ISSN 2347 - 3983
Volume 9. No. 8, August 2021
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter19982021.pdf
https://doi.org/10.30534/ijeter/2021/19982021

Mechanical Properties of Modified Engineered Cementitious Composites (MECC) Incorporating Marble Dust

Ezaz Ali Khan[1], Sajjad Wali Khan[2], Akhtar Gul[3], Khan Shahzada[4]
[1,2,3,4]Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan
[1]ezazali@uetpeshawar.edu.pk
[2]drsajjadwalikhan@uetpeshawar.edu.pk
[3]akhtarwazir@uetpeshawar.edu.pk
[4]khanshahzada@uetpeshawar.edu.pk

ABSTRACT

Engineered cementitious composites (ECC) are a type of high-performance fiber reinforced cementitious composite. ECC has different applications in the construction field due to its inherent characteristics of high tensile strain. The main concern regarding ECC is its high cost. The content of cement is high contributing to its cost. In this research work, the cement in ECC is replaced with marble dust and its mechanical properties such as compressive strength and flexure strength have been assessed. For this purpose, both cubes and cylinders were tested at different test ages for finding the compressive strength development with time and observe the shape effect of specimens on the compressive strength of ECC mixes. Beam members were tested for finding the flexure strength of ECC mixes. Deflection gauge was also installed at the mid span on the bottom surface of the beams to find the maximum mid span deflection before failure. The compression test results of both cylinders and cubes revealed that using of marble dust has negative effect on the compressive strength of ECC. The flexure strength result showed that marble dust can be used up to some extent replacing cement will increase the flexure strength. The result of mid span deflection suggests that by incorporating marble dust in ECC, its ductility increases.

Key words : Compressive strength, ECC, marble dust, flexure strength

1. INTRODUCTION

Cement based products are an important component of the construction industry. Among these products one which is finding immense applications especially in retrofitting is Engineered Cementitious Composite (ECC). In 1992 the ECC design model was presented by V. C. Li [1]. ECC comes under the category of High-Performance Fiber Reinforced Cementitious Composites (HPFRCC). The stress-strain curve of ECC shows that it exhibits strain hardening behavior in contrast to Fiber Reinforced Concrete (FRC) which exhibits strain softening pattern [2]. ECC fails with high tensile strain ranging from 1% to 8% as compared to normal concrete having strain value of 0.01%, showing that ECC is far more ductile than normal concrete and this ratio is practically 300 times [3],[4]. Multiple fine cracks are developed in ECC as a result of uniaxial tensile force, the average crack width is up to 100 mm while the crack spacing ranges from 3 to 10 mm [5]. The application of ECC can enhance the service life of a structure and ultimately reduce the cost of maintenance and repair works [6].

The usual constituents of ECC are cement, fine silica sand, fly ash, admixture (High range water reducer (HRWR) or superplasticizer), fibers and water. Coarse aggregate are omitted in ECC. In ECC the fracture toughness of matrix is limited, while coarse aggregate modify the track of fracture increasing the fracture toughness of the matrix [7]. Furthermore, the sand used is also of fine size because larger size sand reduces the mechanical properties of ECC due to fiber balling and clumping [8]. Fly ash is used as a replacement to cement in the ECC. Tight crack width and well spread multiple crack widths can be obtained by using high quantity of fly ash in the ECC [9]. Different types of fibers have been used in ECC in the past. However, the most common types are Polypropylene (PP), Polyvinyl alcohol (PVA), and Polyethylene (PE) fibers. The tensile characteristics of PVA fibers are superior to PP fibers while PE fibers are considerably expensive as compared to PVA fibers. At present PVA fibers are the most used fibers in the production of ECC, referred to as PVA-ECC [9]. PVA fibers are hydrophilic in nature, increasing the chemical and frictional bond between fiber and matrix, so PVA fibers are surface oiled to achieve strain hardening criteria. Optimum range of oiling agent to achieve considerable strain in ECC ranges from 0.8 to 1.2% (by weight) [10]. Most commercial PVA fibers in the market are oiled.

