Experimental Investigation on the Properties of Gap Graded Aggregate Medium Strength Concrete

Arathy S. Mohan, M. Nazeer

Abstract: ***Concrete is a mixture of cementations material, aggregate, and water. Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. Thus concrete properties are highly affected by physical properties of its aggregate. The particle size distribution of coarse and fine aggregate (grading of aggregate) may have an effect on concrete behaviour. However, due to the inherent difficulties related to the characterization of fine sized particles, little research has been made to evaluate the effect of grading. In the present investigation, packing density of combined aggregate is considered as the criteria for aggregate gradation thus selecting four combinations of gap graded aggregate for making medium strength (M40) concrete mixes. The workability, density and strength results from these concrete mixes are finally compared with conventional concrete to propose a suitable aggregate gradation. Within the premises of this study, it is concluded that gap graded concrete, though of a relatively stiffer and drier mix, can be placed and finished without undue effort for the non-structural, massive construction works demand less workability wherein continuously graded concrete has been customarily used heretofore. A considerable saving in cement content, sand and notable improvements in mechanical properties are the realistically achievable advantages through the use of gap graded concrete. Good control and, above all, care in handling, so as to avoid segregation, are essential.***

Index Terms: ***aggregate, gap graded, gradation, packing density***

I. INTRODUCTION

Concrete is a very strong and versatile mouldable construction material. It consists of cement, sand and aggregate mixed with water. Aggregates are used in concrete for very specific purposes. It provides a rigid skeletal structure and to reduce the space occupied by the cement paste. Both coarse aggregates (particle sizes of 20 mm to 4.75 mm) and fine aggregates (particle sizes less than 4.75 mm) are required but the proportions of different sizes of coarse aggregate will vary depending on the particular mix required for each individual end use. Changes in aggregate gradation, maximum size, unit weight, specific gravity, reactivity, soundness and moisture content can all alter the character and performance of the concrete mix [1]. For every combination of aggregate mixed with a given amount of cementitious materials and cast at a constant consistency, there is an optimum combination which can be cast at the lowest w/c and produce the highest strength. The optimum mixture cannot be used for all construction due to variations in placing and finishing needs [2]. Coarse aggregates used in concrete making contain aggregates of various sizes. This particle size distribution of the coarse aggregate is termed as “Gradation”. Proper gradation of coarse aggregate is one of the most important factors in producing workable concrete [3]. It ensures that a sample of aggregates contains all standard fractions of aggregates in required proportion such that the sample contains minimum voids. Minimum voids require minimum paste to fill the voids in aggregate. Minimum paste means less quantity of cement and less quantity of water, leading to increased economy, higher strength, lower shrinkage and enhanced durability [4].

Gap graded aggregate consists of aggregate particles in which some intermediate size particles are missing. Assumption made in well gradation is that voids created by the higher size of aggregate will be filled-up by immediate next lower size of aggregate and again some smaller voids will be left out which will again be filled-up by next lower size aggregates. Practically it has been found that voids created by a particular size may be too small to accommodate the very next lower size. Therefore, the next lower size may not be accommodated in the available gap without lifting the upper layer of the existing size. Therefore, Particle Size Interference is created which disturbs the very process of achieving the maximum density [5]. In order to avoid this, in gap graded aggregates, certain particle sizes are intentionally omitted.

Advantages of Gap Graded Aggregate Concrete [6]:

- Requires less cement as net volume of voids is reduced.
- Requirement of sand is reduced by 26 to 40%.
- Specific area of total aggregates will be reduced due to less use of sand.
- Point contact between various size fractions is maintained, thus reducing the dying shrinkage.
- Increase strength and reduce creep and shrinkage.

Disadvantage:

Manuscript published on 30 October 2016.
***** Correspondence Author (s)
Arathy S. Mohan*, PG Scholar, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala, India.
Dr. M. Nazeer, Associate Professor, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala, India.

- As it shows greater proneness to segregation and change in anticipated workability, close supervision is required.

II. OBJECTIVES

The objectives of the present investigations may be outlined as follows:

- Initial investigation on gap grading to achieve maximum aggregate packing density.
- Well performed aggregate composition is studied for the performance in medium strength (M40 grade) concrete for workability and strength properties.

