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PHYSICAL PROPERTIES OF FOAMED CONCRETE INCORPORATING COCONUT FIBRE

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Graphical abstract

Abstract

Nowadays, the high cost of conventional construction material becomes the dominating factor which affecting the housing system in our country. As an alternative method to overcome this disadvantage which is decreasing the strength of the building, it is important to do research on any alternating materials which will decrease the cost and increase the strength of concrete. This conventional construction material likewise made some problems to nature. But coconut fiber, which is natural fiber, makes no impact on environment furthermore increases the strength of concrete compares to other fiber. This paper focuses on the investigation and experimental analysis on the physical characteristics of lightweight foamed concrete (LFC) incorporating coconut fibers composites with different volume percentage of fibers 0.2 and 0.4. LFC is produced by cement paste or mortar in which air-voids are entrapped in the mortar by the suitable foaming agent. Two densities of LFC, 850 and 1200 kg/m³, were cast and tested. Approximately 0.75% of cement percentage of super plasticizer was used to enhance workability of the fresh mix. The results of the test showed that the both of physical properties of the concrete increases with curing age and quantity of coconut fiber.

Keywords: Foamed concrete, physical properties, mortar, coconut

Abstrak

Kini, kos tinggi bahan binaan konvensional menjadi salah satu faktor yang memberi kesan kepada sistem perumahan di negara kita. Sebagai kaedah alternatif untuk mengatasi kelemahan ini, adalah penting untuk melakukan penyelidikan terhadap bahan yang akan mengurangkan kos dan meningkatkan kekuatan konkrit. Bahan pembinaan konvensional juga menimbilkan beberapa masalah terhadap alam semula jadi. Tetapi serabut kelapa merupakan serabut semula jadi yang tidak membawa kesan buruk ke atas alam sekitar dan meningkatkan kekuatan konkrit berbanding dengan serabut lain. Tumpuan kertas kerja ini adalah untuk mengenai penyiasatan dan analisis eksperimen ke atas sifat fizikal konkrit berbusa ringan (LFC) yang menggabungkan komposit serabut kelapa dengan peratusan jumlah yang berbeza iaitu 0.2 dan 0.4. Konkrit ringan berbusa (LFC) dihasilkan daripada campuran simen atau mortar beserta gelembung udara yang dihasilkan daripada agen campuran tertentu. Dua ketumpatan yang berbeza LFC, 850 dan 1200 kg / m³, disediakan dan diuji. Sejumlah 0.75% superplasticizer digunakan daripada peratusan simen untuk meningkatkan kebolehkerjaan bancuhan. Keputusan ujian menunjukkan bahawa kedua-dua kekuatan fizikal dan mekanikal konkrit meningkat dengan meningkatnya umur dan kuantiti serabut kelapa.

Kata kunci: Konkrit berbusa, sifat fizikal, mortar, kelapa

1.0 INTRODUCTION

These days, the construction industry needs to produce and find new systems and technologies for the future. The construction industry is no more subject to conventional ideas of construction that include reinforced concrete, brickworks and timber, but is gradually moving towards more high technology. Innovations that consist of a variety of methods and applications will be important in the future. Lightweight foamed concrete (LFC) is one of the most recent advancements in solid concrete technology that provides many advantages in construction [1].

LFC is known as a lightweight concrete that is engendered by cement paste or mortar in which air-voids are entrapped in the mortar by an acceptable foaming agent. LFC can be created in a wide range of densities ranging from 400 kg/m³ to 1600 kg/m³ by opportunely controlling the amount of foam incorporated into the mortar slurry. A foaming agent that is diluted in water will produce bubbles from pressure integrated by a compressor machine. Each density has its own function based on the building requirement or purpose [2].

The use of LFC in construction industry has grown rapidly due to its good characteristics. LFC has many advantages such as lightweight, high flow ability, controlled low strength, good sound insulation, minimal consumption of aggregate and excellent thermal insulation [3]. LFC is self- flowing and is easily manufactured. It can be utilized as a part of different applications in buildings, and can thus fulfil the current needs in the construction industry. LFC is very fluid and can easily be poured into various shapes and sizes to satisfy current sophisticated building designs. Because of its valuable characteristics, it is also able to fill enclosed spaces [4].

