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### Cover

The 60-story Kitahama building in Osaka, Japan uses ECC in the building core. Coupling beam and Reinforced core wall structure shown as an inset image.

Cover image source:  
Wikipedia and Victor C. Li, James R. Rice  
Distinguished University Professor of  
Engineering E. Benjamin Wylie Collegiate  
Professor of Civil Engineering University  
of Michigan, Ann Arbor, MI USA

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Shamsher Bahadur Singh

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Website: [www.icjonline.com](http://www.icjonline.com) e-mail: [info@icjonline.com](mailto:info@icjonline.com) [editor@icjonline.com](mailto:editor@icjonline.com)

## Dear Readers,

Focussed on the built environment, our need is more durable infrastructure that requires less frequent repair, and more resilient infrastructure that minimize disruption of life in a major load event. To that extent, with research papers on Concrete that is ductile, and with autogenous crack width control capability, generally known as Engineered Cementitious Composites (ECC) or Strain-Hardening Cementitious Composites (SHCC), Prof. Dhanda K. Mishra brings to you the present edition.

Prof. Dhanada K. Mishra has rich academic and professional experience. He is a visiting Research Scholar at Hong Kong University of Science and Technology (HKUST). He has received his Ph.D. degree in Civil Engineering from the University of Michigan, Ann Arbor and has researched under the guidance of Prof. (Dr.) Victor C. Li. He has served at the Kalinga Institute of Industrial Technology (KIIT) University as its first Dean of Research and as the Principal of the Jagannath Institute of Technology and Management (JITM), during its transformation to become the Centurion University. Currently, he is on sabbatical leave from his position as Director KMBB Engineering College, Biju Patnaik University of Technology (BPUT). His research interests include low cost housing, compressed earth construction, fly ash and other industrial waste utilisation and advanced concrete technology.

We thank our vibrant and committed team of Reviewers and Guest Editors for extending their exemplary support in these unusual times. We hope you enjoy reading this edition. Please do share your comments and feedback with us.

I am pleased to share the level of interest in our digital platforms has increased. The ICJ website ([www.icjonline.com](http://www.icjonline.com)) has attracted a three-fold increase in the traffic to its monthly edition pages and on open access content pages over the last year. We will continue to upload more open access articles for our readers through this month.

I do hope we can all keep positive in these unusual times. Please continue to stay safe and healthy!

Production Editor  
Indian Concrete Journal



## Dear Colleagues,

The construction industry contributed to 6% of global GDP as per the Boston Consulting Group (BCG) report for the World Economic Forum (WEF) published in 2017<sup>1</sup>. The threat of climate change, rapid demographic shifts and growing demand for resilient and sustainable infrastructure would enhance its importance even further. It is estimated that a global infrastructure investment of 3.3 trillion US dollars per year is needed in the years from 2016 through 2030<sup>2</sup>. The construction industry also accounts for 25-40% of the carbon emissions and is the largest user of raw materials<sup>1</sup>. To meet these challenges, there is an urgent need for high-performance construction materials with high strength and ductility, lightweight, excellent durability, good constructability, as well as low cost and minimum environmental impact. WEF has captured some of these trends in a Construction Industry Transformation Framework<sup>3</sup>. It emphasizes the opportunities for significant gains in areas of new material technologies. Unfortunately, the development of innovative material technology in construction has been infrequent and takes a long time to the market compared to other fields. 3D printing,

third generation construction chemicals, low carbon cements such as Limestone Calcined Clay Cement (LC<sup>3</sup>), Building Information Modelling (BIM), construction automation, self-sensing and self-healing materials are some examples of such innovations that are transforming the construction sector. Engineered Cementitious Composites (ECC) is one such novel material technology, which is also known as Strain Hardening Cementitious Composites (SHCC). ECC is part of the High Performance Cement Composites (HPCC) that helps converting a brittle material like concrete into a ductile material – popularly known as ‘Bendable Concrete’.

The current issue focuses on the topic of ‘Fiber Reinforced Cementitious Composites’ or FRCC, which is the broad class of materials that includes ECC.

The first paper by Prof. Sivasubramaniam from National Institute of Technology (NIT) Puducherry and his multi-institutional team of co-authors is a comprehensive literature review of structural application of ECC. It summarizes the important research work done on a range of topics from shear and flexural behavior of structural components to seismic performance of ECC structures.

In the second paper of this issue, Prof. Rongxin Guo and his colleagues from the Kunming University of Science and Technology in China have proposed an interesting approach to the micromechanics-based design of ECC using the flexural test method. They have measured the bridging stress versus crack opening relationship in notched tension samples to determine the effect of fiber volume fraction on the composite properties. This in turn helps determining the optimum fiber content for a given combination of matrix, fiber and interface that meets the conditions of strain hardening.

