EPS RHA Concrete Bricks – A New Building Material

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ABSTRACT

Reuse of agricultural wastes and industrial by-products for building materials has been gaining popularity in the recent years. Agricultural waste material; namely rice husk ash (RHA), and industrial by-product; namely expanded polystyrene beads (EPS) are discarded in large amounts globally, causing increased environmental problems. Therefore, this paper introduces innovative efforts of the combined use of RHA and EPS wastes for the production of EPS RHA lightweight concrete bricks. Results showed that the commercial development of EPS RHA bricks is not only highly promising but also effectively sequestering the accumulation of these waste materials.

KEYWORDS: Renewable material, Solid waste, Lightweight concrete brick, Compressive strength, Sorptivity, Thermal conductivity.

INTRODUCTION

Nowadays, clay bricks are considered one of the most important building materials used to construct walls for buildings. Due to the unsustainable mining of clay soil for clay brick making, cement bricks have been introduced into the industry providing more alternatives. However, the production of cement bricks consumes an enormous amount of cement. Besides, the production of cement is not environmentally friendly. The manufacturing of cement is not only a high energy consuming process, but the production of each tonne of cement releases approximately 1 ton of carbon dioxide (CO_2) into the environment due to the calcinations of the raw materials and the combustion of fuels (Malhotra, 2004). In light of the economic benefits, conservation of natural resources, energy saving and environmental friendliness, the use of alternative materials from waste products has become the main focus of engineers and researchers.

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Rice Husk Ash (RHA) is an agricultural waste material which possesses excellent pozzolanic activity (Zhang and Malhotra, 1996). It is obtained by burning rice husk to remove volatile organic carbon such as cellulose and lignin. Annually, approximately 600 million tons of rice paddy is produced (Chandrasekhar et al., 2003). For every 1000 kg of paddy milled, about 200 kg of husk is produced, and when this husk is burnt, about 40 kg of RHA is generated (Cook, 1986). RHA has 90–95% amorphous silica (Metha, 1992). It is highly porous, lightweight and has a high surface area (Della et al., 2002). Many previous researches showed that RHA can be used successfully in other building materials such as bricks and blocks without any degradation in the quality of products (Nasly and Yassin, 2009; Rahman, 1988).

Besides the strength, the lightweight property of the building materials is an important parameter which has challenged engineers and researchers today to come up with durable lightweight building materials. The conventional method of producing lightweight concrete is by adding lightweight aggregates to the concrete mix. Pumice, scoria, volcanic cinders, tuff, expanded clay, diatomite and shale are the most commonly used lightweight aggregates. Today, the applications of lightweight concrete have extended to building materials such as lightweight concrete bricks. However, the increasing use of these non-renewable lightweight aggregates will cause a significant depletion of natural resources. Therefore, an alternative source for lightweight aggregates is through the utilization of lightweight aggregates from waste materials.

EPS waste is an industrial by-product dumped by most of the packaging industries. It is well known as a stable low density foam of non-absorbent, hydrophobic, artificial ultra-lightweight and closed-cell nature aggregate (Short and Kinniburgh, 1978; Sussman, 1975). It is suitable for the production of building materials with low density in wide applications like load-bearing concrete blocks and composite flooring systems (Cook, 1983; Godwin, 1982). It is expected that the low thermal conductivity properties of the EPS will give it a value-added advantage when incorporated in concrete brick as it can produce concrete bricks with better thermal resistivity.

In the current paper, due to the combined benefits of RHA and EPS wastes, these wastes are used as partial replacement for cement and aggregate respectively in the production of economically affordable and environmental friendly new building material – lightweight concrete bricks. Two types of curing regimes were used to cure the RHA EPS concrete bricks; namely 7-day water curing and full water curing as the control curing. This paper presents the research work undertaken to study the main properties; namely compressive strength, sorptivity and thermal conductivity of this new composite building material.

