Performance of Eco Engineered Cementitious Composites Containing Supplementary Cementitious Materials as a Binder and Recycled Concrete Fines as Fine Aggregate

M R Md Zain¹, C L Oh¹ and L S Wee²

¹School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
²School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Johor Pasir Gudang Campus, 81750 Masai, Johor, Malaysia
Corresponding author: raizam@uitm.edu.my

Abstract. Engineered cementitious composites (ECC) mixtures demand a large cement content, which is detrimental to their sustainable development because mass cement production is hazardous to the environment and human health. Thus, this paper investigates the mechanical performance of eco engineered cementitious composites (ECC) under axial compressive loading and direct tensile strength tests. The eco ECC used in this investigation was comprised of cement, superplasticizer, fly ash (FA) or ground granulated blast furnace slag (GGBS), polypropylene (PP) fibre, water and recycled concrete fines (RCF). Two (2) eco ECC mixture series were designed and prepared. GGBS70 (70 percent GGBS + 30 percent cement), FA70 (70 percent Fly Ash + 30 percent cement), GGBS80 (80 percent GGBS + 20 percent cement), and FA80 (80 percent Fly Ash + 20 percent cement) are the four Cement-GGBS and Cement-Fly Ash combinations examined in this study. Also every combination had two different RCF percentages, R0.2 (0.2 percent RCF) and R0.4 (0.4 percent RCF). The main objective of this research is to determine the optimum mix design for eco ECC that contains supplementary Cementitious Materials (SCMs) such as GGBS or FA. Additionally, recycled concrete fines (RCF) were used as a substitute for sand. The influence of different cement replacement materials and RCF content on compressive and tensile strength was experimentally investigated. The inclusion of GGBS as a partial replacement of cement in the eco concrete mixture results in greater compressive strength than Fly Ash (FA). The test results revealed that increasing the RCF content in the ECC mixture resulted in higher compressive and tensile strength. When the sand to binder ratio was adjusted between 0.2 and 0.4, the compressive and tensile strength of the ECC mixture increased.

1. Introduction
Construction began with the intention of reaching human needs for shelter, as well as protecting themselves from inclement weather and wildlife. Humans begin to refine their construction practices over time, shifting from natural sources to synthetic materials, which boosts the durability of building structures. As a result of the widespread use of synthetic materials, particularly concrete, as the primary element, the demand for cement industries has grown. Ordinary Portland cement (OPC) has been used in engineering for hundreds of years as an essential component of concrete. Cement manufacturing necessitates extensive use of fossil and biomass fuels [1] as well as a vast amount of raw materials and energy [2]. It is reasonable to say that raw material depletion has worsened in...
tandem with rising cement demand. Besides that, the industry is reported to contribute approximately 5% to 8% of global CO2 and greenhouse gas emissions due to the cement manufacturing process [3]. It was revealed to have resulted in poor air quality and noise pollution [4], including such particulate matter releases from raw mills, kiln systems, clinker coolers, and cement mills (air pollution) and noise pollution during the raw material preparation process, storage of materials, and the heavy machinery used [1,5,6]. According to research findings, cement manufacturing emits approximately 0.8 tonnes of carbon dioxide into the environment for every tonne of cement produced [4]. If particulate matter is suspended in the atmosphere for an extended period of time, it can form haze, which can endanger human health, such as severe respiratory and cardiovascular problems, which can lead to death.

Concrete is a composite material with multiple components (cement, water, coarse aggregates, and fine aggregates). Because it has only 0.1 percent strain capacity, conventional concrete is reported to be particularly brittle and rigid [7]. Concrete fractures are generally triggered by the material's inability to withstand tensile force [8], which reduces the toughness and durability of concrete. Steel reinforcement is thus required to withstand high tensile forces. Reinforced concrete structures, on the other hand, are facing serious problems as a result of extreme environmental and mechanical conditions. As a result, concrete must be modified to ensure long-life structures while keeping future generations in mind.