The quantity of cement in ECC is high. For M45 ECC mix design for one cubic meter of ECC produced on average 506 kg of cement is required, resulting in a cost of 62.74 USD (as of 2021). Different researchers have studied use of filler materials to decrease the quantity of cement such as fly ash [11]-[13], stone slurry powder [14], and solid ceramic waste powder [15]. Marble dust can also be a reasonable option to replace cement. In Pakistan about 160.1 million tons identified reserves of marble are present [16]. This marble dust if left unutilized can damage the world ecosystem. Serious negative effects can be caused due to this marble dust such as lung cancer, skin, and eye diseases [17], loss to flora and fauna [18], water pollution upon mixing with water in natural streams and rivers [19]. Successful application of marble dust replacing cement may result in the reduction of quantity of cement leading to production of low cost ECC.

While finding the mechanical properties of a material, compressive strength is an important property to be considered. Different sizes and shapes of samples are recommended in the standards for finding the compressive strength. Cylinder sizes such as 100 mm diameter and 200 mm height [20], and 150 mm diameter and 300 mm height [21] are commonly used. Cubic specimens of 150 x 150 mm [22] and 50 x 50 mm [23] are normally used. Different research work have been carried out in the past to find the effect of sample size and shape on the compressive strength of concrete[24]–[28]. The relationship between compressive strength and slenderness ratio (l/d) have been proposed by different researchers[24],[29]-[32]. It was observed that the compressive strength of cylinder is lower than that of cube of the same material [25],[33]-[34]. However, the work done on ECC to find the shape effect on compressive strength is not as extensive as done on concrete specimens.

In this research work the effect of incorporation of marble dust with replacing of cement on the mechanical properties of PVA-ECC has been studied. Compressive tests and flexure bending tests are the two main type of tests performed in this research work. Compression test has been performed on cylinders and cubes on different test ages to ascertain the strength development with time and shape effect of the Modified ECCs (MECC). Flexure test has also been performed to determine the bending characteristics of the MECCs.

2. EXPERIMENTAL PACKAGE

2.1 Materials and Mixture design

As ECC design is based on micro properties of individual materials. Therefore, it is necessary to define the individual material properties. Following the classification mentioned in ASTM C150 [35], ordinary Portland cement was used. The specific gravity of cement was 3.14. Preliminary tests were performed on cement before use. Tests such as consistency, initial and final setting time and fineness of cement were performed according to ASTM standards and the cement was found to be satisfactory. Local sand with a maximum size of 2.38 mm and specific gravity of 2.64 was used. Following the classification presented by ASTM C618 [36], Type F fly ash was selected to be used in the production of ECC mixtures. Imported oiled PVA fibers were used for the ECC mixtures. The fiber diameter was 40 µm, length of 12 mm, specific gravity of 1.3 g/cm^3, tensile strength of 1600 MPa and Young's Modulus of 41 GPa. The materials used are shown in Figure 1.

One test mix designated as ECC and four modified mixes designated as MECC-5, MECC-10, MECC-15, and MECC-20 having 5%, 10%, 15%, and 20% of marble dust respectively were prepared. The M45 mix design presented by V. C. Li [2] was selected as design basis for the mixes. However, as the cement fineness is low in Pakistan as compared to cement produced in countries such as America and Canada, therefore the water/binder ratio was kept as 0.38. Different types of admixtures with different admixture/binder ratios were employed as can be seen in Figure 2 and the one giving the best result in terms of flow and workability was selected. The mixture proportions are presented in Table 1.

Figure 1: Materials used for production of ECC (a) sand (b) cement (c) fly ash (d) marble dust (e) PVA fibers

Figure 2: Different types and quantities of admixtures used for production of ECC

Table 1: Mix IDs and their proportions

Mix ID	Cem-ent	Fly Ash	MW P	Sand / binde r	Water / binde r	PVA (by vol.)	HRW R / binder
ECC	1	1.2	0	0.38	0.38	1%	0.01
MECC - 5	0.89	1.2	0.11	0.38	0.38	1%	0.01
MECC - 10	0.78	1.2	0.22	0.38	0.38	1%	0.01
MECC - 15	0.67	1.2	0.33	0.38	0.38	1%	0.01
MECC - 20	0.5	1.2	0.5	0.38	00.38	1%	0.01

The dry ingredients cement, sand, fly ash, and marble dust were first dry mixed. To this dry mix water and HRWR were added and a uniform paste was prepared. In the end PVA fibers were added and mixed for even dispersion of the fibers in the matrix.

