ENHANCEMENT OF TENSILE STRENGTH OF LIGHTWEIGHT FOAMED CONCRETE THROUGH WOVEN FIBERGLASS MESH JACKETING

ANISAH MAT SERUDIN, MD AZREE OTHUMAN MYDIN & ABDUL NASER ABDUL GHANI

School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia

ABSTRACT

Recently, the development of textile fabric as reinforcing element for concrete structure had gain attention by building component manufacturers. Many researchers reported that the confinement of concrete via textile fabric had showed a significant enhancement in concrete strength. They also highlighted that concrete with aggregate that less than 2mm has great matrix-to-fibre bond. This information leads the authors to investigate the potential utilization of textile fabric as reinforcing element for Lightweight Foamed Concrete (LFC) since it utilizes fine aggregate with dimension that not more than 2mm. LFC has extremely low tensile strength due to its brittle nature. In this research paper, authors will reveal the assessment of splitting tensile strength of LFC strengthened with woven fiberglass mesh in order to change the typical brittle behaviour to elastic-plastic behaviour. The mix ratio applied in this research was fixed where the cement-to- sand ratio is 1:1.5 while water was maintained at 0.45. There are three designed densities were measured in this study which were 600 kg/m³, 1100 kg/m³, and 1600 kg/m³. The 160 g/m² of woven fiberglass mesh was used as confinement material to the LFC, where the number of layer(s) employed being examined. The results show enhancements of 507% (600 kg/m³), 343% (1100 kg/m³), and 332% (1600 kg/m³) for tensile strength of LFC strengthened with woven fiberglass mesh compared to unreinforced LFC.

KEYWORDS: *Foamed Concrete, Tensile Strength, Fibermesh, Textile Fabric, Confinement*

Received: Jun 08, 2020; **Accepted:** Jun 28, 2020; **Published:** Aug 29, 2020; **Paper Id.:** IJMPERDJUN2020963

INTRODUCTION

Nowadays, sustainable development is increasingly in demand within the building and construction industry. A lot of studies have been conducted to fulfil this demand. The potential use of lightweight foamed concrete (LFC) in the construction industry is of growing interest among researchers. However, LFC is a brittle material that needs reinforcement to increase its strength, ductility, and toughness to delay structural failure. The use of steel reinforcement in LFC results in corrosion problems, which will affect its long-term durability, and will require maintenance at a high cost. In addition, steel reinforcement also increases with the weight of the structure.

According to Cibulka et al. (2019), lightweight concrete can be specially reinforced using grid shaped fibres also known as textile fabric. Yin et al. (2017) also stated that fine-grained concrete can be chosen to accomplish good bonding between the textile fabric and matrix. Besides, Dalal et al. (2017) also highlighted that fluid concrete with a maximum aggregate size of less than 2 mm is needed to provide sufficient binding, and to allow the load of the matrix to be transferred to the reinforcement. Therefore, the combination of LFC (produced by using fine aggregate/sand) and textile fabric can produce a lightweight and thin concrete element with a high load-bearing capacity. Nevertheless, Portal et al. (2017) stated that textile-reinforced concrete (TRC) has been coined as a versatile high-performance composite material, but it has not been sufficiently acknowledged due to the lack of design specifications.

As mentioned by Gayathri et al. (2018), many researchers have been working with the idea of improving the performance of concrete by developing high-performance fibres, namely, TRC. They also explained that TRC is a type of reinforced concrete in which the fabric cage is utilized as a tensile reinforcing material in concrete. Volkova et al. (2016) also reported that reinforced concrete with high-strength textile fabrics (carbon and glass) has a greater residual load-bearing capacity, and is thus able to maintain the integrity of a structure after exposure to the maximum applied load. They also highlighted that the strength of concrete reinforced with carbon and glass textile fabrics is significantly increased compared to unreinforced concrete.

