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ASSESSMENT OF THERMAL CONDUCTIVITY, THERMAL DIFFUSIVITY AND SPECIFIC HEAT CAPACITY OF LIGHTWEIGHT AGGREGATE FOAMED CONCRETE

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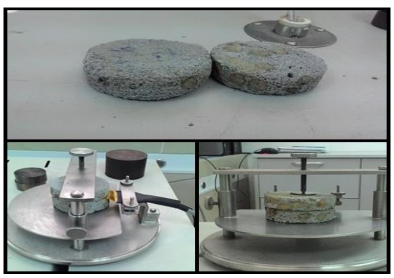
Graphical abstract



Abstract

This paper focuses on experimental study to investigate the thermal conductivity, thermal diffusivity and specific heat capacity of lightweight aggregate foamed concrete. All the specimens used were tested at 1250 kg/m^3 of concrete density. The mix design proportion used for cement, sand and water ratio was 1: 2.67: 0.50. The artificial lightweight aggregate were used as additives by volume percentage of 10%, 13% and 17% based on specific density of artificial lightweight aggregate. Thermal test result shows that thermal conductivity value has fulfill the requirement for semi structure with thermal insulation characteristic which is below than 0.75W/mK and the specimen highest value is 0.66 W/mK. The rate for thermal diffusivity shows that high percentages of lightweight aggregate will reduce the thermal diffusivity. Specific heat capacity test show that the reading was higher when the percentage of lightweight aggregate is higher in lightweight concrete. This is due to the existence of moisture in the lightweight aggregate.

Keywords: Foamed concrete, lightweight aggregate, thermal conductivity, thermal diffusivity, specific heat capacity

Abstrak

Kertas kerja ini menumpukan kepada kajian eksperimen untuk mengkaji kekonduksian haba, kemeresapan haba dan kapasiti haba spesifik konkrit ringan berbusa beragregat. Ke semua spesimen yang digunakan telah diuji pada ketumpatan 1250kg/m^3. Peratusan rekabentuk campuran digunakan untuk nisbah simen, pasir dan air ialah 1: 2.67: 0.50. Agregat ringan tiruan telah digunakan sebagai bahan tambahan mengikut peratusan 10%, 13% dan 17% berdasarkan kepadatan agregat ringan buatan. Keputusan ujian haba menunjukkan bahawa nilai keberaliran haba memenuhi keperluan untuk struktur semi dengan ciri-ciri penebat haba iaitu di bawah nilai 0.75W/mK dan spesimen paling tinggi ialah 0.66 W/mK. Kadar untuk kemeresapan terma menunjukkan bahawa peratusan yang agregat ringan yang tinggi akan mengurangkan kemeresapan terma tersebut. Ujian kapasiti haba spesifik menunjukkan bahawa bacaan adalah lebih tinggi apabila peratusan agregat ringan adalah lebih tinggi di dalam konkrit ringan. Ini adalah disebabkan oleh faktor kelembapan dalam agregat ringan.

Kata kunci: Konkrit berbusa, agregat ringan, kekonduksian haba, kemeresapan haba, kapasiti haba spesifik

1.0 INTRODUCTION

Concrete is the crucial material used in the construction industry. In general, the varieties types of method are used to create a new product and give high improvement in quality [1]. In Malaysia, the use of other types of concrete that have low density with acceptable strength needed in construction is still low [2]. This is due to less of specialist in building materials to invent and try to come out with a new product [3]. The invention of new concrete products requires a lot of brainstorming about how to reduce the usage of normal concrete during construction due to its high cost, requires a lot of labour, need some aggregates that can consume to a heavy in mass and increase the density but at the same time still maintain its function [4]. Lightweight foamed concrete is very popular with its low densities range from 300-1800 kg/m³ but in term of strength is still low compared than normal concrete [5]. Therefore, the additions of artificial lightweight aggregate are used and could give the escalation in its strength [6]. Therefore, by studying on this, it hopefully the lightweight foamed concrete with artificial lightweight aggregate can be commercialized widely in the future especially in Malaysia, with low densities, better strength, reduce in costs and the most crucial one, lightweight foamed concrete can be apply as part of structural purposes such as beams, columns, foundations, and slabs [7].

