Lecture Notes in Civil Engineering

Pala Gireesh Kumar
Kolluru V. L. Subramaniam
S. Moses Santhakumar
Neelima Satyam D. *Editors*

Recent Advances in Civil Engineering

Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)

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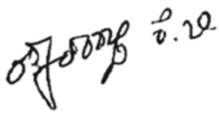
In the memory of ***Late Dr. Bhupathiraju Vissam Raju****, Founder Chairman of Sri Vishnu Educational Society, and* ***Late Smt. Bhupathiraju Seethamma****, "Recent Advances in Civil Engineering: Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)" is dedicated in their honor for their commendable contributions, endowments, benefactions, and service to society.*

Foreword

Civil engineering is an embrace of copious disciplines with diversified strands of research opportunities. Invigorating the zest and zeal to explore the expanse of civil engineering is an engrossing quest, one such fascinating endeavor of civil engineering cognates to "Recent Advances in Civil Engineering: Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)." With sustainability as a principal firm, the proceedings of ScTACE 2021 encompassed the innovational analysis, investigations, and research works targeting new-flanged trends of civil engineering disciplines. It has dazzled my spirit and enthusiasm for supplemental learning and proposals of novel techniques. The intensity of sustainable approaches with avant-garde technology is a culmination where the readers discover it to be credible with all the advanced and futuristic gatherings at one locus. Pointing to the necessity of sustainable strategies, the authors have intensified the concepts with facts and records obtained from tests and trials. The factual tone of methods of ScTACE 2021 Proceedings has dented me with a remarkable outreach for an acquaintance in recent inclinations. And I take utmost gusto in proposing a word of the work proffered through the proceedings and believe it is worth spending time in exploring the concepts embodied in it.



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Preface

Research has always set a gateway for new theories and proposals. These hold ascendancy and escalation of knowledge. In the accord to appraise the society on sustainability relating to the value-added research in terms of the latest technologies, the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering, ScTACE 2021, convened on October 14–16, 2021, has devised to formulate as Recent Advances in Civil Engineering: Proceedings of ScTACE 2021. Elevating the aspect of research as the peak core of any field, ScTACE 2021 is tasked up with exposing new studies and innovative research works to the competitive world outside through the proceedings. Besides the honorable commendation to the innovations and studies, ScTACE 2021 toiled the feature of exchanging knowledge. As education is focal and highly fascinated with the revamping of new trends, technologies, and advancements in civil engineering, this proceedings of ScTACE 2021 intensified socializing of research works and studies carried by rendering a notable lecture series put together to summon strength in technical aspects of civil engineering. Holding on to the intent, ScTACE 2021 contrived and comprehended lecture series with the goal of sharing knowledge by emphasizing eminence to all the fields concerning civil engineering such as structures, transportation, geotechnical, environmental, remote sensing, water resources, hydraulics, with interdisciplinary studies and research proposals. With the comprehended research works embodied collectively, ScTACE 2021 featured sustainability as a supreme motive behind all the aspects as it holds the future of a nation. To ignite the prosperity of civil engineering by correlating it to sustainability, "Recent Advances in Civil Engineering: Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)" tasks up the act of propounding the power of sustainability that can heal, rule, and dwell the world into a better and sophisticated place of livelihood with advancements in both, nature and technology sustainably.

Bhimavaram, India — Pala Gireesh Kumar
Kandi, India — Kolluru V. L. Subramaniam
Tiruchirappalli, India — S. Moses Santhakumar
Indore, India — Neelima Satyam D.

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With the collective efforts of honorable and dearly beloved and their praiseworthy contribution, ScTACE 2021 has witnessed the charm of success. In this regard, I express my sincere thankfulness and appreciation to the co-editors of "Recent Advances in Civil Engineering: Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)," Prof. Kolluru V. L. Subramaniam, IIT Hyderabad; Prof. S. Moses Santhakumar, NIT Trichy; and Dr. Neelima Satyam D., IIT Indore, for being the most radiant aid to the proceedings.

Also, I extend my thankfulness to the General Chair of ScTACE 2021, Prof. Shen-En Chen, from the University of North Carolina; General Co-Chair, Dr. Narasimha Murthy, Transportation & Traffic Engineering Consultant, USA; Scientific Committee Chair, Prof. D. Nagesh Kumar from IISc Bangalore; and Program Committee Co-Chair, Mr. Mahdi Feizbahr from Iran; for being such an honor to ScTACE 2021. Furthermore, I like to acknowledge the continuous efforts of the CRC Committee for their honest and ethical reviews. Likewise, I proffer my thankfulness to Sri K. V. Vishnu Raju Garu, Chairman, SVES; Sri Ravichandran Rajagopal Garu, Vice-Chairman, SVES; Sri K. Aditya Vissam Garu, Secretary, SVES; Dr. G. Srinivasa Rao, Principal, SVECW; Dr. P. Srinivasa Raju, Vice Principal, SVECW; and the entire management of Sri Vishnu Educational Society and SVECW for providing the needed support and encouragement. Also, sincere thankfulness and warm wishes to all the authors who bestowed valuable time and work with ScTACE 2021.

