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NOVEL APPROACH FOR STRENGTHENING LIGHTWEIGHT FOAMED CONCRETE WITH TEXTILE CARBON GRID LAMINATES

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Abstract:
People in the construction industry around the world have acknowledged the future need for construction materials that are low in self-weight, long-lasting, simple to construct, cost-friendly and yet more environmentally sustainable. One of the suggestions in the frontline has been the finding, developing and utilizing of alternative, non-conventional building materials including the potential use of lightweight foamed concrete. Lightweight foamed concrete which is produced with Portland cement is noble in compression but fragile in tension because it comprises various micro pores that tend to crack. Hence this research project explored the potential use of textile carbon grid laminates with reinforced lightweight foamed concrete. One of the major problems faced in reinforced lightweight concrete construction is the corrosion of reinforcing steel which ominously distresses the lifespan and robustness of concrete assemblies. Hence, textile carbon grid laminates as a replacement to welded wire mesh can commendably abolish the delinquent of decomposition as they are protected from corrosion. Three densities of lightweight foamed concrete of 800kg/m^3, 1100kg/m^3 and 1400kg/m^3 will be cast and tested with 3 different types of textile carbon grid laminates which are 130g, 145g and 160g (weight per square meter). The parameters that will be evaluated are compressive strength, flexural strength, splitting tensile strength, scanning electron microscopy, performance index and failure modes. The results obtained showed that the incorporation of textile carbon grid laminates had improved the flexural strength, compressive strength and splitting strength of lightweight foamed concrete. When the basis weight of textile carbon grid laminates increases (from 130g to 160g), the greater the tensile bond strength of lightweight foamed concrete. As the load increases on the lightweight foamed concrete, a flew in the matrix may spread over the specimen cross-section.

Keywords: Bending strength, Foamed concrete; Mechanical properties; Textile carbon grid laminates

1.0 INTRODUCTION

Construction industry is one of the most significant sectors in Malaysia in engendering our country's economic development. Generally the concept of construction used in Malaysia is on a fixed conventional method (Kumar, 2015). Throughout the past few decades, our country has started to change the construction method to meet the current needs due to high demand in producing new housing, high-rise buildings and other infrastructure's development (Othuman Mydin et. al, 2015).

Besides, the worldwide construction has acknowledged that the future construction materials use need to be more light, durable, simple to use, economic and environmentally sustainable. Many researches are being conducted to find the best materials for construction material (Ramamurthy, 2009). Throughout the last decades, many construction firms are using reinforced lightweight concrete as the construction materials (Islam et. al, 2015). Even though the reinforced concrete is used extensively, but it has its restriction.

Based on the research conducted by Olaoye et. al (2013), he found that the major problem of using reinforcement in concrete is the corrosion of reinforcing steel which expressively distresses the life and robustness of the concrete structure. Hence, this research project explored the potential use of textile carbon grid laminates with reinforced lightweight foamed concrete. Textile carbon grid laminates as a replacement to welded wire mesh can commendably abolish the delinquent of decomposition as they are protected from corrosion.

2.0 LITERATURE REVIEW

The scientific study of natural fiber reinforcement has followed the growth with synthetic fibers. The reasons for incorporating fibers into cement-based materials are commonly to increase the flexural strength, impact toughness, control of cracking and change in failure behavior to give post-crack load-bearing capacity and change in the flow characteristics of the fresh material. (Basharrr et. al, 2016). La Mantia and Morreale (2011) state that in their research high performance fiber reinforced composites are considered by complex elastic limit and strain hardening type of reaction, linked with numerous cracking. As the load upsurges on the composite material, a flew in the matrix may extent over the specimen cross-section. The mechanics of this spread depends on the size of the flaw, the properties of the fiber reinforcement and matrix toughness. If the composite is sufficiently reinforced, the bridging fibers will share the load and transfer it to the other parts of the composite. Multiple cracking occurs when the subsequent transferred load cracks the matrix again. Textile carbon grid laminates is softer, so it just disperses the deformation stress but is unable to share the tension of adhesive layers. When the basis weight of textile carbon grid laminates increases, the greater the tensile bond strength of specimen, but the increase is not obvious (Soleimanzadeh & Othuman Mydin, 2013).

