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# Properties of Pavement Quality Concrete Prepared with Recycled Coarse Aggregate

**P. Murthi, Almas Khan, K. Poongodi, R. Gobinath**

***Abstract:** The investigation is intended to evaluate the impact of substitution of demolished concrete debris as coarse aggregate (CA) in pavement quality concrete (PQC). The strength characteristics of PQC such as compressive strength, tensile strength, flexural strength and impact strength after adding recycled coarse aggregate (RCA) are experimentally determined in laboratory environment. Specimens of M30 grade concrete were prepared and tested. The RCA was substituted up to 50% by replacing CA content. Based on the investigation results, it was found that reduction of slump value due to the substitution of RCA in concrete. There is no remarkable reduction of compressive strength and flexural strength up to 30% and 40 % replacement of CA respectively in all the curing periods. The impact strength was reduced due to addition of RCA and observed 8% reduction after adding 20% RCA. It is suggested that RCA may be used up to 20% as CA in PQC.*

***Key words:** Pavement quality concrete, Recycled aggregate, Flexural strength, Impact strength*

## I. INTRODUCTION

The pavements are basically two types such as Flexible and Rigid pavement. Flexible pavements are basically negligible flexural strength whereas rigid pavement has acts as a structural member having slab action and has sufficient flexural strength while transmitting vehicle axle load to the subgrade. Pavement Quality Concrete (PQC) is normally employed for providing a strong surface of rigid pavements. PQC is also used for construction of runways in airports in order to distribute the heavy impact load from wheel to sub-grade layers [1]. The conventional normal grades concrete are not technically suitable for preparing PQC and hence it is recommended to develop M30 grade and more to achieve the requirements of PCQ [2]. Lower w/c ratio is considered for getting higher strength and hence the slump value is relatively lower than that of same grade of conventional concrete. Apart from the cementitious materials, aggregate content also plays vital role for strength development of PQC. Both fine aggregate (FA) and CA are cautiously selected before preparing the PQC and free from any dirt deposit. The hard and clean CA of maximum size of 20-25mm is only suitable for developing PQC.

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Corresponding Author
***Dr.P.Murthi***, Professor, Centre for Construction methods and Materials, Department of Civil Engineering, S R Engineering College, Warangal, dr.murthi@srecwarangal.ac.in.
**Almas Khan,** Final year UG student, Department of Civil Engineering, S R Engineering College, Warangal.
**Dr.K.Poongodi,** Professor, Department ofCivil Engineering, S R Engineering College, Warangal.
**Dr.R.Gobinath,** Professor and Head, Department of Civil Engineering, S R Engineering College, Warangal.



Based on the literature evidences, it is said to be that the research activities are carrying out all over the world to identify the suitable alternate to the aggregate to meet the future demands [2-7]. The industrial by-products [3-7] and building debris [1, 8-14] are being considered for the research activities to meet performance of structural concretes.

The debris obtained from demolished building waste is not suitable for direct substitution to concrete instead of CA [14]. The old concrete wastes are to be prepared to suit as CA in concrete since the old mortar portions are normally adhered in the hardened concrete debris which causes the reduction in the required performance of concrete [14-16]. The RCA has to be upgraded properly by removing the unwanted old mortar deposits before using as CA. The concrete, which is used for construction of rigid pavement, requires more impact energy absorption characteristics. Toughness is defined as the total energy absorbed prior to complete failure of the specimen. Under these circumstances, the RCA is proposed for developing PQC and this investigation is intended to evaluate the suitability of RCA with respect to the strength characteristics of PQC.

## II. MATERIALS AND EXPERIMENTAL METHODS

### A. Materials Used

#### 1) Cement

Portland Pozzolana Cement (PPC) cement as per the requirements to IS: 1489-1991 (Part-I) [17] was used in this study. The physical properties such as fineness and specific gravity were determined and found as 276 $m^2/g$ and 3.15 respectively. The chemical compositions of cement are shown in Table 1.