Ultimately, I extend my heartfelt gratitude to value the support rendered by every individual who aided in the successful completion of "Recent Advances in Civil Engineering: Proceedings of the 2nd International Conference on Sustainable Construction Technologies and Advancements in Civil Engineering (ScTACE 2021)."

Dr. Pala Gireesh Kumar
Conference Chair and Chief Editor—ScTACE 2021
Head and Associate Professor—CE, SVECW (A)

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About the Editors

Dr. Pala Gireesh Kumar Head and Associate Professor of Department of Civil Engineering, Shri Vishnu Engineering College for Women (Autonomous), Bhimavaram, has obtained his B.E. (Civil Engineering) from Sri Venkateswara University College of Engineering Tirupati, India; Masters in Transportation Engineering and Management from National Institute of Technology Tiruchirappalli (NITT), India and Ph.D. in Civil Engineering from National Institute of Technology Tiruchirappalli (NITT), India. He was honored with a National Award from the Government of Tamil Nadu for the best project during the year 2014, Best Paper Award received for the Paper presented in International Conference (FEAST 2018), NIT Trichy, and also won the International Best Researcher Award of the year 2020 in the area of Terramechanics and Nano Materials in Pavements from Idamas Learning Center, Malaysia and World Research Council (WRC). He holds the position as a National Advisory Committee member of the International Conference on "Advancements and Innovations in Civil Engineering" (IC-AICE-2021). Dr. Pala was induced as the Editorial board member of *Journal of Review in Science and Engineering* and also a reviewer of the Transportation Research Board (TRB), *International Journal of Engineering Sciences Advanced Computing & Bio-Technology* (IJESACBT), *Global Journal of Research in Engineering*, USA, *Silicon Journal* and two more journals. Besides all, Dr. Pala is the Ambassador of PROCEDIA, the Conference Managing System, representing India. He has blazoned 18 publications at International Conferences, 15 plus at National Conferences, 30 plus Publications in well reputed international and national journals, and a monograph titled *Speed Detection and Management—An ITS Application*, with Lambert Publishers, UK and authored two book chapters as well. Dr. Pala successfully organized two editions of Conference Series on Sustainable Construction Technologies and Advancements in Civil Engineering and was the mastermind behind the milestone success. Dr. Pala's area of interest relates to Terramechanics and Nano Materials in Pavements, Traffic Safety, Pedestrian and Driver Behaviour Analysis, Self Healing Pavements, Pavement Evaluation, and Management, and Traffic Simulation.

Prof. Kolluru V. L. Subramaniam Professor of Department of Civil Engineering, Indian Institute of Technology Hyderabad, has obtained his B.E. (Civil Engineering) from Indian Institute of Technology Delhi, India; M.S. from University of Toledo, Toledo, USA and Ph.D. from Northwestern University, Evanston, USA. He was awarded Teaching Excellence Award in IIT Hyderabad (2011 and 2016), Outstanding Young Researcher Award & Catell Research Fellow award in 2006, Early Career Award from National Science Foundation of USA in 2003, ASCE Faculty Award from City College of New York in 2003, ACI—James Instrument Award in 1999 for research in Nondestructive Testing of Concrete and Walter P. Murphy Fellowship from Northwestern University (1995–1996). Prof. Subramaniam fashioned the position of Editorial Board Member of *Cement and Concrete Composites* (Elsevier), Associate Editor of *Journal of Materials in Civil Engineering* (ASCE) from 2004–2010. 2018–current, Associate Editor of *Journal of Bridge Engineering* (ASCE) in 2009 and a Guest Editor of *International Journal for Computational Methods in Engineering Science and Mechanics* in 2014. He has 45 publications at International and National Conferences, 90 plus Publications in well reputed international and national journals and authored two book chapters as well. Professor Subramaniam's areas of interest are behavior of concrete and masonry structures; alkali-activated binders and geopolymers; rheology control and 3D printing; fiber-reinforced concrete; sensor development for concrete structures and infrastructure monitoring; low-cost housing solutions with prefabricated elements; and repair systems and strengthening of concrete.

