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Thermal Properties of Foamed Concrete with Various Densities and Additives at Ambient Temperature

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Abstract. This paper will focus on experimental investigation to observe the effects of different densities and additives on the thermal properties of foamed concrete by means of Hot Disk Thermal Constant Analyzer, so as to obtain a few fundamental thermal properties for prediction of its fire resistance performance. For this study, samples of three different densities of 700kg/m^3, 1000kg/m^3 and 1400kg/m^3 and various additives were investigated to study the effects of densities and additives on the thermal properties of foamed concrete. The additives used in this research were pulverized fuel ash (PFA), silica fume, palm oil fuel ash (POFA), wood ash, polypropylene fibre, steel fibre and coir fibre. It should be pointed out that the lowest density of foamed concrete (700kg/m^3) has provided best thermal insulation properties due to large amount of pores and high percentage of air entrapped because air is poorest conductor of heat than solid and liquid. Also, foamed concrete with coir fibre achieved lowest thermal conductivity because it possess high heat resistance due to its large percentage of hemicellulose and lignin and exhibited high heat capacity as well due to the formation of uniform pores and voids in foamed concrete.

Introduction

These days, critical challenge in the society is the climate change and need massive energy savings in construction. Selection of proper building materials which able to function as thermal barrier in order to prevent heat and fire has to be done to minimize the usage of energy and enhance the comfort zone of indoor environment [1]. Foamed concrete has excellent thermal insulation properties and the value of typical thermal conductivity is between 0.23 and 0.42 W/mK at 1000kg/m^3 to 1200kg/m^3 respectively [2]. Variations in the value of density due to pore formation produce significant effect in thermal performance of foamed concrete. Practically, the thickness of normal weight concrete have to be five times more than foamed concrete to achieve similar thermal insulation [3]. Foamed concrete can be extensively used in non-structural applications [4] such as roof slope, floor levelling and insulating layers of walls and void filling projects [5]. Moreover, the thermal properties of foamed concrete can be designed by changing the material parameters such as cement paste, foam size and fraction volume [6]. According to the mechanical properties, these materials are capable of being used as insulating material for both semi-load bearing and insulating elements [7]. Finally, fundamental values of thermal have been investigated experimentally for prediction of its fire resistance performance and to fulfill the knowledge gap in utilizing of various types of additives.

Materials and Experimental Setup

Ordinary Portland cement CEM1 produced by CIMA group of companies under the name of "Blue Lion" used in this study. According to ASTM C150 (2005), Ordinary Portland cement was complied with Type I Portland cement. Besides that, natural sand obtained from riverbed used as a filler in the mixes. Foaming agent used in this research is Noraite PA-1. This chemical agent was diluted with tap water with the ratio of 1:33 by water volume. The range of foam density was controlled between 65-70 kg/m^3.The samples of additives were prepared at the density of 1000 kg/m^3 because it has useful amount of mechanical properties and also for comparison purpose. Cement-sand ratio and water cement ration used in this study is 1:1.5 and 0.45 respectively. Totally 16 mixes were prepared and tested in the laboratory. The additives used in this study can be classified into two groups which are, fibre (natural and synthetic) and pozzolanic materials.

Figure 1, The samples and experimental setup of Hot Disk Thermal Constant Analyzer test

Thermal conductivity tests were performed by means of Hot Disk Thermal Constant Analyzer according to BS EN 12664 [8]. The surface of the foamed concrete sample needs to be larger than the diameter of the hot disk censor to allow sufficient duration for ambient recording. The samples sized 40mm in height and 75mm in diameter were prepared. Before the test, the samples were placed in the oven at temperature 105 °C ± 5 °C for 24 hours to remove moisture content in it as the moisture will lead to the high heat transfer rate.

Results and Discussion

Table 1, Thermal properties of foamed concrete samples with different densities

Sample	Density (kg/m^3)	Thermal conductivity (W/mK)	Thermal Diffusivity (mm^2/s)	Specific Heat Capacity (J/m^{3}k)	Percentage of Porosity (%)
Normal FC (NFC-1)	700	0.24	0.39	879	68
Normal FC (NFC-2)	1000	0.49	0.58	845	57
Normal FC (NFC-3)	1400	0.74	0.69	794	35

Table 1 shows different values of thermal properties of foamed concrete samples with various densities. In this study, the value of thermal conductivity of foamed concrete obtained was between 0.24W/mK to 0.74W/mK at 700kg/m^3 to 1400kg/m^3 respectively. Due to amount of voids and formation of enclosed pores, different measurements were obtained in thermal properties. At 700kg/m^3 the thermal conductivity of foamed concrete sample seems to gets lower due to higher percentage of porosity content. Large amount of pores and air voids will be induced at this phase. It has been observed that air is poorest conductor of heat than solid and liquid due to its molecular structure [9]. Furthermore, transferring of heat normally occurs from high temperature to low temperature to achieve thermally equilibrium. The lower density of foamed concrete creates more pores and voids, so that it fastened the heat transferring to reach thermal equilibrium [10]. More heat is released to the surroundings as it cannot store heat energy within it due to low entrapped air in high density mix, hence the specific heat capacity of the samples will be lowered. Since air pores dominating at low density, it increases the rate of heat transfer through the sample to achieve thermal equilibrium. In order to equalize redundant temperature, the air entrained in high porosity mixes that act as heat sink allows rapid migration of heat. The rate of heat movement will get slower due to less porous and large connected area of matrix and the capability to store heat energy also will be diminished.