3.0 METHODOLOGY

3.1 Materials

To produce lightweight foamed concrete, 4 main materials used are ordinary Portland cement, fine sand, clean water and stable foam. The textile carbon grid laminates used in this research was supplied by TKS Bio Sdn Bhd. For this research 3 different types of textile carbon grid laminates were used which are 130g, 145g and 160g. Table 1 demonstrates the technical specification of the textile carbon grid laminates. Figure 1 shows the textile carbon grid laminates were cut into different sizes to fit into the moulds. Figure 2 shows the foamed concrete poured in the moulds

Table 1: Technical specification of textile carbon grid laminates

Chemical compound	Portland cement
Quality Assured Facility	ISO 9001:2008
Mesh size	4mm x 4mm
Weight per square meter	130 g/m^2 , 145 g/m^2 , 160 g/m^2
Ignition Point	759.2°F (404°C)
Melt Point	320°F (160°C)
Specific Gravity	0.91
Compliance	ASTM C 1116/C 1116M

Figure 1: Textile carbon grid laminates was cut into different sizes to fit into the moulds

Figure 2: Foamed concrete poured in the moulds

3.2 Laboratory Tests

The compressive strength test was conducted by using compressive strength machine. The test was performed in accordance with BS EN 12390-3:2009 (2002) using a cube specimen size of 100mm x 100mm x 100mm (Figure 2) at 7, 28 and 60 days. Flexural strength of foamed concrete was established using GoTech GT-7001-C10 Universal Testing Machine as been shown in Figure 3. The test was carried out according to procedure in it was conducted according to BS EN 1521:1997. All the procedures and specimens tested in the tensile splitting test were covered at 7, 28 and 60 days of age by referring to the ASTM C496 standard. The specimen size used was 100mm in diameter and 200mm in height cylinder. The sample was placed flat between the loading surfaces of the compression machine as been demonstrates in Figure 4. A light microscope, was used to observe the formation of foamed concrete microstructures.

3.3 Mix Proportions

There were total of 12 mixes were prepared for this research. The mix design proportions for 800 kg/m^3, 1100 kg/m^3 and 1400 kg/m^3. Table 2 shows the mix proportions of this study. Three different types of textile carbon grid laminates were used (130g, 145g and 160g). For all mixes, the sand-cement ratio was fixed at 1:15 and the water cement ratio also was fixed at 0.45.

Table 2: Mix Proportions

Sample	Mix Density (kg/m^3)	Textile carbon grid laminate types	Mix Ratio (S:C:W)	Cement (kg)	Fine Aggregates (kg)	Water (kg)
FC800-CNTRL	800	-	1:1:5:0.45	21.17	31.76	9.53
FC800-110G	800	130gram	1:1:5:0.45	21.17	31.76	9.53
FC800-130G	800	145gram	1:1:5:0.45	21.17	31.76	9.53
FC800-160G	800	160gram	1:1:5:0.45	21.17	31.76	9.53
FC1100-CNTRL	1100	-	1:1:5:0.45	28.76	43.13	12.94
FC1100-110G	1100	130gram	1:1:5:0.45	28.76	43.13	12.94
FC1100-130G	1100	145gram	1:1:5:0.45	28.76	43.13	12.94
FC1100-160G	1100	160gram	1:1:5:0.45	28.76	43.13	12.94
FC1400-CNTRL	1400	-	1:1:5:0.45	36.34	54.51	16.35
FC1400-110G	1400	130gram	1:1:5:0.45	36.34	54.51	16.35
FC1400-130G	1400	145gram	1:1:5:0.45	36.34	54.51	16.35
FC1400-160G	1400	160gram	1:1:5:0.45	36.34	54.51	16.35

4.0 RESULTS & DISCUSSION

4.1 Compressive strength

Figures 3, 4 and 5 demonstrate the influence of different types of textile carbon grid laminates on compressive strength of 800kg/m^3, 1100kg/m^3 and 1400kg/m^3 densities correspondingly. There was a noticeable increase of compressive strength with increase in size of textile carbon grid laminates for all densities. For instance, for 800 kg/m^3 density, there were noticeable increases of compressive strength of 17%, 24% and 34% for FC800-130G, FC800-145G and FC800-160G respectively in comparison with control specimen (FC800-CNTRL). From these results, it can be concluded that textile carbon grid laminates help in preventing the promulgation of cracks in the plastic state in the cement matrix when load was applied (Meheddene et. al, 2014).