Prof. S. Moses Santhakumar Professor of Department of Civil Engineering, National Institute of Technology, Tiruchirappalli, has obtained his B.E. (Civil Engineering), Masters (Transportation Engineering) and Ph.D. (Transportation Engineering) from Indian Institute of Technology, Madras. He holds lifetime membership in Indian Roads Congress, ISTE, Institute of Urban Transport, and also a member of Highway Research Board & Institution of Engineers. Professor Moses has 10 publications in International and 19 publications in National journals. He has about 47 articles published in National Conferences and 14 in International Conferences. Professor Moses is known for his expertise in consultancy works and has successfully completed 13 consultancy activities. In addition, he has a major advancement in the field of sponsored research activities that included Indo-German Project on Transportation System Management for Indian Cities, DOD Project on Sea Trial of Wave Energy Device at the Ocean Engineering Centre, MHRD Project on Strengthening of the Transportation Engineering Laboratory, Election Commission Project on Computerization of Electoral Process, AICTE Project on Multimedia Tools for Teaching of Civil Engineering, MHRD Project on GIS-GPS Based Monitoring of Public Transport Vehicles, DRD Project on On-line Monitoring of Rural Development Schemes (ongoing), NRRDA Responsibility of Scrutiny of PMGSY Project Proposals (ongoing), NRRDA Project on Traffic Volume Studies on PMGSY Roads (ongoing), NRRDA Project on Rural Road Pavement Performance Study (ongoing) and, Coir Board Project on Coir Geotextiles for Rural Roads (ongoing). Professor Moses research interests comprehends CAD in Transportation Engineering, Transportation Planning, Computer Simulation and GIS.

Dr. Neelima Satyam D. Head and Associate Professor of Department of Civil Engineering, Indian Institute of Technology Indore, has obtained her B.E. (Civil Engineering) from Sri Venkateswara University, Tirupati, India; Masters (Geotechnical Engineering) and Ph.D. (Civil Engineering) from Indian Institute of Technology Delhi. Dr. Neelima was honoured with numerous awards embracing CIDC Vishwakarma Academician Award 2021 from Construction Industry Development Council, Overseas famous scientist project from Ministry of Science and Technology, Guangdong, China (2020–2021), JSPS Research Fellow Award from University of Tokyo (2012–2013), Career Award for Young Teachers (CAYT) from AICTE in 2012, Young Engineers Award from The Institution of Engineers (India) in 2011, Young Scientist Research Award, BRNS from Department of Atomic Energy in 2011, Young Woman Engineer award from INWES-International Network of Women Engineers and Scientists in 2012 and Best technical paper award from IGC (IIT Madras, Chennai) for the Innovations in field exploration and In situ testing in 2006. In addition to the honours and achievements, Dr. Neelima holds membership in American Concrete Institute, Institution of Engineers (India), American Society of Civil Engineering, Earthquake Engineering Research Institute, International Geosynthetics Society (India), International Society for Rock Mechanics and Rock Engineering (India), International Society for Soil Mechanics and Geotechnical Engineering, and Engineering Council of India. She is also a life member of Association of Consulting Civil Engineers (India), Indian Science Congress Association, Indian Society for Technical Education, Indian Concrete Institute, Indian Society of Engineering Geology, Indian Society of Earthquake Technology, European Geosciences Union (EGU), and Indian Geotechnical society. She has published 39 articles in international and national journals and seven articles in conference proceedings. Dr. Neelima's area of research interest includes geotechnical earthquake engineering, dynamic soil structure interaction analysis, liquefaction hazard and mitigation, environmental geotechnics, landslide research and rock mechanics and underground structures.

Self-compacting Concrete Using Tobacco Waste Ash

K. Ashwin Thammaiah, P. Manu Prasad, C. N. Nishchel, Ravi S. Ballavur, and Y. M. Rohith

Abstract The present experimental investigation is an effort to understand characteristics of Tobacco Waste Ash and to examine fresh and hardened state characteristics of self-compacting concrete manufactured using Tobacco Waste Ash as a partial replacement for cement. Tobacco Waste Ash is an industrial by-product that is considered as a waste but has the potential to be utilized as partial replacement for cement thereby reducing cement demand and contributing towards sustainability. Energy Dispersive X-ray Analysis is performed to have a knowledge of elemental composition of tobacco waste ash along with cement and fly ash. Nan Su's method of mix design is followed to proportion self-compacting concrete. Optimum replacement percentage corresponding to maximum compressive strength is determined by partially replacing cement with tobacco waste ash at10, 12, 14, 16, 20, 25 and 30%. Fresh state properties are assessed by Slump flow test, L-box test, V-funnel test and U-box test and later hardened concrete properties are determined. The results indicated an improvement in fresh state properties like cohesiveness and segregation resistance and also had positive effect on hardened properties like compressive, flexural tensile and split tensile strength when cement is replaced at optimum replacement percentage.

