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Durability Properties of Foamed Concrete with Fiber Inclusion

Hanizam Awang, Muhammad Hafiz Ahmad

***Abstract*—**An experimental study was conducted on foamed concrete with synthetic and natural fibres consisting of AR-glas, polypropylene, steel, kenaf and oil palm fibre. The foamed concrete mixtures produced had a target density of 1000kg/m^3 and a mix ratio of (1:1.5:0.45). The fibres were used as additives. The inclusion of fibre was maintained at a volumetric fraction of 0.25 and 0.4%. The water absorption, thermal and shrinkage were determined to study the effect of the fibre on the durability properties of foamed concrete. The results showed that AR-glass fibre has the lowest percentage value of drying shrinkage compared to others.

***Keywords*—**Foamed concrete, Fibres, Durability.

I. Introduction

FOAM concrete is classified as a lightweight concrete which could be based on either mortar or a cement paste in which stable bubbles are entrapped within the mortar's matrix by using a protein or a synthetic based foaming agent. With a wide densities ranging from as low as 300 kg/m^3 to as high as 1800 kg/m^3, lightweight foamed concrete (LFC) is applicable to be used in multiple applications such as trench reinstatement, roofing insulation, void filling, floor construction, culvert's or bridge approach, bridge strengthening and many more [1]. LFC has been gaining huge amounts of attention due to its high flow-ability, low self-weight, reduced aggregate consumption, controlled low strength and its admirable thermal insulation [2]. In addition, LFC is considered to be an environmental friendly material due to its minimal usage of aggregate and its high potential to incorporate waste materials [3].

The low elastic modulus of the aggregate and high cement usage in the production of LFC has generally increased the drying shrinkage of LFC [4-6]. The inclusion of fibre into LFC is one approach to enhance its durability properties. The inclusion of low volumetric fractions of short fibre has been proven to reduce the impact of early age shrinkage on concrete durability [7]. Barluenga and Hernandez [8] stated that the maximum crack length of concrete pointed out in their research had been proven to control drying shrinkage at early ages. It acts as the concrete reinforcement when the concrete cracks.

Hanizam Awang is a Ph.D holder lecturing at the department of Building Technology, School of Housing, Building & Planning, Universiti Sains Malaysia (e-mail: hanizam@usm.my).

Muhammad Hafiz Ahmad is an MSc candidate at the department of Building Technology, School of Housing, Building & Planning, Universiti Sains Malaysia.

II. Materials and Mix Proportions

A. Materials

The cement used is a Type I cement (OPC) complying with BS EN 196 of the British Standards [9]. Natural sand from a local river bed was used as fine sand in this study. A sieve analysis was conducted on the sand and it fell into zone 3 according to BS EN 12620 [10].

The foaming agent used in the production of foamed concrete is a protein based agent called (Noraite PA-1) which is manufactured in Malaysia. The foaming agent was diluted in water at a ratio of 1:30. Density of foam used is estimated between 65-80 g/liter. There were five different types of fibre were used, namely AR-glass, polypropylene, steel, kenaf and oil palm fibre.

B. Mix Proportions & Casting of Foamed Concrete

A total of 11 mixes were prepared for this study. Table I describes in detail the mix design proportion used in this research. The target density sought is 1000kg/m^3 with a 100kg/m^3 difference between target and wet densities. A mix ratio of one part binder to two parts of filler (1:1.5) was used with constant water to binder ratio (W/B) of 0.45. Synthetic and natural fibres consisting of AR-glass (GF), polypropylene (PF), steel (SF), kenaf (KF) and oil palm (OPF) fibre were used. Two percentages of fibres included in each fibrous specimen at 0.25% and 0.4% out of the total volume fraction. Normal foam concrete, NF is the control mix. Both Kenaf and Oil palm fibre were fairly treated with 0.1 mol of Sodium hydroxide (NaOH) solution for a night. The foaming generator used through this research is locally fabricated and marketed under the product name Portafoam. For the curing method, plastic sheet wrapping is used according to BS 7542 (1992) [11]. The specimens are wrapped in polythene until a day before testing [12]. For shrinkage test, the specimen is left for air dried at standard laboratory temperature.