2.2 Specimen fabrication and curing conditions

For the compressive strength test cylinder having a diameter of 100 mm and height of 200 mm were fabricated. Three (3) number of cylinders were fabricated for each trial. Cube specimens having 50 x 50 mm dimensions were fabricated for compressive test. Three (3) number of cubes were casted for each trial. For flexure test five (5) number of beams were casted for each trial. The beams having length of 355 mm while width, and height of 101 mm each were constructed and tested to assess its flexural capacity. The specimens were removed from its casting cases after 28 hours and left in dry environment for 4-6 hours and then placed in curing till testing date.

2.3 Experiment Procedure

The compressive strength of cylinder was evaluated following ASTM C39 [21] as shown in Figure 4. The cylinders were tested at age of 14, 28, 56, and 91 days of age. Following the procedure of ASTM C617 [37] proper gypsum capping of the cylinder was done prior to testing as shown in Figure 3. Cubes were tested following the procedure defined by ASTM C109 [23] as shown in Figure 5.The cubes were tested at age of 14, 28, 56, and 91 days of age. Flexure strength test was conducted following ASTM C1609 [38] as shown in Figure 6. Beams were tested at an age of 91 days. Four-point loading conditions were provided. The span length was taken as 305 mm for flexure test. Deflection gauge was also installed at the midpoint on the bottom face of the beams to find the maximum mid span deflection before failure to determine the ductility of the different ECC mixes under consideration. A total of 60 cylinders, 60 cubes, and 25 beams were fabricated and tested.

Figure 3: Gypsum capping of cylinder specimens

Figure 4: Testing of cylinder specimen

Figure 5: Testing of cube specimen

Figure 6: Experimental setup for bending test of beam specimens

3. RESULTS AND DISCUSSION

3.1 Compressive strength from cylinders

The compressive strength results of cylinders are presented in Figure 7. From which it can be noted that by increasing the marble dust quantity the compressive strength decreases and this trend is followed for all mixes at all test ages. The decrease in compressive strength at 91 days as compared to ECC mix is 16.2%, 24.8%, 27.2% and 44.1% for MECC-5, MECC-10, MECC-15, and MECC-20 respectively. The decrease in compressive strength is considerable when the marble dust quantity is increased from 15% to 20%. In addition to this, a considerable increase in compressive strength is observed even after 28 days for all mixes.

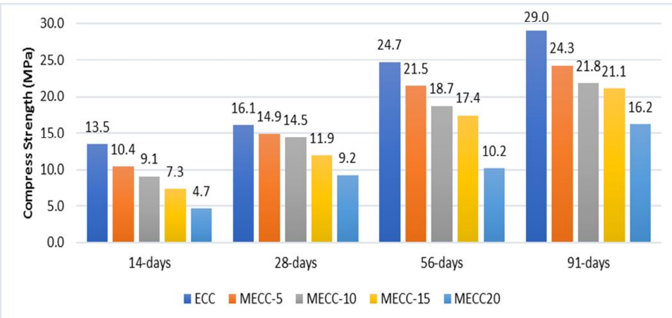

Figure 7: Compressive strength development of cylinders with days

3.2 Compressive strength from cubes

The compressive strength results of cubes are presented in Figure 8, from which it can be seen that by increasing the marble dust quantity the compressive strength decreases and this trend is followed for all mixes at all test ages. The decrease in compressive strength at 91 days as compared to ECC mix is 12.9%, 24.0%, 26.3% and 41.8% for MECC-5, MECC-10, MECC-15, and MECC-20 respectively. Following similar trend as that of the cylinders the decrease in compressive strength is considerable when the marble dust quantity increased from 15% to 20%. A considerable increase in compressive strength was also observed for cubes even after 28 days for all mixes. This is due to the high quantity of pozzolanic fly ash and marble dust in the ECC mixtures.