Keywords Self-compacting concrete · Tobacco waste ash · Supplementary cementitious materials · Optimum replacement percentage

K. Ashwin Thammaiah (✉) · P. Manu Prasad · C. N. Nishchel · R. S. Ballavur · Y. M. Rohith
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1 Introduction

In early 1980s the construction sector began to emerge as a prominent sector in the society, and subsequently, the need for quality concrete grew rapidly. But, the issue of concrete structures long term durability had become a significant problem in the construction industry together with the reduction in availability of skilled workers. As an attempt to overcome this problem, Okamura proposed a type of High-Performance Concrete known as self-compacting concrete in the year 1986 in Japan with the first prototype being developed in1988 [1, 2]. SCC was the greatest discovery in Concrete Technology which overcame the drawbacks of ordinary concrete like ability to fill and pass along with segregation resistance. SCC is a type of concrete that can easily flow into sections that are narrow and heavily reinforced by the virtue of its own weight without the need for any kind of external or internal mechanical vibration. To achieve these rheological properties, it is necessary to have high percentage of fines like cement in the mix, but this being uneconomical it is also undesirable considering its effect on concrete and environment [3].

The annual production of cement worldwide in 2020 was 4.1 billion tonnes and by 2050 this is further estimated to increase upto 5.8 billion tonnes. India is the second-largest producer of cement worldwide with an annual production of 329 million tonnes whereas in terms of consumption India stands at 327 million tonnes in the 2020 and is expected that by 2025 it may rise to 550 million tonnes. A new way to satisfy this spiking demand for cement is to increase the use of SCMs, pozzolans or fines in production of concrete and at the same time, there is need to unlock new SCMs. Reduced carbon footprint of SCMs results in lesser impact on environment than OPC [4]. Partial replacement of cement with SCMs is an economical way to produce durable concrete [5]. The rising pressure for sustainable waste management and resource efficiency is a pressing issue. Another solution to this is the use of industrial and agro by-products which are generally considered as waste as they reduce cement demand and contribute to sustainability. Greener and sustainable SCC with enhanced properties could be achieved by using agro and industrial by-products [6]. In addition to increased compressive strength, they have reduced materials cost and carbon dioxide emissions which encourages the use of agro-waste ash [7]. Tobacco waste ash is one such material that has the required properties to be used in concrete.

TWA is a by-product from tobacco processing unit obtained by incineration of processing waste which primarily contains ashes of dried tobacco stems and midribs of tobacco leaves. As TWA has lower specific gravity than cement, it increases the paste content per unit volume of concrete and also the unit weight of mortars made with this waste ash is lesser than that of plain cement mortars [4, 8]. The studies have found that it leads to an increase in compressive, flexural tensile and split tensile strength values of the specimens increases by adding 10–12.5% of TWA [5, 9]. Till date a very few researches have been conducted on utilization of tobacco waste ash and its application in concrete.

2 Materials

A good knowledge of various materials and the selection of most suitable material is the first essential step in production of any type of concrete. By proper choice of materials that meet our requirements, we can achieve the desired properties upto a certain limit through conventional concrete. So, materials selection becomes a vital part of production of concrete.

2.1 Cement

53 Grade Ordinary Portland Cement (OPC) that conforms to IS: 12269-2013 was utilized in the mix and tests were performed in accordance to IS: 4031 (Part V)–1988. The cement used had a specific gravity of3.048 and had an initial setting time of 185 min and a final setting time of 315 min.

2.2 Fly Ash

The adverse effects of high cement content in concrete and also on environment can be reduced utilization of alternate materials like this. Class F fly ash is utilized in the mix and it is found to have a specific gravity of 1.97.

2.3 Tobacco Waste Ash

TWA is relatively a new material and most of its characteristics are still unexplored. So initially the materials' specific gravity was tested using kerosene to prevent any reaction that might take place between them during testing. Specific gravity of TWA was 2.42 which is lesser than that of cement but is more than that of fly ash.

2.4 Fine Aggregate

The fine aggregate used in mix is manufactured sand. They are inert in nature and act as filler and give bulk to the concrete. They are prepared by crushing the hard stones such as granite, trap, basalt, etc. The properties are listed in Table 1 and were tested as per the standard procedure coated in IS 2386:1983. The fineness modulus of fine aggregates was determined to be 2.699 and as per IS specifications they corresponded to Zone-II.

