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# Strength and Durability Characteristics of Sustainable Structural Concrete Influenced by Multiwalled Carbon Nanotubes: An Experimental Exertion

**Vijaya Bhaskar. A, M. Shanmugasundaram**

***Abstract:** The developments of using Multiwalled carbon nanotubes (MWCNTs) in sustainable structural concrete is increasing due to its extraordinary strength and stiffness properties, but the durability studies in this area are very less. In this exertion, the effect of incorporation of different dosages (0 % - 0.40 %) of MWCNTs has been made to study the strength and durability characteristics of sustainable structural concrete. Concrete mixes were evaluated for compressive strength, Chloride permeability and Ultrasonic pulse velocity at various ages of 7, 14, 28, 56 and 90 days. The results obtained from these tests are unveiling, the incorporation of 0.25 % MWCNTs by weight of cement material performed more desirable.*

***Index Terms:** Compressive strength, Durability, Multiwalled carbon nanotubes (MWCNTs), Rapid chloride penetration test, Ultrasonic pulse velocity test.*

## I. INTRODUCTION

Research on Carbon Nanotubes (CNTs) has been growing extensively from the past decades due to its wide range of desirable properties to be used as a reinforcement material in cement-based composites. Properties like Young's modulus of up to 1 TPa and tensile strength of 20-100 GPa make it exceptional in having high strength and stiffness [1]. CNTs have the potential to restrict the propagation of nano-cracks and to enhance the low tensile strength and low strain capacity of cement-based materials. Prevention or reduction in crack initiation is another advantage of using CNTs. In the cement pastes and mortars, it helps in enhancing the fracture properties and early age strain capacity [2,3]. The factors that determine the efficiency of CNTs are its type, nature of interaction with the cement matrix and the dispersion quality [4].

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***** Correspondence Author

**Mr. A. Vijaya bhaskar*:** B. Tech degree in the Department of civil Engineering from SPEC Nellore, and M. Tech in Structural Engineering from VIT Chennai,

**Dr M. Shanmugasundaram:** B.E degree in Civil Engineering from RCET Madurai, M.E in Structural Engineering, TCE Madurai.



In spite of many advantages, the dispersion, and separation of CNTs pose a challenge due to high surface area and strong Vander Waals force which makes them agglomerate. To overcome this challenge of dispersing CNTs in the cement matrix various methods of dispersion of CNTs have been proposed by authors [5,6]. The increment in strength arises from three main effects that are show cased by CNTs. The three properties are filler, nucleation and bridging effect. The filling of pores in between the hydration products with CNTs is the filler effect [7,8].

It has also been found through scanning electron microscopy (SEM) that CNTs help in the formation of C-S-H products by acting as nucleation sites resulting in faster and uniform hydration of cement compounds [8,9]. The crossing over of the CNTs over the microcracks is known as the bridging effect which helps in preventing the further growth of cracks [10]. SEM results have provided evidence for the bridging effect of CNTs [11,12]. Konsta et. al. [3] has found that the contribution from the nucleation and bridging effects can result in the formation of stronger links between hydration products thereby increasing the stiffness of C-S-H bond. Many studies have been done focusing on the mechanical characterization of mortars and cement pastes reinforced with CNT. But it has been found that there has been an only scarce study on the durability of concrete reinforced with CNTs. Considering this fact, the study has been carried out to investigate the durability behaviour of MWCNTs reinforced concretes with different proportions of MWCNTs. Through this study, an optimal quantity of MWCNTs can be arrived at with enhanced performance of concrete. In this exertion, strength and durability characteristics of sustainable structural concrete influenced by different ratios of MWCNTs were investigated.

## II. MATERIALS AND METHODOLOGY

Ordinary Portland cement of grade 53 conforming to IS 12269 used for this experimental investigation. Natural river sand obtained from Tamil Nadu river sand was used as fine aggregate and were tested as per IS 383-1970. Ordinary tap water was used in this work which was devoid of organic matter and salts at room temperature. MWCNTs were purchased from United Nanotech Private Limited from Bangalore which had an outer diameter of 20-40 mm, the inner diameter of 5-10 mm and a length varying between 10 to 30 nm.