Throughout the modern era, the concrete production process has been improvised to meet the evolving industrial and construction needs. Multiple studies were conducted in order to develop a solution for creating a more sustainable and quality way of building, so that the performance and durability of the buildings would improve. The incorporation of engineered cementitious composite (ECC) into structures as a substitute for conventional concrete has become one of the studies that were conducted to resolve this concern. The characteristics of ECC are very different from those of conventional concrete. ECC is very ductile, as opposed to conventional concrete, which is brittle. ECC ingredients are specifically developed to withstand various cracking and regulate crack width [9]. ECC has been shown to be more flexible than conventional concrete because it has more than a 3 percent of strain capacity [7]. This is due to the ECC's fibres, which aid in increasing the impact resistance of concrete through bridging action [8]. Nevertheless, ECC necessitates a high cement usage to compensate for the lack of strength caused by the absence of coarse aggregates. As a result, there is an urgent need to consider using green or eco-friendly construction materials.

Growing issues of sustainability between many of the construction material resources, as well as public awareness of the problem, pave the way for green or eco construction as a new, innovative method to replace the conventional method. Among the alternative solutions are the use of Supplementary Cementitious Materials (SCMs), recycled concrete aggregates, and many other industrial wastes. SCMs are frequently used as a supplementary cementitious material in attempt to lessen the cement content of concrete. SCMs also improves the workability of hardened concrete, as well as its strength and durability. Green components such as Ground Granulated Blast-furnace Slag (GGBS), fly ash (FA), silica fume, eggshell and recycled concrete fines (RCF) have been widely used in ECC studies to find a way towards sustainable development [10][11][12].

The blend of SCM and RCF in a mixture is regarded as eco Engineered Cementitious Composites (ECC). Due to the fineness of particles, ground granulated blast-furnace slag (GGBS) mix has greater mobility characteristics. Earlier studies have shown that increasing the GGBS content in the concrete mix improves workability and reduces water absorption [13], thereby increasing the durability of the concrete. The performance of concrete in terms of strength by varying the percentage of fine aggregates substitution and cement replacement in their mixture have been performed by numerous numbers of researchers. Fly ash is often used as a supplementary cementitious material, and mechanical properties has been examined utilising diverse proportions of fly ash varying from 0% to 60% [14]. Dhanya et al. [15] investigated the strength characteristics of concrete employing steel fibre and GGBS as partial substitutes for cement. The findings of the study demonstrate that partial substitution by both GGBS and steel fibre enhances the performance of the concrete. Besides that, researchers [16,17] signify that incorporating an appropriate amount of fly ash, can strengthen the performance of concrete comprising recycled concrete aggregate (RCA).
ECC is made up of cement, water, fly ash, sand, fibre, and water reducer. Whereas, conventional concrete is only composed of water, cement, coarse and fine aggregates, and it cannot withstand various cracking owing to the lack of fiber-matrix interaction. Polypropylene (PP) fibres and polyvinyl alcohol (PVA) fibres are two examples of fibres which could be used in ECC. Because PP fibre is widely available in Malaysia, it was used in this study's ECC mix for comparisons in terms of compressive strength, tensile strength, and failure mechanisms, alongside GGBS or fly ash as partial cement replacement and RCF as sand replacement in ECC mix.

2. Methods
The aim of this study is to investigate the mechanical behaviour of ECC in terms of compressive and tensile strengths using GGBS and Fly Ash, respectively. The Universal Testing Machine (UTM) was used to conduct laboratory testing on ECC specimens containing SCM as a binder and RCF as fine aggregates. Laboratory assessment was performed to evaluate the ultimate tensile strength and compressive strength of eco ECC subjected to direct tensile and compression tests, as well as to observe the failure generation mechanism of the eco ECC. The following sub-topics provide detailed explanations of the materials, mix design proportions, specimen preparation, and test methods.