Table 1 Fine and coarse aggregate properties

Sl. No.	Properties	Result	
		Fine aggregate	Coarse aggregate
1	Specific gravity	2.692	2.602
2	Water absorption (%)	3.92	0.799
3	Bulk density of loose aggregate (kg/m^3)	1674	1415
4	Bulk density of compacted aggregate (kg/m^3)	1858	1505

2.5 *Coarse Aggregate*

In SCC the coarse aggregate size is usually restricted to maximum of20 mm. In structures with congested reinforcement, 10 mm size aggregate suits the best. However, when the reinforcement spacing is high 20 mm size aggregates can be used whenever. Well graded cubical or rounded aggregate best suits the requirement of SCC. In the present study, 12.5 mm and 6.3 mm nominal size granite stone aggregates are used. The properties were tested as per IS 2386:1983 and are specified below in Table 1 along with fine aggregate properties.

2.6 *Sieve Analysis*

Sieve analysis was done for fine aggregates, coarse aggregates of 12.5 mm and downsize, coarse aggregates of 6.3 mm and downsize, combined coarse aggregate in which the 12.5 mm and 6.3 mm aggregates were taken in the proportion of 60:40, respectively by weight and then combined coarse and fine aggregates in the proportion of 43:57, respectively by volume. The gradation curve of all aggregate proportions used is presented in Fig. 1.

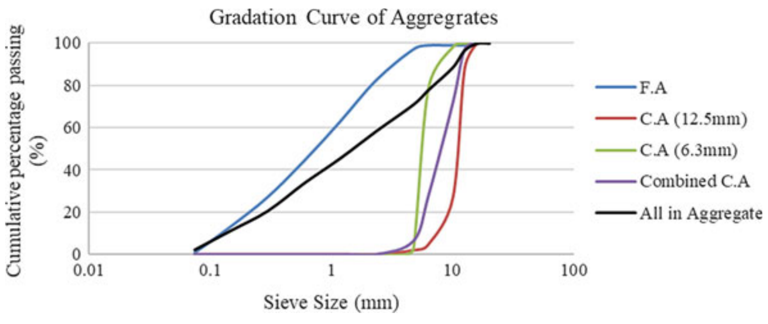


Fig. 1 Gradation curve of aggregates

2.7 Superplasticizer

In our present study Master Glenium SKY 8233 was the superplasticizer used, which conforms to the specifications of IS:9103–1999 and its specific gravity is 1.08. It is a polycarboxylic ether based new generation superplasticizer. The dosage of superplasticizer was determined by performing Marsh cone test and was found to be 0.3%.

3 Methodology

The following sections explain the methodology adopted for design of SCC using TWA, sample preparation and testing procedures.

3.1 Energy Dispersive X-ray Analysis

To understand the elemental composition of TWA, EDAX test was performed on it. Along with TWA, EDAX test was also conducted on cement and fly ash as it would serve as a reference in analysing the characteristics of TWA. Energy Dispersive X-Ray Analysis works on the principle that X-ray is a type of high energy electromagnetic radiation when incident on an atom of the material, core electrons gets ejected. The electron removed from the atom creates a vacant space in the stable system which can be occupied by another electron of higher energy and this is accompanied by release of energy which is unique to each element of periodic table. Using this principle, it is possible to identify various elements present in a material along with the proportion in which each individual element exists. The EDAX spectrum of all the three materials can be seen in Figs. 2, 3 and 4. The quantitative results of EDAX tests present the weight percentage and atomic percentages of various elements present in a sample and are presented in Table 2. From quantitative results, it can be inferred that cement has highest percentage of elemental calcium which makes it hydraulic in nature. TWA also has good amount of elemental calcium but is slightly lower in comparison to cement. This calcium can help in improving the properties of concrete