MATERIALS

EPS and RHA

EPS used in the entire research were collected locally. The maximum size, specific gravity and fineness modulus of the EPS aggregate used were: 8mm, 1.05 and 5.50, respectively. RHA used was obtained from Thailand. The ash was first ground using a Los Angeles grinding machine until it met the ASTM C 618 fineness specification. Its Loss On Ignition (LOI), specific gravity and specific surface area were: 6.78%, 2.02 and 20220 m^2/kg, respectively. X-ray fluorescence (XRF) analysis showed that its main constituent was silica (87.97%). According to ASTM C 618, this RHA can be considered as an artificial pozzolan (Moayad et al., 1984; Ramezanianpour et al., 2007). X-ray diffraction (XRD) analysis also confirmed that RHA was mainly amorphous silica formation in quartz mineral group. The functional groups of silicon dioxide in RHA were also characterized by Fourier Transform Infrared Spectroscopy (FTIR) using Shimadzu Iraffinity-1. Fig. 1 shows the FTIR spectrum of RHA.

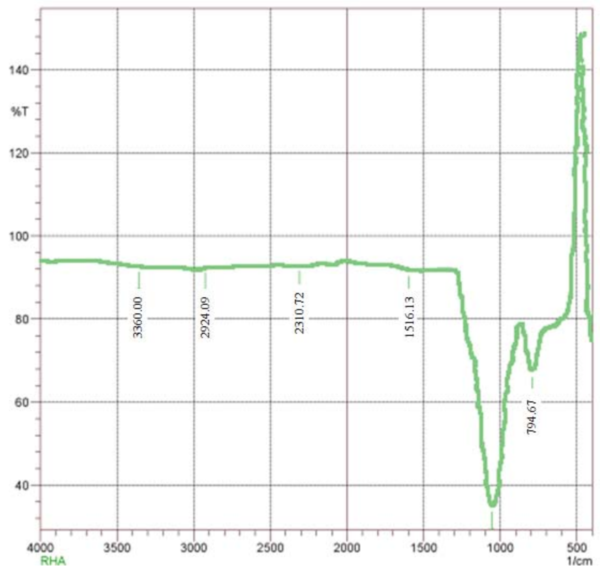


Figure 1: FTIR spectrum of RHA

The functional group of silica or silicate is described in the wave number region of 450-475 cm^{-1}, 750-800 cm^{-1} and 1000-1100 cm^{-1}. The band around 450- 475 cm^{-1} is due to the bending vibration of Si-O-Si while the presence of the wave number region of

750-800 cm^{-1} is attributed to the symmetric stretching mode of the Si-O-Si bond. The Si-O-Si asymmetry stretching vibration of the structural siloxane bond was represented by the wave number region of 1000-1100 cm^{-1} (Jackson et al., 1990). The FTIR spectrum again confirmed the existence of the functional group of Si-O-Si in RHA and the presence of silica in RHA which promotes pozzolanic activity.

Other Materials Used

ASTM Type I Ordinary Portland cement was used in this investigation. The chemical composition and physical properties of the cement conformed to MS 522: Part 1: 2003. It has a specific gravity of 3.05. River sand with maximum aggregate size of 1.18mm, having specific gravity, fineness modulus and moisture content (air-dry) of 2.60, 1.4 and 0.66%, respectively, were used. Glenium C380 superplasticizer was used as chemical admixture in the mix while potable water was used for mixing and curing.

Mixture Compositions

Five types of concrete mixes were prepared in this research. The mix proportion was adopted by volume. Sample A which acts as a control sample has a Cement: RHA: Sand: EPS ratio of 1: 0: 1.5: 1.5. Samples B, C, D and E contain different levels of RHA replacement as shown in Table 1. The amount of superplasticizer used was 800 ml per 100 kg of cement.