Despite the fact that LFC has great qualities as said before, the mechanical properties of foamed concrete is weak compared to normal concrete. Numerous studies have been done to overcome this issue and it has been demonstrated that foamed concrete can still be used as a building component [5]. As for now, the material has virtually limitless applications in the construction industry, and in building and civil engineering works, ranging from lightweight partitions, walls and secondary structural components to primary structural components [6]. Foamed concrete has so far been utilized principally as a filler material in structural building works [7].

There is currently a great deal of interest in developing the technology for using natural fiber in cement composites. The utilization of natural fiber as reinforcement in concrete has been comprehensively investigated in numerous countries [8]. The natural fiber, which can be utilized as a part of the production of building materials, are presently mainly those based on coconut, bamboo, cane, henequen and sisal fibers [9]. These days numerous researches are made on the natural fiber which are easily accessible in large quantity and are very cheap. Among this natural fiber, coconut fiber can possibly be utilized as substitute coarse aggregate in concrete [10]. Coconut fiber is extracted from the external shell of a coconut and it is agricultural waste items obtained in the processing of coconut oil. The common name, scientific name and plant family of coconut fiber is Coir, Cocos nucifera and Arecaceae (Palm), respectively [11].

There are two types of coconut fibers, brown fiber extracted from matured coconuts and white fibers extracted from immature coconuts. Brown fibers are thick, strong and have high abrasion resistance [12]. White fibers are smoother and finer, additionally weaker. Coconut fibers are commercial available in three structures, specifically bristle (long fibers), mattress (relatively short) and decorticated (mixed fibers). These different types of fibers have different uses relying on the necessity. In engineering, brown fibers are mostly utilized.

As indicated by the official website of International Year For Natural Fiber 2009 the development of coconut tree are around 12 million worldwide which produces 5,00,000 tons of coconut fiber annually and are accessible in large amounts in the tropical regions of the world, most particularly in Africa, Asia and America. In Asia it is predominantly produced and exported from India and Sri Lanka, followed by Thailand, Vietnam, the Philippines and Indonesia. Around a large portion of the coconut fibers produced is exported in the form of raw fiber [13].

Coconut fiber is the hard stony endocarp but lightweight and naturally sized. Due to the stiff surfaces of organic origin, they will not contaminate or leach to produce toxic substances once they bound in the concrete matrix. In addition, coconut fibers are lighter than the conventional coarse aggregate so the resulting concrete will be lightweight. Therefore, it can be used as a good replacement of coarse aggregate to produce structural concrete in the construction industry [14].

To overcome the problem faced by LFC, many researches has been made on lightweight concrete incorporating of coconut fiber additionally which decreases the utilization of convectional cement and reduces the cost of concrete as well. When combining coconut fiber with LFC, it will increases the toughness of the material so that the product can withstand handling and a structural load. The overall goal for this research is to make more and more awareness about the advantages and uses of coconut fiber and introducing it as a cheap and easily available natural fiber which did not affect the environment [15].

2.0 EXPERIMENTAL SETUP

2.1 Scanning Electron Microscope (SEM)

The scanning electron microscope was used to determine the thickness and cross section of fibers. Figure 1 shows the SEM. SEM is capable to produce high resolution images of a sample surface. A SEM can resolve much smaller feature than a standard microscope, down to nearly 2 nanometers. In a classical Scanning Electron Microscope (SEM), electrons are thermionically emitted from a tungsten or lanthanum hexaboride (LaB6) cathode and are accelerated towards an anode alternatively; electrons can be emitted via Field Emission (FE). Tungsten is used because it has the highest melting point and lowest vapour pressure of all metals, thereby allowing it to be heated for electron emission. When the primary electron beam interacts with the sample, the electrons lose energy by repeated scattering and absorption within a teardrop-shaped volume of the specimen known as the interaction volume, which extends from less than 100 nm to around 5µm in to the surface [16]. Figure 2 shows the small pieces of each specimens used to test on SEM.