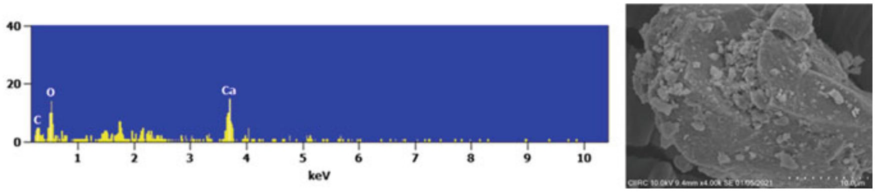


Fig. 2 EDAX spectrum and SEM image of cement

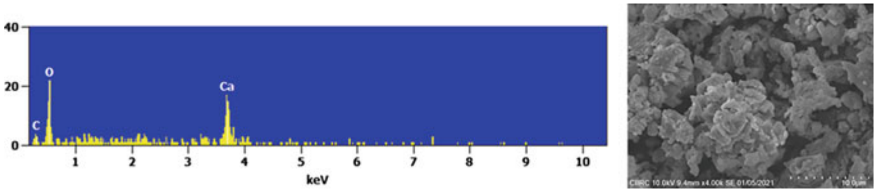


Fig. 3 EDAX spectrum and SEM image of TWA

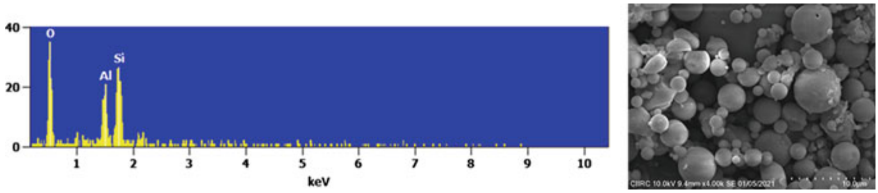


Fig. 4 EDAX spectrum and SEM image of fly ash

Table 2 Quantitative results of EDAX test on cement

Elements	Weight %	Atom %	Weight %	Atom %	Weight %	Atom %
	Cement		TWA		Fly Ash	
C K	2.13	5.16	1.12	2.56	–	–
Ca K	76.24	55.43	69.48	47.31	–	–
O K	21.63	39.40	29.39	50.13	29.22	41.69
Al K	–	–	–	–	23.32	19.74
Si K	–	–	–	–	47.46	38.57
Total	100.00	100.00	100.00	100.00	100.00	100.00

when cement is partially replaced with TWA. Further, it is understood from the spectrum that the amount of silicon and aluminium is less in cement and negligible in TWA. This implies that TWA may only be slightly pozzolanic in nature due to low silicon and aluminium elemental percentages. It is not mentioned in the quantitative results as its percentage is relatively in comparison to quantity of other elements. However, in fly ash, the elemental composition of silicon and aluminium is high which makes it evident that it is pozzolanic in nature while the amount of elemental calcium is very less so it is not mentioned in quantitative results. Along with these results, SEM images of cement, TWA and fly ash were captured. Figures 2, 3 and 4, respectively show the images of particles of these materials at a magnification of 10 microns. From these figures, it can be seen that TWA and fly ash particle sizes are lesser than cement at same magnification level. This implies that they are finer than cement and can fill up the voids in them making concrete more impermeable and durable. Also, it can be seen that the fly ash particle shape is spherical and this enhances rheology of fresh concrete by ball bearing effect.

3.2 Determination of W/C Ratio

Trial mixes were prepared with different w/c ratios ranging between 0.35 and 0.45 which is said to be an ideal range and water content is not allowed to exceed 210 L/m^3 as per EFNARC guidelines [6, 10]. Based on the slump flow, cohesiveness of the mixes and visible bleeding if any, a w/c ratio of 0.40 was selected for design of SCC.

3.3 Determination of Optimum Replacement Percentage

Literature review suggests that for most of the materials the graph of mineral admixture replacement of cement versus its compressive strength follows as optimal curve. The compressive strength reaches a maximum value at certain point of replacement than the rest and value corresponding to that strength is known as optimum replacement percentage. Initially, eight different mortars including control mix were prepared by replacing OPC with TWA by 10, 12, 14, 16, 20, 25 and 30%. 70.6 mm size mortar cubes were cast at first. After curing it for 14 days, compressive strength test was done. Then using these results, concrete cubes of 100 mm size were cast using three different replacement percentages which had higher mortar compressive strength than the rest. Finally, among these three one was selected as optimum replacement percentage which yielded the highest compressive strength of concrete.

3.4 Mix Proportioning

The materials characteristics were tested first, then using these results a trial mix was designed to determine the w/c ratio. Final mix was designed using the selected w/c ratio and correspondingly proportion of various materials was calculated. For proportioning of SCC, Nan Su's method of mix design was adopted. The value of Nan Su's coefficient was taken as 10, a packing factor of 1.06 and ratio of fine to total aggregates by volume is considered as 0.57 and it ranges between 0.50 and 0.57 in Nan Su's method [2]. The mix proportions of control SCC mix and SCC with optimum TWA is presented in Table 3.

Table 3 Mix proportions

Mix	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	TWA (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Superplasticizer dosage (%)
Control Mix	199.13	432.5	65.34	–	1011.43	645.18	0.3
SCC TWA	199.13	380.6	65.34	51.9	1011.43	645.18	0.3

3.5 Tests on Fresh Concrete

Fresh state properties of SCC were tested as per the standard specifications provided in EFNARC guidelines. After the concrete was mixed it was immediately used for testing as delaying it causes a change in fresh state characteristics. Slump flow test, L-Box, V-Funnel, U-Box and segregation resistance test was conducted on fresh mix.