TABLE I
DESIGN MIX PROPORTION

Mix.	OPC (kg)	Sand (kg)	Water (kg)	Fibre (%)	Wet density (kg/m^3)	Foam (m^3)	Slump (mm)
NF	29.6	44.4	13.3	-	1128	0.042	25
SF25	29.6	44.4	13.3	0.25	1138	0.040	25
SF40	29.6	44.4	13.4	0.40	1140	0.040	25
GF25	29.6	44.4	13.5	0.25	1132	0.041	25
GF40	29.6	44.4	13.5	0.40	1133	0.041	25
PF25	29.6	44.4	13.5	0.25	1128	0.039	25
PF40	29.6	44.4	13.6	0.40	1128	0.038	24
KF25	29.6	44.4	13.6	0.25	1125	0.041	25
KF40	29.6	44.4	13.6	0.40	1134	0.040	24
OPF25	29.6	44.4	13.6	0.25	1125	0.040	25
OPF40	29.6	44.4	13.7	0.40	1126	0.039	24

III. RESULTS AND DISCUSSION

A. Water Absorption

The percentage rate of water absorption for all kind of fibre LFC is presented in Fig. 1. It can be drawn that the lowest result in the rate of water absorption is illustrated by steel fibre. This is followed by the polypropylene fibre LFC and the control specimen. GF40 resulted in the highest rate of water absorption while SF40 recorded the lowest percentage among all specimens. Steel and polypropylene are known to be a hydrophobic type of fire which it repels water. But as for glass, kenaf and oil palm fibre absorbs more water compared to the steel and polypropylene fibre due to its surface morphology that consists of more voids.

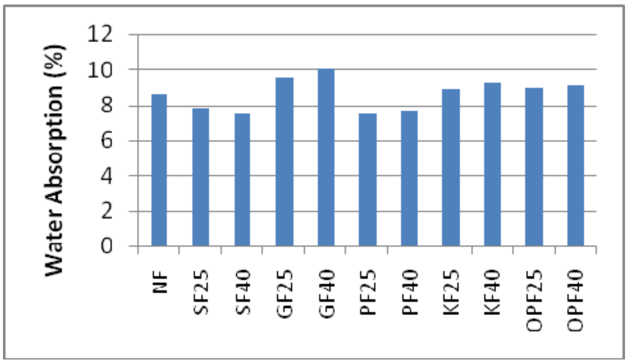

Fig. 1 Water absorption rate

The water absorption rate is said to be intimately related to pores and voids in concrete. The formation of pores and voids are different with different inclusions of fibre and fillers. In this case, both fibres and pores determine the rate of water absorbance. However, the internal structure of LFC consists of entrained air voids and capillary pores which mean that not all pores and voids aggressively reacted to water absorbance [13]. They also suggested that the main factor contributing to water absorbance is the amount of paste content. Theoretically, structures with higher pores volume create high connectivity which increases the flowability of fluid molecules. Hearn et al. [14] suggests that this kind of mechanism exists via the capillary effect which is driven by the force of osmosis pressure. Fibre type plays an important role in such manner. The transmission of fluid molecules through the porous structure would be obstructed in random ways as if the fibre has no tendencies to absorb fluid molecules. But if the interfacial surface of the fibre itself is porous by nature, the fluid molecules flowability is higher.

Volume of foam used was supposedly to have a big influence towards water absorption rate too. Higher volume of foam decreases the amount of paste included in specimens thus decreases the water absorption rate [15]. But in this research, these parameters cannot be counted as big attributions as the volume of foam used is set to constant. The volume of foam inclusions only varies within ± 0.005 kg/m^3 as presented in Table I. Since the density parameter of specimen tested is set to only 1000kg/m^3, the inclusions of foam volume won't be having so much variation of range.

B. Drying Shrinkage

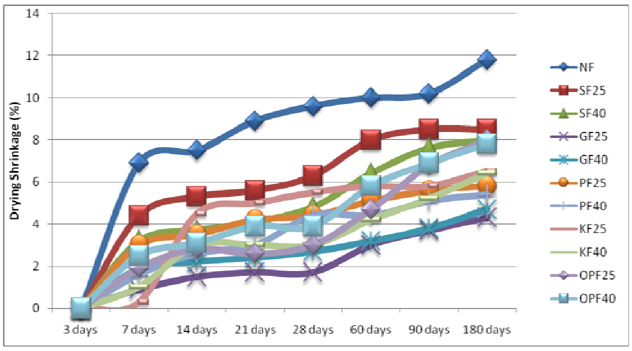

Fig. 2 Percentage of drying shrinkage

Drying shrinkage of LFC is known to be a critical problem. The absence of solid aggregate in LFC makes the particles in LFC tend to get closer with the evaporation of water hence increases the shrinkage value of LFC. However, the inclusions of fiber have been proven to restrict drying shrinkage. It has always been supported by many researchers that the inclusion of fibre contributes to lower drying shrinkage value of concrete. Saje et al. [16] stated that fibre has the ability to retain water, hence delay the rate of water evaporation and lessen the drying shrinkage value.