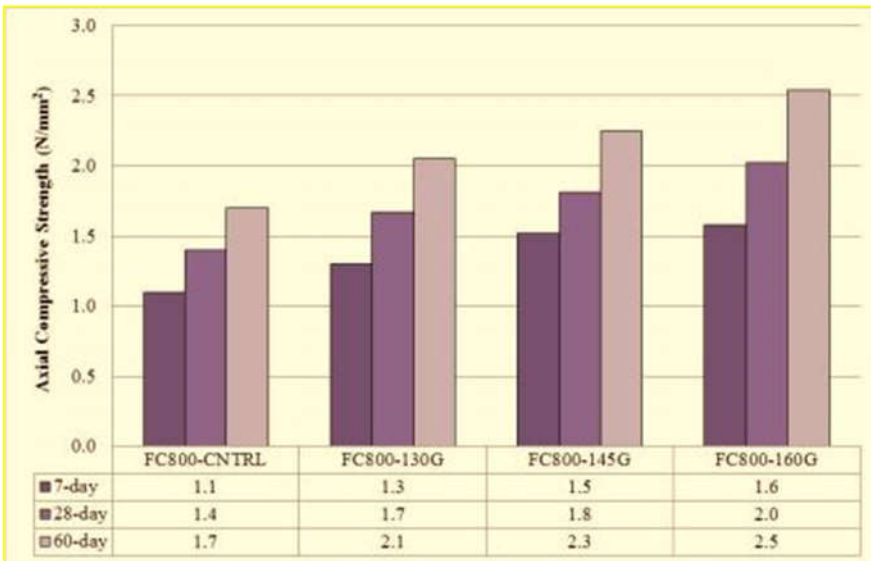


Figure 3: Influence of different types of textile carbon grid laminates on compressive strength of 800kg/m^3 density

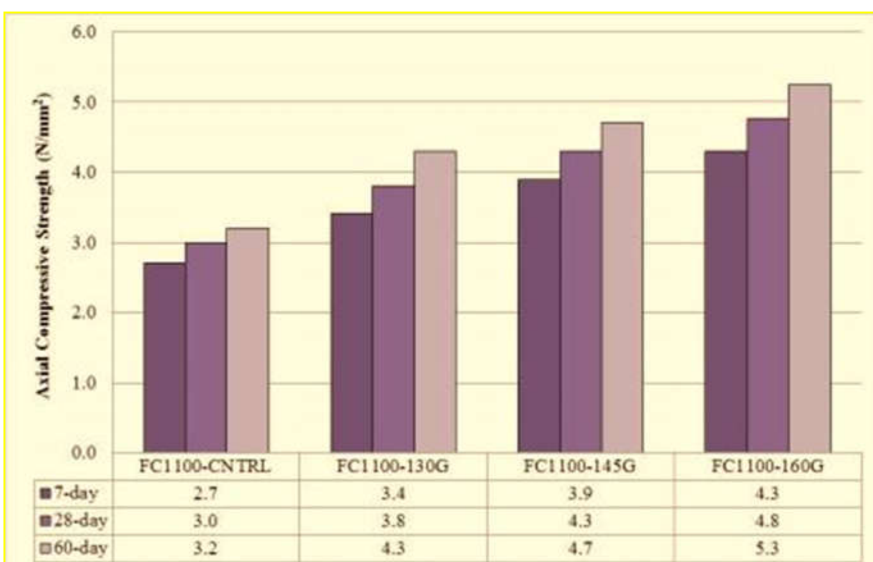


Figure 4: Influence of different types of textile carbon grid laminates on compressive strength of 1100kg/m^3 density