2.1. Materials
The raw materials used in the concrete were Ordinary Portland Cement (OPC), recycled concrete fines (RCF), water, FA or GGBS, PP fibres, and SP as shown in figure 1. The RCF employed in ECC was taken from the demolished building which act as fine aggregates replacement and it was crushed and sieved to a size below 600 µm. The PP fibre used had a diameter of 19.5 m and a length of 6 mm. In all ECC mixtures where the binder is a cement-GGBS mixture, the water binder ratio was set at 0.27. Moreover, the amount of SP was kept under control at around 10 kg/m$^3$ to ensure the workability of the ECC mortar. Table 1 show the elemental compositions of OPC, GGBS and FA.

![Materials](image1.png)

**Figure 1.** Materials used in the production of ECC (a) OPC, (b) GGBS, (c) RCF, (d) PP fibre, (e) SP

| Chemical compositions | MgO  | Al$_2$O$_3$ | SiO$_2$ | P$_2$O$_5$ | SO$_3$ | K$_2$O | CaO | TiO$_2$ | MnO | Fe$_2$O$_3$ |
|------------------------|------|-------------|---------|------------|--------|--------|-----|---------|------|-------------|
| OPC                    | 0.96 | 2.13        | 12.80   | <LOD       | 2.69   | 0.53   | 77.53| 0.18    | 0.06 | 3.12        |
| GGBS                   | 4.03 | 10.15       | 35.67   | <LOD       | 3.80   | 0.29   | 43.68| 0.58    | 0.19 | 1.61        |
| FA                     | 1.29 | 16.11       | 72.76   | 0.23       | 0.37   | 1.06   | 1.41 | 0.99    | 0.09 | 5.69        |

* LOD embodies Low on density

Figure 2 depicts the particle size distribution or grading curves of sand and RCF. As observed in figure 2, sand has larger particle sizes than RCF. Based on these results, it can be indicated that RCF, rather than sand, should be used in ECC matrix since RCF has a smaller particle size distribution and aids in the development of ductility in ECC samples.
2.2. Mix design proportions and specimen preparation

For the experimental investigations, three series of concrete mixtures were designed and prepared. Among the three series of concrete mixtures, series 1 and 2 were created to investigate the effects of different percentage variations of GGBS and RCF. In this study, four Cement-GGBS and Cement-Fly Ash combinations are investigated. Every combination had two different RCF percentages, R0.2 (0.2 percent RCF) and R0.4 (0.4 percent RCF) as depicted in table 3. For instance, mixture ID GGBS70R0.2 indicates that the mixture contains 30 percent cement, 70 percent GGBS and 0.2 percent RCF. The other remaining mixture (series 3) acts as control mixture, in which no SCMs or RCF substitution (water/cement ratio is equal to 0.46). The mix proportion of normal concrete and ECC mixtures are presented in table 2 and table 3.

**Table 2. ECC mix proportion.**

| Specimen designation | Unit weight (kg/m³) |  |  |  |  |  |  |  |
|----------------------|--------------------|---|---|---|---|---|---|
|                      | OPC    | Water | FA  | GGBS | RCF | SP | PP Fiber |
| GGBS80R0.2           | 286    | 358   | -   | 1143 | 286 |
| FA80R0.2             | 286    | 358   | 1143| -    | 286 |
| GGBS80R0.4           | 257    | 350   | -   | 1028 | 518 |
| FA80R0.4             | 257    | 350   | 1028| -    | 518 |
| GGBS70R0.2           | 429    | 386   | -   | 1001 | 286 |
| FA70R0.2             | 429    | 386   | 1001| -    | 286 |
| GGBS70R0.4           | 385    | 350   | -   | 900  | 518 |
| FA70R0.4             | 385    | 350   | 900 | -    | 518 |

