
PROPERTIES OF INDUSTRIAL BOILER ASH AS SAND REPLACEMENT AND THERMAL IMPROVEMENT IN AERATED CONCRETE

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Abstract: This paper review the utilization of Industrial Boiler Ash (IBA) replacing sand has been introduced in aerated concrete for common use in building construction. The Industrial Boiler Ash from Tanjung Bin Power Plant, Malaysia was used in this study. It is believed beneficial as by adding this precious material, it may improve properties of aerated concrete mechanically and thermally especially in the effect on improving the thermal conductivity. This paper presents the effects of using different character of mixing constituent such as various amount of foaming agent and range of superplasticizer content on the compressive strength. Besides that determination on the final product properties in microstructure were also investigates. The results show that using the IBA have a lower density compared to normal sand with a dry density of 1.408kg/m³ which a compressive strength of 5.258 MPa but also observed beneficial as it might improve the thermal conductivity behavior with 0.52 W/mK compared to normal mortar concrete having 2.52 W/mK. This indicate that the use of Industrial Boiler Ash aerated concrete give a less impact of heat due to low thermal conductivity created.

Keywords: Industrial boiler ash, aerated concrete, sand replacement, thermal conductivity, thermal coal power plant, thermal comfort

1.0 Introduction

Malaysia, a hot and humid country has given a great impact especially for determining the thermal comfort in buildings. Basically, the tropical climate region, received an equally sun radiation during the day time. The peak and intensity stays in between 0.7 to 1 KW/m² all year round (Din *et al.*, 2012) . Building materials absorb heat from the sun and subsequently reradiate to the surrounding and causes the ambient temperature to increase at night time (Chow & Roth, 2006). Dense concrete and brick offer excellent

load bearing but hardly for insulation. As far as mineral wool is concerned they offer good thermal but without non-load bearing (Wittman, 1983). In conjugate, initiative has been concentrated for improving the efficiency of building materials in having lower thermal insulation.

Aerated concrete known as lightweight concrete that has been used in current construction materials, having an entrapped air voids by means of foaming agent produced from cement, lime, silica sand and some of pozzolanic materials (Esmaily & Nuranian, 2012) . It is a presence of light weight small bubble in a uniform distribution mixing (Zuo Jun, 2012). Such invention, lots of other extensive research progress aiming in improving the thermal, hygric and other structure properties. Majority, researched innovation proved that either the replacement of cement or fine aggregate proven that it might lower the density as well as thermal conductivity hence create a better insulation. As been cited by Demirbog the reduction density of mortar means probably due to high air content. This has been agreed in Fu and Chung, 1997 cited in Demirbog study showed that low thermal conductivity is related to high air void. This proved that the thermal conductivity differ, depends upon the pore structure of the lightweight aggregates (Alengaram *et al.*, 2013), density of concrete and cement paste matrix. Thus, the pores structure the main factors affecting thermal conductivity.

Tanjung Bin coal power station is one of the four coal power plants in Malaysia, producing 180 tons/day of Boiler Ash (BA) and 1,620 tons/day of fly ash from 18,000 tons/day of coal burning (Marto *et al.*, 2010). Hence, abundant of ashes lagoons remain untouched and ends up at landfill ever since operation. Previous study shows that lot of researchers have implemented the idea of mixing the industrial by product such as replacement of BA into the aerated concrete for sand replacement (Wongkeo & Chaipanich, 2010; Ravasan, 2014). Normally the coal ash is used as sand replacement due to the fact that it has the similar particle size distribution as that of natural one. Moreover, BA being in the porous form can improve the thermal conductivity of structure. According to the findings of (Kurama *et al.*, 2009) the addition of BA as sand replacement can improve the thermal conductivity up to 0.2202 W/mK as compared to the reference having 0.3610 W/mK as thermal conductivity value besides improving the strength (Al-Rawas *et al.*, 2005). The long term benefit of insulation is that it may reduce the cost of cooling as well as reducing the pollution of the environment (Al-Jabri *et al.*, 2005).