Figure 1 Scanning Electron Microscope (SEM)

Figure 2 The small pieces of each specimen used to test on SEM

2.2 Water Absorption Test

The water absorption test aids in determining the durability of LFC. For LFC, the moisture movement becomes more complicated as a more complex microstructure formation is produced. To determine the absorption, three cored cylinder with a size of 100 mm x 75 mm were placed in oven at 100°C for 24 hours. After oven for 24 hours, the samples were immersed in water as shown in Figure 3 for approximately 30 minutes. The difference in weight before and after test was calculated. The absorption test was conducted when the samples achieved 3, 7 and 28 days [17].

Figure 3 The samples were immersed in water for 30 minutes

2.3 Impact Load Resistance

In order to determine the impact load sustained by the FRC test specimens, two load cells with load capacity of 200 kg each were used to measure the support reactions. An LVDT with 50 mm capacity was used to measure the mid-span deflection. The impact load was introduced by a steel ball (weight = 200 g), which was dropped from a height of 800 mm onto the specimen. The steel ball was dropped repeatedly till the ultimate failure of the LFC test specimens. The impact load and the resulting deflections were simultaneously recorded using the Kyowa data acquisition system at data sampling frequency of 1000 Hz. The data acquisition condition was set to trigger mode in order to eliminate any unwanted data obtained during the time interval between each impact pulse received by the specimen [18]. The triggering signal was set up such that when the reading of a load cell exceeded 1 kgF, the recording system would be activated and the data would be saved in a log file. Then, the data acquisition was stopped after 2 s from the time of impact. Thus, each impact pulse contained 2000 data points, and these data were exported for subsequent analysis. The impact energy absorbed by the specimens was analyzed pulse by pulse. LFC panel specimens with dimensions of 300 mm x 125 mm x 30 mm were prepared for this test. Thus, small-sized specimens have limited space for the LVDT installation at mid span because the steel ball would collide with the LVDT when dropped from the specified height. Therefore, a stiff steel pin extending from the mid span was attached to the specimen using araldite. The movement of the steel pin corresponds to the mid-span deflection, which was measured using the LVDT. Total energy absorptions were calculated as the sum of total area under the load–deformation curve generated from each blow using trapezium method. The Figure 4 shows the impact load resistance test.

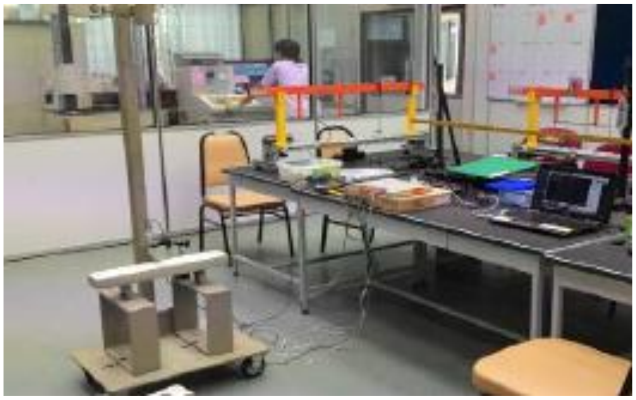

Figure 4 Setup of impact load resistance test

3.0 RESULTS AND DISCUSSION

3.1 Scanning Electron Microscope Test (SEM)

Scanning Electron Micrograph (SEM) was used to observe the physical formation and morphology of coconut fibers. The coconut fiber used in this research was of brown fiber type. According to R. M Rowell (2009), the brown coconut fiber was obtained from matured coconuts and has a higher content of lignin. Lignin in this fiber can be used as binders, surface-active agents and dispersant. Figure 5 shows the SEM photograph of coconut fiber surface which covered with some small voids and crack which make the surface looked rough. Figure 6 showing cross-section of coconut fiber. Cross section of fiber has clearly shown a hole in the middle of it and small holes around it as illustrated in above figure. It is roughly estimated 15-20% holes exists compared with a single cross section of fiber. It has also been observed that the surface of coconut fiber is not smooth. So in a matrix, it can make strong bond with other materials [19].