Comparative studies have been conducted to discover the influence of textile fabrics and short fibres as reinforcing elements in a cement matrix. According to a study by Peled and Mobasher (2005) on the tensile strength of a cement matrix reinforced with glass fabric and glass fibre (same cement matrix), the woven reinforcement provided a superior tensile strength. When subjected to a load, the textile fabric exhibited a better performance than the composite reinforced with short fibres (Boisse et al., 2005). This phenomenon was discussed by Dalal et al. (2017), who showed that the low strength of the short fibres due to the lack of arrangement in the matrix caused some of the fibres to be positioned perpendicular to the direction of the applied load. Thus, the application of a textile fabric can address this problem since the direction (position) of the reinforcement in the cement matrix can be adjusted to the desired design besides increasing the load-bearing capacity of the structure. Hence this study is conducted to observe the potential use of woven fiberglass mesh confinement of splitting tensile strength of Lightweight Foamed Concrete (LFC).

LITERATURE REVIEW

According to Neville (2011), the tensile strength is correlated to the compressive strength, although this relationship depends on multiple factors such as the aggregate type and particle size distribution, the age of the concrete, the curing process, and the air content. Besides, Thakrele (2014) reported that the tensile strength of LFC can be as high as 0.24 times its compressive strength, with an ultimate strain of about 0.1%. Parra and Gomez (2011) mentioned that the splitting tensile strength for self-compacting concrete is lower than normal vibrated concrete due to the absence of aggregate-paste bonds in the matrix. Moreover, Amran et al. (2015) posited that the factors influencing compressive strength will equally affect the tensile strength and vice versa. Additionally, the proportion of flexural strength to axial compressive strength is around zero when LFC is designed with a density that is below 300 kg/m³. Table 1 shows the splitting tensile strength results from a lower to a higher density, as examined by Jalal et al. (2017).

Table 1: Results of Splitting Tensile Strength from a Lower to a Higher Density (Jalal et al., 2017)

Density (kg/m ³)	Splitting tensile strength (N/mm ²)
400	0.10
500	0.20
600	0.30
700	0.35
800	0.45
900	0.55
1000	0.65
1200	1.10
1400	1.20
1800	1.60

Kearsley (1999) mentioned that LFC is claimed to be weak and non-durable, with high shrinkage behaviour, and it should not be exposed to an aggressive atmosphere, where the unprotected reinforcement applied in LFC would be vulnerable to corrosion, even when the external attack is not very severe. Therefore, many studies have been carried out to improve the behaviour and performance of LFC. One such method is the inclusion of fibres in the mortar paste. The fibres are used to modify the tensile and flexural strengths, toughness, impact resistance, and fracture energy to arrest the formation and propagation of cracks, thereby improving the strength and ductility of LFC (Ahmad et al., 2010; Aydin, 2013; Bagherzadeh et al., 2012; Nahhas, 2013). Chandramouli et al. (2010) also proved that the inclusion of glass fibres improves the strength of the material by increasing the force required for deformation, and enhances the toughness by increasing the energy required for crack propagation. In addition, Ibrahim et al. (2014) explained that the flexural strength of LFC can be improved by introducing fibres into the matrix, where the progressive bending of the fibres slows down the propagation of cracks. Besides, Ranjbar et al. (2016) reported that when LFC expands under a bending load, thereby leading to cracking, the crack has a restricted distance over which it can spread before reaching the fibres, where it is prevented from growing.

Textile fabrics are used as reinforcement in concrete (Gayathri et al., 2018). This material was developed as an alternative to overcome the drawbacks of fibre-reinforced polymer (FRP), which are mainly associated with the use of epoxy resins (high cost, poor performance in high temperatures, inability to be applied on wet surfaces, and incompatibility with substrates such as concrete or masonry) (Koutas et al., 2019). Al-Gemeel and Zhuge (2018) verified that FRP materials have poor pore resistance, and the organic polymer rubble is classified as a hazardous material with poor information having been established on its disposal. Therefore, to alleviate the problems arising from FRP materials, textile fabrics were developed as a reinforcing element in concrete structures.

The first textile-based composite material was produced in Europe, and it is known as textile reinforced concrete (TRC) or textile reinforced mortar (TRM). It should be strictly noted that the inorganic matrix is not classified as concrete due to the very small size of the aggregates, while in the US, the materials are called fabric reinforced cementitious matrix (FRCM) systems (Koutas et al., 2019). Textile fabrics have gained attention due to their significant advantages, which are their high strength-to-weight ratio, ability to be manufactured in complex shapes, non-corrosive nature, and low thermal conductivity (Karaduman et al., 2017). Many studies have been conducted to investigate the mechanical properties of textile fabric reinforcements, and the major materials that have been utilized in civil engineering are carbon, glass, and basalt.

