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THE EFFECT OF GROUND GRANULATED BLAST FURNACE SLAG CONTENT ON MECHANICAL PROPERTIES OF POLYPROPYLENE FIBER ENGINEERED CEMENTITIOUS COMPOSITES

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ABSTRACT
This study investigates the effects of ground granulated blast furnace slag (GGBS) content on mechanical properties of engineered cementitious composites (ECC) made of polypropylene (PP) fiber and local sands. Three different percentages of GGBS (50%, 60% and 70%) were used in the same series of PP fiber content of ECC mixtures. PP fiber varied at 1.5%, 2.0% and 2.5% in volume fraction. Compression tests and three-point bending tests were carried out after 28 days of curing. Test results demonstrated improved compressive strength and flexural behaviour of ECC compared to normal concrete. The effects of GGBS content in the performance of compression and flexural are discussed. It can be concluded that the use of the high GGBS content (up to 70%) yielded ECC with the highest compressive strength. Meanwhile, the greatest flexural behaviours are exhibited by ECC with 50% and 60% of GGBS when the fiber content at 2.5% in volume fraction.
Keywords: ECC, GGBS, fiber, compression test, flexural test.

INTRODUCTION
The shortcoming of normal concrete and fiber reinforced concrete (FRC) is brittleness when subjected to tensile loading. As the compressive strength of concrete rises, the brittleness increases. Engineered cementitious composites (ECC) came after the intensive research, which are designed to have the characteristics of moderate strength concrete with increased tensile strain capability [1-6]. The uniqueness of ECC is the superior tensile ductility and tight steady state crack widths [7]. ECC concrete that was developed in the last decade is proven to contribute to a more sustainable, safer and more durable material. ECC is cost effective and constructed using conventional construction equipment [8]. During the service life of the structure the enhancement of ECC performances under mechanical and environment loads are expected to reducing the cost of maintenance and repair, thus contributing to significant improvement of civil infrastructure sustainability [9]. In addition, ECC usually uses the low amount of fiber content, typically 2% by volume fraction [3,10-12]. The tensile strain capacity of ECC is more than 3% thus, it makes ECC behaving more like ductile metal rather than a brittle glass [8,13].

The ingredients for ECC mixture are almost similar with normal concrete, but there is no coarse aggregate used in ECC. Moreover, the use of fiber in ECC is significant in resulting the tensile ductility of ECC. ECC added the High-Range Water Reducer (HRWR) agent to increase workability of mixture [13]. The elimination of the coarse aggregate in ECC mixture causes the use of high cement content compared to normal concrete. The use of high cement content will increase the carbon dioxide amount, which responsible for 5% of global greenhouse gas emission [14]. The powder content in ECC is high as the cement is combining with other cementitious materials such as, silica fume, fly ash, GGBS etc. to increase the paste content [3,15-17].

With the consideration of sustainability environment, more sustainable construction materials were introduced including the development of green ECC. The development of green materials is designed by the substitution of materials such as cement replacement, sand replacement and fiber replacement [12,16-19]. The use of industrial waste material in ECC is to reduce environment footprint and resource consumption while limit the impact of the wastes to material performance. GGBS is one of the common cement replacement materials which is by product, served as eco-friendly material without dumping it to the ground. The use of GGBS as cement replacement in ECC mixture does not only increase the strength but also improves fiber bridging property that resulted in better ductility of the ECC [16].

EXPERIMENTAL
In this study, three different percentages of GGBS (50%, 60% and 70%) were used to examine the effects of GGBS content with different fiber volume fraction on the mechanical performance of ECC in terms of compressive and flexural. The ECC mixtures in this study are made of Portland cement, GGBS, local sand, HRWR, water and polypropylene (PP) fiber. The properties of materials used, mix design, and test performed are given in the subsequent paragraphs.

Materials
GGBS was used to replace cement by the amount of 50%, 60% and 70% in ECC mixtures. GGBS supplied by YTL Cement Marketing Sdn Bhd with the properties as shown in Table 1. These properties complied with *MS EN 15167-1:2010.* For the type of fiber, Dunamis™ Hybrid Fiber MS-H-1 (Monofilament polypropylene fiber) with the length of 6 mm and 19.5 μm in diameter was used. The fiber was supplied by Mighty Shield Industries SDN BHD. Based on manufacturer's declaration; the tensile strength and density of fiber was 787.75 MPa and 910 kg/m^3 respectively. Portland cement having the specific density of 3.15 g/cm^3 and fine aggregate from the local natural sources and it was sieved in order to get the fine aggregate size of less than 600 μm. Lastly, Polycarboxylic Ether (Master Glenium) was employed as a function of High range water reducer (HRWR) to adjust the workability of the GGBS-ECC.