**Table 1. Chemical compositions of cement**

| Components | Composition (%) |
|---|---|
| $SiO_2$ | 24.12 |
| $Al_2O_3$ | 5.21 |
| $Fe_2O_3$ | 3.83 |
| CaO | 61.73 |
| MgO | 1.58 |
| LoI | 1.02 |

#### 2) Aggregates

Locally available river sand conforming to grade zone – II [18-19] was used as FA. The fineness modulus and specific gravity of river sand was determined and found as 2.65and 2.76 respectively. The 20 mm size CA was collected from nearby rock mines and tested for suitability. The specific gravity and fineness modulus of CA were determined as 2.76 and 7.07 respectively.

The concrete waste collected from building debris and separated from the undesirable materials presence in the debris. The concrete waste is allowed to reduce the size by crushing and 20 mm size RCA was collected for further process of removal of old mortar presents in RCA. The selected quantity of RCA was immersed in 0.1 molar of $H_2SO_4$ solution to remove adhered mortar. Further the treated RCA is allowed to saturate and dried for 24 hours before using as CA in PQC. The suitability of RCA is tested and found the specific gravity and fineness modulus was 2.69 and 7.33 respectively. The grain size distribution curve for CA and RCA are shown in Fig. 1. The crushing value and impact value of all combination of aggregates are shown in Table 2.

### 3) Mix proportioning

M30 grade concrete was considered in this investigation and the mix proportioning was arrived as per IRC: 15-2011[20]. The final mix proportion for 1m$^3$ of the proposed grade of PQC was selected after various trials of investigations and shown in Table 3. The natural CA was replaced by RCA at 10, 20, 30, 40 and 50% by weight of CA.

**Table 2. Crushing and Impact strength of CA and RCA**

| CA (%) | RCA (%) | Crushing strength (%) | Impact strength (%) |
|---|---|---|---|
| 100 | 0 | 12 | 14 |
| 90 | 10 | 15 | 17 |
| 80 | 20 | 19 | 21 |
| 70 | 30 | 21 | 23 |
| 60 | 40 | 24 | 25 |
| 50 | 50 | 28 | 29 |

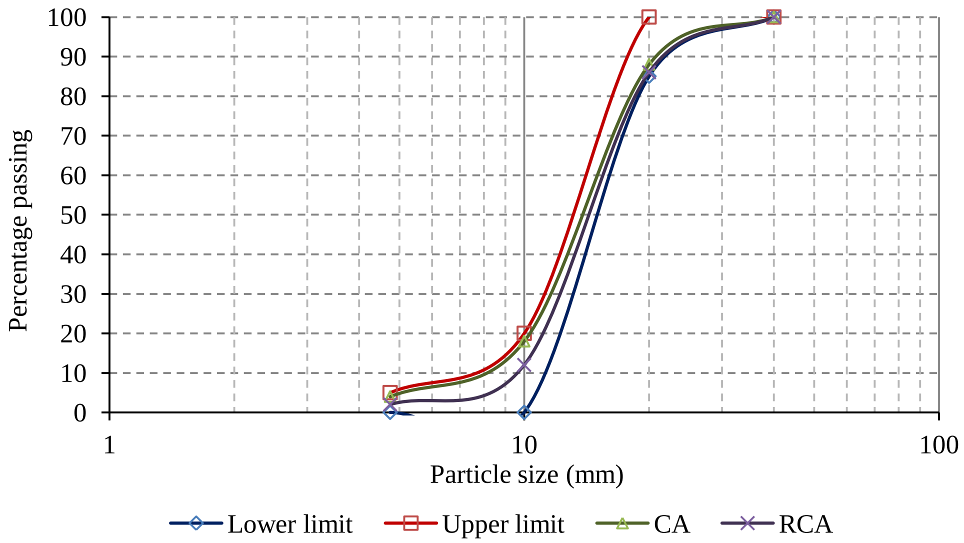


**Figure 1. Grain size distribution of CA and RCA Samples**

**Table 3. Mix proportioning of M30 grade PQC**

| Mix ID | Cement (kg/m$^3$) | Sand (kg/m$^3$) | CA (kg/m$^3$) | RCA | | W/C | Water (l/m$^3$) |
|---|---|---|---|---|---|---|---|
| | | | | % | (kg/m$^3$) | | |
| R0 | 362 | 747 | 1113 | 0 | 0 | 0.47 | 170 |
| R10 | 362 | 720 | 1002 | 10 | 111 | 0.47 | 170 |
| R20 | 362 | 720 | 890 | 20 | 223 | 0.47 | 170 |
| R30 | 362 | 720 | 779 | 30 | 334 | 0.47 | 170 |
| R40 | 362 | 720 | 668 | 40 | 445 | 0.47 | 170 |
| R50 | 362 | 720 | 556 | 50 | 557 | 0.47 | 170 |

## B. Testing methods

### 1) Workability

As per IS: 1199-1959, the slump cone test wasperformed to appraise workability of the fresh PQC [21] and slump value test is shown in Fig. 2. The compactor factor (CF) test wasconducted since the workability of PQC was noticed as low slumpvalue and shown in Fig. 3.