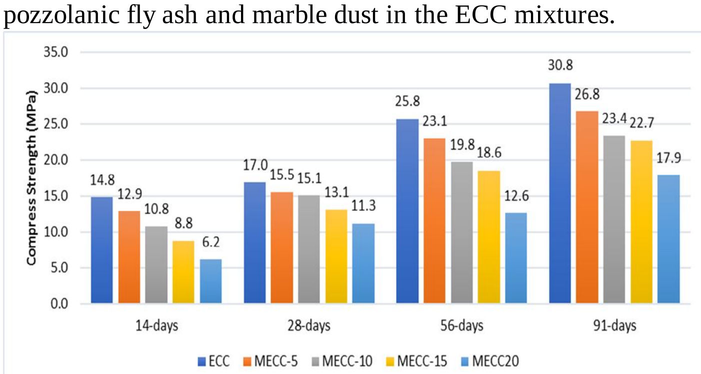

Figure 8: Compressive strength development of cubes with days

3.3 Comparison between cylinder and cube results

The comparison between the compressive strength results of cylinders and cubes is presented in Table 2 and Figure 9. The compressive strength of cubes was greater than the cylinders for all mixes at all testing age. On average the compressive strength of cubes is 9.5% more as compared to the cylinders.

From the compression test results of both the cubes and cylinders, it can be deducted that marble dust only act as a filler material and does not act as a cementitious material in the ECC.

Table 2: Compressive strength test results of cylinders and cubes

ID	Test Age (days)	Comp. Strength (MPa), Cylinder	Comp. Strength (MPa), Cube	COV (%), Cylinder	COV (%), Cube
ECC		13.5	14.8	5.84	4.03
MECC -5		10.4	12.9	5.51	9.64
MECC -10	14	9.1	10.8	1.17	8.89
MECC -15		7.3	8.8	6.69	6.35
MECC -20		4.7	6.2	12.42	8.36
ECC		16.1	17.0	4.13	5.19
MECC -5		14.9	15.5	4.93	4.46
MECC -10	28	14.5	15.1	3.41	5.21
MECC -15		11.9	13.1	5.86	7.69
MECC -20		9.2	11.3	3.38	3.04
ECC		24.7	25.8	1.48	5.85
MECC -5		21.5	23.1	3.12	4.27
MECC -10	56	18.7	19.8	4.69	10.02
MECC -15		17.4	18.6	8.08	6.90
MECC -20		10.2	12.6	7.65	9.97
ECC		29.0	30.8	4.86	2.97
MECC -5		24.3	26.8	2.38	6.76
MECC -10	91	21.8	23.4	8.60	3.82
MECC -15		21.1	22.7	3.88	4.02
MECC -20		16.2	17.9	12.52	10.80