Table 2, Thermal properties of 1000 kg/m^3 density samples with different types of additives

Samples	Reference	Thermal Conductivity W/mK	Thermal Diffusivity mm2/s	Specific Heat Capacity (J/m3k)	Porosity (%)
Control mix	NFC-2	0.49	0.58	845	57
POFA (25%)	POFA-25	0.46	0.53	868	50
POFA (40%)	POFA-40	0.43	0.49	878	61
Polypropylene Fiber (0.2%)	PF-0.2	0.47	0.54	870	48
Polypropylene Fiber (0.4%)	PF-0.4	0.44	0.49	898	50
Steel Fiber (0.25%)	SF-0.25	0.45	0.52	865	55
Steel Fiber (0.4%)	SF-0.4	0.42	0.47	894	59
Silica Fume (10%)	SLF-10	0.43	0.49	878	49
PFA (15%)	PFA-15	0.44	0.50	880	48
PFA (30%)	PFA-30	0.41	0.46	891	45
Wood Ash (5%), PFA (15%)	W5-P15	0.41	0.46	891	49
Wood Ash (10%), PFA (15%)	W10-P15	0.44	0.50	880	54
Coconut Fiber (0.2%)	CF-0.2	0.41	0.44	932	48
Coconut Fiber (0.4%)	CF-0.4	0.38	0.40	950	46

Results were obtained as shown in Table 2 when a fixed proportion was used for all the mixes with additives mentioned in the table under controlled environment to quantify thermal properties of foamed concrete. The table has clearly showed that all the additives used have improved the thermal properties when compared to the control mix sample. Among these additives, coir fibre produced tremendous development in thermal properties at ambient temperature. It achieved lowest value of thermal conductivity about 0.38W/mK, meanwhile control mix have recorded only about 0.49W/mK. Coir fibre as natural biodegradable product has high percentage of hemicellulose and lignin which contribute to the high heat resistant. It also can stored more heat energy as it has uniform pore formation inside the foamed concrete. Small and uniform pores were induced by swelling and shrinking of coir fibre in a concrete during mixing and drying process (Hasan et al, 2012) lead to low thermal conductivity. The impact of polypropylene fibre in thermal properties is not effective as coir fibre. Polypropylene fibres contain hydrophobic characteristics and it will retain water in the concrete, thus air pores will be formed. These pores lead to high porosity and eventually enhance thermal properties of the sample. SF-0.25 and SF-0.4 have recorded lower thermal conductivity about 8.16% and 16.7% respectively than control mix. Air pores were produced around the steel fibres due to retained water and very little movement. Apart from that, pozzolanic materials showed similar development in thermal properties due to chemical reaction during hydration process. PFA contributes high thermal properties in foamed concrete by compacting microstructure and deforming closed cell structure due to reduction of temperature in hydration process. Low amount of silica fume in the study can improve thermal properties significantly due to large content of silicon dioxide. It has produced fine pores and voids in pozzolanic reaction with cement and assisted in storing heat energy because large connected pores in control mix failed to store heat within it. Due to low pozzolanic characteristic, PFA added together with wood ash to enhance its characteristics. Thermal properties of foamed concrete will be ruined when amount of wood ash added is high because wood ash contain large median particle than cement. POFA is also a pozzolanic material which can reduce total rise of temperature and delays the time to decrease critical size of pores and eventually can increase the specific heat capacity of a sample.

Conclusion

This study indicated that the thermal properties of foamed concrete is influenced by its dry density and can be improved by various types of additives At low density, large amount of pores and air voids will be produced and at this density thermal conductivity will be lower because air is poorest conductor of heat than solid and liquid due to its molecular structure. Also, coir fibre has recorded lowest thermal conductivity because it possess high heat resistance due to its large percentage of hemicellulose and lignin and exhibited high heat capacity as well due to the formation of uniform pores and voids in foamed concrete.

References

[1] BCA Foamed concrete: Composition and properties. Report Ref. 46.042, Slough, 1994
[2] M.A. Othuman Mydin, Thin-walled steel enclosed lightweight foamcrete: A novel approach to fabricate sandwich composite. Australian J. of Basic & Applied Sciences, 5 (2011): 1727-1733
[3] H.G. Kessler, Cellular lightweight concrete, Concr. Eng. International, 1998, pp. 56-60.
[4] M.A. Othuman Mydin, Y.C. Wang, Structural Performance of Lightweight Steel-Foamed Concrete-Steel Composite Walling System under Compression. Journal of Thin-walled Structures, 49 (2011): 66-76
[5] M.A. Othuman Mydin, Y.C. Wang, Mechanical properties of foamed concrete exposed to high temperatures. Journal of Construction and Building Materials, 26 (2012): 638-654
[6] M.A. Mydin, Y.C. Wang, Thermal and mechanical properties of Lightweight Foamed Concrete (LFC) at elevated temperatures. Magazine of Concrete Research, 64 (2012): 213-224
[7] C.L. Huang, Pore Structure Properties of Materials, Fu-Han, Taiwan, 1980, pp. 34-43.
[8] S. Soleimanzadeh, M.A. Othuman Mydin, Influence of High Temperatures on Flexural Strength of Foamed Concrete Containing Fly Ash and Polypropylene Fiber, International Journal of Engineering, 26 (2013): 365-374.
[9] M.A. Othuman Mydin, An Experimental Investigation on Thermal Conductivity of Lightweight Foamcrete for Thermal Insulation. Jurnal Teknologi, 63 (2013): 43-49
[10] M.A. Othuman Mydin, Y.C. Wang, Elevated-Temperature Thermal Properties of Lightweight Foamed Concrete. Journal of Construction & Building Materials, 25 (2011): 705-716