III. EXPERIMENTAL PROGRAMME

A. Materials

The constituents used for the mixes were ordinary Portland cement (OPC) 53 grade [7], fine aggregate, coarse aggregate, water and super plasticizer. The fine aggregate used was M – sand conforming to IS: 383 – 1970 [8] specification for Zone II gradation and 20 mm nominal size crushed and washed aggregate was used as coarse aggregate. The super plasticizer (Ceraplast 300) used was Naphthalene formaldehyde based liquid with 60% water and a density of 1.24 g/cm^3.

B. Mix proportioning

The grade of concrete prepared for the experimental study was M40. The proportion used in the investigations shown in Table-1 [9]. The study was limited to the preparation of five different types of mixes. One is control mix and remaining four by varying the aggregate gradation.

Table 1.Concrete mix proportion

Grade of Concrete	Concrete Mix Proportion				
	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	w/c ratio	Super plasticize r (l/m^3)
M40	320	779.69	1251.12	0.43	2.8

C. Details of mixes

The experimental investigation consists of two phases. These phases include initial investigation of packing density and testing the early age and hardened concrete properties of the concrete made from well performed combinations of aggregate obtained from the initial packing density findings.

1) Phase I- Determination of packing density:

- Using the different set of sieves[IS: 2386 (part1)-1963] [10], 20 mm, 16 mm, 6.3 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µ, 300 µ,150 µ, 75 µ aggregates were sieved and separately stored into various size ranges as follows using a sieve shaker shown in Fig. 1.
  - 20mm - 16mm, 6.3mm - 4.75mm, 4.75mm - 2.36mm, 2.36mm - 1.18mm, 600µ - 300µ, 300µ - 150µ, 150µ - 75µ
- From the above size ranges, five combinations were selected.
- Various combinations selected for the investigation are:
  1. 20mm – 16mm, 6.3mm - 4.75mm, 2.36mm - 1.18mm
  2. 20mm – 16mm, 6.3mm - 4.75mm, 300µ - 150µ
  3. 20mm – 16mm, 4.75mm - 2.36mm, 600µ - 300µ
  4. 20mm – 16mm, 4.75mm - 2.36mm, 150 µ - 75µ
  5. 20mm – 16mm, 6.3mm - 4.75mm, 600µ - 300µ

Fig. 1. Sieve shaker

- Aggregates in each combination is filled into a cube mould of 10cm with proper vibration and compaction for duration of 3minutes to the top of the mould and leveled as shown in Fig. 2. In each trial, the percentage weight of aggregate fraction is varied.

Fig. 2. Packing density determination

- Finally, the weight of each size range of aggregate filled in the mould is found out separately and by knowing the volume of cube, packing density for each trial is calculated.

2) Phase II- Preparation of test specimens:

The study is limited to the preparation of five different types of mixes. One control mix and the remaining four mixes are prepared by changing the total aggregate content in the control mix into gap graded fractions which is pre-determined from the Phase I study.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Standard moulds were used for casting 100mm cube specimens, 150mm diameter and 300mm height cylinders, 100mm×100mm ×500 mm prisms and a custom made mould for shear specimens. A total of 155 specimens were casted for finding the mechanical properties [11, 12].

IV. RESULTS AND DISCUSSIONS

A. *Phase I*

Phase I includes the investigation on gap grading to achieve maximum aggregate packing density. Ten trials each were conducted for the five combinations as prescribed in experimental programme and the values are shown in Table 2 to Table 6. The trial having maximum packing density value is selected for fixing the aggregate gradation and the granular fraction, for this, in each combination, the best value of packing density is selected. For the packing densities of nearer values, the combination having higher coarse fraction is selected, else the water required for wetting the fine aggregate will be more and it may affect the workability, for a given water-cement ratio.