**Table 3. Normal concrete mixture proportion (kg/m³)**

| OPC   | Water | Coarse Agg. | Sand |
|-------|-------|-------------|------|
| 415   | 195   | 1135        | 605  |

Normal concrete mixtures were made by mixing cement, water, fine aggregates, and coarse aggregates in a concrete mixer and left them to mix uniformly. The mixture was then poured with water and mixed for 10 minutes. When preparing ECC specimens, similar procedures were followed. Cement, GGBS or FA, and RCF were mixed uniformly in a concrete mixer for 3 to 5 minutes. In order to prepare an ECC mix containing PP fibre, combine the superplasticizer, water, and PP fibre in a clean bucket. After thoroughly mixing the PP fibre and SP in water, they were slowly and evenly poured into the concrete mixer, where all binders were thoroughly mixed. Following the completion of
the mixing process, fresh concrete was moved and carefully placed at cylindrical (for compression) and dog bone (for tensile) formworks, as can be seen in figures 3(a) and 3(b). All of the fresh concrete in the formworks was left for 24 hours to harden before going through the curing process for 7 days and 28 days.

2.3. Test methods
Using a 3000 kN compression machine, five (5) cylindrical ECC samples of 50 mm in diameter and 100 mm in height from each mix, along with five (5) cylindrical normal concretes, were tested up to failure at its 7 days and 28 days compressive strength. During the test, ECC specimen was loaded at 0.5 mm/minute (constant rate). Then, eco ECC plate samples in the shape of a dogbone with a cross sectional dimension of 330 x 40 x 13 mm were prepared, characterized, and tested subjected to direct tensile test. Figure 4 depicts the tensile test performed on a Shimadzu Machine.

3. Results and discussion
The experimental results, such as compressive strength, tensile strength, and failure mechanism, were elaborated and discussed in detail in the subsequent sections.

3.1. Axially compressive strength of concrete specimens
The average results of compressive strengths for all specimens subjected to compression test at 28 days were expressed as demonstrated in table 4.
Table 4. Compressive strength of concrete specimens under axial compressive loading.

| Series | Specimen designation | Ave. Compressive Strength 28 days (MPa) | Enhancement Factor (%) |
|--------|----------------------|----------------------------------------|------------------------|
| 1      | GGBS80R0.4           | 30.70                                  | 0.88                   |
|        | GGBS80R0.2           | 28.25                                  | 0.81                   |
|        | FA80R0.4             | 12.59                                  | 0.36                   |
|        | FA80R0.2             | 6.72                                   | 0.19                   |
| 2      | GGBS70R0.4           | 40.84                                  | 1.16                   |
|        | GGBS70R0.2           | 35.94                                  | 1.03                   |
|        | FA70R0.4             | 22.45                                  | 0.64                   |
|        | FA70R0.2             | 12.86                                  | 0.37                   |
| 3      | Normal concrete      | 35.00                                  | -                      |

As can be seen in table 4, the mixture ID delineates GGBS70R0.0.4 had the highest compressive strength at 28 days of curing age with 40.84 MPa, followed by GGBS70R0.2 with 35.94 MPa. The increment ratio of the ECC specimen from the normal concrete specimen is implied by the enhancement factor, as shown in table 4. Use of 70% GGBS replacement of cement with PP fibre in ECC specimens enhances the compressive strength of ECC specimens by 1.03 and 1.16, respectively, when compared to conventional concrete. The increment could be attributed to the use of eco materials, GGBS, and the addition of fibres such as PP fibre, which have been shown to improve the microstructure of the concrete. The addition of GGBS to ECC concrete improves its mechanical properties. Because of the higher workability of GGBS, the ECC mixture bonds well, improving compressive strength. The action of the fibres contained also made a significant contribution to the ECC mixtures' higher compressive strength. But since normal concrete cannot withstand tensile force, fibres are added primarily to assist in carrying tension within the concrete matrix. Table 4 also demonstrates that certain ECC samples containing 70% or 80% fly ash had a significant reduction in compressive strength when compared to normal concrete specimens. These outcomes may be possible as a result of the addition of RCF content in ECC samples, which may contribute in concrete strength degradation attributed to the prevalence of impurities in RCF [17].

