Lightweight Concrete Bricks Produced From Industrial and Agricultural Solid Waste

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Abstract— **The continuous extraction of natural non-renewable resources such as lime and natural aggregates for the production of concrete, the introduction of sustainable development to overcome the issues of natural resource depletion has been gaining increased attention. The main objective of this research is to address the potential use of both agricultural and industrial wastes namely Rice Husk Ash (RHA) and Expanded Polystyrene (EPS) respectively as raw material for the production of 'Green' lightweight concrete bricks. RHA was used as partial cement replacement, while the EPS was used as partial aggregate replacement in the mixes. Five different mix proportions were prepared. Sample A acts as the control sample (without RHA) and has a Cement: Sand: EPS ratio of 1.0: 1.5: 1.5, while samples B, C, D and E have RHA replacements of 5%, 10%, 15% and 20% respectively. The samples were tested for fresh concrete namely slump, fresh concrete density and air content while the hardened concrete properties tested were sorptivity, compressive strength and thermal conductivity. It was determined that EPS RHA concrete brick gives promising results.**

Keywords: Rice Husk Ash (RHA), Expanded Polystyrene Beads (EPS), Compressive strength, Sorptivity, Thermal Conductivity.

I. INTRODUCTION

In the 21st century, cement is becoming one of the largest manufactured products in the world, playing a pivotal role in developing countries. Due to the widespread applications of concrete, it has brought a massive momentum to the vast production of cement which caused uncontrollable emission of carbon dioxide (CO_2) and other greenhouse gas (GHGs) into our atmosphere. The production of one tonne cement produces an equal one tonne of CO_2 into our atmosphere. The enormous emissions of CO_2 have caused global warming and greenhouse effects which in turn cause environmental issues to become an alarming concern.

The problem of accumulation of unmanaged solid waste is another environmental issue concerned by the world today. Industrial solid waste namely expanded polystyrene beads (EPS) and agricultural waste namely rice husk ash (RHA) have been facing a serious problem for disposal. Normally, these waste materials are burnt or sent to landfills. The burning of these waste materials posses serious air pollution. In addition, the disposal of EPS in landfills also does not provide an environmental friendly solution since EPS is not biodegradable.

In light of the escalating concerns for environmental issues, the concept of sustainable development and energy conservation has become of paramount importance. One such method is through the introduction of recycling solid wastes into useful supplementary raw materials for new building materials.

Rice husk is an agricultural by-product abundantly available in rice producing countries. It constitutes about 20% of the weight of rice. When burnt, 20% of rice husk's weight remains as a waste material in the form of RHA. RHA contains high amount of silica [1]. It is a highly pozzolanic material which combines quickly with calcium hydroxide (CH) forming a secondary calcium silicate hydrate (C–S–H) [2]. Therefore, it is a suitable mineral admixture for cement and concrete [3].

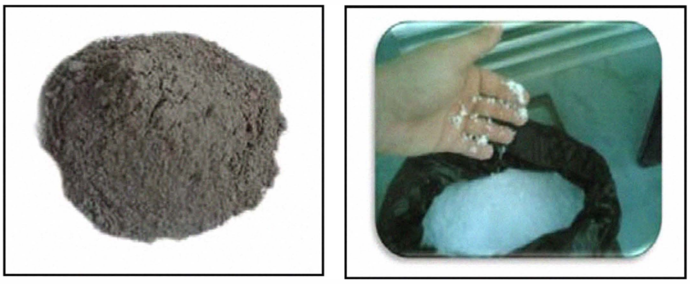
Expanded polystyrene (EPS) waste is a by-product from the packaging industry. It is one of many lightweight, low strength materials with good energy absorbing characteristic. It is well known for its good thermal and acoustic insulation properties leading mainly to non-structural applications including precast roof and wall panels and lightweight infill blocks [4]. It can easily be incorporated in mortar or concrete to produce lightweight concrete, with a wide range of densities [5].

In this study, solid waste namely EPS and RHA were used as partial replacement for cement and aggregate respectively in order to produce 'green' lightweight concrete bricks. The fundamental engineering properties namely compressive strength, sorptivity, water absorption and thermal conductivity of the brick specimens were investigated.