### 2) Compressive strength

Compressive strength of PQC was determined using 150 x 150 x 150 mm size cube specimens and average results obtained from three specimens was considered as the result of the investigation. Motorized compression testing machine was utilised as per IS: 516–1959 [22] and the rate of loading was maintained as 2.5 kN/s [23] and as shown in Fig.4.

The compressive strength test was conducted after the curing periods of 3, 7 and 28 days.

**3) Flexural Strength Test**

Flexural strength was investigated with 100mm x 100mm x 500 mm size prisms as per IS: 516–1959[22] in a single point loading set up as shown in Fig.5. The applied load 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 applied load
b = breath of the beam
d = depth at failure point
L = supported length

**4) Impact strength test**

The impact test of concrete was conducted in the accordance with ACI 544.2R-89 as shown in Fig. 6. The concrete disc of 152 mm diameter and 63.5 mm thickness was prepared and tested with drop hammer testing machine. The hammer weight is 44.5 N and height of drop is 457 mm. The impact load was loaded over a 63.5 mm steel ball which was located over the concrete disc. The number of blows required to produce initial crack (N1) and the number of blows needed to cause complete failure (N2) was noted. From the observations of number of blows, the impact energy was calculated using the formula

$$E_I = Nwh$$

Where, $E_I$ = impact energy (N-m),
N = number of blows,
w = weight of the drop hammer (N),
h = height of drop hammer (m).

**Fig. 2. Slump test**

**Fig. 3. Compaction Factor Test**

**Fig.4. Compressive strength test**

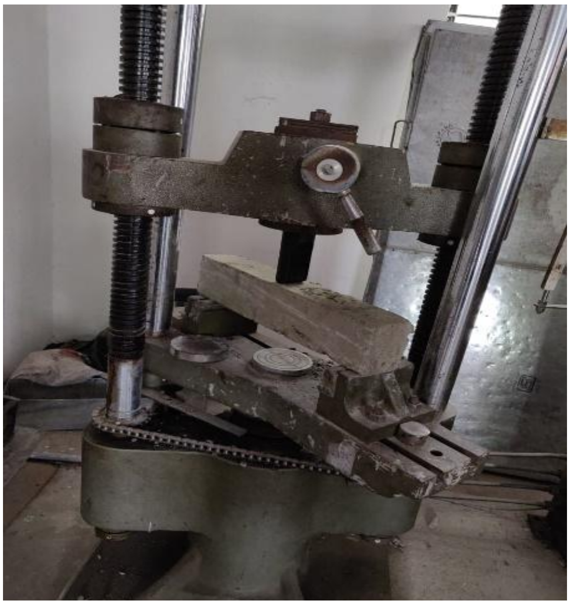

**Fig.5. Flexural strength test**

Fig.6. Impact strength test

## III. RESULTS AND DISCUSSION

### A. Workability

#### 1) Slump test

The slump test was conducted to determine workability of fresh PQC and the results are shown in Table 4.The slump value of PQC with natural CA was measured as 28 mm. When CA was replaced by RCA, the slump value was reduced linearly from 28 mm to 6 mm after adding 50% RCA as shown in Fig.7. The noticed reduction of slump value after addition of RCA is mainly due to morewater absorption of RCA than the natural CA [10-11].