Table 2. Packing density trials for Combination 1

Trial No.	20mm-16mm (%)	6.3mm-4.75mm (%)	2.36mm-1.18 mm(%)	Density (kg/m^3)
1	56.56	26.26	17.17	1950
2	63.34	22.84	13.70	1980
3	63.16	28.95	7.89	1900
4	71.07	20.58	8.33	2040
5	70.15	21.39	8.45	2010
6	65.00	20.00	15.00	2000
7	70.00	19.50	10.50	2000
8	71.14	19.40	9.40	2010
9	65.98	20.30	13.70	1970
10	58.12	33.00	8.86	2030

Table 3. Packing density trials for Combination 2

Trial No.	20mm-16mm (%)	6.3mm-4.75mm (%)	300µ-150µ (%)	Density (kg/m^3)
1	63.85	21.51	14.64	2185
2	59.07	16.81	24.12	2260
3	68.48	13.15	18.37	2205
4	66.51	18.12	15.37	2180
5	72.23	10.11	17.64	2150
6	65.03	16.55	18.42	2145
7	56.08	20.25	23.67	2345
8	64.67	16.16	19.17	2165
9	67.64	14.35	18.01	2055
10	66.59	15.25	18.16	2065

Table 4. Packing density trials for Combination 3

Trial No.	20mm-16mm (%)	4.75mm-2.36 mm (%)	600µ-300µ (%)	Density (kg/m^3)
1	57.85	27.13	15.02	2230
2	66.45	18.64	14.91	2280
3	63.60	19.30	17.10	2280
4	62.44	19.96	17.60	2255
5	62.34	18.18	19.48	2310
6	64.27	19.78	15.95	2225
7	64.18	20.44	15.38	2275
8	63.21	21.26	15.53	2305
9	60.46	25.75	13.79	2175
10	59.92	25.80	14.28	2200

Table 5. Packing density trials for Combination 4

Trial No.	20mm-16mm (%)	4.75mm-2.36 mm (%)	150µ-75µ (%)	Density (kg/m^3)
1	62.75	22.66	14.59	2295
2	69.73	22.83	7.44	2015
3	67.63	20.14	12.23	2085
4	64.00	20.67	15.33	2250
5	69.07	21.65	9.27	2029
6	69.17	16.79	14.04	2114
7	68.45	13.58	17.97	2130
8	64.33	19.45	16.22	2110
9	60.35	16.55	18.42	2100
10	56.50	20.25	23.25	2295

Table 6. Packing density trials for Combination 5

Trial No.	20mm-16mm (%)	6.3mm-4.75 mm (%)	600µ-300µ (%)	Density (kg/m^3)
1	70.24	19.51	10.24	2050
2	62.17	16.52	21.30	2300
3	63.84	20.14	16.02	2185
4	70.06	15.08	14.75	2155
5	64.10	20.50	15.40	2208
6	59.85	19.73	20.42	2250
7	60.20	16.37	23.43	2215
8	68.25	15.53	16.22	2201
9	70.53	13.85	15.62	2147
10	71.20	17.61	11.20	2095

Among the five combinations, the Combination 1 with packing density 2040 kg/m^3 is the least one, so it is omitted from further study. The selected four combinations are designated as shown in Table-7.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 7.Mix designation

Mix Designation	Aggregate Fraction	
C	All in aggregate	CA - 61.61 % FA - 38.39 % Density-2030 kg/m^3
C1	20mm - 16mm (68.48%) 6.3mm - 4.75mm (13.15%) 300μ - 150μ (18.37%)	CA - 81.63% FA - 18.37% Density - 2205kg/m^3
C2	20mm - 16mm (63.21%) 4.75mm - 2.36mm (21.26%) 600μ - 300μ (15.53%)	CA - 63.21% FA - 36.79% Density - 2305kg/m^3
C3	20mm - 16mm (62.75%) 4.75mm - 2.36mm (22.66%) 150μ - 75μ (14.59%)	CA - 62.75 % FA - 37.25 % Density – 2295 kg/m^3
C4	20mm - 16mm (62.17%) 6.3mm - 4.75mm (16.52%) 600μ - 300μ (21.30%)	CA - 78.69 % FA - 21.30 % Density – 2300 kg/m^3

CA- Coarse aggregate, FA- Fine aggregate

Even though C1, C2, C3 and C4 mixes were showing similar packing densities, approximately 2300 kg/m^3, the significant difference between these mixes is that C1 and C4 is having higher coarser fraction (81.63 %, 78.69 % respectively) where as C2 and C3 is having closer value (63.21 %, 62.75 % respectively) compared to the aggregate fraction in the control mix.