The purity of these carbon nanotubes conformed to 96 %. Dispersion of MWCNTs was achieved by using ultrasonicator with a time period of 60 minutes for each sample. Fig 1 shows the nine achievable mixes were distinguished with various ratios of MWCNTs, for this experimental work.The compressive strength of concrete cubes of size 150X150X150 mm (IS: 516-1959) was tested for varying periods of 7, 14, 28, 56 and 90 days. Nine mixes with different dosages of MWCNTs were prepared for the experimental work, with 3 specimens for each mix. The cast specimens after curing were tested under a compression testing machine of capacity 2000 KN in accordance with Indian Standard specification (IS: 516-1959) [14]. Rapid Chloride Penetration test (RCPT) is used to check the flow of chloride ion or the penetration of chloride ion into the specimen in accordance with ASTM C 1202-2003. The procedure of Ultrasonic Pulse Velocity test (UPV) is followed according to IS: 1311:1992 for all the specimens and the results were assessed according to IS 1311 (Part 1): 1992.

## III. RESULTS AND DISCUSSION

### A. Compressive Strength

Figure 1 shows the results of compressive strength. The 7 days compressive strength of the concrete for CM (Control Mix), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN- 0.35 and MWCN -0.40 was found to be 36.71 MPa, 40.12 MPa, 44.06 MPa, 47.34 MPa, 47.98 MPa, 51.26 MPa, 45.61 MPa, 39.56 MPa and 33.12 MPa. The increase in percentage was noted as 10.69 %, 18.67 %, 24.31 %, 25.32 %, 30.10 %, 21.44 %, 9.42 % and 8.18 % respectively. Whereas as the minimum strength was observed in the MWCN-0.40 (33.12 MPa) and maximum strength was observed in the MWCN -0.25 (51.26 MPa). Addition of Multiwalled carbon nanotubes will increase the strength up to the dosage of MWCN- 0.25. From the dosage of MWCN-0.3, the strength was slightly decreased. The decreased strength was noted as 45.61 MPa, 39.58 MPa and 33.12 MPa for MWNTs- 0.3, MWCN-0.35 and MWCN-0.40 respectively.

The 14 days compressive strength of the concrete for CM (Control Mix), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN - 0.35 and MWCN - 0.40 was found to be 47.03 MPa, 53.62 MPa, 57.06 MPa, 60.01 MPa, 63.39 MPa, 68.26 MPa, 61.34 MPa, 50.14 MPa and 40.68 MPa. The increase in percentage was noted as 13.83 %, 19.03 %, 23.01 %, 27.11 %, 32.31 %, 24.68 %, 7.85 % and 13.56 % respectively. The 14 days strength obtained was found to be a little higher when compared to 7 days strength. Whereas as the minimum strength was observed in the MWCN-0.40 (40.68 MPa) and maximum strength was observed in the MWCN-0.25 (68.26 MPa). Addition of Multiwalled carbon nanotubes will increase the strength up to the dosage of MWCN- 0.25. From the dosage of MWCN-0.3, the strength was slightly decreased. The decreased strength was noted as 61.34 MPa, 50.14 MPa, 40.68 MPa for MWCN-0.3, MWCN-0.35, and MWCN-0.40respectively.

The 28 days compressive strength of the concrete for CM (Control Mix), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 57.46 MPa, 63.41 MPa, 66.75 MPa, 70.43 MPa, 73.68 MPa, 78.39 MPa, 70.96 MPa, 58.69 MPa and 51.24 MPa .The increase in percentage was noted as 11.13 %, 15.58 %, 19.99 %, 23.52 %, 28.11 % , 20.58% respectively. The strength was decreased for MWCN-0.35 and MWCN-0.40 mixes the decreased percentage was noted as 3.98% and 9.97 % respectively. The 28 days specimen showed a strength percentage which was a little higher when compared to 14 days strength. Whereas as the minimum strength was observed in the MWCN-0.40 (51.24 MPa) and maximum strength was observed in the MWCN-0.25 (78.39 MPa). Addition of Multi walled carbon nanotubes will increase the strength up to the dosage of MWCN- 0.25. From the dosage of MWCN-0.3, the strength was slightly decreased. The decreased strength was noted as 70.96 MPa, 58.69 MPa and 51.24 MPa for MWCN-0.30, MWCN-0.35 and MWCN- 0.40 respectively.

The 56 days compressive strength of the concrete for CM (Control Mix), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 58.29 MPa, 64.36 MPa, 68 MPa, 72.19 MPa, 74.58 MPa, 79.32 MPa, 71.58 MPa, 59.96 MPa, and 53.29 MPa. The increase in percentage was noted as 10.95 %, 15.72 %, 20.61 %, 23.15 %, 27.74 %, 19.93 %, 4.41 % and 7.54 % respectively. The 56 days specimen showed a strength percentage which was a little higher when compared to 28 days strength. Whereas as the minimum strength was observed in the MWCN-0.40 (53.29 MPa) and maximum strength was observed in the MWCN-0.25 (79.32 MPa). Addition of Multiwalled carbon nanotubes will increase the strength up to the dosage of MWCN- 0.25. From the dosage of MWCN-0.3, the strength was slightly decreased. The decreased strength was noted as 71.58 MPa, 59.96 MPa and 53.29 MPa for MWCN- 0.3, MWCN-0.35 and MWCN-0.40 respectively.