3.6 Casting of Concrete Specimens

After quickly assessing the fresh state characteristics, the same concrete sample was used for casting cubes, beams and cylinders. Moulds were previously prepared and the inner surfaces were oiled so that concrete does not adhere to the surface. Cubes of 100 mm size, cylinders of 200 mm height and 100 mm diameter and beams of size 100 mm $\times$ 100 mm $\times$ 500 mm were cast. Concrete was left to harden for a day as superplasticizer was used, later demoulded and immersion curing was done to test the hardened properties of SCC.

3.7 Tests on Hardened Concrete

Hardened state characteristics is also a significant part of SCC as a concrete with good fresh state properties but uncertain hardened properties would not have much significance. So, it is essential for SCC to have required hardened properties along with good fresh characteristics. The compressive, flexural tensile and split tensile strength of hardened concrete was tested as per standard guidelines.

4 Results and Discussion

The optimum replacement percentage and test results of fresh and hardened concrete are discussed in the upcoming sections.

4.1 Optimum Replacement Percentage

Mortar cubes of 70.6 mm size were cast with various replacement percentages and compression test was conducted on these mortar cubes at an age of 14 days and variation in compressive strength is shown in Fig. 5.

The graph shows that average mortar compressive strength is highest for the replacement percentage of OPC with TWA in the range of 10–14%. Beyond 14% the compressive strength starts to reduce gradually at a study rate and decreases at a higher rate when replacement is increased beyond 25% upto 30%. At 25% replacement, the compressive strength is almost same as that of the control mix mortar. But it is difficult to conclude the optimum value from the graph as there does not exist a single. So further three concrete mixes containing 10%, 12% and 14% TWA were prepared along with control mix and 100 mm size cubes were cast whose compressive strength was tested after curing for 7 and 28 days. The comparison of 7 days and 28 days compressive strength is presented in Fig. 6.

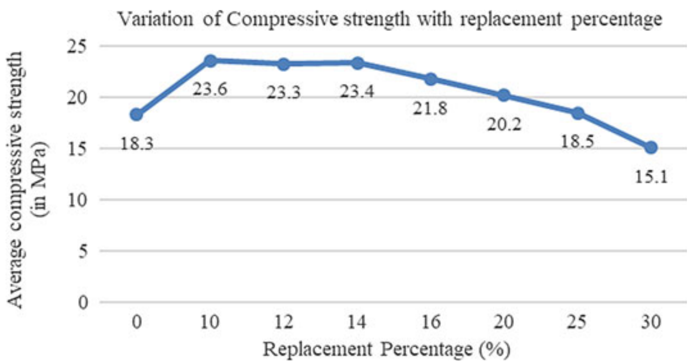
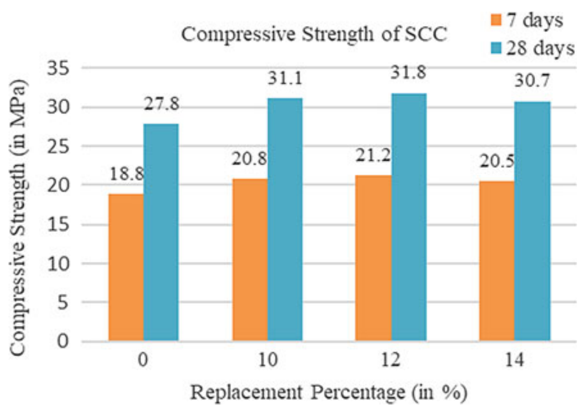


Fig. 5 Variation of compressive strength of mortar cube with replacement percentage

Fig. 6 Comparison of compressive strength of SCC at various replacement percentages



The results show that compressive strength of concrete is maximum at a replacement level of 12% compared to the rest. This implies that optimum replacement percentage of OPC with TWA is 12% by weight. In upcoming sections, SCC containing 12% TWA as replacement for OPC will be denoted as SCC TWA.

4.2 Fresh Concrete Properties

Various tests conducted on fresh state SCC is presented in Fig. 7 and their outcomes are listed in Table 4. Slump flow of SCC containing TWA was less than that of control mix. But even though there is a reduction in slump flow, by visible observation we were able to identify that SCC containing TWA was more cohesive, resistant to segregation and also has good viscosity. The results of T_{500} was parallel to slump flow and as SCC TWA had higher cohesiveness and viscosity it takes more time to reach the 500 mm spread circle in comparison to control mix but both the results were found to be within the specified range.