Mix Proportion and sample preparation
Basically, the design of mix proportion of GGBS-ECC is based on the study conducted by Lee [20-21]. There were three (3) series of PP fiber content (1.5%, 2.0% and 2.5%) employed in this study. For each series, GGBS varied at 50%, 60% and 70%. The water to binder ratio and sand to binder ratio were fixed at 0.27 and 0.2, respectively. Binder is the combination of cement and GGBS. The amount of HRWR was constant at 10 kg/m^3 to provide workability of the ECC mortar. In this way, eight different mixtures have been produced. The details of mixture proportions are given in Table 2. Designation of G50C50F1.5%S0.2 refers to 50% of GGBS, 50% of cement, 1.5% of fiber (in volume fraction) and sand to binder ratio of 0.2. Fiber dispersion is very important for obtaining excellent mechanical properties of hardened ECC. Therefore, the following mixing process was adopted to make PP fiber well-dispersed in fresh GGBS-ECC mortar. First, the dry powders (including GGBS, cement and fine aggregate) were mixed for 1–2 min. Then, followed by

adding the water and HRWR and mixing until the required fluidity and uniformity of mortar were achieved, the mixing time was about 3-5 min. Finally, the fibers were added slowly into the mixture and mixed for another 6-8 min until the fibers were evenly dispersed in the mortar without balling. The fresh GGBS-ECC was then cast into 76 x 38 x 350 mm rectangular prism and 50 x 50 x 50 mm cube molds. The demolding was carried out after 24 hours and specimens were cured at the room temperature for another 27 days.

Table 1 Properties of GGBS (Provided by YTL marketing Sdn. Bhd.)

Tests	Units	Specification MS EN 15167-1:2010	Test Result
Specific Surface Area	m^2/kg	275 min	435
Setting Time	mins	-	255
-Initial			
-Ratio (GGBS/ Test Cement)	-	2 max	1.4
Soundness	mm	-	< 1
Compressive Strength	MPa	-	27.1
Mortar Prism 7 days			
(1:3:0.5) 28 days	MPa	-	50.0
Activity Index 7 days	%	45 min	61
28 days	%	70 min	92
Chloride (Cl)	%	0.10 max	0.01

Table 2 Mix proportion of ECC mixture in kg/m^3

Mix ID	Mix No.	Cement (C)	GGBS (G)	Polypropylene Fiber (F)	Sand (S)	Water (W)	HRWR
G50C50F1.5%S0.2	1	726	726	14	290	392	10
G60C40F1.5%S0.2	2	578	867	14	289	390	10
G70C30F1.5%S0.2	3	436	1016	14	290	392	10
G50C50F2.0%S0.2	4	723	723	18	289	392	10
G60C40F2.0%S0.2	5	575	863	18	288	388	10
G70C30F2.0%S0.2	6	436	1016	18	290	392	10
G50C50F2.5%S0.2	7	719	719	23	288	388	10
G60C40F2.5%S0.2	8	572	858	23	286	386	10

Performance Test

Compressive strength and flexural behavior of GGBS-ECC were determined through compression test and three-point bending test. Both tests were performed on the 28^{th} day after casting. Three (3) cubes specimen with dimension of 50 x 50 x 50 mm was used for compressive test for each mixture. Fig. 1 shows a typical cube specimen of ECC that was ready for the compression test. Six (6) rectangular specimens with size of 76 x 38 x 350 mm were employed for each mixture in flexural test for obtaining the flexural behavior of ECC incorporating 50–70% GGBS. The specimens were loaded to achieve failure with constant rate of 0.4 mm/min and test was conducted by using UTM machine Shimadzu AG-50 kN.