Mix Composition and Experimental Setup

To investigate the effects of woven fiberglass mesh in LFC, three different densities were designed which were 600 kg/m³, 1100 kg/m³, and 1600 kg/m³. These densities represent as non-structural, semi-structural, and structural building elements for the respective density. Besides, the number of layer(s) employed also being analysed to studied more detailed about its effect to the LFC. 160 g/m² of woven fiberglass mesh was selected due to its advantages such as low self-weight, alkali resistant, flexible, durable, and cheaper than other material (carbon, steel, etc).

In order to get the comparable results, the mix ratio for this research was fixed to 1:1.5 (cement-to-sand) ratio and water constant at 0.45. The cement used was Type 1 Portland cement which was applied according to ASTM C150-04 (2004). Fine sand with dimension size is less than 1.18 mm was selected as a filler to produce LFC. As highlighted by Nambiar and Ramamurthy (2006), the fine sand produced better strength in LFC as the use of coarse sand in a compound

matrix cause the pores to become bigger and create an inconsistent mix. Clean water was used to bind the cement and filler through the process of hydration, thereby causing the hardening of the mortar paste. Besides, an important ingredient in producing the LFC is the foaming agent where the protein-based agent was chosen. Fig. 1 and 2 show the position of woven fiberglass mesh confining the LFC.

Figure 1: Woven Fiberglass Mesh was Cut to Fit into the Mould.

Figure 2: Woven Fiberglass Mesh Confining the Specimen all Around.

The tensile strength of concrete can be determined by the application of a direct tensile stress or indirect tensile strength. In this study, the indirect tensile strength was applied, according to ASTM C496/C496M (2004) standard. A Universal Testing Machine (GTECH GT- 7001-BS300) was used to perform the splitting tensile test. Three cylindrical specimens measuring 100Ø mm x 200 mm were tested at day-7, day-28, day-56 and day-180, and the average value at each tested day was recorded as the final result of the splitting tensile test. Equation 1 was used to determine the splitting tensile strength, while the setup for this test is shown in Fig. 3. In this test, also known as the Brazilian test, the indirect tensile strength obtained is related to the compressive strength, water-to-cement ratio, and age of the concrete, and it is useful for experiments with brittle materials, where the compressive strength is higher compared to the tensile strength.

Equation 1

Where, P = Maximum Load Carried by Specimen, L = Length of Specimen, D = Diameter of Specimen

Figure 3: Setup for Splitting Tensile Strength Test.

RESULTS AND DISCUSSION

As reported by Amran et al. (2015), the factors that influence compressive strength equally affect the tensile strength of LFC. Thus, unconfined LFC, which is brittle, possesses a lower tensile strength. This was proven by the results of the splitting tensile strength obtained in this study, which showed a similar trend as that of the compressive strength, as shown in Fig. 4, Fig. 5, and Fig. 6. These three figures demonstrated that the tensile strength of the unconfined and confined LFC grew increasingly as the curing age progressed. The volume of foam also significantly affected the tensile strength. For instance, the tensile strength obtained for the control specimen with a density of 600 kg/m^3 at day-180 was 0.14 N/mm^2 , and this tensile strength then increased by 229% after the foam volume was reduced to obtain the desired density of 1100 kg/m^3 . An increase of 122% in the tensile strength was also achieved for the LFC specimens with a density of 1600 kg/m^3 as only a small amount of foam was needed to achieve this preferred density compared to a density of 1100 kg/m^3 . However, the results of the tensile strength obtained for the control specimens were considered to be low due to the absence of a reinforcing element in the matrix. Thus, the confinement of LFC with different number of layers of woven fiberglass mesh improved the performance of the LFC in terms of its tensile strength.