3.2. Tensile strength of ECC concrete specimens

The average crack width, ultimate tensile strength and ultimate tensile strain of ECC tested based on the direct tensile test are shown in table 5.

Table 5. Tensile Performance of ECC specimens.

| Specimen designation | Ave. Crack Width (mm) | Ultimate Tensile Strength (MPa) | Ultimate Tensile Strain (%) |
|----------------------|------------------------|--------------------------------|-----------------------------|
|                      | Min. | Max. | Ave. |                          |                           |
| Normal Concrete      | -    | -    | -    | 3.33                       | 0.88                       |
| GGBS80R0.4           | 0.10 | 0.44 | 0.27 | 6.07                       | 1.27                       |
| GGBS80R0.2           | 0.16 | 0.40 | 0.28 | 3.13                       | 0.49                       |
| FA80R0.4             | 0.20 | 0.48 | 0.34 | 2.19                       | 0.30                       |
| FA80R0.2             | 0.12 | 0.40 | 0.26 | 2.79                       | 0.35                       |
| GGBS70R0.4           | 0.14 | 0.50 | 0.32 | 7.99                       | 0.10                       |
| GGBS70R0.2           | 0.16 | 0.40 | 0.28 | 5.26                       | 0.45                       |
| FA70R0.4             | 0.16 | 0.36 | 0.26 | 3.06                       | 0.52                       |
| FA70R0.2             | 0.14 | 0.60 | 0.37 | 2.47                       | 0.48                       |
The first cracking strength is typically defined as its first response to the decline at which the response of tensile stress deviates from linearity. In general, all ECC specimens have higher first cracking strength than normal concrete. With a tensile strength of 7.99 MPa, GGBS70R0.4 has the highest tensile strength. It demonstrates that using GGBS as a cement replacement improved the tensile behaviour. Meanwhile, ECC specimens denoted as FA80R0.4 has the lowest tensile strength of 2.19 MPa. The mixture ID GGBS80R0.4 has the highest tensile strain value of 1.27 percent, and the mixture ID denotes as GGBS70R0.4 has the lowest tensile strain value of 0.10 percent.

Figure 5 depicts a graph of tensile strength versus displacement for a mixture containing 70% cement replacement and 0.2 percent RCF when compared to normal concrete. It demonstrates that the GGBS-cement combination (GGBS70R0.2) has a higher tensile strength value of 5.26 MPa when compared to the Fly Ash-cement combination (FA70R0.2) and normal concrete, which have lower values of 2.47 MPa and 3.33 MPa, respectively. This demonstrates that the tensile strength of the mixture containing 0.2 percent RCF with 70 percent GGBS-cement combination (GGBS70R0.2) is greater than the tensile strength of the mixture containing 70 percent Fly Ash-cement combination (FA70R0.2) and normal concrete. Furthermore, when the mixture contains 80 percent cement replacement with 0.2 percent RCF is compared to normal concrete, the normal concrete has a higher value of tensile strength with 3.33 MPa compared to the GGBS-cement combination (GGBS80R0.2) and Fly Ash-cement combination (FA80R0.2), which have lower values of 3.13 MPa and 2.79 MPa, respectively. In terms of tensile strength, this demonstrates that the normal concrete mixture outperforms the mixture containing 0.2 percent RCF and 80 percent cement replacement.

![Figure 5](image_url)

Figure 5. Tensile strength-displacement curve between 70 % and 80% of GGBS and Fly Ash replacement for 0.2 % RCF.