The 90 days compressive strength of the concrete for CM (Control Mix), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 59.34 MPa, 66.10 MPa, 69.38 MPa, 73.49 MPa, 76.62 MPa, 83.58 MPa, 74.46 MPa, 60.08 MPa and 54.38 MPa. The increase in percentage was noted as 12.13 %, 16.28 %, 20.96 %, 24.19 %, 30.50 %, 21.99%, 3.32 % and 6.80 % respectively. The 90 days specimen showed a strength percentage which was a little higher when compared to 56 days strength. Whereas as the minimum strength was observed in the MWCN-0.40 (54.38 MPa) and maximum strength was observed in the MWCN-0.25 (83.58 MPa). Addition of Multiwalled carbon nanotubes will increase the strength up to the dosage of MWCN- 0.25. From the dosage of MWCN-0.3, the strength was slightly decreased. The decreased strength was noted as 74.46 MPa, 60.08 MPa and 54.38 MPa for MWNTs- 0.3, MWCN-0.35 and MWCN-0.40 respectively[13].

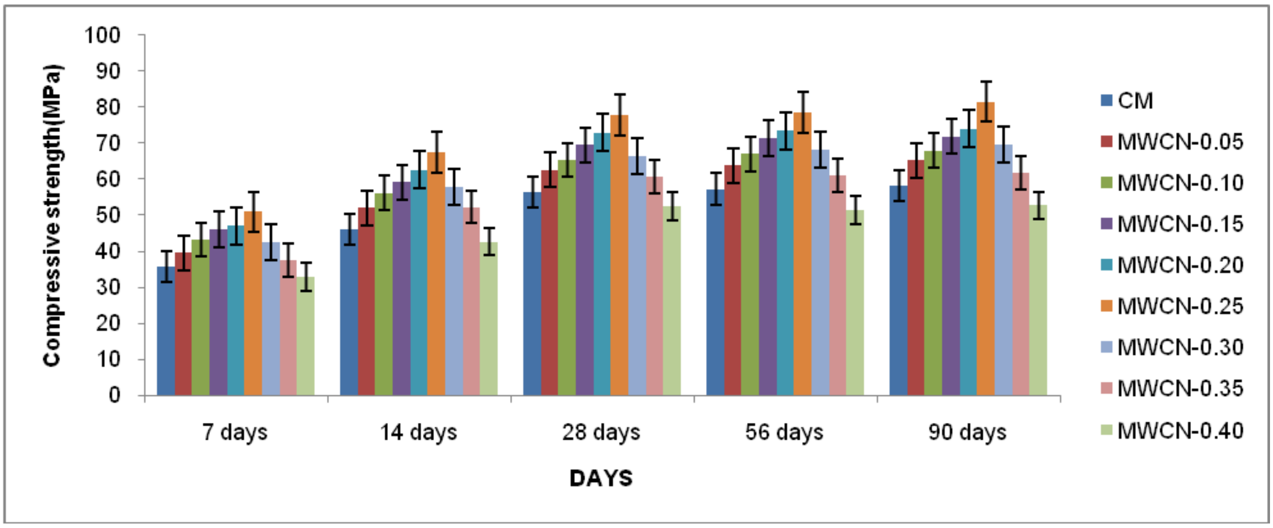


**Figure 1 Compressive strength**

### B. Rapid Chloride Penetration Test

The results of the Rapid Chloride Penetration test are shown in Fig.2. The results show that the specimen with 0.25% MWCNTs has a total charge passage of fewer than 2000 coulombs which indicates that the quality of the concrete used in that specimen is excellent according to the standard specifications. The specimen MWNTs-0.25 had the least chloride ion passage irrespective of the curing age of the specimens which classifies the concrete of the specimen as low permeable concrete.

The 7 days Coulombs passed of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCNTs-0.35, and MWCN-0.40 was found to be 850.23, 790.87, 671.32, 534.21, 531.65, 462.11, 1043.23, 1087.45 and 1589.21 respectively.

The 14 days Coulombs passed of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35, and MWCN-0.40 was found to be 830.32, 769.78, 654.77, 522.3, 511.64, 443.56, 1027.86, 1067.32 and 1577.1 respectively.

The 28 days Coulombs passed of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35, and MWCN-0.40 was found to be 800.09, 755.16, 634.89, 510.7, 500, 423.87, 1005.22, 1034 and 1550.6 respectively.