1.1 Thermal Conductivity

Thermal conductivity is important in material science, research, building insulation and related fields, especially where high operating temperatures are achieved [8]. From previous study, shows that the lightweight foamed concrete provide better thermal insulation properties and indicates it's as highly potential to be used as a material in building construction especially in hot climate country like Malaysia [9]. Thermal conductivity *k*, is amount of heat passes through the homogeneous materials, 10mm to 20 mm in thickness ,diameter of specimen more than 30mm and the quantity of heat will flow through unit area in unit time when difference units of temperature exists between the faces of unit thickness of materials [10]. Thermal conductivity also known as property of material shows its ability to conduct heat [11]. For this study, thermal conductivity test has been done to lightweight foamed concrete with artificial lightweight aggregate [12]. Some studies shows, aggregate with less thermal conductivity produces less conductive concrete and conversely. In this test, all the specimen thicknesses are 20mm with 75mm diameter; it has been kept in oven for 24 hours with 80°C before testing [13]. The testing will be doing using transient plane source technique; the measurement of specimen is based on recording the temperature rise of source plan heating the surrounding of the sensor. So, the reading will depend on distribution and percentages of artificial lightweight aggregate exist in specimen [14]. Table 1 demonstrates thermal conductivity value of some common building materials.

Table 1 Thermal conductivity value of some common building materials

Material/substance	Temperature – 25°C k (W/mK)
Cement, mortar	1.73
Concrete	1.0 - 1.8
Lightweight Foam concrete	0.1 - 0.3
Lightweight aggregate concrete	0.4 - 0.7
Clay	0.15 - 1.8
Sand	0.25 - 2

1.2 Thermal Diffusivity

Thermal diffusivity is the ratio of the time derivative of temperature to its curvature, quantifying the rate at which temperature concavity is "smoothed out". In a sense, thermal diffusivity is the measure of thermal inertia [15]. In a substance with high thermal diffusivity, heat moves rapidly through it because the substance conducts heat quickly relative to its volumetric heat capacity [16].

1.3 Specific Heat

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius [17]. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat [18]. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature. But, for this test the specific heat will be depends on the values of thermal conductivity, thermal diffusivity and densities of specimen.

2.0 MATERIALS

The material of cement, fine sand, and water, was prepared by a design ratio of 1: 2.67: 0.5. The foaming agent (Noraite PA-1) was prepared one part of foaming chemical with 30 parts of water (1:30) and also artificial lightweight aggregate were prepared with difference percentage based on specific density casting to be used in the mixing to form the lightweight foamed concrete. The target dry density is 1250 kg/m³.

2.1 Cement

Cement is a hydraulic binder which, when mixed with water, it forms a paste and hardened due to hydration reaction and process. Cement normally will retain its strength and stability even under water after its get hardened (BS:12–1996). Strength characteristic of cement is especially different when mixed it with chemical admixtures and this was further supported by the firing of cement to partial fusion at 1500 °C. In this present investigation of lightweight foamed concretes, the Ordinary Portland cement of CASTLE cement with 52.5 grades was used.

2.2 Water

In foamed concretes, the water quantity should be adequate because if the water is insufficient during the initial reaction of cement in mixing, the cement will withdraw or hydrate the water from the foam [22]. However, if excessive water is used, most of the investigators said there is no crucial effect unless the segregation will occur and cause the drying shrinkage to increase. The water content ratio has to depend upon the types of binders and the strength of the concrete needed to achieve adequate workability. In most of the cases reported, the value of the water content ratio will be between 0.4 – 1.25. In this study, based on a calculated mixed design, the water content ratio needed is 0.5.