The main concern of this study is to determine the effects of using BA as sand replacement in aerated concrete. In the early part of the experiment the aerated concrete behavior was studied for its usage along with aluminum powder as well as superplastizer in order to provide the best strength and density for the normal aerated concrete with 100 % replacement of BA instead of sand. The whole study is focusing on Non autoclaved aerated concrete, meaning that the aerated concrete is being air cured in a normal weather condition of tropic climate. The reason is being non autoclaved due to

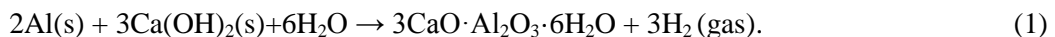
save the energy as well as the determination of strength for natural curing while at the same time, saving up the cost in production stage.

At the end of the research, the investigation towards the microstructure behavior has been analyze using SEM images test. Besides that, the study also did compare the results with existing commercial aerated concrete as well as the normal aerated concrete that using sand as fine aggregate in order to see a critical effect on the microstructure. In extension, the study related more on the development of green lightweight concrete which is expected to improve the behavior of thermal in concrete as well as and reduce the amount of ash getting dumped up in the landfill as an alternative construction material for the builder.

2.0 Materials and Methods

2.1 Materials Used for the Experiment

The materials used in this study consisted of normal Portland cement, calcium hydroxide (lime), BA, aluminum powder, super plasticizer and water. Normally, as stated by Kula *et al.*, 2002, BA is often used as a low-cost replacement for more expensive sand for concrete production. The BA in figure 1 was obtained from the Tanjung Bin Power Plant, Malaysia, dried in oven at the temperature of $110^{\circ}\text{C} \pm 5$ for 24 hour and then was sieved before storing it in an airtight container. The BA used in this study confirms with the BS 882: 1983 and ASTM C 33-84 standard grading requirements for making the fine aggregates and aluminum powder was used as a pore-foaming agent which can react with calcium hydroxide to form hydrogen gas (gas bubbles) in the cement slurry. The reaction for making aerated concrete was done according the method of (Short & Kinniburgh, 1963) as shown in (Eq. 1)



Besides that the powder form of plasticizer classified as the type of super plasticizers sulfonated naphthalene and confirming with the ASTM C-494-05 (ASTM 2005a) type A and ASTM type B, D respectively were employed in all agro-industry aerated concrete. Superplasticizer was being introduced as admixtures as it may add fluidity to the concrete while less water is being used. In addition, it also plays a significant role to reduce the flocculation of cement grains (Malier, 1992). In the case of aerated concrete production, insufficient presence of superplasticizer may fail the dispersion of cement particles thus producing a mix with a very low workability. Hence, the created medium cause's disruption to the aeration process which is crucial for decreasing the density of aerated concrete. Besides that, the use of BA in fine aggregate will also create a higher expansion as compared to sand with the increment percentage of superplasticizer. This

might due to the porous structure of bottom ash which requires a lot water content hence leads to the reduction of compressive strength (Singh & Siddique, 2013).



Figure 1: Boiler ash (BA) collected from the power plant

At the end of the stage, the test Scanning Electron Microscopy which has been a primary tool in order the investigation of complex internal structures and hydrated cement pastes for many years (Diamond, 2004). Basically this study determined the information about the sample including external morphology (texture), chemical composition, and crystalline structure. Normally, the small pieces of broken sample were taken from the specimens which has been is subjected to curing for 28 days. Prior to testing the specimen were dried for 24 hours in an oven in order to remove moisture. Later the samples were broken up into small pieces with the size of 5 mm. Then the microstructures of the specimens were microstructures of the specimens were analyzed by scanning electron microscope model Jeol, JSM-5600. The images of microstructure were taken at magnification of 500x, 600x, 750x and 2000x.

2.2. Particle Size Grading Distribution of Boiler Ash from Coal Power Plant

Normally the BA from Tanjung Bin power plant has major size range in between 20mm to less than 150 μ m. BA is usually a well graded material, although variations in particle size distribution may be encountered in BA samples taken from the same power plant at different times. From the analysis below, figure 2, shows that the particles distribution of BA sample that used in this research, follow the overall limit by BS 882:1992. For this sample, the BA satisfies class M fine aggregate which represent well-graded fine class. This represent that it is suitable to be used as fine aggregates to replace sand.