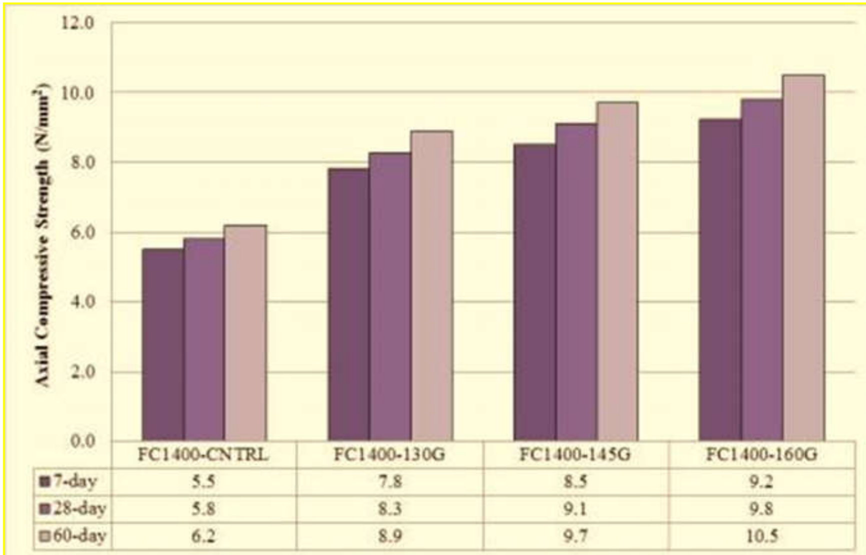
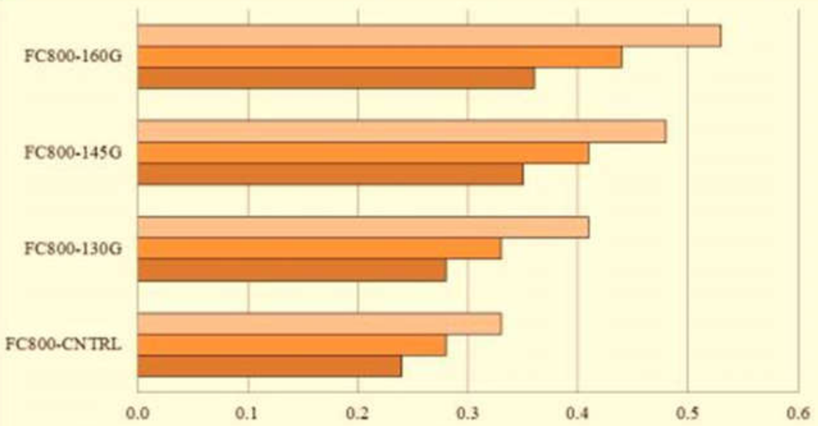


Figure 5: Influence of different types of textile carbon grid laminates on compressive strength of 1400kg/m^3 density

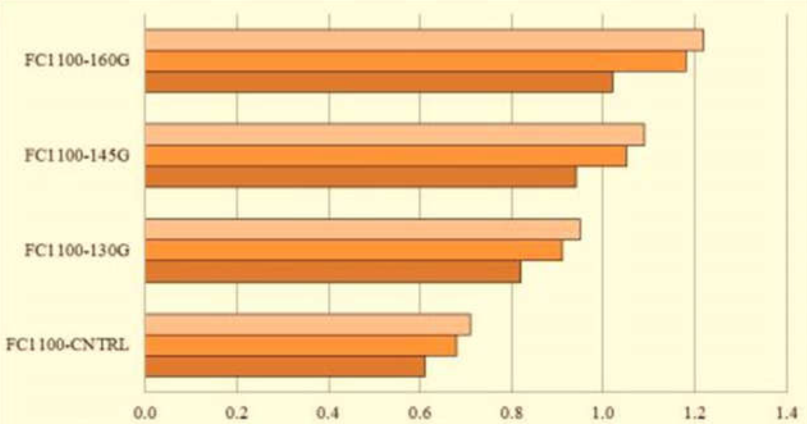
4.2 Three-point bending strength

Figures 6, 7 and 8 exhibit the effect of different types of textile carbon grid laminates on three-point bending strength of 800kg/m^3, 1100kg/m^3 and 1400kg/m^3 densities respectively. For all densities studied in this research, there was a noticeable increase of three-point bending strength with increase size of textile carbon grid laminates. For example, for 1400 kg/m^3 density, there were clear rises of three-point bending strength of 30%, 38% and 46% for FC1400-130G, FC1400-145G and FC1400-160G correspondingly compared to control sample (FC1400-CNTRL). When the lightweight foamed concrete expands under three-point bending load which will lead to cracking, the crack has a restricted distance over which it can spread before reaching the textile carbon grid laminates, preventing the crack from growing (Ranjbar et. al, 2016).