Fig. 1 Compression test

RESULTS AND DISCUSSION

Compressive Strength

Compressive strengths for 24 cubes of ECC and three cubes of normal concrete (control) were obtained through compression test. The results of compressive strength for 28 days cube specimen of ECC and normal concrete are presented in Table 3. Generally, results indicate that ECC specimens achieved higher compressive strength compared to control specimen (normal concrete). By adding fiber to the cementitious matrix, shear stress induced by the compression can be reduced and hence increased the compressive strength of the ECC specimens.The compressive strength value of ECC specimens varied between 55 to 90 MPa depending on the mix design proportion. Fig. 2 shows the compressive strength of ECC in different GGBS content and fiber content. When the fiber content was constant at 1.5% and 2.0%, increasing of GGBS from 50% to 60% reduces the compressive strength at around 20 -24 %. For example, at fiber 1.5%, the compressive strength of the ECC Mix No. 1 and 2 decreased from average of 89.64 MPa to 68.21 MPa when the GGBS content increased from 50% to 60%. However, the compressive strength was recovered up to 20% and 62% respectively at 1.5% and 2.0% fiber content when GGBS content added from 60% to 70%. For example, the compressive strength of ECC Mix No. 2 and 3 with fiber 1.5% increased from average of 68.21 MPa to 82.15 MPa when GGBS increased from 60% to 70%. At fiber content of 2.5%, increasing GGBS from 50% to 60% subsequently improved compressive strength of ECC. Generally, results indicated the feasibility of using large amount of GGBS as cement replacement. This can be observed that even the fiber content was as low as 1.5% or 2.0%, the compressive strength of 82–92 MPa can be obtained. Therefore the use of 70% of GGBS combined with 1.5% or 2.0% of fiber can lead to the development of green ECC which is more economical and sustainable construction materials. Fig. 3 shows the typical failure mode of ECC cube specimens after compression tests in which failure is not severe compared to normal concrete. Under compression test, normal concrete specimens tend to crush. But for ECC specimens, fiber inside reinforced and bridging the large crack and led to the minor failure.

Table 3 Compressive strength of ECC specimens at 28 days

Mixture ID	Mix No.	Compressive strength (MPa)
Control		23.66 ±1.30
G50F1.5%S0.2	1	89.64 ±0.96
G60F1.5%S0.2	2	68.21±12.27
G70F1.5%S0.2	3	82.15±1.80
G50F2.0%S0.2	4	71.24±6.01
G60F2.0%S0.2	5	55.73±2.15
G70F2.0%S0.2	6	90.30±0.16
G50F2.5%S0.2	7	55.08±4.71
G60F2.5%S0.2	8	63.34±3.89