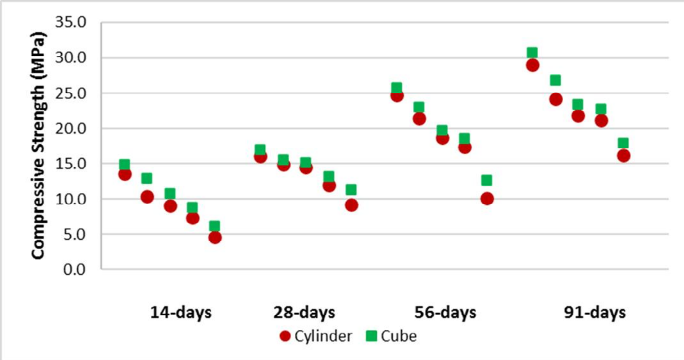

Figure 9: Comparison between compressive strength results of cylinders and cubes

3.4 Flexure strength results

The flexure strength and maximum mid span deflection of beams are presented in Table 3. From Figure 10 it can be seen that the flexure strength increases as the marble dust quantity increases, but after increase from 15% to 20% the flexure strength decreases. The reason for this increase may be the fact that the marble dust acts as a filler rather than cementitious material. This property of marble dust leads to decrease the chemical bond between fibers and matrix, which makes the strain hardening criteria more suitable for the MECC mixes as compared to the ECC mix. The reason for decrease in the flexure strength of MECC-20 is because of the lower compressive strength of MECC-20 mix as compared to other mixes. The result of the maximum mid span deflection before failure of beams as shown in Figure 11 revealed that by increasing the marble dust quantity, the deflection increases meaning that the ductility increases. The increase in deflection was not much significant up to MECC-10 but was steeper when moving from MECC-10 towards MECC-15 and MECC-20. The maximum deflection was observed for MECC-20 mix.

Table 3: Flexure strength and mid span deflection results from bending test of beams

ID	Flexure strength (MPa)	Avg. max mid span deflection (mm)	COV(%) Flexure strength	COV% mid span deflection
ECC	7.4	1.47	4.37	8.38
MECC-5	7.6	1.48	3.59	10.22
MECC-10	8.2	1.52	3.71	8.45
MECC-15	8.2	1.71	3.61	6.67
MECC-20	6.1	1.91	6.81	7.54

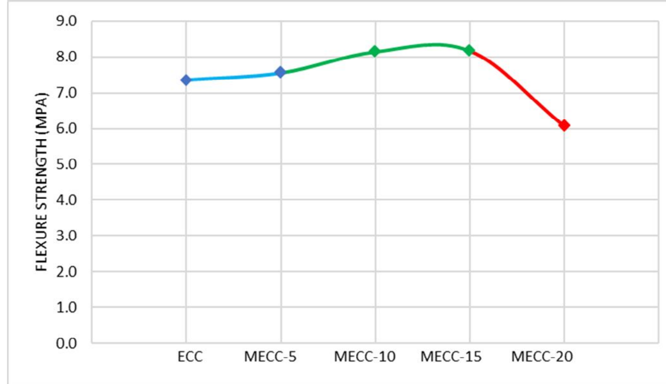

Figure 10: Flexure strength of the mixes

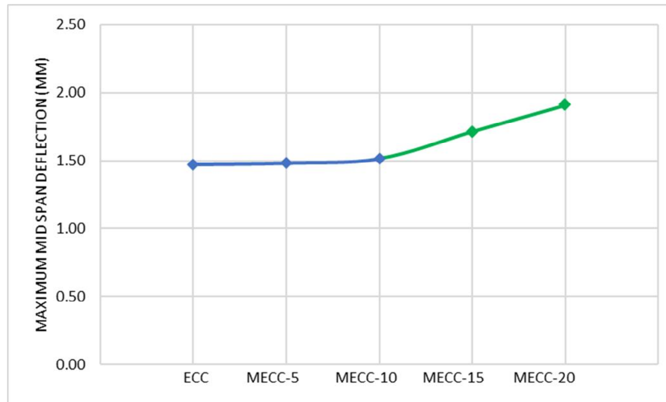

Figure 11: Maximum mid span deflection for the mixes

4. CONCLUSIONS

The following conclusions can be drawn from this research work.

- The compressive strength results for both the cylinders and cubes showed that marble dust act as a filler in ECC, lowering the compressive strength. A significant decrease in the compressive strength was observed when moving from MECC-15 to MECC-20. Indicating that the marble dust quantity should not be increased from 15%.
- The compressive strength results showed that the strength obtained from cubes is always more as compared to that obtained from cylinders. On average the compressive strength obtained from cubes is 9.5% more than that obtained from cylinders.
- The flexure strength increased as a result of increase in marble dust quantity. With MECC-15 having the greatest flexure strength of about 8.17 MPa, which is 11.2% greater than the flexure strength of the ECC mix. Showing that marble dust favors the strain hardening behavior of ECC.
- By increasing the marble dust quantity, the maximum mid span deflection under bending increases, indicating that marble dust makes ECC more ductile.