The third paper from the ECC research group at Hong Kong University of Science and Technology led by Prof. Christopher K. Y. Leung illustrates a real life case study in which a practical ECC mix has been designed for a specific structural application. The innate crack width control ability of ECC is used to design an improved water-tight structure. It uses a new lower cost Chinese PVA fiber as opposed to the commonly used Kuraray fiber from Japan and crushed rock fines as aggregate to make ECC commercially competitive.

The fourth paper by Prof. Savas Erdem and his colleague from the University of Istanbul reports a piece of very interesting work on the fire resistance of fiber reinforced composite pavement designed for high heating rate from the exhaust of a fighter jet. It reveals the importance of using mineral fibers like basalt and metallic fiber like steel together with the polymeric fiber like PVA, in order to retain required strength and impact energy at high temperature.

The fifth paper from Dr. Bharati Ganesh and colleagues from NITTE-MIT demonstrates the correlation between static and dynamic measurement of elastic modulus of Ultra High Performance Concrete (UHPC).

The sixth paper by Maninder Singh et al. from National Institute of Technology (NIT) Kurukshetra deals with flexural performance and durability characteristics of hybrid fiber reinforced ECC where the commonly used PVA fiber is partially replaced by PET and steel fibers. Certain advantages including lower cost were observed which may help promote use of ECC in real life applications.

Finally, we have also included a short review of the book titled Engineered Cementitious Composites authored by

Prof. Victor C. Li and published by Springer last year. This review has been contributed by Prof. S. B. Singh.

We hope this issue will be a stimulating read for undergraduate and post-graduate students, researchers, faculty members and practicing engineers. While India has a long and rich tradition of research in the field of concrete science and technology including fiber reinforced concrete, much remains to be done in the fields of advanced cement based composites such as ECC. We hope the December 2019 issue and the current issue will provide some much needed encouragement to researchers, particularly in India, in taking up explorations in these exciting new areas.

I would like to express my sincere gratitude to my Ph.D. supervisor and guide Prof. (Dr.) Victor C. Li for his constant mentoring, my host at HKUST Prof. Christopher K. Y. Leung for his support and specifically Assistant Professor Dr. Jing Yu for his prompt assistance in making this issue possible. We thank all our reviewers for their valuable support in enhancing the quality of the publication. I would also like to thank Sri Soumya Ranjan Patnaik, Chairman KMBB College of Engineering and Technology for having permitted my sabbatical at HKUST.

As the world grapples with the unprecedented Covid19 pandemic, I hope you are staying safe and healthy. I join you in looking forward to a brighter future as humanity learns the right lessons and rebuilds a climate-resistant and equitable new world.

**Dhanada K. Mishra\***

Guest Editor, ICJ

## REFERENCES

1. Arulanandam, P. M., Singh, S. B., Kanakubo, T., and Sivasubramanian, V. R. (2020), "Behavior of Engineered Cementitious Composite Structural Elements – A Review." *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 05-28.
  2. Guo, R., Fu, C., Yang, Y., and Yan, F. (2020), "Effect of Fiber Content on the ECC Bridging Stress-Crack Opening Behavior and Flexural Strain Hardening Properties." *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 29-38.
  3. Shan, K. A., Ratnayake, D., Yu, J., Mishra, D. K., and Leung, Christopher K. Y. (2020), "Optimization of Low-Cost Polyvinyl Alcohol (PVA) Fiber Reinforced Engineered Cementitious Composites (ECC) for Practical Applications." *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 39-48.
  4. Gurbuz, E., Erdem, S., "Experimental Behaviour of Hybrid Fiber Reinforced Engineered Cementitious Composites for Concrete pads Supporting joint Strike Fighter F35-B." *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 49-55.
  5. Ganesh, B., Ramesh M. N., Santhosh K., Manoj V. (2020). "Correlation of Dynamic and Static Modulus of Elasticity of UHPC". *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 56-65.
  6. Singh, M., Saini, B., Chalak, H. D. (2020). "Performance characteristics of ECC using micro fibers in hybridization". *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 66-73.
  7. Singh, S.B. (2020), "Engineered Cementitious Composites (ECC): Bendable Concrete for Sustainable and Resilient Infrastructure." *The Indian Concrete Journal*, Vol. 94, No. 6, pp. 74-75.
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1. World Economic Forum, *Shaping the Future of Construction: Inspiring Innovators Redefine the Industry*, Geneva: Boston Consulting Group, 2017, 96 pp.
  2. Woetzel, J., Garemo, N., Mischke, J., Hjerpe, M. and Palter, R., *Bridging Global Infrastructure Gaps*. McKinsey Global Institute; June 2016, 60 pp.
  3. World Economic Forum, *Shaping the Future of Construction: A Breakthrough in Mindset and Technology*, Geneva: Boston Consulting Group. 2016, 64 pp.