/C	Water (l/m <sup>3</sup> )	SP (%)
				(%)	(kg/m <sup>3</sup> )			
RCA0	400	720	1090	0	0	0.45	180	0
RCA10	400	720	981	10	109	0.45	180	0.1
RCA20	400	720	872	20	218	0.45	180	0.2
RCA30	400	720	763	30	327	0.45	180	0.3
RCA40	400	720	654	40	436	0.45	180	0.4
RCA50	400	720	545	50	545	0.45	180	0.5

**B. Testing methods**

*1. Workability*

The slump value and compaction factor tests were conducted to evaluate workability of the fresh PQC according to the guidelines suggested by IS: 1199-1959 [23] and slump value test is shown in Fig. 2. The CF test is used for concrete which have low workability. The compactor factor test is conducting in the laboratory environment as shown in Fig. 3.

*2. Compressive strength*

Compressive strength of PQC was conducted using motorized compression testing machine and the loading was applied at a rate of 2.5 kN/s as per IS: 516-1959 [24] as shown in Fig.4. The cube specimen of 150 x 150 x 150 mm size was casted and strength was investigated after the curing periods of 3, 7 and 28 days immersed in curing tubs.

*3. Flexural Strength Test*

Flexural strength was investigated with 100mm x 100mm x 500 mm size prisms as per IS: 516-1959[24] in a single point loading set up as shown in Fig.5. The rate of load applied was maintained at a rate of 1.85 kN/s. The Flexural strength was calculated using the formula:

$$f_t = \left[ \frac{PL}{bd^2} \right]$$

Where,  $f_t$  = modulus of rupture

P = maximum load applied

b = breadth

d = failure point depth

L = supported length



**Fig. 2. Slump test**



**Fig. 3. Compaction Factor Test**

*4. Water absorption test*

Concrete cubes of 150 mm size are allowed to dry for 24 hours and measured dry initial weight ( $W_1$ ). The oven dried specimens are dipped in water for 24 hours and measured saturated weight ( $W_2$ ). The rise in weight expressed in percentage of its original dry weight is the water absorption of concrete [25].

$$\text{Water absorption (\%)} = \left[ \frac{(W_2 - W_1)}{W_1} \right] \times 100$$



**Fig.4. Compressive strength test**



**Fig.5. Flexural strength test**

### III. RESULTS AND DISCUSSION

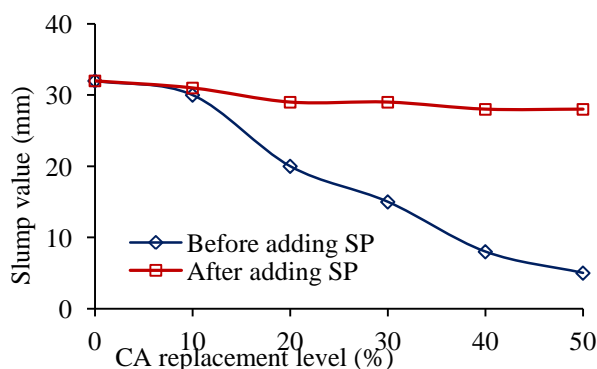
#### A. Workability

##### 1. Slump test

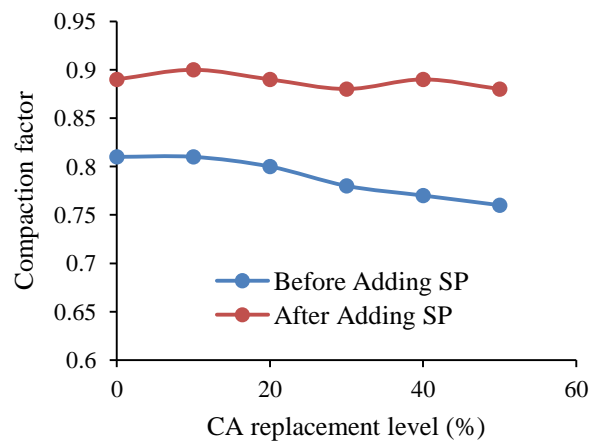
The workability of fresh PQC was measured using slump test. The results of slump value of PQC after adding RCA are shown in Fig.6. The slump value of the control PQC was observed as 32mm. The steady losses in slump was observed while adding RCA. The substitution of 10% RCA had shown the slump value of PQC as 30 mm and the slump value decreased up to 5 mm when 50% addition of RCA. The reduction of workability after addition of RCA is noticed due to relatively higher absorption behaviour of RCA than the conventional aggregate [26]. However the slump value had sustained between 28 mm to 32 mm by adding SP in order to avoid excessive manual compaction to maintain cohesiveness of fresh concrete. The results of slump value after adding SP is shown in Fig. 6.