Figure 6 represents the tensile strength-displacement curve for a mixture containing 70% cement replacement and 0.4 percent RCF when compared to normal concrete. It indicates that the GGBS-cement combination (GGBS70R0.4) seems to have a higher tensile strength value of 7.99 MPa when compared to the Fly Ash-cement combination (FA70R0.4) and normal concrete, which have lower values of 3.06 MPa and 3.33 MPa, respectively. This shows that the tensile strength of the mixture containing 0.4 percent RCF with 70 percent GGBS-cement combination (GGBS70R0.4) is significantly greater than the tensile strength of the mixture containing 70 percent Fly Ash-cement combination (FA70R0.4) and normal concrete. In addition, as can be seen in figure 6, the tensile strength of the mixture containing 0.4 percent RCF with 80 percent GGBS-cement combination (GGBS80R0.4) is greater than the tensile strength of the mixture containing 0.4 percent RCF with 80 percent Fly Ash-cement combination (FA80R0.4) and normal concrete. In this study, the tensile performance of eco ECC (GGBS and Fly Ash as partial cement replacement) were measured through laboratory testing to assess its strength and failure behavior. Tensile strength test yields consistent results in the eco ECC containing Fly Ash, with the value of its strength remaining in the small range of 2.19 MPa to 3.09 MPa. While the green ECC containing GGBS exhibits inconsistency in the results, ranging from 3.13 MPa to 7.99 MPa. This can be explained by the physical properties of
GGBS and Fly Ash. The GGBS is irregular in shape, whereas the Fly Ash is regular. The irregular shape has less workability but a higher bonding strength, whereas the regular shape has better workability but not strength due to poor interlocking behavior and a weak bond strength.

Figure 6. Tensile strength-displacement curve between 70% and 80% of GGBS and Fly Ash replacement for 0.4% RCF.

3.3. Failure behavior of ECC concrete specimens

The dog bone shape specimen is used to regulate the location of the cracking in order to ensure that the cracking occurs in the middle section of the specimen. The shape is in the form of a dog bone because of the stress concentration at the narrow neck, which yields a more accurate result. Pure tension occurs at the narrow neck area [18]. When the sample is loaded with a tensile force, the shoulders are wider than the gauge section, causing a stress concentration in the middle. This stress concentration increases the likelihood of the sample rupturing away from the ends. This indicates that cracking during the tensile strength test was mostly observed in the middle of the dog bone specimen, as shown in figure 7. Nonetheless, cracks in the specimen can also be seen about one-third from the middle section of the specimen.

Figure 7. Mode of failure of eco ECC specimens under direct tensile strength test.
4. Conclusions
The following conclusions can be drawn based on the findings of experimental tests on ECC specimens incorporating SCMs (GGBS or FA) as a binder and RCF as fine aggregates under compressive and direct tensile strength tests.

i) The inclusion of 70% GGBS to ECC concrete specimens improves its compressive strength performance compared to normal concrete. The greater workability of GGBS allows ECC mixture to bond well thus boosting compressive strength. The action of the fibres contained, which support in carrying the tension within the concrete matrix, also contributed to the higher compressive strength attained by the ECC specimens.

ii) Meanwhile, compressive tests on eco ECC specimens containing 70% and 80% fly ash reveal a significant reduction in strength compared to the control concrete specimens. This could be due to the inclusion of RCF content in ECC samples, which might also contribute to concrete strength degradation caused by the presence of impurities in RCF.

iii) Tensile strength tests signify that the eco ECC containing Fly Ash produces consistent results, with the value of its strength remaining in the low range, as opposed to the green ECC containing GGBS, which yields inconsistent results. The GGBS has an irregular shape (less workability but a higher bonding strength), whereas the Fly Ash has a regular shape (has more workability but less strength due to poor interlocking behaviour and a weak bond strength).

iv) The cracking behavioural pattern has mostly been detected in the middle of the dog bone specimen during the tensile strength test, as well as some crack can also be seen about one-third from the middle section of the specimen.