The time taken by concrete to empty V-Funnel was higher for SCC TWA. Small flow time does not alone mean good filling ability, but as V-Funnel flow time also gives an indication of plastic viscosity to a certain extent, it can be inferred that SCC TWA has higher viscosity than the control mix. Further flow time after 5 min was

Fig. 7 Tests on fresh concrete: slump flow, V-Funnel, L-Box and U-Box test, respectively

Table 4 Fresh state properties of SCC

Test method	Control mix	SCC TWA	EFNARC recommendations
Slump flow (in mm)	690	640	550–850
T_{500} (in s)	3.2	4.6	>2
V-Funnel (in s)	8.3	10.7	6–12
V-Funnel $T_{5\ min}$ (in s)	10.4	11.9	Increase upto 3 s in V-funnel flow time
L-box (H_2/H_1)	0.89	0.84	0.8–1.0
U-box ($H_2 - H_1$)	22	26	0–30
Sieve segregation resistance (in %)	16.3	12.4	0–20

also tested. This gives an indication of segregation of concrete. As the control mix was less cohesive and viscous, the increase in flow time was higher after 5 min due to slight segregation compared to SCC TWA which had only slight increase in flow time which indicates that it is less prone to segregation.

The ratio of heights of concrete flow is higher for control mix, still slight segregation of aggregates was observed behind the rebars. However, the mix was uniform over the total length of flow in case of SCC TWA and despite lower height ratio, it had good passing ability. The results were found to be within the range specified by EFNARC.

The difference between the results of U-Box test of SCC TWA and control mix is not very high. In control mix, upward flow of concrete is due to lower viscosity of control mix while SCC TWA flows uniformly upward in the adjacent section as a cohesive mix maintaining homogeneity.

The sieve segregation test results were found to lie within the range specified by EFNARC guidelines. The results indicated that SCC TWA has higher segregation resistance and visible observations helped to identify that the water retention ability of SCC TWA was improved in comparison to control mix.

4.3 Hardened Concrete Properties

Curing of casted cubes, beams and cylinders was done by immersing in water so that the concrete gets required moisture and temperature to develop strength. Due to the prevailing pandemic situation, it was unable to test the hardened concrete after 7 and 28 days of curing but were rather tested at an age of 60 days and results are listed in Table 5.

Based on these results it is noticed that 60 days average concrete compressive strength with optimum replacement percentage of TWA is about +13.59% higher than the control mix which does not contain any amount of TWA. The chemical characterization results have shown that TWA contains good amount of elemental calcium and also its particles are fine than that of cement. So, the increase in strength of concrete containing TWA can be presumed to be result of filler effect and nucleation by TWA.

Cylinders of height 200 mm and diameter100 mm were used for split tensile test at 60 days age. From the results, it is noticed that there is an increment in split tensile strength of about +5.1% in SCC containing 12% TWA in comparison with control mix.

Table 5 Hardened state properties of SCC

Mix type	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural strength (MPa)
Control Mix	33.1	2.94	1.78
SCC TWA	37.6	3.09	1.84

Beams of length 500 mm, width 100 mm and depth 100 mm was tested at the age of 60 days to obtain the flexural tensile strength of SCC by application of two-point loading. An increase in only about +3.3% was noticed in the flexural strength of SCC containing 12% TWA in comparison with control mix.

5 Conclusions

From the key findings of this experimental investigation we were able to draw the following conclusions:

- Nan Su's method of mix design is a simple tool to proportion SCC mixes. Based on our results we were able to identify that this method yields low paste volumes which affect the target strength of SCC. It is balanced using TWA as partial replacement for OPC that has lower specific gravity than cement, which increases the amount of powder content per cubic meter of concrete
- TWA enhances the rheological properties of SCC in fresh state by improving the cohesiveness, segregation resistance, water retention ability and passing ability due to its increased fineness and lower specific gravity than cement
- The strength of SCC at early ages is lower than the target strength due to the utilization of fly ash but later increases beyond the age of 28 days. The designed target strength of SCC is achieved at an age of 60 days
- The increase in compressive strength of SCC by TWA in addition to that of OPC is attributed to its filler effect and nucleation in SCC
- At 12% replacement of OPC with TWA the compressive strength of cubes increases by +13.59%, split tensile strength of cylinder specimen increases by +5.1% and flexural tensile strength of beams is found to increases by +3.3% in comparison to the control mix with no TWA
- TWA can be effectively utilized in SCC as a partial replacement for OPC to enhance its rheological and mechanical properties provided it is replaced at optimum percentage.

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