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Foamed Concrete: Potential Application in Thermal Insulation

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Abstract *- Foamed concrete is one of the materials in lightweight concrete category which also known as closed cell structure and have lower density between 300 kg/m3 to 1600kg/m3 and thermal conductivity properties between 0.10W/mK to 0.66 W/mK. The compressive strength of foam concrete is just about 1 to 60Mpa compare to normal concrete which achieved 100Mpa in compressive strength. The thermal conductivity of normal concrete is about 1.6 W/mK with 2200 kg/m3 density. This papers focus on the thermal insulation properties of foam concrete. Closed cell structure in foam concrete plays important roles in providing great thermal insulation performance. The aim of this paper is to evaluate the concepts of thermal insulation, the properties of foamed concrete and also thermal comparison with other materials. Some of the application of foam concrete as thermal insulation materials and future potential of natural fibre as additive in foam concrete in order to improve the thermal insulation performance.*

Keywords: Foamed concrete, lightweight concrete, closed cell structure, Thermal conductivity.

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I. INTRODUCTION

During the last decades, foam concrete has becoming a very well known materials or structure that has excellent properties especially in thermal insulation performance. Nowadays, with the global warming phenomenon that becoming worst day by day, the usage of foam concrete panel as thermal insulation is a great idea and at the same time it's really relevant. Furthermore, foamed concrete also has undoubted benefits in providing excellent thermal insulation which improving that popularity gained by foam concrete not just because of their low density behavior. Foamed concrete which is sometimes referring to as cellular concrete is a versatile material which consists principally of a cement-based mortar or paste mixed with at least 20% by volume air.

According to Jones [1], foamed concrete has a very surprisingly history where it was already patented in 1923 for the mainly use as an insulation material by Roman. However, the lack of specialized materials and equipment, limited the usage of this materials. One of the earliest and development of research on foamed concrete was carried out in the Netherlands by the CUR in the late 1980s and 1990s. By this development it was helping in establish foamed concrete as an accepted building material and at the same time widening the usage of this material. Furthermore, the Specification for the Reinstatement of Openings in Highway (1996) helped in increase production and broadens the scope of application of foamed concrete in UK in last 15 years.

For instance, Kearsley in his article has stated that the usage of foamed concrete is increasing and in this recent years foamed concrete has been used as a structural materials in schools, apartments and housing developments in countries such as Libya, Russia, Brazil, Mexico, Indonesia, Saudi Arabia, Singapore and Egypt. Meanwhile, in Britain, foamed concrete has been used in many field of usage like highways, bridge, tunnels and also void infills. Beside that, in South Africa, foamed concrete has been applied to manufacture support structures in deep mining, while research is being conducted in the Ukraine in order to investigate the heat resistant of foamed concrete. Various researchers have been working for many years in order to expand the use of foamed concrete in construction industry.

However, the usage of foamed concrete in was not widely use in the market because of the lack of knowledge on the credibility of this material as great insulation materials. The main requirement of an insulating material is it must have low thermal conductivity. This is generally the main property of the insulating material but the structure of the material also one of the important factors which may contribute to the

insulating effect. Thermal conductivity of foam concrete depends on their density. In other words, by lowering the density, a lower thermal conductivity can be achieved.

For instance, foamed concrete is also known as porous materials and has made by mixing sand, water and cement which we call that slurry. And then slurry will mix with stable foam to produce foam concrete. Stable foam is also known as air-bubble. The combination of air, water and forming agent in foam generator will produced pre-forming solution. And then, pre-forming solution will add with air in order to produce stable foam. Subjected to the topic, there are a few parameters that are considered in this research in order to characterize the thermal performance of foamed concrete. The term thermal insulation itself is refer to a material or combination of materials that when properly applied, retard the rate of heat flow by conduction, radiation and convection. Its retards heat flow into or out of the building due to its high thermal resistance [2].

Conduction occurs when heat travels through a medium. That's why thermal conductivity is defined as the time rate of steady state heat flow (W) through a unit area of thick homogenous materials in direction perpendicular to isothermal planes and in simple word conductivity is the ability of material to conduct heat [3]. Insulation also rated in terms of thermal resistance called R-value, which shows the resistance to heat flow. Resistance is the insulating quality of material. In the other words, thermal resistance defines as a measure of the resistance of heat flow as a result of suppressing conduction, convection and radiation [4]. All of these parameters are much related which each other in order to get an effective thermal conductivity.

II. CONCEPT OF THERMAL INSULATION

According to classification given by RILEM [5], lightweight concrete used for insulation purpose may provide strength as low as 0.5Mpa and a density less than 1450kg/m3. Based on the production of foam concrete, stable foam is added in order to get or to produce air bubbles or voids in foam concrete. Basic concepts can be explained on this foamed concrete as cellular materials which categorized in closed-cell structures. In recent article studied by Vesenjek [6], they concluded that cellular material with closed-cell structures has advantages in thermal insulation. It just simple concepts apply in this cellular material which is by trapping air bubbles within the concrete, a lightweight, insulating material is formed.