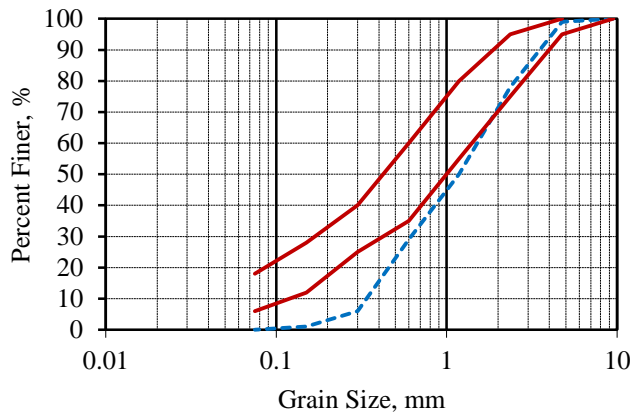


Figure 2: Sieve analysis graph of boiler ash

2.3. Preparation of Mix Proportions

In this research, cement/calcium hydroxide (lime) /sand ratio (C: CH: S ratio) were used based on Ing, E, 2010 in Eurocode 6. The novelty for this study was BA has been used 100% replacing the sand. One set of control specimen in order to find the best mix for control aerated concrete with bottom ash replacing sand has been determined. The 100% bottom ash as the fine aggregate is been set as the control specimen. The specimen has been mixed with three different stages which the first stage was the mixing preparation of cement, hydrated lime, and BA. Next, the additives were added with aluminum powder and super plasticizer. At the end of the stage the water is added before cast in the form of cubes ($70 \times 70 \times 70$ mm). All specimens were left in the mold for 24 h before demolded and subjected to water curing for 28 days.

All specimens were tested to determine compressive strength at the age of 7 and 28 days. Compressive strength test was conducted in accordance to BS 1881:116 (British Standard Institution 1983) Part 3. The agro-industrial aerated concrete which having the lower dense with an adequate strength and lower in thermal conductivity suitable for non load bearing application as stated in ASTM C129-85 (ASTM 1990) was chosen as the optimum design mix for control. In this research focused on the non autoclaved aerated concrete due to the awareness on reducing the effect on global warming even though as been stated by Tada in (Chandra and Bjornstorm, 2002) claim that non autoclaved will produced a lot of macro-size distribution which will not influence the strength. At the end of the experiment, the thermal conductivity test has been identified, using BS EN 12664:2001 standard.

2.4. Investigation on the Infrared Camera towards the IBA Aerated Concrete

Thermal imaging, known as thermography, is the production of non-contact infrared or heat pictures (heat spectrum). Portable infrared cameras scan samples, then instantly convert the thermal images to pictures for monitoring or quantitative temperature analysis. The thermaCAM P45 is a highly refined infrared inspection system. In this study, an infrared camera (ThermaCAM from FLIR Systems) with 640 x 480 pixels with thermal sensitivity of 0.08°C, full colour and working in the wavelength band of 7.5 to 13 μm and a specified accuracy of ± 2 °C of reading. The thermal images were recorded at interval 2 hours from 9:00 am until 8:00pm during this study. In conclusion to this research, the analysis of the heat transfer has been investigated together with the determination on time lagged in conjugate with the peak temperature of the week.

3.0 Design Mix of IBA Aerated Concrete

Based on BS EN 1996-1-1, standard mix design for aerated concrete, few sets of trial and error was adopted to determine by having various percentage of mixes. Various mix ratios were obtained with different percentage of foaming agent, superplasticizer and water binder ratio shown in Table 1. Based on the compressive strength test which has been conducted at the age of 28 days in accordance to BS 1881:116 (British Standard Institution 1983) three different water cementitious has been varies with 0.3% and 0.45%. In order to study the effect of aluminum powder towards the strength different study has been used by varying the amount ranging from 0.65 to 2% by dry mix weight materials. The influence of the amount of superplasticizer toward compressive strength were also studied by preparing three different quantity ranging from 0.5 to 1.4% from total of cementitious materials. The superplasticizer used not exceed 1% because of the reduction in strength and not economical in practice. Table 2 indicates the overall view on the characteristic of having and optimum design of non autoclaved aerated bottom ash concrete. The results proved that the optimum mixed referred in table 1, gives the highest strength that stands the superplasticizer at 1.5% from total cementitious content and aluminum of 0.75% which gaved 5.258 MPa subjected to water cured at 28 days.