	FC800-CNTRL	FC800-130G	FC800-145G	FC800-160G
60-day	0.33	0.41	0.48	0.53
28-day	0.28	0.33	0.41	0.44
7-day	0.24	0.28	0.35	0.36

Figure 6: Influence of different types of textile carbon grid laminates on bending strength of 800kg/m^3 density



	FC1100-CNTRL	FC1100-130G	FC1100-145G	FC1100-160G
60-day	0.71	0.95	1.09	1.22
28-day	0.68	0.91	1.05	1.18
7-day	0.61	0.82	0.94	1.02

Figure 7: Influence of different types of textile carbon grid laminates on bending strength of 1100kg/m^3 density

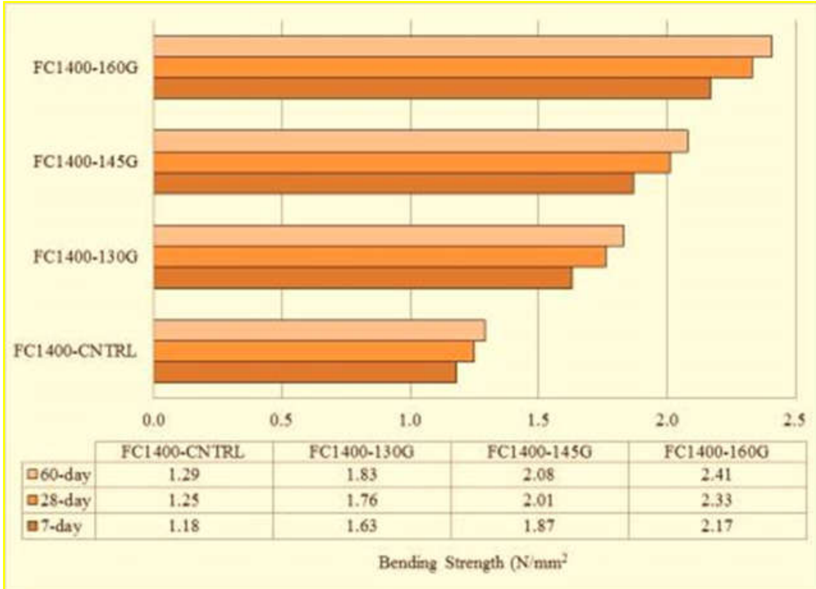


Figure 8: Influence of different types of textile carbon grid laminates on bending strength of 1400kg/m^3 density

4.3 SEM Analysis

Figure 9 shows the morphology of textile carbon grid laminates in cement matrix. It can be seen from Figure 9 that the graphite boundaries which unveil along the edge of the textile carbon grid laminates can be utilized to efficiently implant the textile carbon grid laminates in the cement matrix thus refining the interfacial bonding between the textile carbon grid laminates and the foamed concrete cement matrix and allowing adequate load transfer across the pores (Lim et. al, 2015).

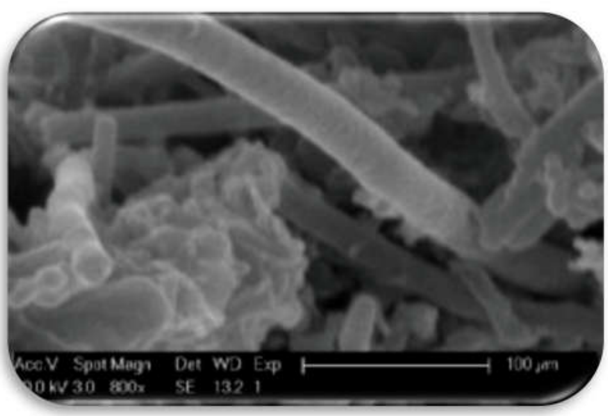


Figure 9: Morphology of textile carbon grid laminates in cement matrix

Figure 10 demonstrates the SEM micrographs of fracture surface of the lightweight foamed mortar reinforced with textile carbon grid laminates. Initially, it is observed that mostly individual textile carbon grid laminates can be identified on the rupture surface. This specifies that decent distribution was accomplished. Figure 10 (right) display a good image of textile carbon grid laminates acting as bridges between pores in the lightweight foamed concrete.