The significant enhancement of the tensile strength of the LFC specimens confined with different number of layers of woven fiberglass mesh is illustrated in Table 2. When the LFC was wrapped in 1 layer of woven fiberglass mesh, the tensile strength increased by 186%, 157%, and 150% for the specimens with densities of 600 kg/m^3 , 1100 kg/m^3 , and 1600 kg/m^3 , respectively, compared to the unconfined specimens. For the confinement with 2 layers of woven fiberglass mesh, the increases in the tensile strength, which were 279%, 237% and 234% for the respective densities, were double those of the specimens confined with 1 layer of textile fabric. Superior augmentations of 507%, 343%, and 332% in tensile strength were accomplished when the LFC specimens with densities of 600 kg/m^3 , 1100 kg/m^3 , and 1600 kg/m^3 , respectively were confined with 3 layers of woven fiberglass mesh.

The incredible enhancement of the tensile strength in LFC proves that woven fiberglass mesh has the potential to be used as a reinforcing element in LFC. This performance also improved as the number of layers of textile fabric for the confinement was increased. The woven fiberglass mesh used in this study not only had strong fibre-to-matrix bonding, but also exceptionally strong fibre-to-fibre bonding, which enabled stretching and prevented the LFC from collapsing. As highlighted by Parveen and Sharma (2013), the enhancement of tensile strength is due to the holding capacity of the fibres, which can aid in the splitting of the concrete.

Figure 4: Tensile Strength of LFC Specimens with a Density of 600 kg/m³ Confined with Different Number of Layers of 160 g/m² of Woven Fiberglass Mesh.

Figure 5: Tensile Strength of LFC Specimens with a Density of 1100 kg/m³ Confined with Different Number of Layers of 160 g/m² of Woven Fiberglass Mesh.

Figure 6: Tensile Strength of LFC Specimens with a Density of 1600 kg/m³ Confined with Different Number of Layers of 160 g/m² of Woven Fiberglass Mesh.

Table 2: Percentage Increase in Tensile Strength of LFC Specimens Confined with 1 Layer, 2 Layers, and 3 Layers of Woven Fiberglass Mesh at Three Different Densities Compared to the Control Specimens at Day-180

Specimen	Percentage increase (%)		
	600 kg/m ³	1100 kg/m ³	1600 kg/m ³
1L-FM	186	157	150
2L-FM	279	237	234
3L-FM	507	343	332

Fig. 7 shows the failure modes of LFC under tension loading. When the control specimen reached its maximum applied load during the testing, it was broken into two pieces by a vertical crack (refer to Fig. 7 (a)). This was caused by the brittleness of the LFC, which failed to resist the crack propagation. For the confined LFC, as shown in Fig. 7 (b), (c), and (d), only a small crack appeared at the top surface of the specimens and a vertical mark at the lateral surface. The specimens did not break into two even after the failure due to the confinement with woven fiberglass mesh, which arrested the occurrence of a major crack. Therefore, this supported the previous statement that the technique of jacketing the LFC in woven fiberglass mesh increased its tensile strength compared to the unconfined specimens.

Figure 7: Failure Modes of LFC Under Tension Loading.

CONCLUSIONS

From this study, the superior enhancement of the LFC specimens wrapped with different number of layers of woven fiberglass mesh was achieved for the splitting tensile strength test. The maximum tensile strength values obtained were 0.85 N/mm², 2.04 N/mm², and 4.41 N/mm² with enhancements of 186% to 567%, 157% to 343%, and 150% to 332%, respectively for the various densities. Hence, this demonstrated that the strengthening of LFC with woven fiberglass mesh enhanced its splitting tensile strength.