Table 1: Design Mix ratio for IBA aerated concrete

W/b ratio (%)	Alum (%)	SP (%)	Compressive Strength (Mpa)	
0.45	0.65	0.50	3.48	
		0.75	3.82	
		1.00	2.75	
	0.70	0.50	0.50	3.21
			0.75	3.76
			1.00	2.37
		0.75	0.50	3.54
			0.75	3.89
			1.00	2.71
	0.3	0.65	1.00	3.78
			1.40	2.22
			1.80	2.22
0.70		1.00	1.00	3.22
			1.40	2.55
			1.80	3.32
		0.75	1.00	3.22
			1.40	3.47
			1.80	2.26
0.3		1.0	0.50	3.50
			0.75	3.18
			1.00	3.63
	1.5	0.50	5.05	
		0.75	4.31	
		1.00	5.26	
	2.0	0.50	3.14	
		0.75	4.07	
			1.00	4.05

Based on BS EN 1996-1-1, few sets of trial and error was adopted to determine by having various percentage of mixes. Various mix ratios were obtained with different percentage of foaming agent, superplasticizer and water binder ratio.

Table 2: Optimum Design Mix of Non Autoclaved Aerated BA Concrete.

Mix proportion	
Cement: Lime :Bottom Ash	1 : 1: 2
Water binder mix ratio	0.29
Aluminum Powder, Alum	1.5%
Superplasticizer, SP	1%
Boiler Ash fineness	4.75mm

4.0 Results and Discussion

4.1 Effect of Aluminum Powder and Superplasticizer in Aerated Concrete.

The strength performance of aerated concrete of aluminum powder content was varied from 0.65% up to 2% which has been illustrated in Figure 3. It is proved that the increasing of aluminum powder may decrease the strength performance of aerated concrete. Nonetheless, reducing the amount of alum powder may retard the occurrences of aeration process. Means that the lower the expansion, will create a lower porosity, hence less thermal effect towards the concrete will be created. As been stated by Hussin *et al.*, 2010 reduction of aluminum powder may leads to the lesser amount of air voids which will causing a low expansion but at the same time if too much of aluminum may creates a higher amount of air bubbles and create a higher expansion which caused towards a fail in strength. This study discovered that an optimum amount of aluminum may leads towards an adequate strength, creating a better wall insulation. This agreed with the finding done by (Narayanan & Ramamurthy, 2000)

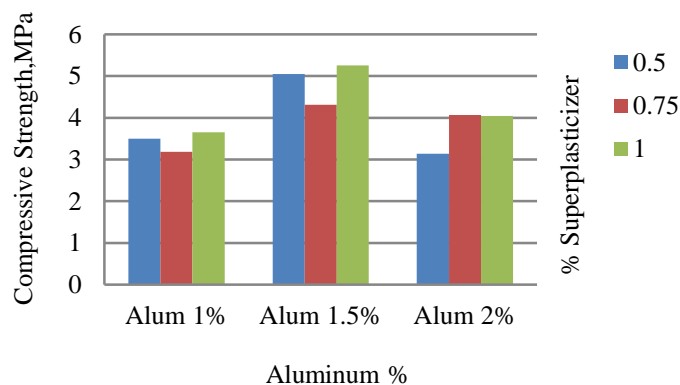


Figure 3: The relationship between aluminum powder and superplasticizer for Non Aerated Control BA at 28 Days

The discussion were continued by the effect on the increasing number in superplasticizer from 0.5% to 0.75% in non autoclaved aerated concrete which shown in figure 3. It proves that superplasticizer, will gradually increase the strength but at certain stage too much workability will create higher expansion which leads to weaker the bonding hence drops the strength. But too low the number of workability it will lead to the low expansion, hence creating uneven pore sizes resulting retarded during the aeration process. Looking at the working system of the chemical admixture, Chandra and Bjornstrom, 2012 highlighted that superplasticizer integrated in the mix are absorbed on the cement particles, which then deflocculated and separate the particles finally

releasing the water entrapped from cement flocs. In the case of aerated concrete production, insufficient presence of superplasticizer may fail the dispersion of cement particles thus producing a mix with a very low workability. Hence, the created medium cause's disruption to the aeration process which is crucial for decreasing the density of aerated concrete.