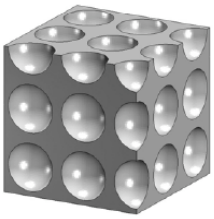

Figure 1; Closed-cell structure

Furthermore, the thermal conductivity of concrete is higher than thermal conductivity in air. In spite the fact that air is known as poor conductors, its still has benefit as a good insulator. So, by introducing holes or air voids in the foam concrete, the thermal conductivity of foam concrete can be reduced.

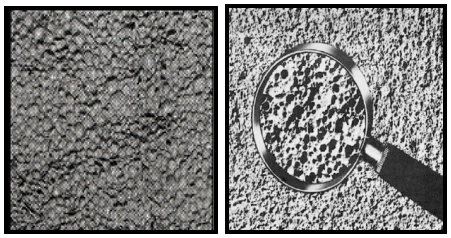

Figure 2: Closed Cell Structure in foam concrete

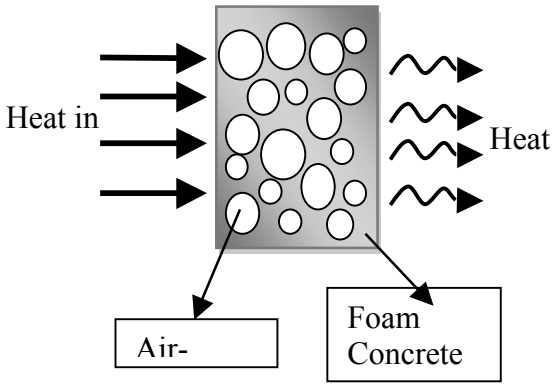

Figure 3: Diagram of air voids in foam concrete.

Figure 2 and Figure 3 shows that air – voids or bubbles in the foam concrete which plays an important role in behave of better thermal insulation properties. Air-voids or air-bubbles which known as closed cell in foam concrete will suppress (by preventing air from moving) heat flow and the air entrapped within the material insulation will provide high thermal resistance (R-value). As we know, the higher R-value, the greater the insulating effectiveness which means the slower (more hours required) for the heat to transfer through a materials. As foam concrete is a self-flowing without coarse aggregate

the possibility of entrapped air is relevant [7]. So, by creating more air-voids or air-bubbles in foam concrete, thermal resistance become high and low thermal conductivity foam concrete can be produced. The lower thermal conductivity also depends on the thickness of the foamed concrete because the higher thickness of foamed concrete, the lower thermal conductivity we get.

III. THERMAL INSULATION PROPERTIES

According to studied done by Jones in his paper on behaviour and assessment of foamed concrete for construction applications stated that the cellular structure of foam concrete has an excellent contribution in providing good thermal insulation properties and thermal conductivity values.

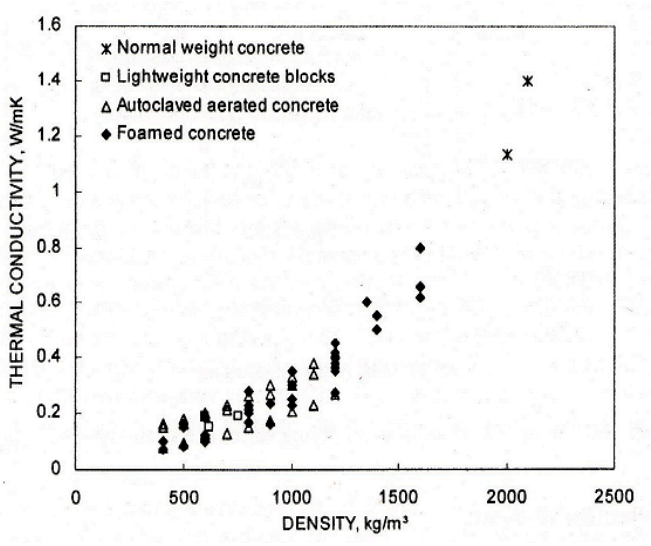

Figure 4: Thermal conductivity of foam and other products [8].

Jones has done a comparison of thermal conductivity between foamed concrete and other concrete products such as normal weight concrete, lightweight concrete and autoclaved aerated concrete. According to the figure 4 we can simplify that the thermal conductivity values of foam concrete are reducing with decreasing of densities in range between 0.1 and 0.7 W/mK for foam concrete with 600 to 1600 kg/m3 densities, there are very high difference compares to normal weight concrete which achieved 1.6 W/mK with 2200 kg/m3 density. Due to the table above it shows that the foamed concrete really has a great potential as thermal insulation material.