2.3 Fine Sand

Commonly, the fine sand is suitable for concrete by having particle sizes from 4 mm to 60 µm with an even distribution of sizes that requires for foamed concretes. This is due to coarse sand might settle in a lightweight during mixing and the foam will then collapse. Some studies, has stated that the sand used is to give the strength towards lightweight foamed concrete, which influences by the amount, type and particle size distribution of sand.

2.4 Foaming Agent

The foamed is mainly added as base material and the main requirement in foam is that the foam must be remaining stable and not falling during pumping, placement and curing. The manufacturer of foam must be in good care due to its low density is about 62-67 g/liter. The foam required is one part of foaming chemical with 30 parts of water (1: 30) at pressure air of 75 Psa. The equality of foamed concretes is literally dependent upon the foam quality it. There are several types of foaming agent which are polymer foam agent, protein foam agent, and surface active agent. Besides, there are two varieties of foaming agents which are synthetic (suitable for a density of 1000 kg/m³ and above) and protein (suitable for a density of 400 kg/m³ to 1600 kg/m³). Therefore, in this study of mechanical properties of lightweight foamed concrete, the Noraite PA-1 (protein based foaming agent) was chosen. The reason is because the protein based has smaller bubble and could create stronger and more stable of bonding structures, better compressive strength and smooth texture compared than synthetic based.

2.5 Lightweight Aggregate

Lightweight aggregates (LWA) are generally manufactured from pumice or volcanic cinders or clays or siliceous rocks. Natural aggregates are those that are taken from naturally occurring rocks by breaking and sieving them in to desired size. Light weight aggregate can also be produced using industrial by-products like heavy metal sludge, mining residues, palm shell, paper sludge, pet bottles, sewage sludge, steel slag, bottom ash, fly ash, marine clay etc. Lightweight aggregate has been use in this study is for this study is artificial lightweight aggregate. Artificial lightweight aggregates (LWAs) are used in many application like lightweight concrete, lightweight brick, as insulation material for road construction or as filter material for water. For this study, the raw material for artificial lightweight aggregate are the combination of silt and palm oil fuel ash (POFA) .With the range of 800-850 kg/m³ for bulk density and the specific density of 1200 kg/m³ this aggregate are suitable to use in lightweight concrete. From previous study, the percentage of natural lightweight aggregate was 10%, 20% and 30% . In this studies, the percentage of lightweight aggregate has been used are 10%, 13% and 17% due to the economical aspect and production of material. Artificial lightweight aggregate are more expensive than normal aggregate and natural lightweight aggregate i.e, coconut shell and palm kernel shell. Manufacture of Artificial lightweight aggregate also will take time to produce in the factory to have a best quality of aggregate. Figure 1 shows the artificial lightweight aggregate used in this research.

Figure 1 Artificial Lightweight Aggregate

2.6 Additive

Admixtures are used to modify the properties of concrete or mortar to make them more suitable to work by hand or for other purposes such as saving mechanical energy. Water reducers, retarders, and superplasticizers are admixtures for concrete, which are added in order to reduce the water content in a mixture or to slow the setting rate of the concrete while retaining the flowing properties of a concrete mixture. Many important characteristics of concrete are influenced by the ratio (by weight) of water to cementations materials (w/cm) used in the mixture. By reducing the amount of water, the cement paste will have higher density, which results in higher paste quality. Table 1 shows the mix design of 3 samples with difference percentages of lightweight aggregate and one control mix design

Table 1 Mix design

Sample ($1m^3$)	Cement	Water	Fine sand	Lightweight Aggregate		Foam
	Kg	Kg	Kg	%	Kg	Litter
LWAc 1	300	150	680	10	120	473
LWAc 2	300	150	644	13	156	454
LWAc 3	300	150	596	17	204	428
LWAc 4	300	150	800	0	0	602

3.0 EXPERIMENTAL SETUP

Thermal properties of lightweight aggregate foamed concrete were carried out via hot disk thermal constant analyser. The hot disk thermal constant analyser is one of the most accurate and expedient method to study thermal properties by adapts the Transient Plane Source (TPS) method. The censor used will be sandwiched between the 2 samples. Size of the sample used is 25 x 50mm with 10mm of thickness. Figure 2 shows the cylinder shape obtained from the prism.