The 56 days Coulombs passed of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35, and MWCN-0.40 was found to be 789.8, 721.4, 602.3, 499.9, 487.6, 400.8, 1000.98, 1026.54 and 1531.42 respectively.

The 90 days Coulombs passed of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35, and MWCN-0.40 was found to be 760.1, 700.4, 589.5, 476.7, 466.2, 378.67, 1000.22, 1019.87 and 1523.16 respectively.

It can be seen from fig-2 shows the average coulombs charge passed is less than 2000, it indicates the quality of concrete is excellent as per standard specifications. The concrete can be classified as very low chloride penetration from Control Mix (CM) to MWCN - 0.25. After MWCN - 0.30 to MWCN - 0.40 the concrete can be classified as low chloride penetration.

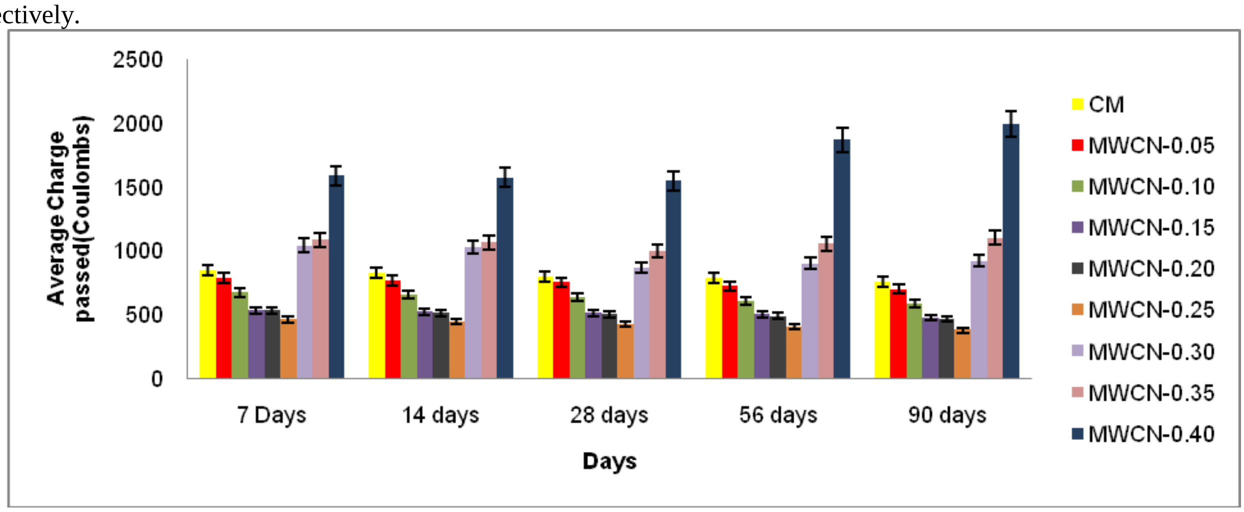


**Figure 2.** RCPT results

### C. Ultrasonic pulse velocity test

The test results obtained show that the quality of concrete used in the specimen was excellent which can be found in Figure 3.

The 7 days ultrasonic pulse velocity of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 4.1 Km/sec, 4.22 Km/sec, 4.29 Km/sec,4.34 Km/sec,4.38 Km/sec,4.55 Km/sec,3.43 Km/sec,3.49 Km/sec and 3.15 Km/sec respectively.

The 14 days ultrasonic pulse velocity of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 4.17 Km/sec, 4.26 Km/sec, 4.31 Km/sec,4.42 Km/sec,4.49 Km/sec,4.62 Km/sec,3.55 Km/sec,3.5 Km/sec and 3.31 Km/sec respectively.

The 28 days ultrasonic pulse velocity of the concrete for Control Mix (CM), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 4.26 Km/sec, 4.31 Km/sec, 4.39 Km/sec, 4.5 Km/sec, 4.56 Km/sec, 4.71 Km/sec, 3.68 Km/sec, 3.62 Km/sec and 3.40 Km/sec respectively.

The 56 days ultrasonic pulse velocity of the concrete for Control Mix (CM), MWCN-0.05, MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 4.28 Km/sec, 4.36 Km/sec, 4.49 Km/sec, 4.58 Km/sec, 4.62 Km/sec, 4.76 Km/sec, 3.56 Km/sec, 3.51 Km/sec and 3.35 Km/sec respectively.