REFERENCES

1. Ahmad, Z., Saman, H. M., & Tahir, P. M. (2010). Oil Palm Trunk Fiber as a Bio-Waste Resource for Concrete Reinforcement. *International Journal of Mechanical and Materials Engineering (IJMME)*, 5(2), 2010. Retrieved from <https://pdfs.semanticscholar.org/32f1/2cff145c9ae23babf64e9c6e49dae39fce05.pdf>
2. Al-Gemeel, A. N., & Zhuge, Y. (2018). Axial performance of textile reinforced composite tubes under compression. *International Journal of Civil Engineering and Technology*, 9(7), 809–823. Retrieved from <https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%29CC.1943-5614.0000882>
3. Amran, Y. H. M., Farzadnia, N., & Ali, A. A. A. (2015). Properties and applications of foamed concrete; A review. *Construction and Building Materials*, 101(December), 990–1005. <https://doi.org/10.1016/j.conbuildmat.2015.10.112>
4. ASTM C150-04. (2004a). Standard Specification for Portland Cement C150-04. *Annual Book of ASTM Standards*, 04(02), 1–8.
5. ASTM C496/C496M-04. (2004b). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens C496/C496M-04. *Annual Book of ASTM Standards*. <https://doi.org/10.1520/C0496>
6. Al-Ameen, Ehsan Sabah, and Mohammed Husam Tawfeeq. "The Effect of Internal Pressure and Temperature on Hoop Strain Behavior in Spherical Composite Shell." *International Journal of Mechanical and Production Engineering Research and Development, (IJMPERD) ISSN (P) (2018): 2 249-6890*.
7. Aydin, S. (2013). Effects of fiber strength on fracture characteristics of normal and high strength concrete. *Periodica Polytechnica Civil Engineering*, 57(2), 191–200. <https://doi.org/10.3311/PPci.7174>
8. Bagherzadeh, R., Pakravan, H. R., Sadeghi, A. H., Latifi, M., & Merati, A. A. (2012). An investigation on adding polypropylene fibers to reinforce lightweight cement composites (LWC). *Journal of Engineered Fibers and Fabrics*, 7(4), 13–21. <https://doi.org/10.1177/155892501200700410>
9. Boisse, P., Gasser, A., Hagege, B., & Billoet, J. L. (2005). Analysis of the mechanical behavior of woven fibrous material using virtual tests at the unit cell level. *Journal of Materials Science*, 40(22), 5955–5962. <https://doi.org/10.1007/s10853-005-5069-7>
10. Chandramouli, K., Srinivasa, R. P., Pannirselvam, N., Seshadri, S. T., & Sravana, P. (2010). Strength properties of glass fibre concrete. *Journal of Engineering and Applied Sciences*, 5(4), 1–6. Retrieved from http://www.arpnjournals.com/jeas/research_papers/rp_2010/jeas_0410_318.pdf
11. Cibulka, T., Musil, L., & Vodička, J. (2019). The Lightweight Textile Reinforced Concrete for Thin-Walled Structures. *Acta Polytechnica CTU Proceedings*, 22, 17–21. <https://doi.org/10.14311/app.2019.22.0017>
12. Dalal, M., Goumairi, O., & Malik, A. El. (2017). Study of the internal confinement of concrete reinforced (in civil engineering) with woven reinforcement. *IOP Conference Series: Materials Science and Engineering*, 254(4). <https://doi.org/10.1088/1757-899X/254/4/042008>
13. Gayathri, C. N., Singh, R. B., & Dhanalakshmi, G. (2018). Mechanical behaviour of textile reinforced concrete. *International Research Journal of Engineering and Technology (IRJET)*, 5(5), 2227–2231. Retrieved from https://www.academia.edu/38216913/IRJET-_Mechanical_Behaviour_of_Textile_Reinforced_Concrete
14. Ibrahim, M. H. W., Jamaludin, N., Irwan, J. M., Ramadhansyah, P. J., & Hani, A. S. (2014). Compressive and flexural strength of foamed concrete containing polyolefin fibers. *Advanced Materials Research*, 911(March), 489–493. <https://doi.org/10.4028/www.scientific.net/AMR.911.489>