Figure 2 Cylinder shape lightweight aggregate foamed concrete obtained from the prism

All specimens that will be tested need to be in dry state condition. Data such as probing depth, time and power used need to be set until constant and allowable rate was accepted. The hot disk thermal constant analyser will give all data such as thermal conductivity (w/mk), thermal diffusivity (mm^2/s) and specific heat (MJ/m^3 K). Figure 3 shows the set-up of hot disk thermal constant analyser for thermal test.

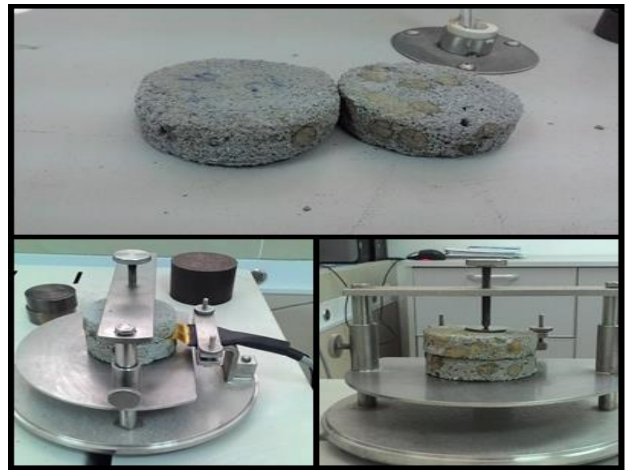


Figure 3 Set-up of hot disk thermal constant analyser for thermal test

4.0 RESULTS AND DISCUSSION

For semi structure with thermal insulation characteristic, RILEM proposed that the thermal conductivity should be below 0.75W/mK [8]. From the data recorded, the entire sample fulfilled the requirement stipulated in RILEM. Through Figure 4, the CTRL specimens were achieving the lowest thermal conduction compare to others which is 0.44 W/mK. For other specimens, LWAC10 was achieving the second lowest which is 0.45 W/m^0C and it been follow by LWAC13 and LWAC17 with 0.49 W/mK and 0.66 W/mK. Based on the result, the thermal conductivity reading was increased when the percentage of lightweight aggregate increase in the specimen. This result also prove that the artificial lightweight aggregate have more conductive value. The aggregate with more thermal conductivity produce high conductive concrete and vice versa.

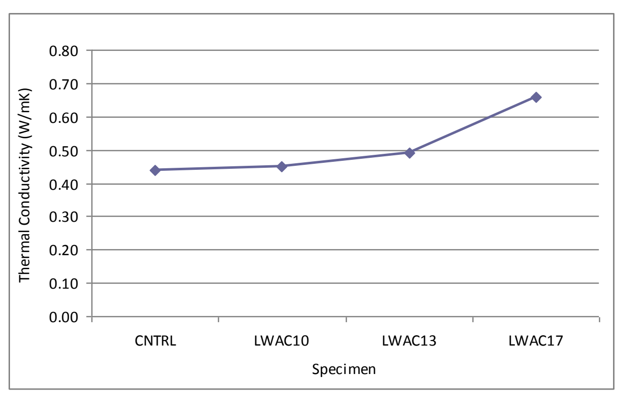


Figure 4 Thermal Conductivity result of LWAC

Based on the Figure 5, the highest readings of thermal diffusivity are CTRL specimen with 1.2 mm^2 /s and its follows by LWAC10 and LWAC 13 with the rate of 0.98mm2/s and 0.75 mm^2/s. The result shows that rate of thermal diffusivity decreased when more percentage of lightweight aggregate in the concrete. The lowest rate was three times than the rate record for CTRL specimen with 0.31mm^2 /s for LWAC17. Low thermal diffusivity also will happen because of the compatibility in relative stiffness between the cement paste and the artificial lightweight aggregate due to the shape of aggregate which is spherical and easy to be mix in concrete.