Table 1. Mix proportions

Samples	kg/m^3				Volumetric replacement of cement with RHA%	Water-Cement ratio
	Cement	RHA	Sand	EPS		
A	425	0	542	219	0	0.5
B	403	14	542	219	5	
C	382	28	542	219	10	
D	360	42	542	219	15	
E	339	56	542	219	20	

EPS RHA Concrete Brick Production

The required amount of fresh concrete to prepare the samples was mixed in a pan mixer with a capacity of 40 litres. All materials, except water and superplasticizer, were first put in a typical pan mixer and mixed for five minutes. After that, the EPS beads were added and thoroughly mixed into the mortar for three minutes. Once a uniform mixture was formed, the fresh concrete was cast into the respective plywood moulds. In order to minimize segregation, all the mixes were compacted by hand tamping. Immediately after casting, the specimens were covered with plastic sheet in order to avoid excess evaporation. One day after casting, the samples were demoulded and cured until the age of test.

Curing Conditions

2 types of curing condition were employed in this investigation; namely full water curing and 7-day water curing. For full water curing condition, the specimens were demoulded after 24±3 hours and immersed in water in the laboratory water tank with a water temperature of 24±2 ˚C and a relative humidity of 100% until the age of testing. For the 7-day curing condition, after the specimens were demoulded after 24±3 hours, they were immersed in water for an additional period of six days. The specimens were then taken out and placed in the laboratory until the age of testing. The temperature and relative humidity for the laboratory condition were 26±3˚C and 73±5%, respectively.

Experimental Testing

The fresh and hardened concrete properties of the EPS RHA concrete bricks were determined in this investigation. The fresh concrete properties investigated included slump (BS1881: Part 102), air content (ASTM C231) and fresh density (BS 1881: Part 107). The main engineering properties for the hardened concrete bricks; namely compressive strength (MS76:1972), sorptivity (Chan and Ji, 1998) and thermal conductivity (ISO 8301) were also determined in this investigation. For compressive strength, sorptivity and thermal conductivity test, the results reported were taken as an average of three tested samples. All samples were tested at 28, 56, 90, 180 and 270 days. Bricks of 215mm x 102.5mm x 65mm size were used for conducting the compressive strength test; while samples with a size of 100mm x 100mm x 100mm were prepared for the sorptivity test. Samples with a size of 300mm x 300mm x 60mm were prepared for the thermal conductivity test.

RESULTS AND DISCUSSION

Fresh Concrete Properties and 28-day Air-dry Density

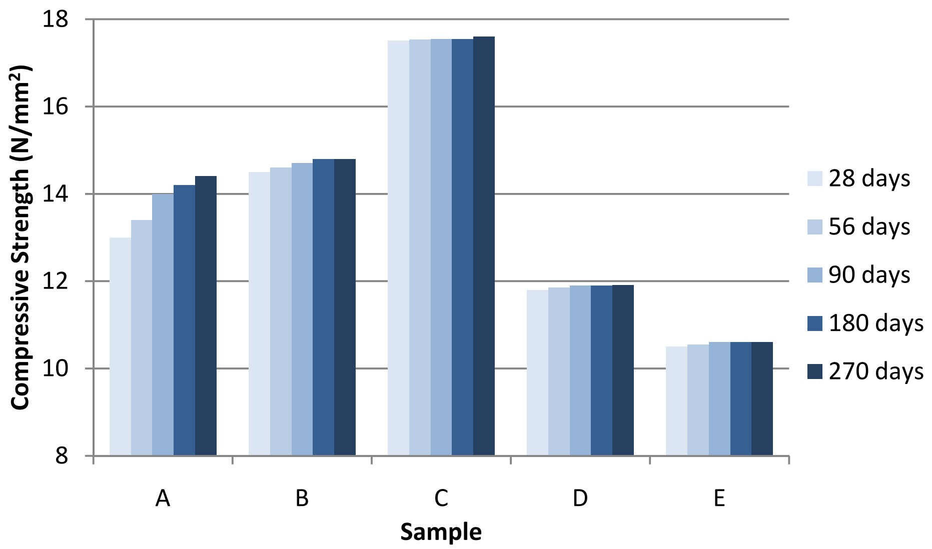
The fresh concrete properties and 28-day air-dry density for the concrete bricks are shown in Table 2. It can be seen that slump and density values reduced with the increase in RHA content. The decrease in slump value is due to the high porosity and the high specific surface area of the RHA particles which caused the mix to become drier. The air content showed an increasing trend as the RHA replacement in the concrete bricks increased. This occurred due to the high porosity of RHA which induces a lot of pores in the mixes. The slump, fresh density and air content for the concrete bricks were in the range of 65-100 mm, 1750-1838 kg/m^3 and 5.2-6.9%, respectively. The air content value is still within the range of 4-8% as stipulated by ACI 213 R-87.