Besides that, the use of BA in fine aggregate will also create a higher expansion as compared to sand with the increment percentage of superplasticizer. This might due to the porous structure of BA which requires a lot water content hence leads to the reduction of compressive strength (Singh & Siddique, 2013). At the end of the stage, this study able to verifies the amount of superplasticizer included in the mix unquestionable which play the outcome of workability of the mixes which actually control the mixtures expansion which in line with the density and strength of this lightweight concrete.

4.2 *Effect of Boiler Ash and Sand as Fine Aggregate in Non Autoclaved Aerated Concrete.*

In producing concrete, cement, sand and water is needed. Nowadays there are so many ideas that came out in order to find the best knowledge that can be replaced by this three core material in producing concrete. The replacement of 100% sand by using BA nowadays seems to be vital. As we know, BA is a wasted product from coal power plant which normally was dumped to the landfill. Back in US, the uses of BA was widely used since the department of environment, has agreed and confirm that it is not included as Hazardous Material. The replacement of BA normally will give a reduction in strength but still comply with ASTM standard requirement. Besides that, the density of the concrete will become lower as the substitution of BA having low specific gravity. The idea of having BA in aerated concrete in order to improve the thermal behavior with having low thermal conductivity, high in time lag with a promising strength.

In comparison of its fineness, sand seems to be finer compared to BA, which normally came in rough and angular shape. A greater incorporation size possesses smaller surface area and makes the workability of mixture to be higher. This will led again towards the creation of pores with a larger size and some of it might lose the interconnected. This will lead towards larger voids forming a highly pores with a lower strength and density. But still, the divergence of using BA in aerated concrete still acceptable, conform with its requirement with having adequate strength and most importantly, exhibit low in thermal conductivity value.

The relationship between strength and density can be observed in figure 4 which clearly illustrated on the reduction of compressive strength but at the same time decreasing in density. Eventhough so, the compressive strength for Non Autoclaved BA is 6.168 Mpa which is still achieved the adequate strength based on BS EN 1996-1-1: Eurocode 6: Design of Masonry Structure. The objective of this research is also concerning the effect

on thermal conductivity which decreasing the density may improve the thermal conductivity value for the concrete. This can be proved by (Kurama et al., 2009). This is also might due to the porous structure of BA which requires a lot water content hence leads to the reduction of compressive strength (Singh & Siddique, 2013).

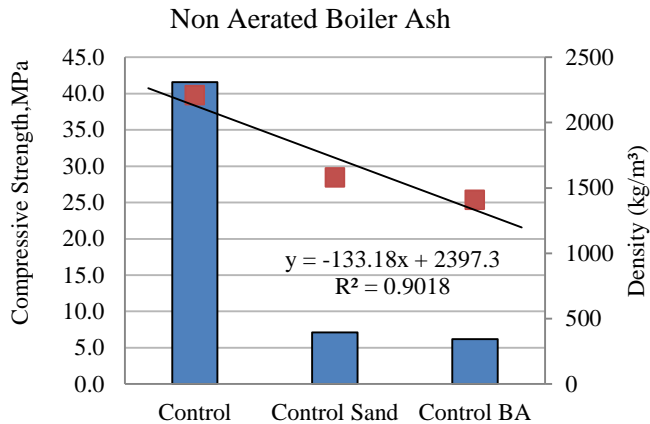


Figure 4: Relationship between strength and density of Control Mortar, Non Aerated Control Sand and Non Aerated Control BA at 28 days.

Figure 5 represent the thermal conductivity value differ with the increasing of density. Hence, it shown that Non Aerated Boiler Ash give the least thermal conductivity of 0.52 W/mK with the least density value of 1.408kg/m³.

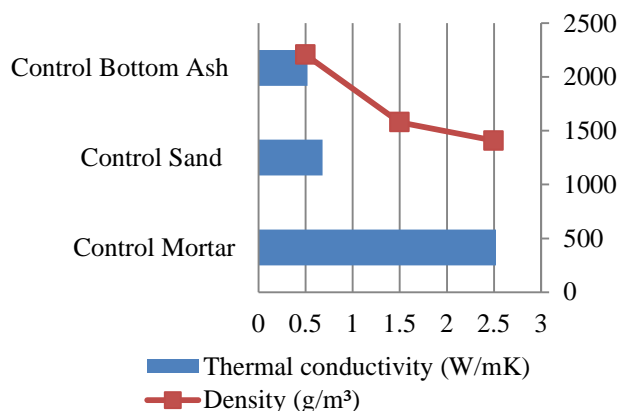


Figure 5: The Relationship between Thermal Conductivity and Density of Control Mortar, Control Sand and Non Autoclaved BA at 28 days.