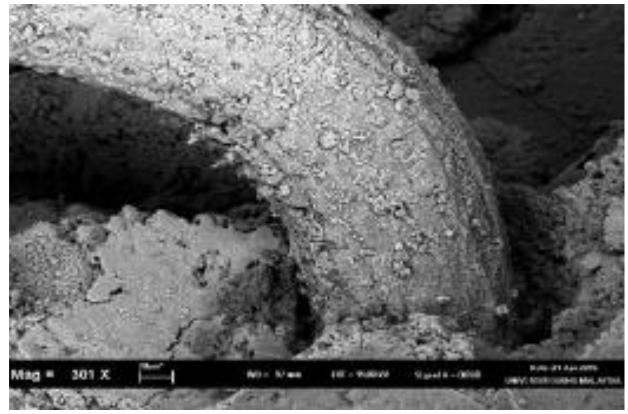

Figure 5 Scanning electron micrograph showing surface of coconut fiber (500x magnifications)

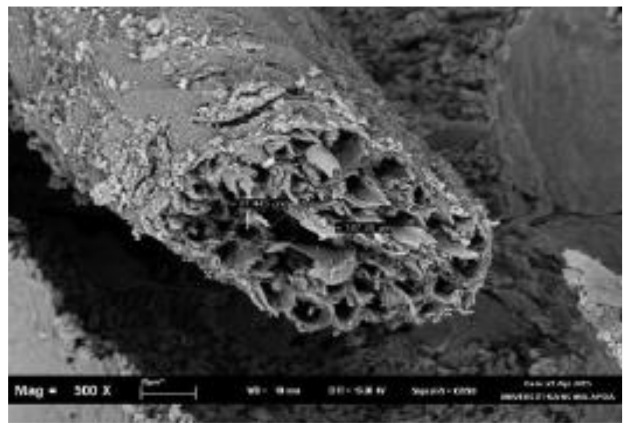

Figure 6 Scanning electron micrograph showing cross-section of coconut fiber (500x magnifications)

Figure 7 shows the fracture surface the 1200 kg/m³ LFC with 0.4 % of coconut fiber. The fracture surface reveals crack bridging that strengthen the composite and small holes due to fiber pull out. Fracture behavior is almost similar with fracture behavior found in concrete. In fracture process of fiber-reinforced concrete, crack bridging effects induced by fibers can improve resistance to crack propagation and crack opening [20]. From the image, it can be seen that there is a big crack at the edge of the sample but this crack does not propagate because of fiber still holds the sample. It was also observed that no cracks propagate across the center of the composite. Long grooves also can be observed that due to delamination of the fiber.

Figure 7 Scanning electron micrograph showing crack bridging, small holes and long grooves on the fracture surface of LFC (50x magnifications)

3.2 Water Absorption Test

It is important to study water absorption as it will affect the durability and other properties of LFC. The transfer of moisture through LFC is complex due to the uncertain formation of the microstructure in a hardened state. Water absorption will also be used to determine and verify several factors that influence the properties of LFC.

The effects of different densities and different percentage of coconut fiber on the water absorption of LFC were investigated. All the specimens were tested at the age of 3, 7 and 28 days. Interpreting water absorption as a percentage increase in mass would give misleading results. This measuring method were used in this study to analyses the water absorption of LFC [21]. Table 1 shows percentage of water absorption of LFC with different densities and different percentage of CF.