Table 2. Slump, air content, fresh concrete density and 28-day air-dry density

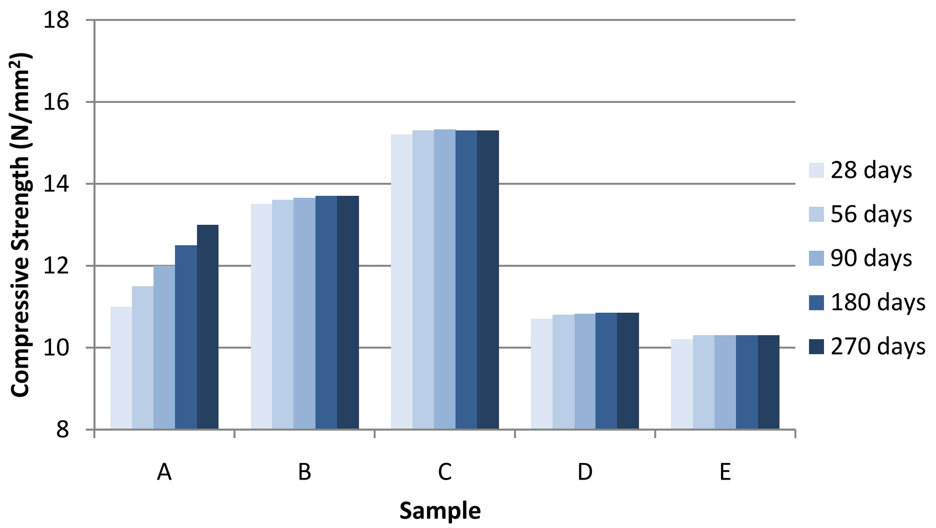
Samples	Slump, (mm)	Air Content, %	Fresh concrete density, (kg/m^3)	28-day air-dry density (kg/m^3)
A	100	5.2	1838	1805
B	90	5.5	1810	1801
C	80	6.1	1790	1769
D	70	6.5	1770	1754
E	65	6.9	1750	1725

Compressive Strength, Sorptivity and Thermal Conductivity

The average compressive strength values at ages of 28, 56, 90, 180 and 270 days are illustrated in Fig. 2 (a) and Fig. 2 (b) under full water curing and 7-day curing conditions. From Fig. 2(a) and Fig. 2(b), it can be noted that samples B, C, D and E do not show any significant increment of compressive strength at the later ages as compared to control sample A. This is due to the high reactivity of RHA which utilized all of the calcium hydrate in the mix to form calcium silicate hydrate (C-S-H) at the early ages. As expected, the highest compressive strength was achieved for all samples under full water curing as compared to 7-day curing condition. At the age of 28 days under full water curing condition, sample C bricks managed to achieve a compressive strength of 17.51N/mm^2 which classifies them as Class 2 load-bearing bricks according to MS76:1972. The increase in RHA replacement up to 10% produced the highest compressive strength under full water curing condition and 7-day curing condition. Beyond 10% RHA replacement, the decrease in compressive strength values was clearly observed. All the EPS RHA concrete brick samples were found to have higher compressive strengths of about 1.2-2.0 times when compared to locally available cement bricks at the age of 28 days. All EPS RHA samples meet the minimum compressive strength of 7 N/mm^2 as stipulated in MS76:1972 for Class 1 load bearing purposes.