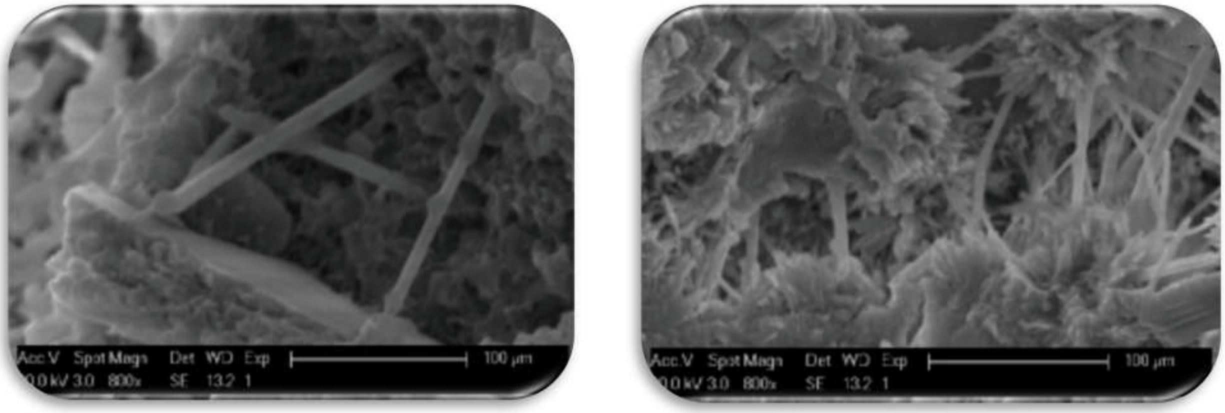


Figure 10: SEM micrographs of fracture surface of cement matrix reinforced with textile carbon grid laminates

Figure 11 shows the SEM micrographs of pull-out of textile carbon grid laminates from cement matrix under axial compression loading. The failure modes of the specimen were textile carbon grid laminates pull-out, textile carbon grid laminates breakage and textile carbon grid laminates debonding from the cement matrix. It can be seen from Figure 11 there are lots of cavities that exist at the cement surface indicating the fiber pull-out failure. A close view of the textile carbon grid laminates surface is shown in Figure 12. Fibrils of the textile carbon grid laminates were peeled from the textile carbon grid laminates surface.

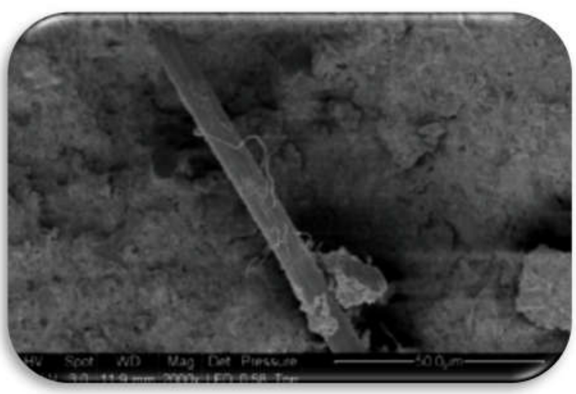


Figure 11: SEM micrographs of pull-out of textile carbon grid laminates from cement matrix

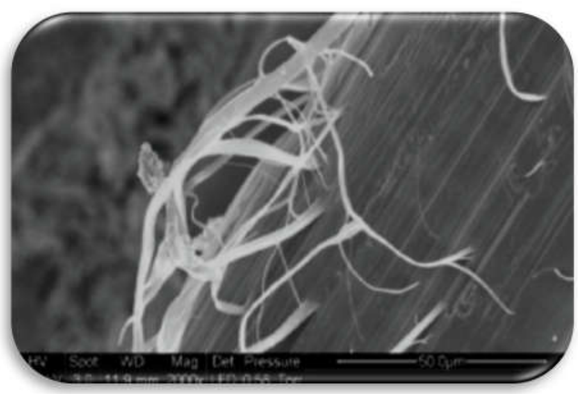


Figure 12: SEM micrographs of textile carbon grid laminates surface in a failed specimen under flexural load