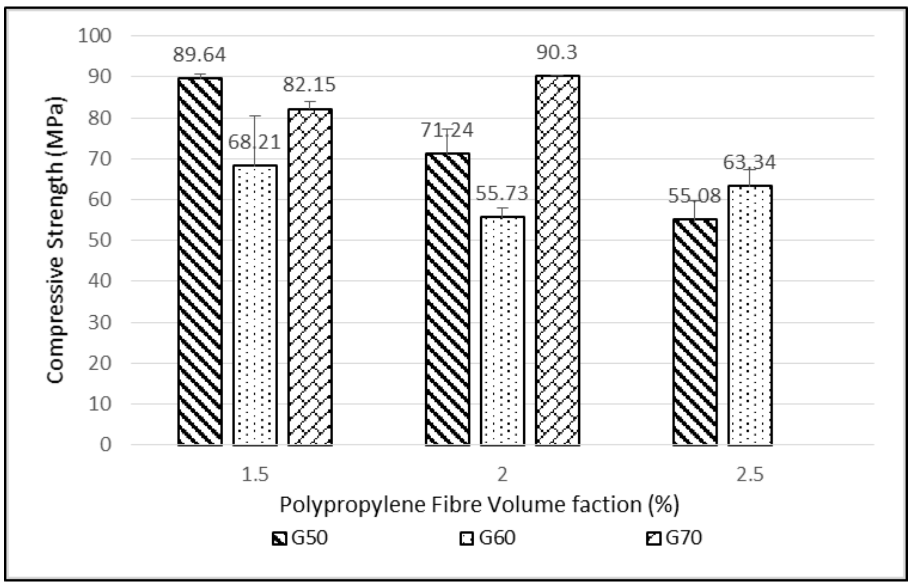

Fig. 2 Compressive strength of ECC at 28 days

Fig. 3 Typical failure mode of ECC cubes after compressive test

Flexural Strength

Table 4 shows the test results of flexural strength and displacement corresponding to flexural strength of ECC and control specimens. Generally, all ECC specimens demonstrated improved first cracking strength and flexural strength compared to that of the control specimens. It is commonly agreed that fibers bridging cracks in cement matrix, thus the first crack has been delayed and higher first crack strength can be obtained in ECC specimens. It should be noted that the flexural strength is referring to the second peak of the stress after first cracking strength is achieved. Fig. 4 shows the flexural stress-mid span displacement curves for the different GGBS content of 50%, 60% and 70% at different fiber contents. There is no similar trends for effect of GGBS content can be observed from the three series of fiber content. For instance, at fiber 1.5% (ECC Mix No. 1,2 and 3), the flexural strength of specimens decreased when the content of GGBS increased from 50% to 60%, while the flexural strength increased when the content of GGBS increased from 60% to 70%. However, at fiber 2.0% (ECC Mix No. 4, 5 and 6), the flexural strength increased when the content of GGBS increased from 50% to 60%, while the flexural strength decreased when the content of GGBS increased from 60% to 70%. However, the optimum GGBS content was 60% at fiber content of 2.0% and GGBS content was 50% at fiber content of 2.5% in order to achieve flexural ductility. The use of large amount of GGBS (70%) has no advantages in terms of flexural behavior of ECC. Specimens with fiber content of 2.0% and 2.5% showed the first cracking strength almost similar to study conducted by Lim [16] that GGBS was employed along with poly(vinyl alcohol) (PVA) fiber. From this study, the first cracking strength of specimens with fiber content of 2.0% and 2.5% was between 4 – 7 MPa, while the study by Lim [16] that utilized 2.0% of PVA fiber gave values of first cracking strength between 4 – 6 MPa. Obviously, the fiber content play important role in flexural strength of ECC specimens. ECC mixture containing 2.5% fiber exhibits greater flexural behavior as compared to ECC contained 1.5% fiber. For example, ECC Mix No. 2 and 7 with fiber content of 1.5% and 2.5% have the flexural strength of 2.7 MPa and 8.72 MPa respectively, in which the increase of fiber content resulted in increase of flexural strength of ECC specimens. This can be seen from the high modulus of toughness (area below the flexural stress – displacement curve) shown by Fig. 4(c). Thus the displacement corresponding to maximum stress, as shown in Fig. 4, can be considered as the indication of ductility of the material.

The typical failure modes of ECC specimen under three points bending test are shown in Fig. 5. Under the severe bending load, ECC specimens exhibited tiny crack as fibers created bridging effect that can be observed in Fig. 5**.** This explains the curve of flexural stress-mid span deflection for ECC specimens undergone displacement hardening and not failed right away after the first crack.

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Table 4 Flexural strength and ultimate displacement of ECC Mixtures at 28 Days

Mixture ID	Mix No.	First cracking strength (MPa)	Flexural Strength (MPa)	Displacement corresponding to Flexural Strength (mm)
Control		2.98 ±0.32	2.98 ±0.32	0.39±0.28
G50F1.5%S0.2	1	3.32±1.81	3.65±0.25	1.36±0.61
G60F1.5%S0.2	2	2.50±1.92	2.79±0.70	1.32±0.91
G70F1.5%S0.2	3	7.21±1.64	3.59±0.26	0.85±0.19
G50F2.0%S0.2	4	5.76±1.20	3.82±0.56	0.70±0.20
G60F2.0%S0.2	5	6.98±0.66	7.76±1.16	1.10±0.18
G70F2.0%S0.2	6	6.30±0.66	5.20±0.34	1.25±0.42
G50F2.5%S0.2	7	4.68±1.22	8.72±1.33	1.12±0.56
G60F2.5%S0.2	8	6.90±0.71	7.94±0.75	1.25±0.39