##### 2. Compaction factor test

The results of CF tests of PQC using RCA are shown in Fig.7. The compaction factor of PQC was observed without any significant reduction up to 20% replacement of CA by RCA and reduced up to 0.76 after adding 50% RCA. However the PQC was developed with SP to maintain the cohesiveness and then the compaction factor was observed in the range of 0.88 to 0.9 and shown in Fig. 9. The specimens of mechanical and durable properties of PQC were prepared by mixing SP along with other ingredient for the investigations [10].



**Fig.6 Slump value of RCA concrete**



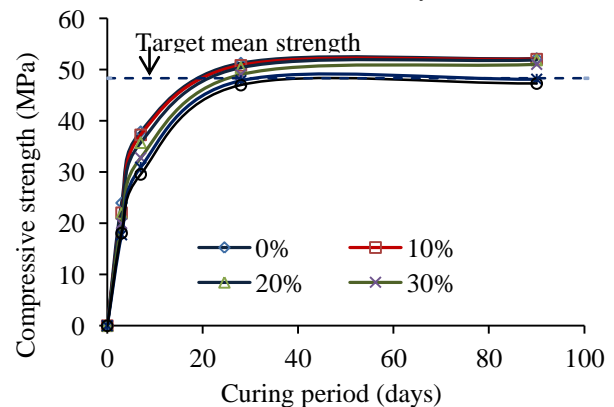
**Fig.7 Compaction factor of RCA concrete**

##### 3. Compressive strength

The compression strength development of PQC with RCA in all the curing period is shown in Fig.8. The insignificant reduction of compressive strength was noticed when conventional CA was replaced by RCA. In the meantime 28 days target strength of designed concrete was considered as threshold limit in strength of the concrete. The substitution of RCA up to 30% achieved the target strength of M40 as per the design stipulation. However, the results obtained from 40% of RCA added PQC was noticed nearer to the Target strength and 50% of RCA in PQC had shown lower than the target value of concrete at 28 days curing period. The similar reduction was observed in all the curing period of the specimen. The strength reduction may be attributed due to the improper bonding between paste and RCA content in the concrete [9,10].

##### 4. Flexural strength

The flexural strength of 28 days cured PQC with and without the RCA is shown in Fig.9. The flexural strength of control PQC was determined as 4.94 MPa and the substitution of 10% RCA had shown the value of 4.99 MPa. The insignificant improvement of flexural strength of PQC was observed up to 20% replacement of conventional aggregate by RCA. Further addition of RCA reduces the flexural strength than that of control concrete. However the variations are observed less than 3% only.



**Fig.8 Compressive strength development of RCA concrete**

5. Correlation between Compressive and Flexural strength

The correlation between compressive strength and the flexural strength of PQC with RCA as aggregate is shown in Fig.10. For normal concrete, IS:456-2000 [27] has suggested the same relationship as  $0.7 \sqrt{f_{ck}}$ . However, the correlation between the compressive strength and flexural strength was predicted as  $f_t = 0.581(f_{ck})^{0.545}$  with higher correlation co-efficient in this investigation. Similar kind of relationship was developed for polypropylene fibre reinforced concrete which shown higher values due to the ductile nature of fibre reinforced concrete [28], high strength concrete which shown similar to the IS code recommendations[29] and roller compacted concrete with lower values since naturally roller compacted concrete having zero slump [30].