Majority, researched innovation conducted in the figure proved that either the replacement of cement or fine aggregate proven that the higher the replacement when the lower the density, the lower the thermal conductivity hence a better insulation created. As been cited by (Demirbog, 2003) the reduction of density of mortar means probably due to high air content. This has been agreed in Fu and Chung, 1997 cited in Demirbog, 2003 study showed that low thermal conductivity is related to high air void. However, study showed by (Wongkeo & Chaipanich, 2010), proved that the thermal conductivity differ, depends upon the pore structure of the lightweight aggregates, density of concrete and the cement paste matrix. Thus, the pore structure is one of the main factors affecting thermal conductivity.

5.0 Microstructure

In aerated concrete, pore system normally divided into 3 regions. Based on Arreshvina, 2006 air pores with a radius of 50 to 500 μm was introduced by hydrogen gas during manufacturing process and as for micro- capillaries of 50nm or less created between the gap of hydration developed in the wall between the air pores. It is also observed that the strength performance also influenced by this characteristic. The increment in strength of aerated concrete indicates the occurrence of hydration process and pozzolonic reaction which creates the C-S-H gel and bonding between its link (Hussin *et al.*, 2010).

The overall SEM observation of aerated concrete in Figure 6 & 7 indicates that the microstructure changes greatly by using BA as sand replacement. Based on the observation, its clearly illustrate the major internal structure of a plain aerated BA concrete consist of calcium hydroxides in hexagonal crystal indicates the occurrence during hydration process (Hussin *et al.*, 2010).

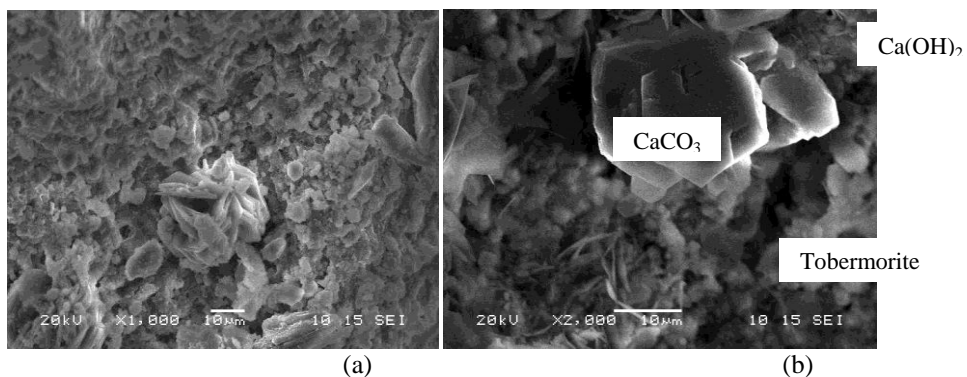


Figure 6: Internal structure of Non Autoclaved BA Aerated Concrete at the
 a) magnification of 1000 \times at age of 28 days b) the magnification of 2000 \times at age of 28 days