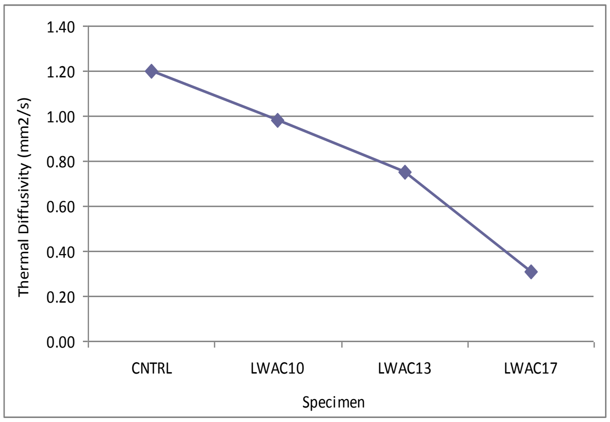


Figure 5 Thermal Diffusivity result of LWAC

From Figure 6, the lowest reading of specific heat are CTRL specimen with 940 J/kg^0 C and its starts increase by sample LWAC10 and LWAC 13 and LWAC17 with the rate of 990 J/kg^0 C , 1035 J/kg^0 C and 1103 J/kg^0 C. The reading will increase when the percentage of aggregate was higher in the concrete due to the water content and air trap in the lightweight aggregate.

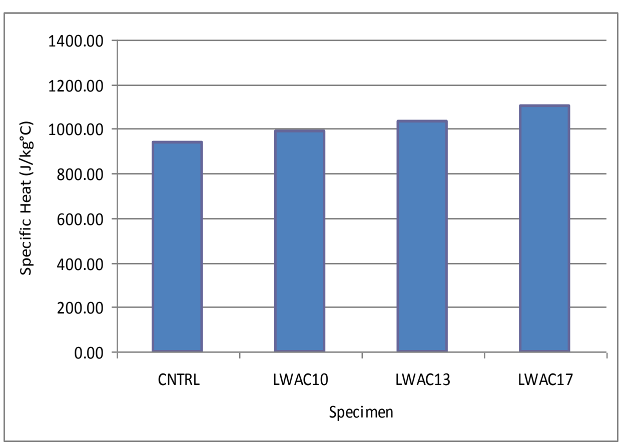


Figure 6 Specific heat result of LWAC

Artificial lightweight aggregate has high in water absorption because it raw material is silt and it has high water absorption. Because of this matter it will increase the amount of energy required to increase a unit mass of material by one unit of temperature at constant pressure. Based, on studies, the reading of specific heat also depends on distribution of lightweight aggregate in the specimen

5.0 CONCLUSION

This paper has deliberately discussed the experimental studies on the thermal properties of lightweight aggregate foamed concrete. Thermal test result shows that thermal conductivity value has full fill the requirement for semi structure with thermal insulation characteristic which is below 0.75W/mK and the specimen highest value is 0.66 W/mK. The rate for thermal diffusivity shows that high percentages of lightweight aggregate will reduce the thermal diffusivity. It shows that, three times reducing of rate between CTRL specimen and LWAC17 specimen which is from 1.2 mm^2 /s to 0.31mm^2/s. Low thermal diffusivity may happen because of the compatibility in relative stiffness between the cement paste and the artificial lightweight aggregate due to the shape of aggregate which is spherical and easy to be mix in concrete. Specific heat test show the reading was higher when the percentage of lightweight aggregate is higher in lightweight concrete. This happen cause of moisture content in the lightweight aggregate due to the high of water absorption of aggregate. When aggregate have high of moisture content it will increase the amount of energy required to increase a unit mass of material by one unit of temperature at constant pressure.

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