IV COMPARISON OF THERMAL CONDUCTIVTY

Table 1; Thermal conductivity comparison with other materials [9].

Material	**Density,kg/m3**	**Thermal conductivity W/mk**
Marble	2700	2.9
Concrete	2400	1.3
Porous clay brick	2000	0.8
Foam concrete	1200	0.38
Foam concrete	1000	0.23
Foam concrete	800	0.18
Foam concrete	600	0.14
Foam concrete	400	0.10
Cork	100	0.03
Silicate Cotton	100	0.032
Foamed polystyrene	25	0.030
Foamed polystyrene	35	0.022

Table 1 shows the thermal conductivity comparison over other insulating materials that commonly used. From the table, it seems that foamed concrete is well suited to thermal insulation applications since it has low values of thermal conductivity compare to normal concrete and other insulation materials. This can be proven by the studied done by Hago [10]. According to the author, main reason of using lightweight concrete over normal weight concrete is because it can provide good thermal insulation for building. Variation densities of foamed concrete give variation value of thermal conductivity.

Beside that , based on studied done by Liew [11], application of foam concrete is variation based on their density such as foam concrete with density 300-600 kg/m3 is usually used as thermal insulation materials for flat roofing with required gradient, foamed concrete with density of 600-900 kg/m3 is used as internal partition wall blocks and panel. Foamed concrete 900 to 1200 kg/m3 density is usually made as external wall blocks and panels and also used for general sound proofing in industrial field. And finally, foamed concrete with density 1200 to 1800 kg/m3 is always applied as a medium weight blocks and slab and large reinforced slab and panel.

Table 2: The comparative characteristics of foam concrete and conventional walling [12].

Walling	Density kg/m^3	K-factor W/mK	Wall thickness required, m	Mass of 1 m^2 of the wall, kg
Ceramic brick	1800	0.8	0.64	1190
Lime-sand brick	1850	0.85	0.64	1250
Limestone sawn	1600	0.35	0.35	880
Slag brick	1400	0.65	0.55	880
Foam concrete	**700**	**0.18**	**0.3**	**210**

Based on Table 2, its shows that foam concrete wall or panel has a low thermal conductivity of 0.18 W/Mk with density 700 kg/m3 with thickness about 0.3m. Compare to another wall product, it seems that foamed concrete has the lowest density with lowest K- factor. The lightness in mass will be an advantage for the production of foamed concrete panel. It is a great opportunity for foamed concrete to be applied as wall panel in order to get good thermal insulation performance.

Generally, in the comparison between foam concrete blocks and standard bricks wall we can see that concrete blocks wall is larger than standard brick wall, so block wall can be constructed faster than a traditional brick wall. By using foamed concrete it will more lightly than conventional concrete block which is easier for us to make it and carry to the site. Additionally, foam concrete blocks wall absorb much less water than bricks that make them have a longer lifespan.

Table 3: Thermal conductivity comparison with different thickness [13].

Concrete Density	K -value			
	50mm	100mm	150mm	200mm
300	1.030	0.580	0.400	0.300
400	1.210	0.690	0.460	0.370
500	1.380	0.800	0.560	0.430
600	1.570	0.930	0.670	0.520
700	1.230	0.890	0.630	0.470
800	1.370	1.000	0.710	0.540
900	1.520	1.130	0.810	0.610
1000	1.690	1.270	0.940	0.700
1100	1.820	1.390	1.020	0.780
1200	2.020	1.550	1.150	0.980
1400	2.310	1.830	1.390	1.080
1600	2.060	2.100	1.630	1.290

Table 2 shows that, the higher thickness of the foam concrete, the lower thermal conductivity value *(k value)* we get. For the application of foam concrete as wall panel, the range of densities that usually used is between 600 to 900 kg/m3.

V. APPLICATION OF FOAMED CONCRETE AS THERMAL INSULATION MATERIALS.

The lightweight and excellent thermal properties of foamed concrete have been a great advantageous in housing or building application. In 1948 and 1958, which is in Middle and Far East area, about 3000 houses were built using 1100 to 1500 kg/m3 density foamed concrete and the condition of these housing was assess after 25 years later and they were found that these residency have performed better which means required least maintenance compare than contemporary timber house or those built with bricks and concrete blocks. In addition, foamed concrete also has been used as roofing insulation in South Africa, while its low density enables the creation of roof slopes [14].

In Malaysia, the application of foam concrete as wall panel becoming popular in these 10 years. The first major application of lightweight concrete foamed concrete in Malaysia is a SMART tunnel project in Kuala Lumpur. Density of foam concrete used is about 1800kg/m3 which achieved compressive strength of 3 N/mm2 at the age of 28 days. This foam concrete block is used to protect the diaphragm wall when the tunnelling machine is coming out into the junction box.

Figure 5: Foamed concrete as blocks and wall panels.