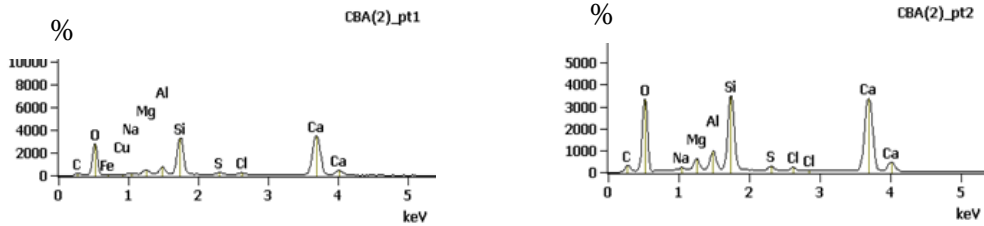


Figure 7: The element exist on Pt2 & Pt3 by using EDS

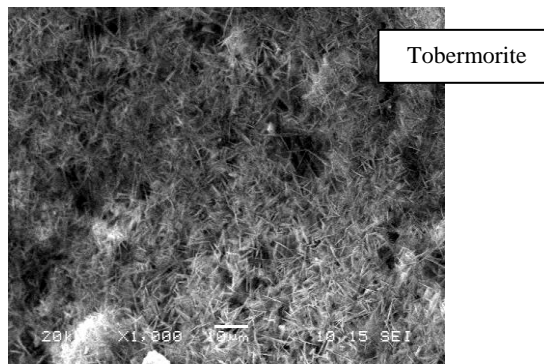


Figure 8: Commercial Aerated Concrete at the magnification of 1000×

In figure 7, shows that there also detection trace has extra calcium silicate gel formed. This can also be proved by EDS testing which proved that the major element presented was Calcium, Silica and minor content of Aluminum, Magnesium and Natrium. As been stated in, Wangkeo & Chaipanich, 2010 discovered that an autoclaved aerated concrete (Figure 8) which is the high-pressure steam curing with temperature exceeds 110°C normally will produce strength due to the formation of 1.1nm tobermorite as the main binding phase. The crystallization that was form mainly is porous and weak which causes a reduction in compressive strength. Hence, they discovered that pozzolanic materials, which are source of silica may produced the tobermorite formation. Therefore, BA can be used as the source of silica in autoclaved aerated concrete.

6.0 Thermal Imager Characteristic

Based on thermal images, it can observed that the normal mortar brick structure have a stronger heat capacity (Din et al., 2012). The test period on figure 9, the control mortar started to absorb heat starts during the beginning of the intensity of solar radiation compared to BA aerated concrete. At 5.00 PM showed a red dark color, most probably

due to a stronger compressive strength among mortar brick with 7 MPa at 28 Days meaning the matrixes produce in between the bonding is stronger compared to BA aerated concrete which gave a porous structure with strength of 5.258 MPa at 28 Days.

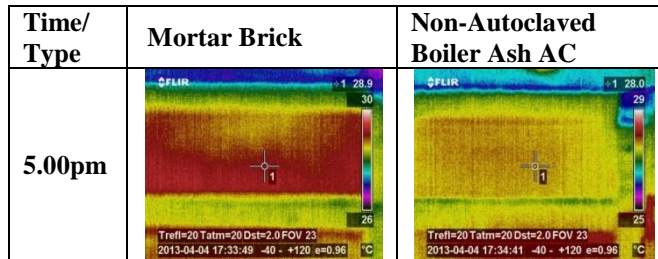


Figure 9: The Thermal Imager Images for different type of Brick at 5.00pm

Red areas in the thermograph on external surfaces building indicated high temperature or high absorption of particular material. High absorption of heat means that the energy stored and accumulated in the material. It slowly changed the color into green therefore, BA gave a better thermal comfort at night due to the heat release before the day started to dawn. This phenomenon is good because this might be one of prevention of UHI.

7.0 Conclusion

Sand has become a perfect material for fine aggregate due to its properties which having a larger surface area and when it being mix with cement, a thicker paste will be created hence producing a stronger strength. As for the BA, since its physical properties which is an amorphous, more Calcium Hydroxide need to be create in order to generate extra bonding for their linkage. Overall, Tanjung Bin Boiler Ash has a great potential use especially as replacement for fine aggregate. Its low specific gravity, ease of compaction, good friction properties represents even more credit. This not only solves the problems associated with the disposal of BA but also reduced expanses of electricity in improving the thermal comfort for end user. Therefore, conclusion can be drawn as:

1. The 100% replacement of BA (0.52 W/m.K) as the sand replacement may enhance the thermal conductivity value compared to the control aerated concrete by sand (0.68 W/m.K).
2. The strength of non autoclave boiler aerated concrete was affected by the aluminum content and the weight of superplasticizer.
3. The optimum mix design which give an adequate result in strength but improve the thermal properties which can act as insulation due to low thermal conductivity and can be utilize for materials especially non-load bearing wall as one of indicator to overcome the Urban heat island issues.

8.0 Acknowledgements

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