ACKNOWLEDGEMENT

We are grateful to University of Engineering and Technology, Peshawar Pakistan for providing the lab facilities for conducting this research work.

REFERENCES

1. V. C. Li. **From Micromechanics to Structural Engineering - The Design of Cementitious Composites for Civil Engineering Applications,** *Structural Eng/Earthquake Eng*, vol. 10, no. 2, pp. 37s-48s, July 1993.
2. V. C. Li. ***Engineered Cementitious Composites (ECC) – Material, Structural, and Durability Performance***, Book Chapter in Concrete Construction Engineering Handbook, Ed. E. Nawy, 2007.
3. V. C. Li. **Tailoring ECC for special attributes: a review**, *International Journal of Concrete Structures and Materials*, vol. 6, no. 3, pp. 135–144, 2012.
4. K. Yu, Y. Wang, J. Yu, and S. Xu. **A strain-hardening cementitious composites with the tensile capacity up to 8%**, *Construction and Building Materials*, vol. 137, pp. 410–419, 2017.
5. J. Zhang, C.K.Y. Leung, and Y. Gao. **Simulation of crack propagation of fiber reinforced cementitious composite under direct tension**, *Engineering Fracture Mechanics*, vol. 78, no. 12, pp. 2439–2454, 2011.
6. M. Li, V. C. Li. **Cracking and healing of engineered cementitious composites under chloride environment**, *ACI Materials Journal*, vol. 108, no. 3, pp. 333–340, 2011.
7. P. Souroshian, A. Kha, and J. W. Hsu. **Mechanical properties of concrete material reinforced with polypropylene and polyethylene fibers**, *ACI Materials Journal*, vol. 89, no. 6, pp. 535-540, 1992.
8. D. De Koker, and G. Van Zijl. **Extrusion of engineered cement-based composite material**, *in Proceedings of the 6th RILEM Symposium on Fiber-Reinforced Concretes (FRC)*, pp. 20–22, 2004.
9. V. C. Li , S. Wang, and C. Wu. **Tensile strain-hardening behavior or polyvinyl alcohol engineered cementitious composite (PVA-ECC)**, *ACI Materials Journal*, vol. 98, pp. 483-492, 2001.
10. E. H. Yang and V. C. Li. **Strain-hardening fiber cement optimization and component tailoring by means of a micromechanical model**, *Construction and Building Materials*, vol. 24, no. 2, pp. 130–139, 2010.
11. E. Yang, Y. Yang, and V. C. Li. **Use of High Volumes of Fly Ash to Improve ECC Mechanical Properties and Material Greenness**, *ACI Materials Journal*, vol. 104, no. 6, pp. 620-628, 2007.
12. Z. Pan, C. Wu, J. Liu, W. Wang, and J. Liu. **Study on mechanical properties of costeffective polyvinyl alcohol engineered cementitious composites (PVA-ECC)**, *Construction and Building Materials*, vol. 78, pp. 397-404, 2015.
13. M. Sahmaran, M. Lachemi, K. M. Hossain, R. Ranade, and V. C. Li. **Influence of aggregate type and size on ductility and mechanical properties of engineered cementitious composites**, *ACI Materials Journal*, vol. 106, no. 3, pp. 308–316, 2009.
14. M. Singh, B. Saini, and H. D. Chalak. **Long term evaluation of engineered cementitious composite containing stone slurry powder**, *Construction and Building Materials*, vol. 264, 120183, 2020.
15. J. Zhao, C. Yan, S. Liu, J. Zhang, S. Li, and Y. Yan. **Effect of solid waste ceramic on uniaxial tensile properties and thin plate bending properties of polyvinyl alcohol engineered cementitious composite**, *Journal of Cleaner Production*, vol. 268, 122329, 2020.
16. Korai and M. Ahmed. **A Report on Marble & Granite**, Trade Development Authority of Pakistan, 2010.
17. M. I. El-Gammal, M. S. Ibrahim, E. A. Badr, S. A. Asker, and N. M. El-galad. **Health Risk Assessment of Marble Dust at Marble Workshops**, *Nature and Science*, vol. 9, no. 11 ,pp. 144–54, 2011.
18. R. P. S. Kushwah.**Scientific Disposal System of Marble Slurry for Clean and Green Environment**, *International Journal of Engineering Sciences & Research Technology*, vol. 3, no. 10, pp. 500–503, 2014.
19. R. A. Hamza, S. El-Haggar, and S. Khedr. **Marble and Granite Waste: Characterization and Utilization in Concrete Bricks**, *International Journal of Bioscience, Biochemistry and Bioinformatics*, vol. 1, no. 4, pp. 286–291, 2011.
20. ASTM C31/C31M-**Standard Practice for Making and Curing Concrete Test Specimens in the Field**, *ASTM Int.*, 2021.
21. ASTM C39/C39M-**Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens**, *ASTM Int.*, 2020.
22. BS-EN-12390-3: **Testing hardened concrete—part 3: compressive strength of test specimens**. *British Standards Institution*, London ,2003.
23. ASTM C109/C109M-**Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)**, *ASTM Int.*, 2020.
24. S. T. Yi, E. I. Yang, and J. C. Choi. **Effect of specimen sizes, specimen shapes, and placement directions on compressive strength of concrete**, *Nuclear Engineering and Design*, vol. 236, no. 2, pp. 115–127, 2006.
25. A. M. Neville. **A general relation for strengths of concrete specimens of different shapes and sizes**. *ACIJ. Proc*, vol. 63, no. 10, pp. 1095–1110, 1966.
26. K. H. Kumar, K. C. V. Shabarish, G. Bhanu, K. D. V. Prasad, Ch. S. Kumar. **An experimental study on effect of replacing natural sand by quarry dust and saw dust on properties of concrete**, *International Journal of Emerging Trends in Engineering Research*, vol. 8, no. 5, pp. 1906-1915, 2020.
27. W. S. Park, J. E. Kim, N. Y. Eom, D. G. Kim, M. S. Cho, H. D. Yun. **Size effect of high performance concrete**