The 90 days ultrasonic pulse velocity of the concrete for Control Mix (CM), MWCN-0.05 MWCN-0.10, MWCN-0.15, MWCN-0.20, MWCN-0.25, MWCN-0.30, MWCN-0.35 and MWCN-0.40 was found to be 4.41 Km/sec, 4.39 Km/sec, 4.61 Km/sec, 4.65 Km/sec, 4.67 Km/sec, 4.92 Km/sec, 3.51 Km/sec, 3.44 Km/sec and 3.15 Km/sec respectively.

It can be seen from fig-3 shows the ultrasonic pulse velocity, it indicates the quality of concrete is excellent as per standard specifications up to the dosage of MWCN-0.25. After MWCN - 0.30 to MWCN - 0.35 the concrete can be classified as good. MWCN-0.40 shows the concrete is medium.

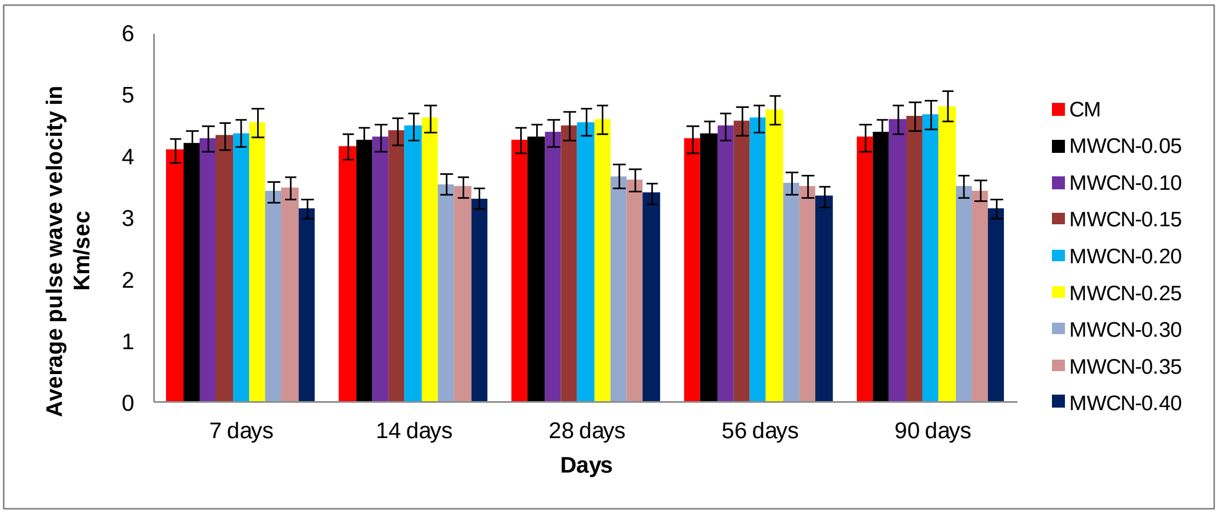


**Figure 3.** UPV results

## IV. CONCLUSIONS

The following conclusions are drawn from the investigation

(1) In the case of compressive strength, the addition of MWCN-0.25 shows the maximum increased strength of 51.26 MPa, 68.26 MPa, 78.39 MPa, 79.32 MPa, and 83.58 MPa in 7,14,28,56 and 90 days respectively.

(2) Rapid chloride penetration values decrease when MWCN are added up to 0.25% by weight of cement. Hence 0.25% of multiwalled carbon nanotubes can be safely added to concrete which would enhance the performance of the concrete.

(3) MWCN-0.25 showed better resistance in all three tests. Hence MWCN-0.25 can be accepted as an optimum ratio.

(4) Hence, the study reveals that multiwalled carbon nanotubes can be used for making durable and impermeable concrete. However, the percentage of Multiwalled carbon nanotubes should be restricted to MWCN-0.25 by weight of cement and the preferred ratio is MWCN-0.25.

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## AUTHORS PROFILE

**Mr. A. Vijaya bhaskar**: He had Completed B. Tech degree in the Department of civil Engineering from SPEC Nellore, and M. Tech in Structural Engineering from VIT Chennai, Pursuing his PhD degree under the guidance of Dr M.Shanmugasundaram. He has 5 international research publications to his credits. He has one year experience in Teaching. His doing research in Multi-walled Carbon nanotubes.

**Dr M.Shanmugasundaram**: He had completed his B.E degree in Civil Engineering from RCET Madurai, M.E in Structural Engineering, TCE Madurai. He completed his Ph.D on 2014 under the esteemed guidance of Dr. K.Sudalaimani, Associate Professor, TCE, Madurai. He has 30+ international research publications to his credits. He had filed three patents. He has 3 years of industrial experience and 10 years of teaching experience. His recent research interests include, sustainable materials and polymer concretes.