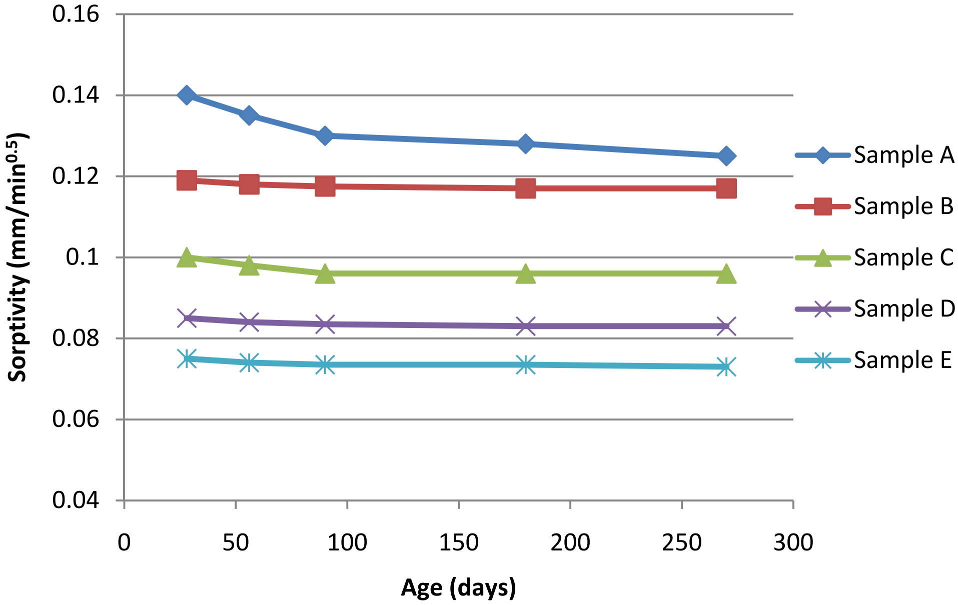


(a) Full water curing condition

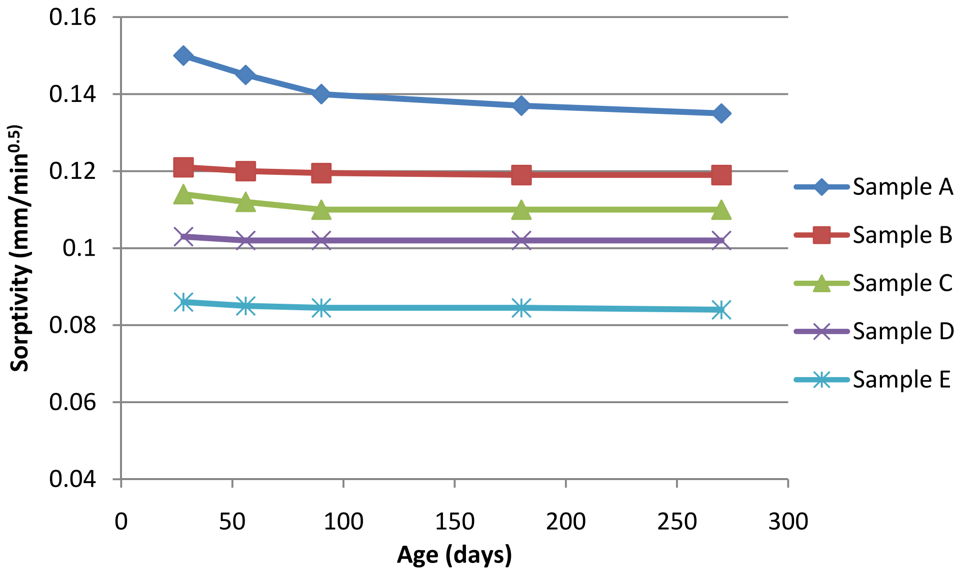


(b) 7-day curing condition

Figure 2: Compressive strength for different samples under different curing conditions