II. EXPERIMENTAL WORKS

A. Materials

Locally produced Ordinary Portland Cement Type I conforming to Malaysian Standard specification MS 522: Part 1: 2003 [6] was used in this entire investigation. Its specific gravity and specific surface (Blaine) were 3.05 and 3500 m^2/kg respectively. RHA was obtained from Sufficients Agricultural Co. Ltd, Thailand. The specific gravity, surface area (nitrogen absorption BET) and fineness as retained on 45μm sieve for the RHA were 2.02, 20220 m^2/kg and 14% respectively. The ash was ground using a Los Angeles grinding machine until it met the ASTM C 618 [7] fineness specification. Its loss of ignition (LOI), silica content and bulk density were 6.78%, 87.97% and 480kg/m^3 respectively. The EPS were collected from Saplastic Packaging (Sarawak) Sdn Bhd. Fig.1 shows RHA and EPS used in this investigation. A superplasticizer was used to improve the workability of the mix. The superplaticizer used was a Glenium C380 Type F admixture. The amount of superplasticizer used was 800ml per 100kg of cement. Potable tap water was used for mixing and curing in this experiment.



(a) (b)

Figure 1: (a) RHA and (b) EPS

B. *Mixture Proportioning*

Five different EPS RHA concrete brick mixtures were produced, tagged as A, B, C, D and E. Due to the lightweight nature of EPS and RHA, all mix proportions were produced by volume. Sample A acts as control sample which contained only cement, sand and EPS. This control sample has cement of 425 kg/m^3, sand of 542 kg/m^3 and EPS of 219 kg/m^3. Samples B, C, D and E have RHA replacement with cement in different percentages of 5, 10, 15 and 20 % respectively while maintaining the same volume of sand and EPS. The water-cement ratio is maintained at 0.5 for all mixes. The mix proportion for each sample is shown in Table I.

Table I: Mix Proportions

Samples	**Ratio (by volume)**				**Water-Cement ratio**
	Cement	**RHA**	**Sand**	**EPS**	
A	1.00	0	1.5	1.5	
B	0.95	0.05	1.5	1.5	
C	0.90	0.10	1.5	1.5	0.5
D	0.85	0.15	1.5	1.5	
E	0.80	0.20	1.5	1.5	

C. *Sample Preparation*

The required amount of fresh concrete to prepare the test samples was mixed in a pan mixer with a capacity of 40 litres. Once a uniform mixture is formed, the fresh concrete was placed into the respective plywood moulds. After casting, the specimens were covered with plastic sheet to avoid excess evaporation. The specimens were demoulded after 24±3 hours of casting and left to cure until the day of testing. All the samples had a 28-day air-dry density of less than 1850kg/m^3 which classifies them as lightweight concrete [8].

D. *Curing Conditions*

Two types curing conditions as shown in Table II were incorporated to study the effect of curing environment on the performance of EPS RHA concrete bricks.

Table II: Curing Regimes

Curing Method	**Temperature (°C)**	**RH (%)**	**Duration of Curing (day)**		
			Mould	**Water**	**Air**
Full water	24±2	100	1	UAT*	0
Air-dry	26±3	73±5	1	0	UAT*

***UAT-Until age of testing**

III. Test Methods

A. *Fresh Concrete Properties*

The fresh concrete properties investigated under this study include workability [9], fresh density [10] and air content [11].

B. *Hardened Concrete Properties*

The hardened concrete properties for EPS RHA concrete bricks tested were compressive strength [12], sorptivity [13] and thermal conductivity [14]. All samples were tested at 3, 7 and 28 days and the results were reported as an average of three tested samples. Bricks of size 215mm x 102.5mm x 65mm were used for compressive strength test. Specimen size of 100mm x 100mm x 100mm was prepared for the sorptivity test while specimen size of 300mm x 300mm x 60mm was prepared for thermal conductivity test.

IV. Results and Discussions

A. *Fresh Concrete Properties*

The results of the fresh concrete properties are presented in Table III. The results demonstrate the tendency of slump to decrease as the RHA ratio increases. The decline in the slump values can be related to the high porosity of the RHA particles as represented by the high specific surface area and LOI value which caused the mix become drier. The fresh concrete density was in range of 1750-1838 kg/m^3. The experimental results indicated that the increased amount of RHA in the mixes produced higher percentage of air content for the mixes. It is due to the porous nature of the RHA which induces more pores in the concrete mix. The air content for the all mixes was within the acceptable range of 4-8% as stipulated by ACI 213R [8].