Table 1 Percentage of water absorption of LFC with different densities and different percentage of CF

Sample	Percentage of water absorption (%)		
	3 days	7 days	28 days
850 kg/m³			
CTRL 850	35.44	26.56	20.55
A 850	46.22	41.3	31.27
B 850	22.66	18.54	15.72
1200 kg/m³			
CTRL 1200	17.24	14.15	11.69
A 1200	21.04	17.51	11.13
B 1200	14.65	12.85	9.6

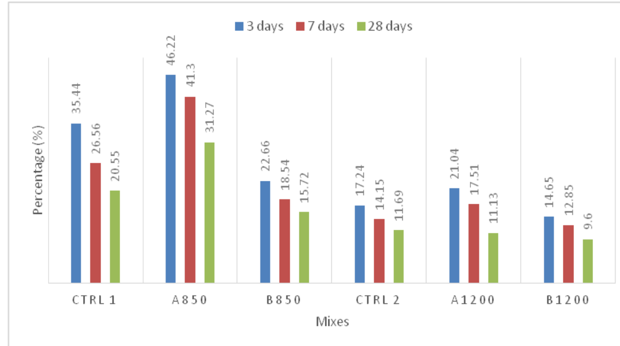

Figure 8 Water absorption results for LFC with different densities and different percentage of coconut fiber

Figure 8 summarizes the water absorption results for LFC with different densities and different percentage of coconut fiber. Based on the analysis, it was found that the density influenced the water absorption significantly. A clear comparison between the two densities of 850 kg/m³ and 1200 kg/m³ was observed with the absorption percentage ranging from 28.98% and 6.13%, respectively. The water absorption in relation to the density increased with a reduction in density. Low density LFC consists of a large volume and size of pores with voids that enable water to penetrate along this microstructure element.

In addition of coconut fiber with LFC, the water absorption increase in both densities with the addition of CF but it decrease tremendously when there was increase in percentage of coconut fiber. Mixture with 0.2% of CF (A850) shows two time higher result than mixture with 0.4% of CF. There was no significant contribution to water absorption. This is because, during mixing CF absorb water and expand. Then at the end of the drying process, the fiber lose the moisture and shrink back to their original dimension leaving very fine voids around themselves. When there are fine voids, the concrete hard to absorb the water. So, it can be expected that the absorption will decrease along with the age of the sample and increase in percentage of coconut fiber.

The physical attributes of the pores, voids and matrix are interrelated with the microstructure formation of LFC. The 850 kg/m³ density required a high amount of foam, thus creating more bubbles. As seen in Figure 9, more and larger sized pores were produced by the LFC with a density of 850 kg/m³. From the Figure 10, lower density of LFC indicates a larger water absorption value or a greater containment of water (larger pore size). Large sized pores lead to weak connections with the matrix that will affect the strength of LFC. The pores are close together and some of the bubbles merge and create larger pores. This factor causes brittleness and a loose microstructure formation, which reduces the capability to resist excessive loads [22].

The high water absorption of the concrete will also affect the density and compressive strength of the concrete. According to Short (1978), lightweight concrete used in water has to be protected by suitable material in order to avoid or may be reduce water absorption of the concrete.

Based on observations made from Figure 9 and Figure 10, an SEM analysis showed that the micro cracks at the surface of the pores are another factor that increased the water absorption of LFC. Micro cracks at the pore surface allowed water to penetrate inside the sample, thus increasing the water absorption.

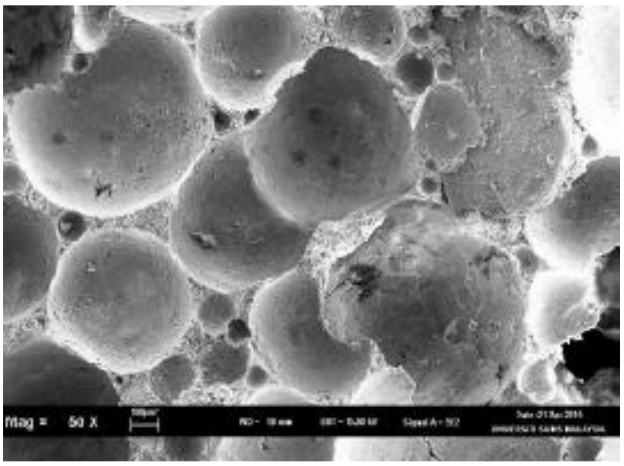

Figure 9 Pores produced by the LFC with a density of 850 kg/m³ (50x magnifications)