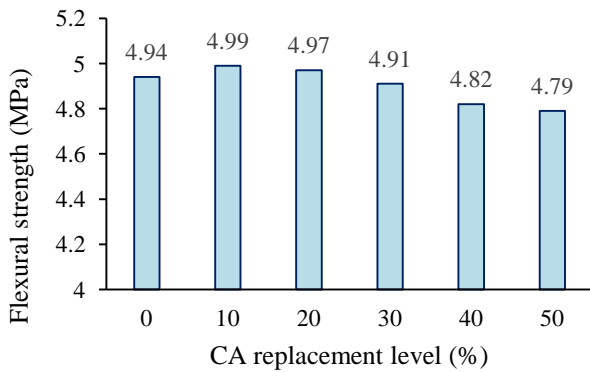


Fig.9 Flexural strength variation of 28 days cured RCA concrete

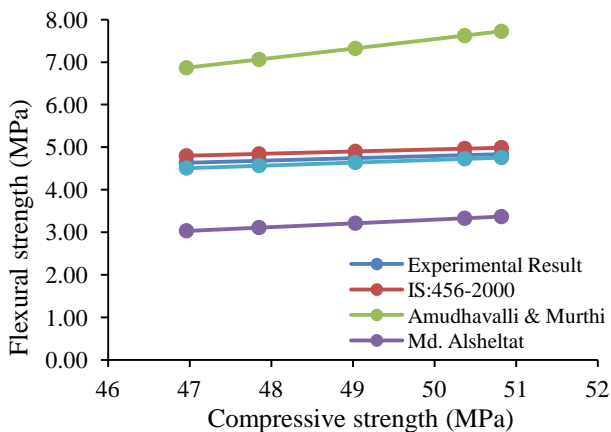


Fig.10 Relationship between compressive and flexural strength

6. Water absorption

The water absorption of 28 days cured PQC with and without the RCA is shown in Fig.11. The water absorption of control PQC was determined as 2.33% and the substitution of 10% RCA had shown the value of 2.43%. The significant linear increase in water absorption of PQC was detected while increasing replacement of conventional aggregate by RCA. The increase in water absorption of 50% RCA based PQC was noted up to 34.33%. However the

water absorption of PQC with RCA is within acceptable limit.

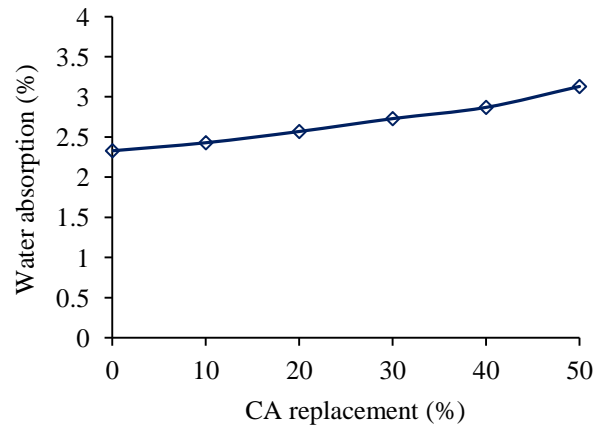


Fig.11 Water absorption

IV. CONCLUSION

Based on the investigation, the following inferences were drawn:

1. The workability of PQC was steadily decreased while adding RCA instead of granite aggregate based on the results obtained from the slump cone test and compaction test.
2. There was no significant reduction of strength noticed up to 30% substitution of RCA. Meantime, the results of 40% RCA added PQC was observed nearer to target strength and 50% of RCA in PQC had shown lower than the target value of concrete at 28 days curing period.
3. The insignificant reduction on flexural strength of the PQC was detected after the addition of 30% RCA.
4. The correlation between the compressive and flexural strength of PQC was predicted as  $f_t = 0.581 (f_{ck})^{0.545}$  with higher correlation co-efficient and the results evidences similar to the IS code provisions.
5. The significant linear increase in water absorption of PQC was observed while increasing the replacement of conventional aggregate by RCA.
6. With the help of results, it is resolved that the RCA could be used up to 40% as CA for PQC.

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