(a) Full water curing condition



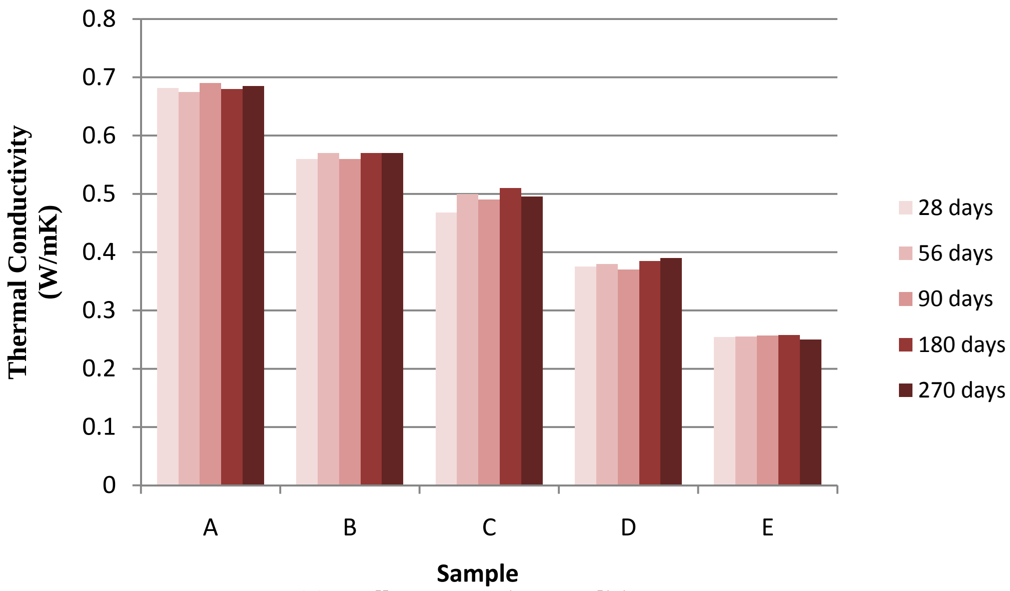
(b) 7-day curing condition

Figure 3: Sorptivity for different samples under different curing conditions

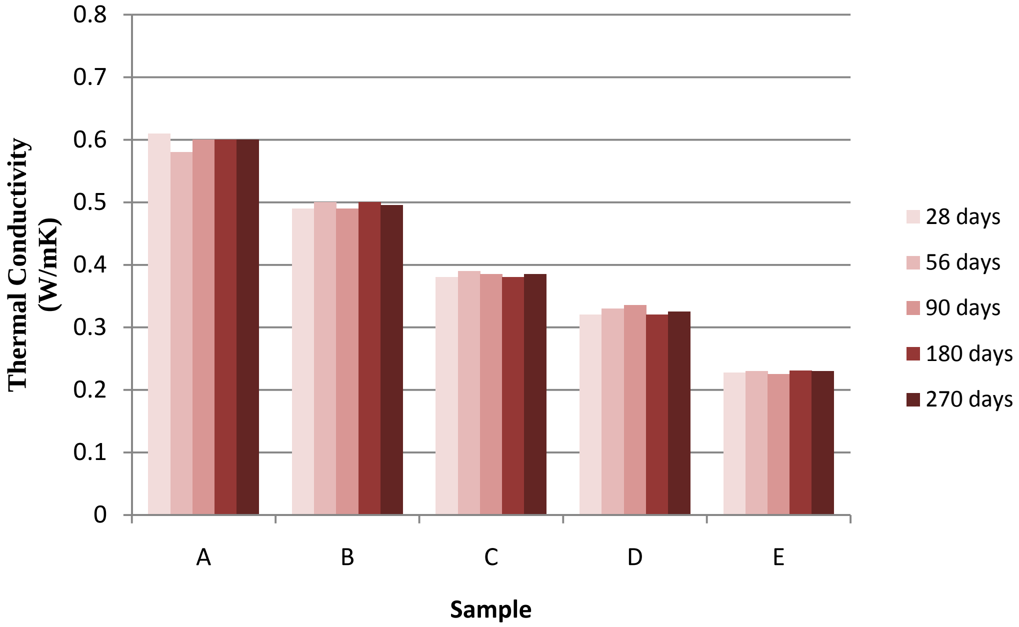
Sorptivity gives a reliable measurement of the surface absorption for masonry units (Reda Taha et al., 2001). Fig. 3(a) and Fig. 3(b) show the sorptivity values for concrete bricks at 28, 56, 90, 180 and 270 days of age under full water curing and 7-day curing conditions. From the results obtained, it can be noted that the sorptivity values for sample A decreased significantly at the age of 28 days until 270 days as compared to other samples. This is because the capillary sorption of sample A reduced due to the cement hydration at the later ages. There were no significant decreases of sorptivity values for samples B, C, D and E at the later ages, since most of the pozzolanic reactions take place at the early ages due to the presence of RHA.