By referring to the result presented in Fig. 2, it can be drawn that AR-glass fibre has the lowest percentage value of drying shrinkage at the final age of testing. It is followed by polypropylene, kenaf, oil palm and steel fibre. These patterns of result can be classified as in agreement with the finding of Saje et al. [16] in which the water retaining ability of fibres determines the drying shrinkage value of its specimens. AR-glass fibre is highly dispersible in water, which is a good attribute that contribute to drying shrinkage. Polypropylene, kenaf and oil palm fibre can still be a good measure since these fibres still have the ability to retain water. But as for steel fibre, it is known to be unable to retain water as steel fibre is a hydrophilic type of fibre.

C. Thermal Conductivity

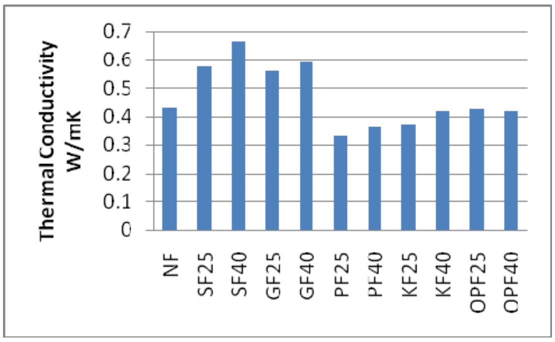

Fig. 3 Thermal conductivity

As shown in Fig. 3, specimens of steel fibre inclusions generate higher thermal conductivity as compared to other fibres. However, this kind of pattern had been expected as steel fibre itself is a very good heat conductor. By observing the difference of sample with and without fly ash, it can be considered that fly ash contributes to lower thermal conductivity. Moreover, the higher inclusions of fibre were recorded to have higher thermal conductivity. Apart from that, polypropylene fibre specimens were observed to be the lowest thermal conductivity among all fibres.

D. Thermal Diffusivity

Fig. 4 shows the thermal diffusivity for all specimens. Polypropylene diffuses less heat compared to other fibres. The effectiveness of fibre to inhibit heat can be measured roughly by the physical properties itself. The specific heat of all the samples is presented in Fig. 5. With almost the same pattern, steel fibre has the highest specific heat. Polypropylene still remains in the low area level of thermal properties. It is proven that polypropylene has the best properties in terms of thermal properties.

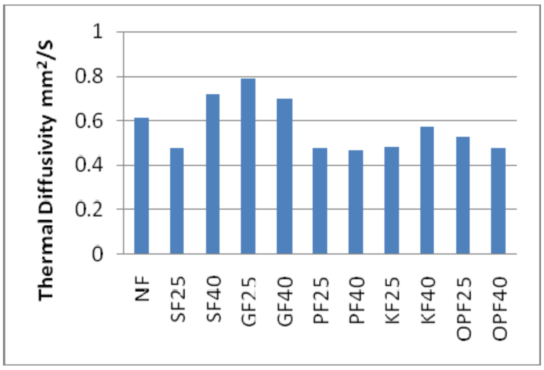

Fig. 4 Thermal diffusivity of all samples

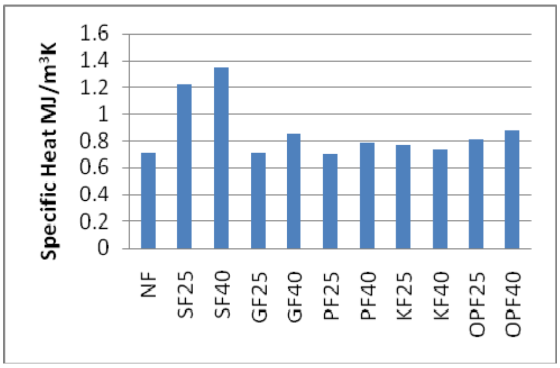

Fig. 5 Specific heat of all samples

E. Scanning Electron Microscopy Test

The Scanning Electron Microscopy Test (SEM) magnification image of polypropylene LFC can be observed in Fig. 6 while Fig. 7 illustrates the image for kenaf LFC with both at 100x magnifications. Both of the images shown there is a gap at the interfacial zone in between fibres and the matrix. However, the gap in between polypropylene fibre-matrix is comparatively smaller than the kenaf fibre LFC. The smaller size of the gap is more likely dependable on the non-absorptive properties of the fibre.