#### 2) Compaction factor test

Compaction factor (CF) was conducted due to the lower value of workability after adding RCA in PQC. The results of CF tests of PQC using RCA are shown in Table.4. The linear reduction of CF was observed due to the replacement of CA by RCA and reduced up to 0.68 after adding 50% RCA from 0.8 without replacement of CA as shown in Fig.8. The reduction of CF was realised due to higher absorption behaviour of RCA than the natural CA

**Table 4. Workability test results**

| Mix ID | CA replacement level (%) | Slump value (mm) | Compaction factor |
|---|---|---|---|
| R0 | 0 | 28 | 0.8 |
| R10 | 10 | 22 | 0.78 |
| R20 | 20 | 18 | 0.74 |
| R30 | 30 | 14 | 0.72 |
| R40 | 40 | 10 | 0.7 |
| R50 | 50 | 6 | 0.68 |

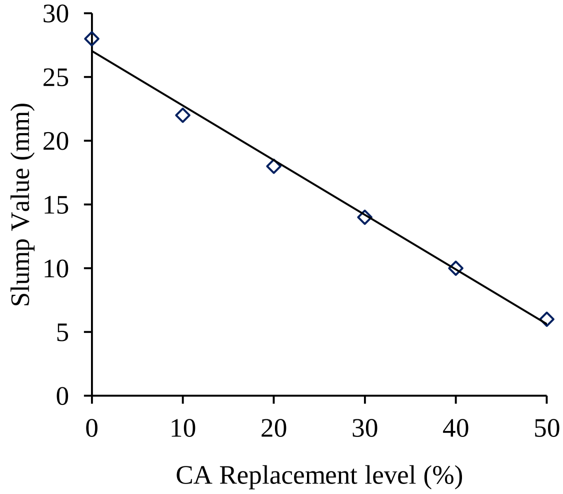


Fig.7. Slump test

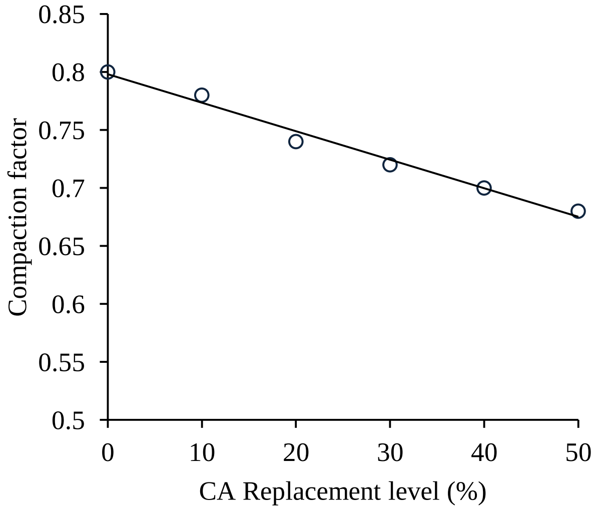


Fig.8. Compaction factor test

### B. Strength Properties of PQC

#### 1) Compressive strength ($f_{ck}$)

Compression strength variations in all the curing period with and without RCA in PQC are shown in Fig.9. The strength at 90 days curing was observed an insignificant improvementcompared to 28 days strength. The strength development after 28 days may be due to the continuous reaction of pozzolanic material present in PPC and hence prolonged curing after 28 days can give more strength due to formation of secondary reaction. An insignificant level of strength reduction was noticed when natural CA was replaced by RCA. The addition of 30% RCA had attained the expected target mean strength of M30 concrete.Further substitution of RCA reduced the strength beyond the target mean strength and concluded that the strength reduction may be due to the improper bonding between paste form and RCA.

**2)Flexural strength ($f_t$)**

The flexural strength of 28 and 90 days cured PQC with and without the RCA is shown in Fig.10. The flexural strength of control PQC was determined as 4.01and 4.29 MPa at 28 and 90 days curing respectively. The substitution of 10% RCA had shown the flexural strength of 4.06 MPa for 28 days cured specimen and 4.28 MPa for 90 days cured specimen. The unimportant variations in flexural strength of PQC were determined up to 20% replacement of natural aggregate by RCA. Further addition of RCA reduces the flexural strength than that of control concrete [15]. However the variations are observed less than 3% only. In all the cases 28 days flexural strength of PQC is 10% of compressive strength and results are shown in Table 5.