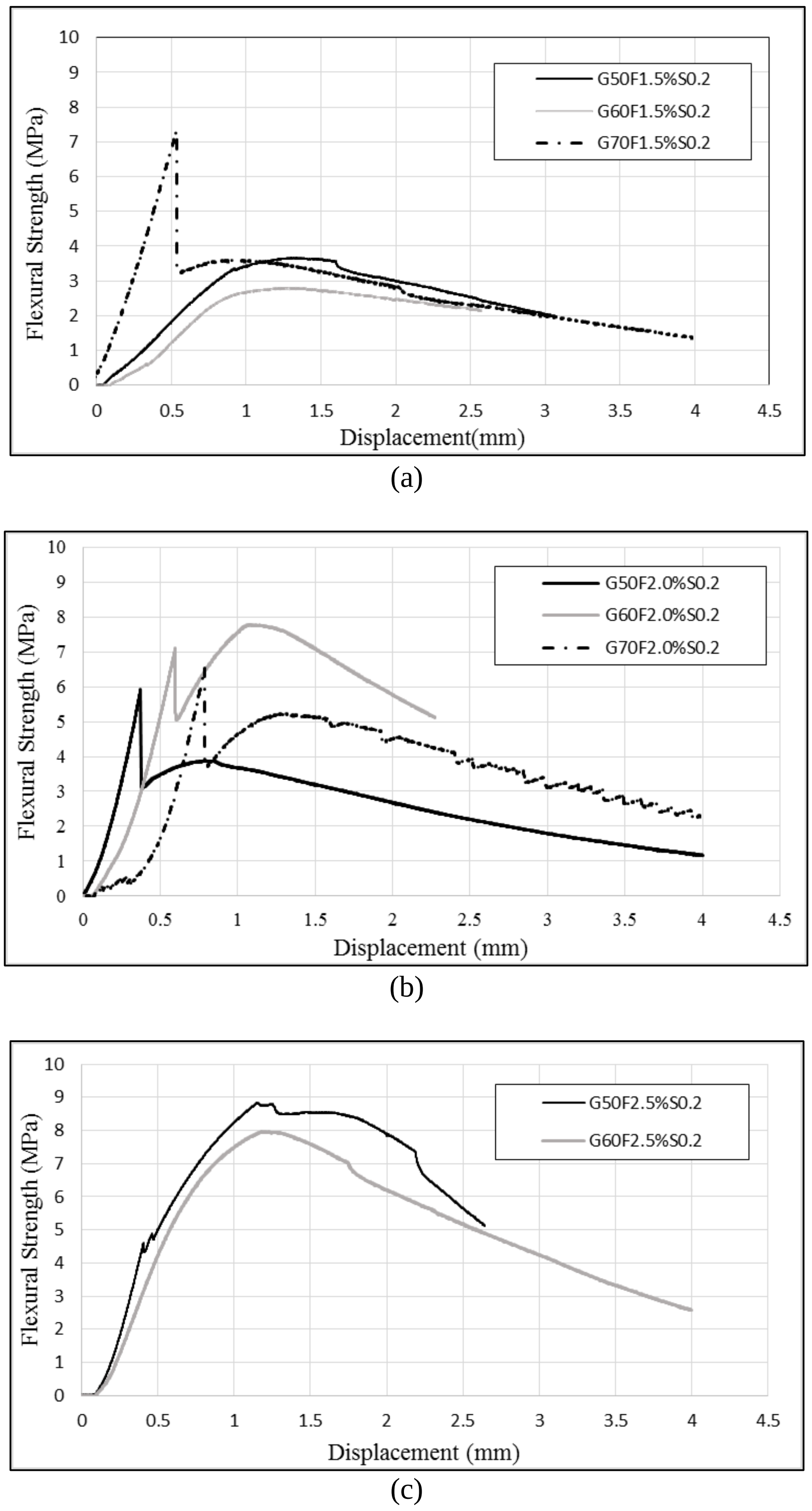

Fig. 4 Flexural stress-mid span deflection curve of different GGBS content (a) Fiber constant at 1.5% (b) Fiber constant at 2.0%) and (c) Fiber constant at 2.5%

Fig. 5 Typical behavior of ECC specimens under flexural test

CONCLUSION

Few series of GGBS–ECC specimens were designed and tested under compression and flexural test. Based on the experimental results and above discussion, the following conclusions can be drawn:

(1) All GGBS–ECC specimens show greater compressive strength (138%-281%) compared to normal (control specimen) used in this study.
(2) The use of large amount of GGBS (70%) is feasible, with the evidence of compressive strength can reach up to 90.3 MPa at fiber content of 2.0%. Increasing GGBS from 50% to 60% demonstrated negative effect in compressive strength of GGBS–ECC at fiber content of 1.5% and 2.0%.
(3) All GGBS–ECC specimens improved the first cracking strength by 11% - 141% compared to normal concrete. The increase of GGBS from 50% to 70% did not show a clear trend for flexural strength. Among all, ECC samples contained 60% of GGBS with 2.0% and 2.5% fiber showed significant enhancement in flexural behavior as the modulus of toughness can be greatly increased.