B. *Phase II*

In phase II, the well performed aggregate compositions selected are studied for the performance in medium strength (M40) concrete such as early age and hardened concrete properties.

1) Workability of fresh concrete

The workability of various mixes was assessed as per the IS: 1199-1959 specification [13].

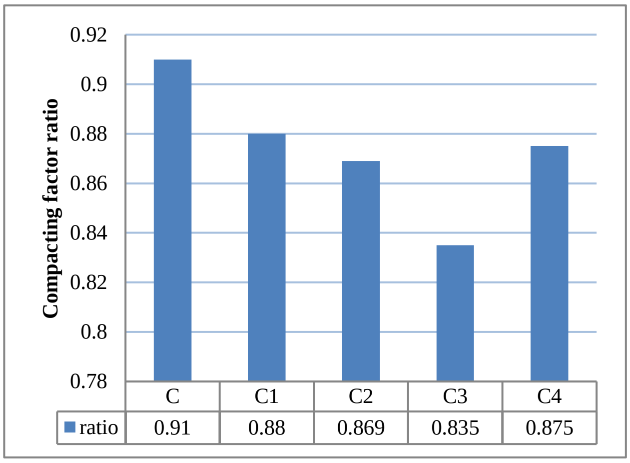

Fig. 3. Compacting factor for various mixes

From Fig. 3, it is observed that the compacting factor varied from 0.91 to 0.835. The highest value was observed for the control mix due to all in aggregate and lowest for C3. Among the gap graded mixes C1 has higher workability due to higher percentage coarse fraction. C2 and C3 having higher fine fraction, takes more water to wet the surface hence less workable.

It may also be observed that, in gap graded aggregate concrete the workability (CF) decreases with the increase in fine to coarse aggregate ratio. Thus it is clear that the reason for reduced workability is due to the presence of fine aggregate fraction in the concrete. However a higher fine to coarse ratio in conventional concrete exhibits improved workability. This is probably due to the continuous grading of aggregate.

Table-8: Fine aggregate to coarse aggregate ratio (F/C) of various mixes

Mix	F/C	Workability (CF)
C1	0.225	0.880
C2	0.582	0.869
C3	0.594	0.835
C4	0.271	0.875

2) Compressive strength of concrete

Figure 4 shows that C1 and C4 mixes have higher compressive strength than control mix. C2 and C3 show less value. C4 is having the highest compressive strength it may be due to high workability and close packing of aggregate fraction.

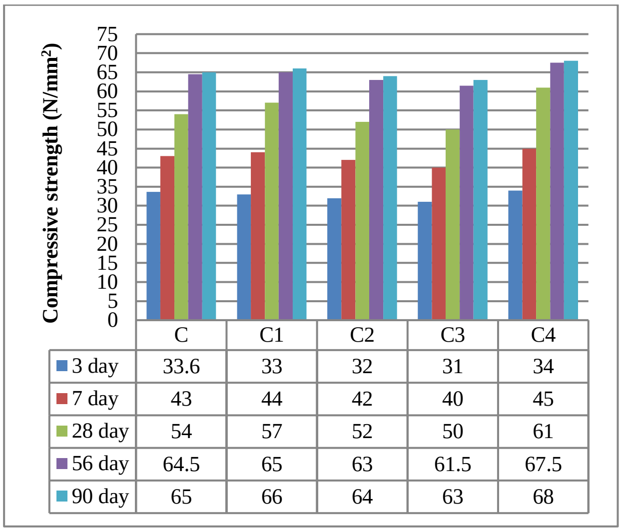

Fig. 4.Compressive strength for various mixes

3) Split tensile strength of concrete

Figure5 shows the variation of split tensile strength for the various mixes after 28 days water curing.

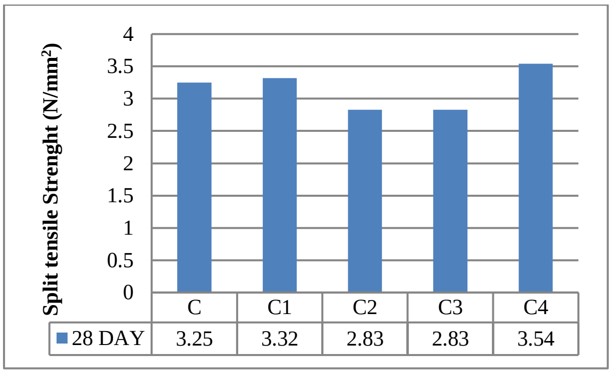

Fig. 5. Split tensile strength variation

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The highest splitting tensile strength was observed for the C4 mix. The Split tensile strength shows the same trend that of compressive strength variation.