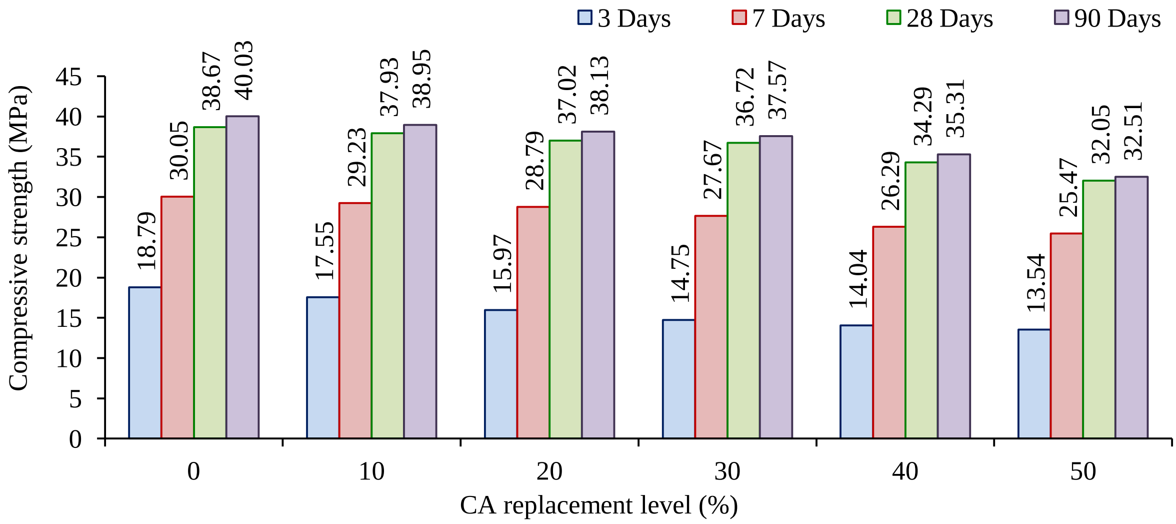


**Fig.9. Compressive strength of PQC with and without RCA**

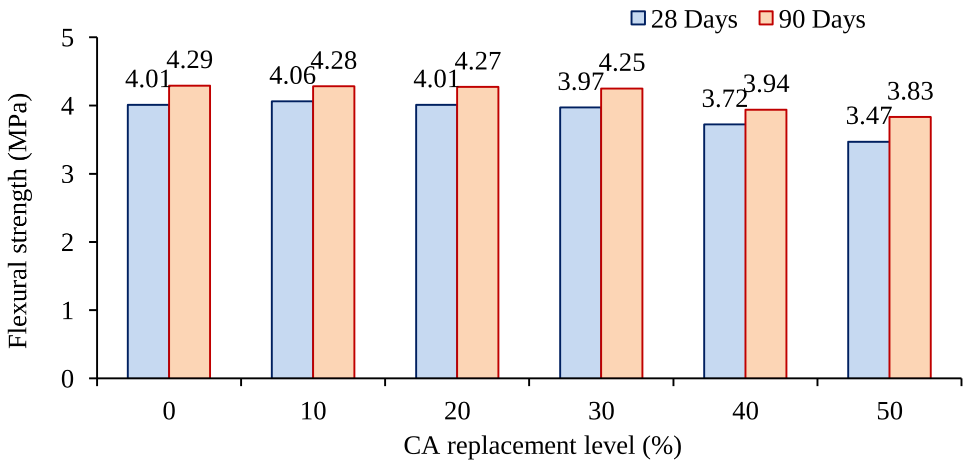


**Fig.10 Flexural strength of 28 and 90 days cured PQC concrete with and without RCA**

**3)Impact strength test**

The variations in impact energy in 28 days curedspecimen with and without RCA in PQC are shown in Fig.11. The impact energy values are calculated against the initial crack and final crack before failure. The impact energy of PQC was gradually decreased while increasing the RCA presence in concrete. The reduction is attributed due to the lower crushing and impact strength of RCA. Only 2% reduction of impact energy was noticed while adding 10% RCA and the reduction of 8% after adding 20%RCA was observed. Further substitution of RCA reduced the impact by gradually.

## IV. CONCLUSION

Based on the investigation, the following inferences were drawn:

1. The linear reduction of slump value and compaction factor of fresh PQC was observed after adding RCA instead of natural aggregate.
2. The compressive strength of PQC up to 30% addition of RCA was observed more than the target mean strength required for M30 grade concrete and the strength of PQC with 30% RCA was observed nearer to target mean strength and the strength of 50% of RCA in PQC was shown lower than the target value of concrete based on 28 days curing period.