Table III: Fresh Concrete Properties

Samples	Slump height, (mm)	Air Content, %	Fresh concrete density, (kg/m^3)
A	100	5.2	1838
B	90	5.5	1810
C	80	6.1	1790
D	70	6.5	1770
E	65	6.9	1750

B. Compressive Strength

The compressive strength of the EPS RHA concrete bricks at 3, 7 and 28 days under full water and air-dry curing are presented in Fig. 2 and Fig. 3. Due to the high reactivity of RHA as exhibited by the high content of amorphous silica and large specific surface area of 20220 m^2/kg, which indicates the porous structures [15], all the concrete bricks with RHA replacement showed higher compressive strength the early age (3 days) as compared to control sample. This is consistent with the findings of other researchers [16]. According to the test results, sample C with 10% RHA replacement showed the highest compressive strength under both full water curing and air-dry curing at all ages.

From the result obtained, the highest 28-days compressive strength value of 17.51 N/mm^2 was obtained from the mix made of 10% RHA replacement (Sample C). This represents an increase in compressive strength of up to 25.75% as compared to the control sample under full water curing. As expected, full water curing produced highest compressive strength at all ages for all samples as compared to air-dry curing condition. However, all brick samples achieved the minimum compressive strength of 7 N/mm^2 according to MS76:1972 [12] for Class 1 load bearing purposes.

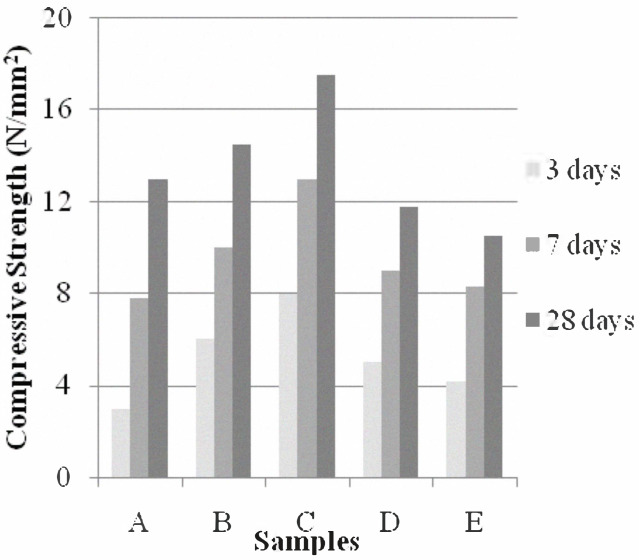


Figure 2: Compressive Strength for different samples under full water curing

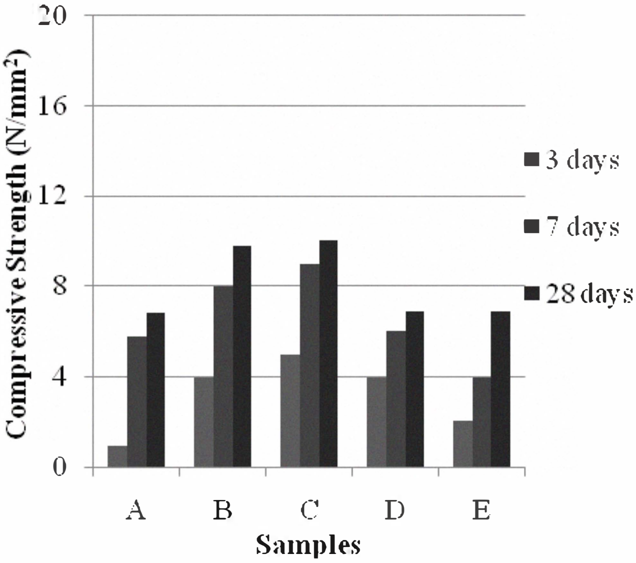


Figure 3: Compressive Strength for different samples under air-dry curing

C. Sorptivity

Sorptivity is a material property that describes the tendency of porous material to absorb and transmit water by capillary suction [17]. As expected, the concrete bricks under air dry curing had higher sorptivity than those samples cured in full water curing. The sorptivity values for full water and air dry curing were in the range of 0.075-0.145mm/$min^{0.5}$ and 0.113-0.186 mm/$min^{0.5}$ at 28 day age respectively. The sorptivity values of the EPS RHA concrete bricks at 3, 7 and 28 days under full water and air-dry curing are presented in Fig. 4 and Fig. 5.