4.4 Performance Index

Axial compressive strength and density of lightweight foamed mortar has interrelated connection. The densities of lightweight foamed mortar for this research were control at 800kg/m^3, 1100kg/m^3 and

1400kg/m^3. As the density for each specimen was varying, performance index of lightweight foamed mortar was calculated to increase the precision of the results obtained through experimental investigation. Figures 13,14 and 15 show the performance index of 800 kg/m^3, 1100kg/m^3 and 1400kg/m^3 densities. Similar trend obtained by performance index, where the performance index is directly proportional to the specimen's curing age. As can be seen from Figure 26, the highest 60-day performance index was achieved by lightweight foamed mortar mix with 160g weight per square meter textile carbon grid laminates, which is 3.2N/mm^2 per 1000 kg/m^3.

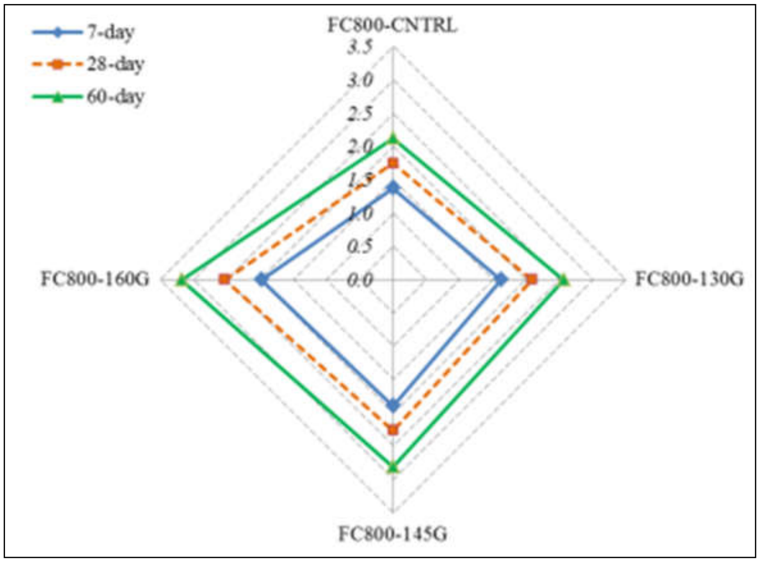


Figure13: Performance index of 800kg/m^3 density mix

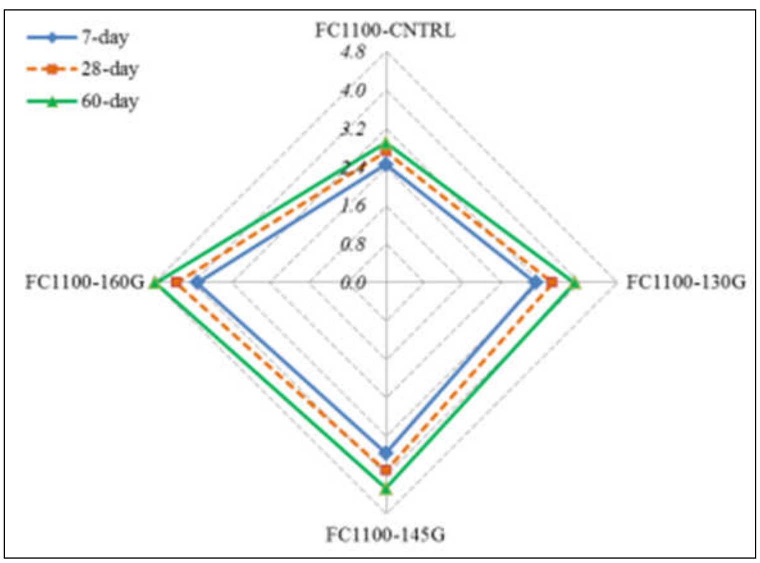


Figure 14: Performance index of 1100kg/m^3 density mix

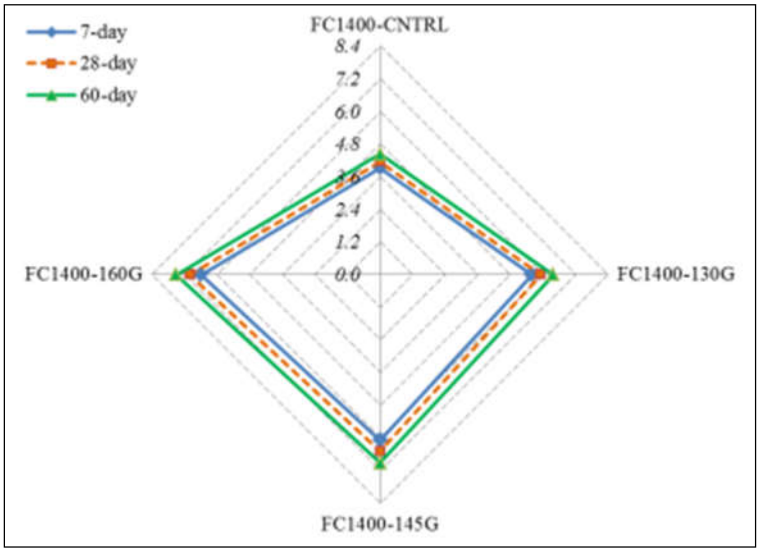


Figure 15: Performance index of 1400kg/m^3 density mix

4.5 Failure modes

The failure modes and patterns of lightweight foamed mortar with textile carbon grid laminates upon axial compressive strength and three-point bending strength were investigated by comparing the results to the control specimen. For the plain lightweight foamed concrete, primarily the cracks occurred near in the side surface of the test piece and it is coterminous inverted shape. Then the shear stress along the diagonal of the samples was clearly formed at ultimate stage. As the load continues to increase, the outer surface of the concrete began to drum and peel. The final failure modes is positive inverted attached the four corners cone. Figure 16 shows the failure pattern of one sample after undergo compressive test. In the case of lightweight foamed mortar reinforced with textile carbon grid laminates, the maximum shear stress was at lower bottom quarter of the sample and the crack lines being formed at the bottom half of the samples. The textile carbon grid laminates really prevent the sample from brittle collapse. This is because the textile carbon grid laminates itself is a soft material. It will bend and break the sample from inside when the sample is tested under axial compression as shown in Figure 17.