From Fig. 3, it can also be seen that the sorptivity values of EPS RHA concrete bricks are affected by different curing conditions and different percentages of RHA replacement with cement. As expected, the 7-day curing condition had higher sorptivity value compared to full water curing. The increase in the RHA replacement in the concrete bricks produced a lower sorptivity value due to the microfiller effect which takes place. This was also reported in a previous study by Goldman and Bentur (1993). The sorptivity values for full water curing and 7-day curing conditions at 28 days of age were in the range of 0.075-0.14 $mm/min^{0.5}$ and 0.086-0.150 $mm/min^{0.5}$, respectively (Poon et al., 2006). In general, these sorptivity values were well compared to lightweight concretes made from oil palm shell (Teo et al., 2010) and Liapor (expanded clay) (EuroLightCon, 2000) which have sorptivity values of 0.06-0.14 $mm/min^{0.5}$ and 0.06 $mm/min^{0.5}$, respectively.

Thermal conductivity is the property of a material describing its ability to conduct heat (Neville, 1999). Fig. 4 (a) and Fig. 4 (b) show the thermal conductivity values of the concrete bricks at 28, 56, 90, 180 and 270 days under full water curing and 7-day curing conditions. It is well known that by lowering the density of concrete, a lower thermal conductivity can be achieved (Short and Kinniburgh, 1978; Kung et al., 1980; Blanco et al., 2000; Khedari et al., 2001; Yücel et al., 2003; Uysal et al., 2004; Laukaitis et al., 2005). From the results obtained, it can be observed that the thermal conductivity of bricks decreases as the percentage of RHA replacement increases. This is due to the porous structure of RHA, which ultimately reduces the density as shown in Table 2. The thermal conductivity of the bricks under full water curing at 28



(a) Full water curing condition



(b) 7-day curing condition

Figure 4: Thermal conductivity for different samples under different curing conditions

days for 5%, 10%, 15% and 20% RHA replacements decreased 17.88%, 31.38%, 45.01% and 62.76%, respectively. These values compare well with past research on concrete containing silica fume (Demirboğa, 2003), where it was found that the concrete mix with silica fume having replacement of 10%, 20% and 30% produced thermal conductivity reductions of 17%, 31% and 40% as compared to plain concrete (Demirboğa, 2003). As shown in Fig. 4, the thermal conductivity increases as the curing condition changes from full water curing condition to 7-day curing condition. The thermal conductivity of samples under full water curing condition is higher than that of 7-day curing condition, because the air voids of the brick are filled with water. Consequently, the thermal conductivity of the bricks under full water curing condition increased significantly as compared to 7-day curing condition at all ages. The concrete ages do not significantly affect the thermal conductivity values. This is consistent with the findings of Kim et al. (2003). Sample C (10% RHA) under full water curing condition had a reduced thermal conductivity by approximately 31.38% at 28 days as compared to control sample A, which indicates that it can act as an energy conservation building material in residential applications.

CONCLUSIONS

The combined use of EPS and RHA wastes as aggregate and cement replacement respectively has been successfully applied to the production of a more eco-friendly, lightweight concrete brick. The EPS RHA concrete brick sample C under full water curing at 28 days presents a good compressive strength of 17.51 N/mm^2 which can be classified as Class 2 load-bearing brick according to MS76:1972. When compared to the control sample (sample A), sample C gives the best results in terms of compressive strength, sorptivity and thermal conductivity values. Hence, it shows good potential for local residential applications. Therefore, these EPS RHA concrete bricks have made these agricultural and industrial wastes a significant contributor to a holistic approach by the concrete brick industry to the global issue of environmental sustainability.

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