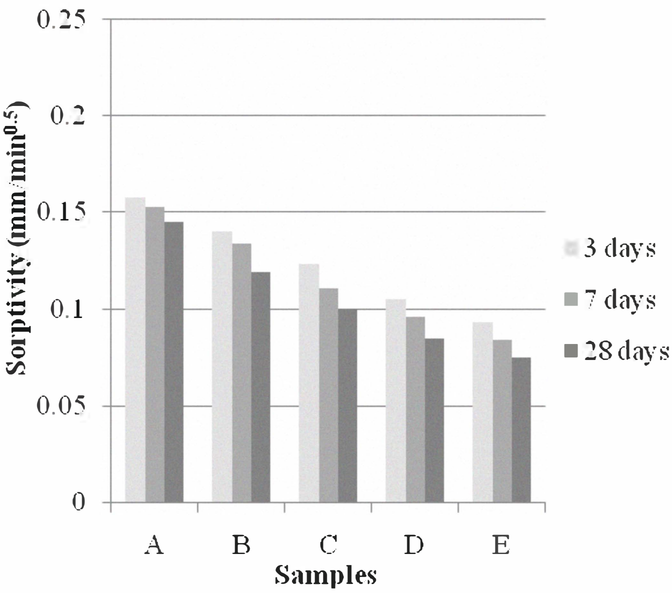


Figure 4: Sorptivity for different samples under full water curing

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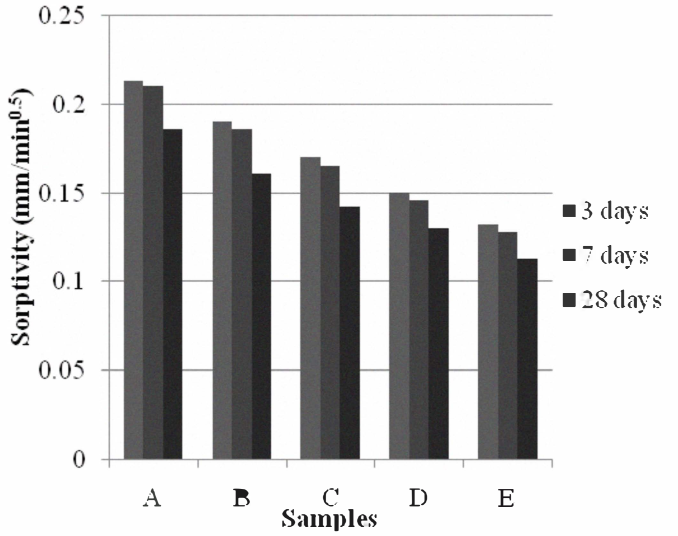

Figure 5: Sorptivity for different samples under air-dry curing

D. Thermal Conductivity

Thermal conductivity is the measurement of the ability of a substance to conduct heat, determined by the rate of the heat flow. Fig. 6 and Fig. 7 show the thermal conductivity values of the EPS RHA concrete bricks at 3, 7 and 28 days under full water and air-dry curing conditions. Fig. 8 shows the relationship between the thermal conductivity of samples cured under full water curing and concrete density.