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REFERENCES

1. Li, V.C. Engineered Cementitious Composites (Ecc) – Tailored Composites through Micromechanical Modeling. *Can. Soc. Civ. Eng.*, (1997) 1–38.
2. Wang, S. & Li, V.C. Lightweight Engineered Cementitious Composites (ECC). in *PRO 30: 4th International RILEM Workshop on High Performance Fiber*, Antoine E. Naaman and H. W. Reinhardt, Eds. Ann Arbor, USA (2003) 379–390.
3. Sathishkumar, P., Sampathkumar, P., Karthik, M. & Vignesh, C. Significance of Various Fibres on Engineered Cementitious Concrete. *Int. J. Sci. Eng. Technol.*, (2016) 4(1): 284–290.
4. Wang, S. & Li, V.C. “Polyvinyl alcohol fiber reinforced engineered cementitious composites: material design and performances,” 2005.
5. Shin, K.J., Jang, K.H., Choi, Y.C. & Lee, S.C “Flexural behavior of HPFRCC members with inhomogeneous material properties,” *Materials (Basel).*, (2015) 8(4): 1934–1950.
6. Yang, E. & Li, V.C. “Strain-hardening fiber cement optimization and component tailoring by means of a micromechanical model,” *Constr. Build. Mater.*, (2010) 24(2): 130–139.
7. Lepech, M.D. “Sustainable Infrastructure Systems usingEngineered Cementitious Composites,” in *Structures Congress 2009. Don’t Mess with Structural Engineers*, (2009) 2232–2241.
8. Dhawale, A.W., Joshi, V.P. & Email, W.S. “Engineered Cementitious Composites for Structural Applications,” *Int. J. Appl. or Innov. Eng. Manag.*, (2013) 2(4): 198–205.
9. Sahmaran, M. & Li, V.C. “Engineered Cementitious Composites : An Innovative Concrete for Durable Structure,” *Struct. 2009 Don’t Mess with Struct. Eng.*, (2009) 2219–2231.
10. Wang, S. and Li, V.C. “Engineered cementitious composites with high-volume fly ash,” *ACI Mater. J.*, (2007) 104(3): 233–241.
11. Li, V.C. “Advances in ECC Research,” *ACI Spec. Publ. Concr. Mater. Sci. to Appl.*, (2002) 206(23): 373–400.
12. Lee, B.Y., Li, V.C., & Kim, Y.Y. “Polypropylene Fiber-Based Strain-Hardening Cementitious Composites,” *2013 World Congr. Adv. Struct. Eng. Mech.*, (2013) 444–457.
13. Gadhiya, S., Patel, T. & Dinesh, S. “Bendable Concrete: A Review,” *Int. J. Struct. Civ. Eng. Res.*, (2015) 4(1): 141–147.
14. Bilim, C., Atiş, C.D., Tanyildizi, H. & Karahan, O. “Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network,” *Adv. Eng. Softw.*, (2009) 40(5): 334–340.
15. Islam, A. Alengaram, U.J. Jumaat, M.Z., Bashar, I.I. & Kabir, S.M.A. “Engineering properties and carbon footprint of ground granulated blast-furnace slag-palm oil fuel ash-based structural geopolymer concrete,” *Constr. Build. Mater.*, (2015) 101: 503–521.
16. Lim, I., Liu, T. & Chan, Y.W. “Effect of Ground Granulated Blast Furnace Slag on Mechanical Behavior of PVA-ECC,” *J. Mar. Sci. Technol.*, (2001) 20(3): 319–324.
17. Zhu, Y., Yang, Y. & Yao, Y. “Use of slag to improve mechanical properties of engineered cementitious composites (ECCs) with high volumes of fly ash,” *Constr. Build. Mater.*, (2012) 36:1076–1081.
18. Yang, E.H., Yang, Y. & Li, V.C. “Use of high volumes of fly ash to improve ECC mechanical properties and material greenness,” *ACI Mater. J.*, (2007) 104 (6):620–628.
19. Hawileh, R.A., Abdalla, J.A., Fardmanesh, F., Shahsana, P., & Khalili, A. “Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement,” *Arch. Civ. Mech. Eng.*, (2017) 17(3): 511–519.
20. Lee, S.W. “Seismic Behaviour of Interior Reinforced Concrete Beam-Column Sub-Assemblages with Engineered Cementitious Composites,” *Magazine of Concrete Research.*,(2017) 1-62.
21. Lee, S.W., Kang, S.B, Tan, K.H. & Yang, E.H. “Experimental and analytical investigation on bond-slip behaviour of deformed bars embedded in engineered cementitious composites,” *Constr. Build. Mater.*, (2016) 127: 494–503.