Foamed Concrete usually used as blocks and wall panels. Blocks and panels can be made for partition and load bearing walls because foam concrete has an excellent behavior in thermal insulation. They can be made with almost any dimensions. Since relatively little equipment is required they can be cast on site to save transportation costs. Beside that, it's also can save labour cost because of the simple casting.

Figure 6: Application of foamed concrete as roof insulation material

Foam concrete also used extensively for roof insulation and for making a slope on flat roof. Beside have good thermal insulation properties it also does not impose a large loading on the building.

VI FUTURE POTENTIAL APPLICATION: NATURAL FIBRE AS ALTERNATIVE ADDITIVE IN INPROVING THERMAL INSULATION PERFORMANCE.

In these recent years, study on the fibre reinforced concrete in lightweight concrete has been expanded widely. But the research is more focus on the fibre reinforced concrete by using synthetics fibre such as steel fibre, polypropylene, glass fibre and carbon fibres. This because of the usage of synthetics fibre has great contribution in terms of the performance of concrete. Such as polypropylene fibre and nylon fibre which are found to be suitable to increase the impact strength. Steel fibres help in improving the flexural and fatigue strength of concrete. Glass and carbon fibres also have excellent potential in tensile strength.

However, natural fibres which also known as agricultural waste also has great advantages in concrete industry that can't be argue by anyone. The growth rate of population, development of industry and technology is the factors that contribute to the increasing of the waste production in the recent years. If there are no effort to solve this problem it will come out with some of environmental problem. Therefore, there is important to find a strategy in order to decrease solid waste problem. One of the strategies is focus on the reduction of waste materials by reuse of solid waste as raw material whenever feasible. Mannan [15], in his research on an agricultural waste, stated that natural fibres such as coconut coir, durian peel and oil palm really has profitable as a low-cost construction material especially in concrete industry as classified in Table 5.

Figure 7: Palm oil fibers

Table 4: Types of agricultural waste application in concrete industry

No.	Type of application	Type of agricultural waste
1	As aggregates for concrete production	Oil palm shell (OPS)/ clinker Coconut shell Rice husk Saw dust
2	In fibre-reinforced concrete: as aggregates for particle board, roofing sheet, and partition panel production	Oil palm fibre Coconut husk Rice straw Sugarcane bagasse
3	As cement replacement material in concrete	Rice husk ash Palm oil fuel ash

So, in this paper, we want to look forward for the potential of natural fibres in improving thermal conductivity performance by using foam concrete product. Based on Table 5, oil palm and coconut husk is the priority material that usually used as fibre-reinforced concrete. At present, Malaysia has produced more than half of the world's total output of palm oil which covered about 2.6 million hectares of land. Thus, this type of fibre may be able to be use as additive in foamed concrete in order to reduce thermal conductivity and at the same time reduce the waste problem. For instance, we knew that palm oil fibre is widely used as fibre reinforced in concrete but there is still lack of investigation or study on their ability in reducing thermal conductivity. Therefore, it is a great opportunity for us to study the potential of this

palm oil fibre as additive in foamed concrete in lowering thermal conductivity value. Beside that, there are also a few more types of fibre that can be study in terms of this topic such as coconut coir and durian peel but for this time we just focus on palm oil fibres.

Khedari, [16] by his research on new insulating particleboards from durian peel and coconut coir has conclude that the use of durian peels and coconut coir fibres as particle board with low conductivity is very practical and it was applicable to apply in building insulation. The effects of fibres reinforcement in concrete are very good. Beside increased ductility and tensile strength. It also act as a resistance to crack propagation due to plastic and drying shrinkage and the important thing is fibre reinforcement will act as resistance to thermal and moisture stresses [17].

For instance, Khedari [18], has investigated the thermal conductivity of soil-cement brick mixing of coconut coir fibre. Result indicates that thermal conductivity of 0.6510 W/Mk was achieved compare to commercial product with 1.5 W/mK densities. Result also showed that the application of fibre as additive in cement brick give lower thermal conductivity compare to commercial product. They have concluded that by increasing the quantity of fibre in cement brick, the thermal conductivity of sample decreased and coconut coir fibre is a good admixture in reducing the thermal conductivity.

VII CONCLUSION

In conclusion, foam concrete seem can be used as a great option as building insulation. Its really have great potential in order to give insulation performance. Although much work has been done on foam concrete, very little research have been done on thermal conductivity of foam concrete. Because cellular concrete is relatively new construction when compared to reinforce or plain normal-weight concrete, it really needs more effort in order to expand the information about its excellent performance in thermal insulation.

In on going research is to use the idea of agricultural waste as admixture with lower thermal conductivity so it can reduce heat transfer into building. By this way, it can provide cooler indoor space and then will decrease the energy consumption of building facilities because foam concrete with low thermal conductivity will act as an air conditioner. In addition, it will provide good sound absorption and hence are environmentally friendly.

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