Figure 16: Plain (control) foamed mortar sample after failure under axial compression

Figure 17: Textile carbon grid laminates reinforced foamed mortar sample after failure under axial compression

At the preliminary stage of loading, no cracks appear on the surface of specimens. With the increase of load, slight cracks begin to appear at the bottom surface of the specimen. Cracks occur between the two concentrated loads on the specimen. As the load continues to increase; cracks gradually extend vertically along the side surface. When the load continues to increase, the crack width of specimen increases gradually, and the final specimen is broken (Figure 18). Textile carbon grid laminates provide better shear force by preventing the widening of cracks due to bending stress (Figure 19).

Figure 18: Plain (control) foamed mortar sample after failure under three-point bending strength

Figure 19: Textile carbon grid laminates reinforced foamed concrete sample after failure under three-point bending strength

5.0 CONCLUSION

An experimental study was conducted to evaluate the potential use of textile carbon grid laminates reinforced lightweight foamed concrete in terms of its mechanical properties. There were 3 densities of lightweight foamed concrete of 800kg/m^3, 1100kg/m^3 and 1400kg/m^3 were prepared and tested with 3 different types of textile carbon grid laminates which are 130g, 145g and 160g (weight per square meter). The results obtained showed that for all densities, the incorporation of textile carbon grid laminates (130g, 145g and 160g) in lightweight foamed concrete aid crack control, in which this carbon grid laminates improved the three-point bending strength and compressive strength of lightweight foamed concrete. Textile carbon grid laminates help in preventing the promulgation of cracks in the plastic state in the cement matrix when load was applied. When the basis weight of textile carbon grid laminates increases (from 130g to 160g), the greater the tensile bond strength of lightweight foamed concrete.

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