Moreover, polypropylene LFC specimen formed smaller and more stable bubbles as compared to those in kenaf LFC. Quite a remarkable number existence of micro cracks was available in Fig. 7. Nevertheless, Fig. 6 captured only a few micro cracks occurred.

The surface structure of the cement paste matrix in both Figs. 6 and 7 show a great difference of brittleness. Fig. 7 stated more micro-pores as a sign of a brittle concrete. Since kenaf fibre is the source of natural fibre, the tensile strength itself is lower compared to the polypropylene fibre. Kenaf fibre seems to be unable to stand the force of fibre pull-out and matrix hydration. As evidenced in Fig. 7, it clearly shows that the fibre has been torn out apart. Unlike the polypropylene fibre, the forms of the fibres are still in a good condition.

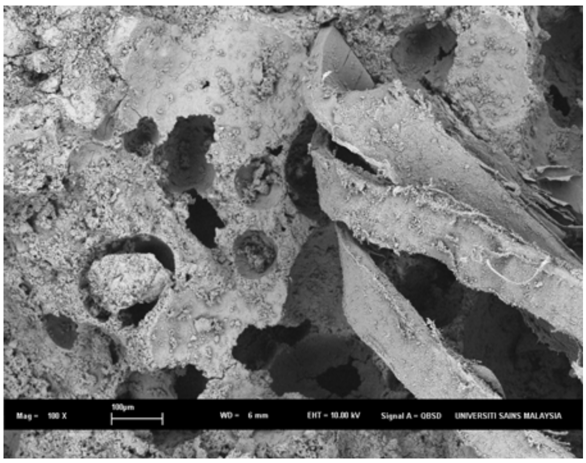

Fig. 6 SEM magnification at 100x of polypropylene fibre

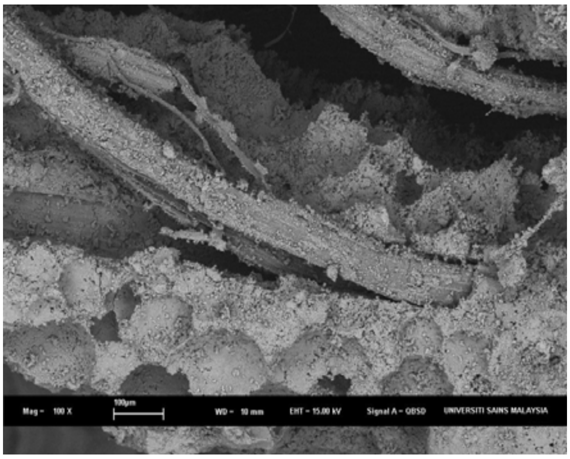

Fig. 7 SEM magnification at 100x of kenaf fibre

IV. CONCLUSIONS

Several conclusions can be made from the research done. All of the conclusions made are listed according to properties as follows:

- The water absorption rate is enhanced by adding steel and polypropylene fibres. But AR-glass, kenaf and oil palm fibre resulted higher absorbance than the control mix. It can be concluded that type of fibre plays a different role in controlling water absorbance. Each kind of fibre has a different surface morphology that plays an important role in the water absorption rate of LFC.
- Fibres inclusion is absolutely effective in handling drying shrinkage problems by LFC. All of the specimens with fibre inclusions resulted lower shrinkage compared to the control specimen. AR-glass fibre is the most effective measure among all fibres in controlling drying shrinkage of LFC.
- In comparison of all 5 fibres used in the test, steel fibre is found to be the poorest in thermal insulation. It recorded the highest among all samples in thermal conductivity and specific heat. Polypropylene fibre is found to be the best sample in thermal insulation among all samples. The higher the percentage of fibre included in a sample, the poorer the thermal efficiency will be regardless of the type of fibre used.

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