with blast furnace slag on compressive strength and modulus of elasticity, *Applied Mechanics and Materials*, vol. 405–408, pp. 2820–2823, 2013.
28. A. Hamad. **Size and shape effect of specimen on the compressive strength of HPLWFC reinforced with glass fibres**, Journal of King Saud University-Engineering Sciences, vol. 29, pp. 373-380, 2017.
29. M. Dehestani, I. M. Nikbin, S. Asadollahi. **Effects of specimen shape and size on the compressive strength of self-consolidating concrete (SCC)**, *Construction and Building Materials*, vol. 66, pp. 685–691, 2014.
30. J. K. Kim, S. T. Yi. **Application of size effect to compressive strength of concrete members**, *Sadhana* vol. 27, no. 4, pp. 467–484, 2002.
31. J. I. Sim, K. H. Yang, H. Y. Kim, B. J. Choi. **Size and shape effects on compressive strength of lightweight concrete**, *Construction and Building Materials*, vol. 38, pp. 854–864, 2013.
32. V. V. Bolotin. ***Statistical Methods in Structural Mechanics*** (Translated by S. Aroni), Holden-Day; First Edition, San Francisco, 1969.
33. J. R. del Viso, J. R. Carmona, G. Ruiz. **Shape and size effects on the compressive strength of high-strength concrete**. Cement and Concrete Research, vol. 38, no. 3, pp. 386–395, 2008.
34. R. L'Hermite, ***Current Ideas on Concrete Technology***. Technical documentation of building and public works, Paris, 1955.
35. ASTM C150/C150M-**Standard Specification for Portland Cement**, *ASTM Int.*, 2020.
36. ASTM C618-**Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete**, *ASTM Int.*, 2019.
37. ASTM C617/C617M-**Standard Practice for Capping Cylindrical Concrete Specimens**, *ASTM Int.*, 2015.
38. ASTM C1609/C1609M-**Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)**, *ASTM Int.*, 2019.