3. The results of flexural strength of the PQC had shown that the substitution of RCA up to 30% was almost equal to control concrete and further increasing the RCA reduced the flexural strength.
4. 8%reduction of impact strength of PQC up to 20% replacement of natural CA by RCA was noticed. The substitution of 30%RCA was reduced the impact strength more than 20% of control concrete.
5. Based on the 28 days cured specimen results, flexural strength of PQC was noticed as 10% of compressive strength.

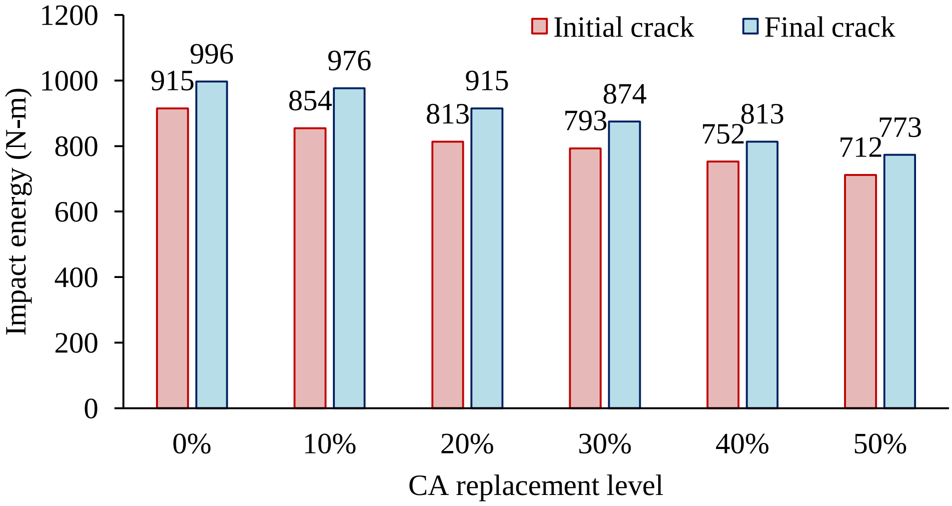


**Fig.11 Impact energy of 28 days cured PQC concrete with and without RCA**

**Table 5 Relationship between compressive strength and flexural strength after 28 days curing**

| CA replacement level (%) | 28 days strength (MPa) | | | | |
|---|---|---|---|---|---|
| | $f_{ck}$ | $f_t$ | $\left[\frac{f_t}{f_{ck}}\right]$ x100 | $f_{st}$ | $\left[\frac{f_{st}}{f_{ck}}\right]$ x100 |
| 0 | 38.67 | 4.01 | 10.37 | 3.24 | 8.38 |
| 10 | 37.93 | 4.06 | 10.70 | 3.25 | 8.57 |
| 20 | 37.02 | 4.01 | 10.83 | 3.21 | 8.67 |
| 30 | 36.72 | 3.97 | 10.81 | 3.14 | 8.55 |
| 40 | 34.29 | 3.72 | 10.85 | 2.98 | 8.69 |
| 50 | 31.15 | 3.47 | 10.83 | 2.79 | 8.71 |

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## AUTHORS PROFILE

**Dr.P.Murthi,** is working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. He has published more than 50 research papers in indexed journals and conferences. He has 32 years of teaching experience including 12 years of research experience. He guided 5 Ph.Ds and currently 1 Ph.D scholar pursuing Ph.D under his supervision. His area of interest in special structural concrete.

**Almas Khan,** is presently studying final year B.Tech. Civil Engineering at S R Engineering College, Warangal, Telangana State.

**Dr.K.Poongodi,** working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. She has published more than 10 research papers in indexed journals and conferences. She has 14 years of teaching experience including 6 years research experience. Her area of interest in Self compacting concrete and Agriculture solid waste as aggregate in concrete and its durability.

**Dr.R.Gobinath,** is presently working as Professor in the department of Civil Engineering of S R Engineering College, Warangal, Telangana, India. He is an active researcher in the field of building materials, geomaterials, sustainable building materials, geotechnology and environmental geotechnology. He has more than 103 papers to his credit and is actively serving in the editorial board of various journals of Springer, IGI global and also serving as reviewer for numerous journals in the field of Civil engineering and material science.