4) Modulus of elasticity

Fig. 6shows the variation of modulus of elasticity for various mixes.

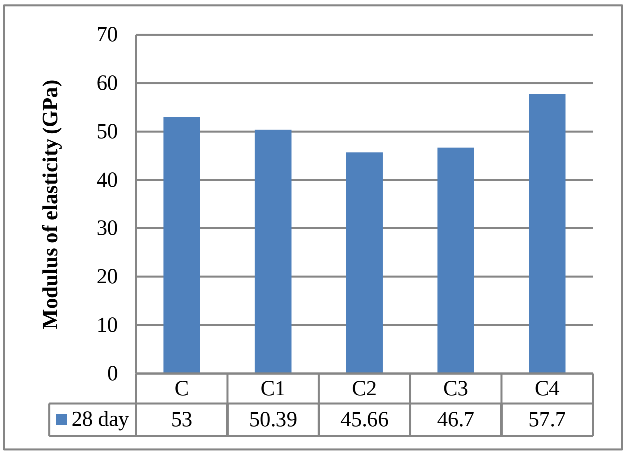

Fig. 6. Modulus of elasticity variation

5) Flexural strength

Figure 7 shows the variation of flexural strength for different mixes.

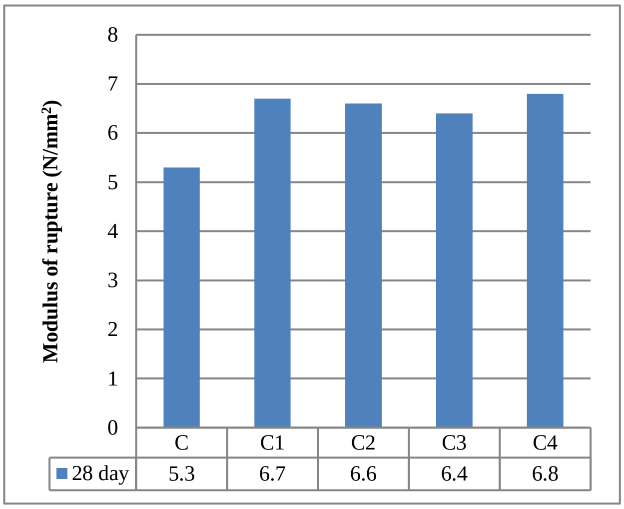

Fig. 7. Flexural strength for various mixes

From the result it can be seen that gap graded mixes shows higher flexural strength than control mix. In control mix, due to well grading there may be a chance for particle size interference leading to gaps in between aggregate, which results in stress concentration while loading. It leads to brittle failure.

6) Shear strength

Figure 8 indicates the variation of shear strength of all mixes at different ages of test. Fig. 9 shows the shear mould and specimen used for the test and a fractured specimen.

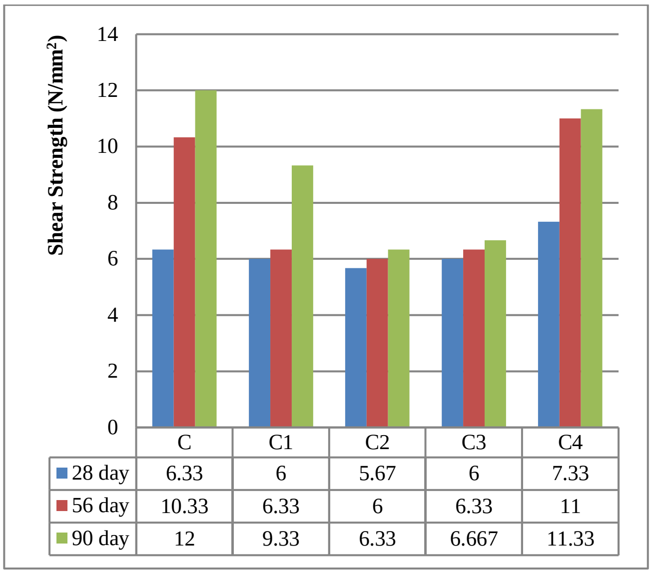

Fig. 8. Shear strength variation of mixes

C1 and C4 mixes were showing higher values compared to C2 and C3 mixes. There isn't any noticeable increase in shear strength for gap graded mixes compared to control mix.