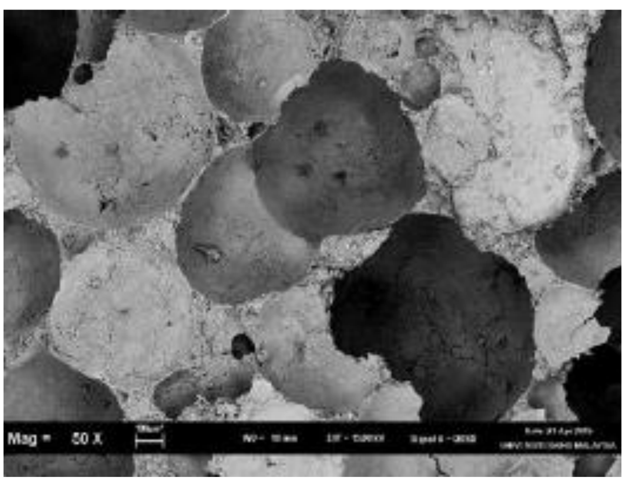

Figure 10 Micro cracks at the pore surface allowed water penetrate inside the sample (50x magnifications)

3.3 Impact Load Resistance Test

Energy absorption was computed from the area under load deformation curves logged from each number of blows during the impact test. Table 2 presents energy absorption of all the specimens.

Table 2 Energy absorption of LFC with different densities and different percentage of CF

Sample	Energy Absorption (KN mm)	
	7 days	28 days
850 kg/m³		
CTRL 850	0.42	1.27
A 850	6.25	25.36
B 850	30.81	38.42
1200 kg/m³		
CTRL 1200	7.2	18.78
A 1200	89	113.04
B 1200	136.51	192.97

The highest energy absorption was obtained by B1200, which was more than 90% higher than the CTRL1200. The same specimens also exhibited the highest energy absorption in both aging, which was recorded as 136.51 kN mm (7days) and 192.97 kN mm (28 days) respectively. In addition, the energy absorption increases with increasing fiber content. This shows that, the discontinuous fibers are important in enhancing the energy absorption capability of concrete.

The CTRL850 and a number of other low fiber content specimens exhibit very low energy. After the specimens were hit several times by the steel ball, the specimens failed abruptly without showing any visible cracks, thus indicating the brittleness of the concrete matrices are. In general, the CF with 0.4% demonstrated high energy absorption capacities in both densities, because good bonding existed between the fiber and the binder phase.

5.0 CONCLUSION

Lightweight foamed concrete (LFC) provides many advantages with a variety of applications. LFC is the material of choice for building construction as it is light weight, and environmentally friendly with good thermal conductivity, acoustical properties and other positive features. It was found that several elements that influence the properties of LFC need to be taken into consideration. When combining coconut fiber with LFC, it will increases the toughness of the material so that the product can withstand handling and a structural load. Coconut fiber has great potential in the production of structural lightweight concrete especially in the construction of low-cost concrete structure.

At the fiber content, the impact energy absorption of LFC was improved as compared to the control concrete. Water absorption is higher as the density decreases due to the large number of pores and their huge size. The capillary pores are another important factor that influences the transport of moisture. Coconut fiber reinforced concrete has shown less number of crack developments and crack width. So, it can be a good alternative in construction industry. Further work need to be done in order to observe the effects of coconut fiber on concrete with various lengths and volume.

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References

[1] Othuman Mydin, M. A., Y. C. Wang. 2011. Elevated-Temperature Thermal Properties of Lightweight Foamed Concrete. *Journal of Construction & Building Materials.* 25(2): 705-716.

[2] Shanmugam, N. E., Lakshmi. B. 2001. State of the Art Report on Steel-concrete Composite Columns. *Journal of Constructional Steel Research*. 57(1):1041-1080

[3] Benayoune, A. A. Abdul Samad, D. N. Trikha, A. A. Abang Ali, S. H. M. Ellinna. 2008. Flexural Behavior of Pre-cast Concrete Sandwich Composite Panel–Experimental and Theoretical Investigations. *Construction and Building Materials.* 22: 580-592.