5. References

[1] Stajianca M and Estokova A 2012 Environmental Impacts of Cement Production Lviv Polytechnic National University of Košice Institutional Repository 138 296-302
[2] Hayati U, Huseyn Y A and Osman Gencel 2016 Investigation on characteristics of blended cements containing pumice, Construction and Building Materials 118 11-19
[3] Claisse P A 2015 Civil Engineering Materials (United Kingdom: Butterworth-Heinemann) pp 163-184
[4] Ziming H, Aiqin S, Zhenghua L, Yue L, Hansong W and Wenzhen W 2020 Effect of wollastonite microfibers as cement replacement on the properties of cementitious composites: A review, Construction and Building Materials 261 119920
[5] Nabilla M, Khairunisa M, Rahimah E, Andri K and Mohd H H 2021 Environmental impact of cement production and Solutions: A review, Materials Today: Proceedings 1-6
[6] Gao W 2003 Noise control engineering (Jiangsu Shen: Wu Hang University of Science and Technology Press)
[7] Uttamraj S, Ashwanth K and Rafeeq M 2016 A Comparative Study on Conventional Concrete and Engineered Cementitious Composites (ECC-PVA) Review, IOSR Journal of Mechanical and Civil Engineering 19-25
[8] Sukumar A and John E 2014 Fiber Addition and Its Effect on Concrete Strength, International Journal of Innovative Research on Advanced Engineering 1 144-149
[9] Li V C 2008 Engineered cementitious composite (ECC): Material, structural, and durability performance, Concrete Construction Engineering Handbook. Second Edition, 1001–1048
[10] Li V C, Michael L, Shuxin W, Martin W and Gregory K 2004 Development of Green ECC for Sustainable Infrastructure Systems Proc. Int’l Workshop on Sustainable Development and Concrete Technology (Beijing, China) 181-192
[11] Md Zain M R, Oh C L, and Lee S W 2021 Investigations on rheological and mechanical properties of self-compacting concrete (SCC) containing 0.6 μm eggshell as partial replacement of cement, Construction and Building Materials 303 124539
[12] Lee S W, Oh C L and Md Zain M R 2019 Mechanical properties of engineered cementitious composites using local ingredients, *Journal of Mechanical Engineering* 16 145-157

[13] Khan A N, Memon, D A, Rizvi S H, Bhanbhro Q and Bheel N 2018 Fresh and Hardened Properties of Ground Granulated Blast Furnace Slag Made Concrete, *International Journal of Modern Research in Engineering and Management* 1 01-07

[14] Alvin H, Vikas S and Arpan H 2014 Effect of fly ash on compressive strength of Portland Pozzolona cement concrete, *Journal of Academia and Industrial Research* 16 145-157

[15] Dhanya R, Arasan G V and Ganapathy R 2017 Study on strength properties of concrete using GGBS and steel fiber as partial replacement of cement, *Journal of Industrial Pollution Control* 1255-1259

[16] Kurda R, de Brito J and Silvestre J D 2017 Combined influence of recycled concrete aggregates and high contents of fly ash on concrete properties, *Construction and Building Materials* 157 554–572

[17] Verian K P, Ashraf W and Cao Y 2018 Properties of recycled concrete aggregate and their influence in new concrete production, *Resources, Conservation and Recycling* 133 30–49

[18] Ke-Quan Y, Zhou-Dao L, Jian-Gua D and Surendra P S 2020 Direct tensile properties and stress-strain model of UHP-ECC, *J. Mater. Civ. Eng.* 32 04019334

**Acknowledgments**

The authors are thankful the Ministry of Higher Education for funding this research via the Fundamental Research Scheme (FRGS) (600-IRMI/FRGS 5/3 (378/2019). The authors would like to express their gratitude to Muhammad Syazwan Obaidah Md Obaidah, who was directly involved in the experimental work. Also, thanks to all technical staff at the Concrete Laboratory, School of Civil Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), Shah Alam for their unwavering support during these studies.