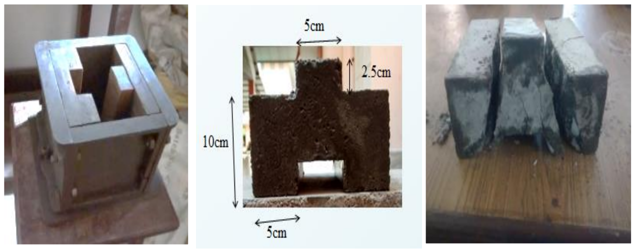

Fig. 9. Shear mould, specimen, fractured specimen

V. CONCLUSION

1. Gap graded mixes are less workable than control mix.
2. A huge percentage reduction of sand is the main advantage.
3. Mechanical properties are found to be satisfactory when compared to control mix values.
4. From the strength results of hardened concrete, C4 mix showed satisfactory results.
5. The content of the coarse aggregate has a significant influence on the compressive strength of gap graded aggregate concrete. Increasing the coarse aggregate content enhances the compressive strength, however it seems that there is an optimum content of the coarse aggregate to reach a maximum compressive strength.
6. Without close supervision, gap graded concrete will result in honeycombing.

REFERENCES

1. Quiroga, P. N. (2003)The Effect of the Aggregates Characteristics on the Performance ofPortland Cement Concrete, Doctoral Dessertation,The University of Texas at Austin.
2. Elices, M. and C.G. Rocco (2008) Effect of Aggregate Size on the Fracture and Mechanical Properties of a Simple Concrete, Journal of Engineering Fracture Mechanics,75, 3839-3851.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

3. Ashraf, W. B. and M. A. Noor (2011) Performance-Evaluation of Concrete Properties for Different Combined Aggregate Gradation Approaches, The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, 14, 2627-2634.
4. Hilf, J. W. (1987) Rolled Concrete Dams Using Gap-Graded Aggregate, Journal of Construction Engineering and Management, 1, 27-33.
5. Meddah, M.S., Zitouni, S. and S. Belaabes (2009) Effect of content and particle size distribution of coarse aggregate on the compressive strength of concrete, construction of building materials, 24, 505-518.
6. Shetty, M. S., Concrete Technology, Ram Nagar, New Delhi, S. ChandPublications,2012.
7. IS: 12269-1987- Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi, 2000.
8. IS: 383-1970, Specification for Coarse and Fine Aggregate from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi.
9. IS: 10262-1982, Recommended guidelines for Concrete Mix Design, Bureau of Indian Standards, New Delhi, 2000.
10. IS: 2386 (Part 1) –1963, Methods of Test for Aggregates for Concrete Part 1- Particle Size and Shape, Bureau of Indian Standards, New Delhi.
11. Al-Sahawneh, E. I. (2015) A New Approach for the Determination of Tensile and Shear Strengths of Normal Weight Concrete, International organization of Scientific Research, 05, 38-48.
12. IS: 516-1959,Method of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi, India.
13. IS: 1199-1959, Methods of Sampling and Analysis of Concrete, Bureau of Indian Standards, New Delhi.

Arathy S.Mohan, P.G. Scholar, Department of Civil Engineering, T.K.M. College of Engineering, Kollam (affiliated to University of Kerala). Graduated from Government Engineering College Kozhikode (affiliated to University of Calicut).

Dr. M. Nazeer, graduated from T.K.M. College of Engineering, Kollam (affiliated to University of Kerala), received master's degree from KREC, Surathkal (affiliated to Mangalore University) and Ph.D. from NIT-Karnataka, Surathkal, is working as Associate Professor at T.K.M. College of Engineering, Kollam. He has got more than 20years of teaching experience, published over 25 papers in National and International journal sand conferences. His research interests include high-performance concrete, durability of concrete and repair of concrete structures. He is the life member of ISTE and ISWE.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)