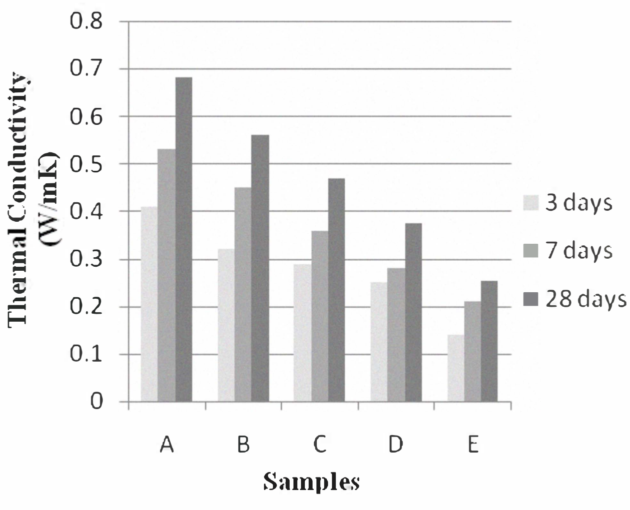

Figure 6: Thermal conductivity for different samples under full water curing

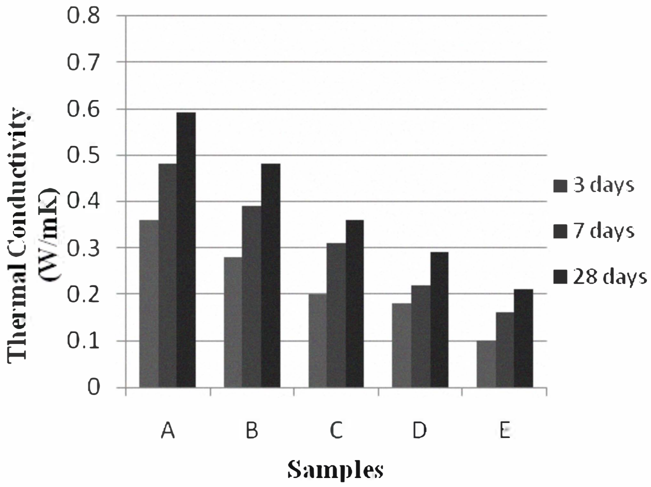

Figure 7: Thermal conductivity for different samples under air-dry curing

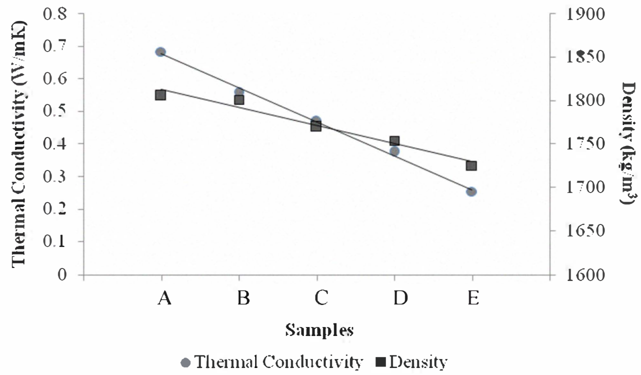

Figure 8: Relationship between thermal conductivity of samples cured under full water curing and 28-day air-dry hardened concrete density.

From Fig. 8, it can be observed that the thermal conductivity decreases as the density of the samples reduced. Previous researchers have also reported that the thermal conductivity generally decreases as the density decreases [18,19]. EPS has a low thermal conductivity value of between 0.36-0.46 W/mK [20]. Therefore, the combined effects of the porous nature of RHA and the low thermal conductivity of raw EPS beads resulted in the lower thermal conductivity of the bricks. Air-dry curing produced concrete bricks with lower thermal conductivity. The thermal conductivity values under full water and air-dry curing at 28 day ages were in the range of 0.254-0.682 W/mK and 0.21-0.59 W/mK respectively. Sample C (10% RHA) under full water curing reduces the thermal conductivity by approximately 31% as compared to control sample A, which is encouraging for higher energy saving potential in residential applications.

V. CONCLUSIONS

EPS RHA lightweight 'green' concrete bricks not only can be considered as environmentally friendly building materials but also shows better energy savings. Based on the experimental results of this investigation, it can be concluded that:

1. The slump, fresh density and air content for EPS RHA concrete bricks was in the range of 65- 100mm, 1750-1838 kg/m^3 and 5.2-6.9% respectively.

2. Sample C with 10% RHA replacement showed the highest compressive strength of 17.51N/mm^2 at 28 days ages under full water (C1) curing. Further replacement of RHA decreases the compressive strength of the samples.

3. All brick specimens conformed to MS 76:1972 [12] as class 1 load bearing brick.

4. The sorptivity values for lightweight concrete bricks under full water and air-dry curing at 28 day ages were in the range of 0.075-0.145 mm/min$^{0.5}$ and 0.113-0.186 mm/min$^{0.5}$ respectively.

5. The increase in the RHA content produced lower thermal conductivity values as compared to the control mix, sample A. The thermal conductivity decreases as the density of the samples reduced. The thermal conductivity values for lightweight concrete bricks under full water and air-dry curing at 28 day ages were in the range of 0.254-0.682 W/mK and 0.21-0.59 W/mK respectively.

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