15. Jalal, M. D., Tanveer, A., Jagdeesh, K., & Ahmed, F. (2017). Foam concrete. *International Journal of Civil Engineering Research*, 8(1), 1–14. Retrieved from https://www.ripublication.com/ijcer17/ijcerv8n1_01.pdf
16. Karaduman, N. S., Karaduman, T., Ozdemir, H., & Ozdemir, G. (2017). Textile Reinforced Structural Composites for Advanced Applications. *Textile for Advanced Applications*, 89–133. <https://doi.org/http://dx.doi.org/10.5772/57353>
17. Kearsley, E. P. (1999). *Just foamed concrete - an overview* (R. K. Dhir & N. A. Handerson, Eds.). London: Thomas Telford.
18. Koutas, L. N., Tetta, Z., Bournas, D. A., & Triantafillou, T. C. (2019). Strengthening of Concrete Structures with Textile Reinforced Mortars: State-of-the-Art Review. *Journal of Composites for Construction*, 23(1), 1–20. [https://doi.org/10.1061/\(ASCE\)CC.1943-5614.0000882](https://doi.org/10.1061/(ASCE)CC.1943-5614.0000882)
19. Manyam, Shiresha, and Padma Alapati. "Eco-Friendly Sisal Union Fabric-Suitability Assessment." (2018). *International Journal of Educational Science and Research (IJESR)* 8, 3, Jun 2018, 77-84
20. Nahhas, T. M. (2013). Flexural Behavior and Ductility of Reinforced Lightweight Concrete Beams with Polypropylene Fiber. *Journal of Construction Engineering and Management*, 1(1), 4–10. Retrieved from <http://researchpub.org/journal/jcem/number/vol1-no1/vol1-no1-1.pdf>
21. Nambiar, E. K. K., & Ramamurthy, K. (2006). Influence of filler type on the properties of foam concrete. *Cement and Concrete Composites*, 28(5), 475–480.
22. Neville, A. M. (2011). *Properties of concrete* (5th editio). Retrieved from <https://igitgeotech.files.wordpress.com/2014/10/properties-of-concrete-by-a-m-neville.pdf>
23. Parra, C. M., & Gomez, F. (2011). Splitting tensile strength and modulus of elasticity of self- compacting concrete. *Construction and Building Materials*, 25, 201–207.
24. Parveen, & Sharma, A. (2013). Structural behaviour of fibrous concrete using polypropylene fibres. *International Journal of Modern Engineering Research*, 3(3), 1279–1282. Retrieved from https://www.researchgate.net/profile/Parveen_Jangra/publication/303783435_Structural_behaviour_of_fibrous_concrete_using_polypropylene_fibres/links/58b82c1f45851591c5d7efa8/Structural-behaviour-of-fibrous-concrete-using-polypropylene-fibres.pdf
25. Parthiban, R., R. Sakthivel, and Srikanth Jetti. "Fabrication and Study of Hardness Behaviour on Gamma Irradiated Ultra-High Molecular Weight Polyethylene (UHMWPE) Plate." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8.2, Apr 2018, 45-52
26. Peled, A., & Mobasher, B. (2005). Properties of fabric-cement composites made by pultrusion. *Materials and Structures*, 39(292), 787–797. <https://doi.org/10.1617/s11527-006-9171-3>
27. Portal, N. W., Thrane, L. N., & Lundgren, K. (2017). Flexural behaviour of textile reinforced concrete composites: experimental and numerical evaluation. *Materials and Structures*, 50(4), 1–14. <https://doi.org/10.1617/s11527-016-0882-9>
28. Ranjbar, N., Behnia, A., Alsubari, B., Birgani, P. M., & Jumaat, M. Z. (2016). Durability and mechanical properties of self- compacting concrete incorporating palm oil fuel ash. *Journal of Cleaner Production*, 112, 72730.
29. Rout, ARUN KUMAR, and JITESH KUMAR Singh. "An Overview of Advanced Fiber Reinforced Polymer Composites and Its Applications." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8 (2018): 311-318.

30. Thakrele, M. H. (2014). *Experimental study on foam concrete*. *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development*, 4(1), 145–158. Retrieved from <http://www.tjprc.org/publishpapers/2-11-1394782454-17>. Civil - IJCSEIERD --Experimental Study On Foam Concrete - Maheshkumar H. Thakrele - Paid Copy.pdf
31. Volkova, A., Paykov, A., Semenov, S., Stolyarov, O., & Melnikov, B. (2016). *Flexural Behavior of Textile-Reinforced Concrete*. *MATEC Web of Conferences*, 53, 1–7. <https://doi.org/10.1051/mateconf/20165301016>
32. Yin, S., Wang, B., Wang, F., & Xu, S. (2017). *Bond investigation of hybrid textile with self- compacting fine-grain concrete*. *Journal of Industrial Textiles*, 46(8), 1616–1632. <https://doi.org/10.1177/1528083716629137>