[4] PCI Committee On Pre-Cast Concrete Sandwich Wall Panels. 1997. *State of the Art of Precast/Prestresses Sandwich Wall Panels.* 42(2): 92-133.

[5] Einea, A., Salmon, D. C., Tandros, M. K., Culp, T. 1994. A New Structurally and Thermally Efficient Precast Sandwich Panel System. *PCI J.* 39(4): 90-101.

[6] E. Losch. 2005. Precast/Prestressed Concrete Sandwich Walls. *Structure Magazine*. April: 16-20.

[7] Wan Abdullah Wan Alwi. 2009. Strength and Durability of Lightweight Foam Concrete as Structural Material. PhD Thesis. Universiti Sains Malaysia. 5-354.

[8] Pessiki, S., and A. Mlynarczyk. 2003. Experimental Evaluation of Composite Behavior of Precast Concrete Sandwich Wall Panels. *PCI Journal*. 48(2): 54-71.

[9] Soleimanzadeh, S., M. A. Othuman Mydin. 2013. Influence of High Temperatures on Flexural Strength of Foamed Concrete Containing Fly Ash and Polypropylene Fiber. *International Journal of Engineering.* 26(1): 365-374.

[10] Davies, J. M. 1993. Sandwich Panels. *Journal of Thin-Walled Structures*. 16(1-4): 179-198.

[11] Othuman Mydin M. A., Rozlan, N. A., Ganesan S. 2015. Experimental Study on the Mechanical Properties of Coconut Fibre Reinforced Lightweight Foamed Concrete. *Journal of Materials and Environmental Science*. 6(2): 407-411.

[12] Othuman Mydin, M. A., Y. C. Wang. 2012. Thermal and Mechanical Properties of Lightweight Foamed Concrete (LFC) at Elevated Temperatures. *Magazine of Concrete Research.* 64(3): 213-224.

[13] Gleich, H. 2007. New Carbon Fiber Reinforcement Advances Sandwich Wall Panels. *Structure Magazine*. April: 61-63.

[14] Othuman Mydin, M. A. 2011. Thin-walled Steel Enclosed Lightweight Foamed Concrete: A Novel Approach to Fabricate Sandwich Composite. *Australian Journal of Basic and Applied Sciences*. 5(12): 1727-1733.

[15] Bush, T. D., and G. L. Stine. 1994. Flexural Behavior of Composite Prestressed Sandwich Panels. *PCI Journal*. 39(2): 112-121.

[16] Lee, B., and S. Pessiki. 2007. Design and Analysis of Precast, Prestressed Concrete Three-Wythe Sandwich Wall Panels. *PCI Journal*. 52(4): 70-83.

[17] Othuman Mydin, M. A., Y. C. Wang. 2012. Mechanical Properties of Foamed Concrete Exposed to High Temperatures. *Journal of Construction and Building Materials.* 26(1): 638-654.

[18] Salmon, D. C., A. Einea, M. K. Tadros, and T. D. Culp. 1997. Full Scale Testing of Precast Concrete Sandwich Panels. *ACI Structural Journal*. 94(4): 354-362.

[19] Frankl, B. 2008. Structural Behavior of Insulated Precast Prestressed Concrete Sandwich Panels Reinforced with CFRP Grid. M.Sc. thesis. Department of Civil, Construction and Environmental Engineering, North Carolina State University, Raleigh, NC.

[20] Othuman Mydin, M. A. 2013. Modeling of Transient Heat Transfer in Foamed Concrete Slab. *Journal of Engineering Science and Technology*. 8(3): 331-349

[21] Othuman Mydin, M. A. 2013. An Experimental Investigation on Thermal Conductivity of Lightweight Foamed concrete for Thermal Insulation. *Jurnal Teknologi*. 63(1): 43-49

[22] M. A. Othuman Mydin. 2015. Effect of Silica Fume and Wood Ash Additions on Flexural and Splitting Tensile Strength of Lightweight Foamed Concrete. *Jurnal Teknologi.* 74(1): 125-129.