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NATURAL FIBER-REINFORCED LIGHT-WEIGHT CEMENT BLOCKS PREPARED FROM WASTE FOR SUSTAINABLE DEVELOPMENT

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Abstract. Low density of the light-weight cement blocks offers an advantage in terms of dead load reduction, which is advantageous in structural design-reduction of size and numbers of load-carrying structural components is possible. Production of cement blocks, however, generally requires Ordinary Portland Cement (OPC) which creates harmful environmental impacts. Utilization of waste as alternative raw materials for cement production is a route to alleviate the problem. This research aims at synthesizing eco-friendly cement-like material for production of light-weight cement blocks. The cement-like material were prepared from eggshells, cockleshells, and rice husk ash (RHA). With high content of calcium oxide and silica, eggshells and cockleshells are potential sources of calcium, whereas RHA is a good source of silicon. Additionally, a fuel-efficient solution combustion technique was employed in synthesis of the cement-like material. Phase identification analysis of the synthesized powder indicated that tri-calcium silicate (C_3S), di-calcium silicate (C_2S), tri-calcium aluminate (C_3A), and tetra-calcium alumino ferrite (C_4AF), which are main constituents of OPC, were obtained. To fabricate eco-friendly light-weight cement blocks, the synthesized cement-like material were mixed with cement, water, and additional RHA and cast into blocks. The optimal compressive strength and density of the cement blocks were in comparable range with the standard light-weight concrete defined by Thai Industrial Standards Institute (TISI) and American Concrete Institute (ACI 213,2001). With jute fiber reinforcement, enhanced compressive strength of 20% was achieved, while elimination of spalling after compression test was clearly evident, implying a more ductile failure.

Keywords: Fiber reinforcement, light-weight cement block, waste.

1. Introduction

As a predominantly agricultural country, agricultural sector in Thailand plays a significant role in economic contribution. With increasing world population and growing demand for agricultural products, considerable amounts of agricultural residues are produced annually. It has been reported that approximately 5 million tons of rice husk are produced in Thailand annually [1]. Residues from poultry industry, one of Thailand's promising agri-food segments, is notable. Production of eggshells in Thailand is estimated to be around 650,000 tons per year [2]. In addition to rice husk and eggs, residue produced from aquaculture is abundant, with approximate amount of 10 thousand tons per year for cockleshells [3]. These remainders are often transformed into waste, disposed in landfill sites and possibly create pollution [4–7]. Efficient utilization of the aforementioned waste is vital to both the economy and environment.

It is well recognized that construction industry is the major consumer of natural resources. To preserve natural resources, emerging technology, such as innovative utilization of waste for construction, is commendable. Since key constituents of cement comprise calcium silicate and calcium aluminate, wastes containing extensive amounts of calcium and silicon have been considered. According to numerous studies, rice husk ash (RHA) contains significant silica content, with the amount exceeding 90 wt% [8, 9]. Cockleshells and eggshells are reported to contain high level of calcium carbonate, in the range between 95 and 99% [10–13]. Hence, rice husk ash, eggshells, and cockleshells can be potential sources of silicon and calcium used as cement-like material.

Along with waste utilization, an efficient route of waste management and reduction of natural resource consumption, production of eco-friendly cement-like material by fuel-efficient techniques can also be a route to save the environment. Reduction of carbon dioxide emissions can provide a positive impact

Components	Components ratio
Tri-calcium silicate (C_3S) and di-calcium silicate (C2S)	0.75
Tri-calcium aluminate (C3A)	0.12
Tetra-calcium alumino ferrite (C_4AF)	0.10
Gypsum	0.03

Table 1. The components of cement-like material.

to the environment. Conventional production of cement requires heating process of raw materials, also called clinker, at the temperature ranging between 1400 and 1600°C. With high temperature calcination, enormous fossil fuel consumption and massive carbon dioxide emission are intensified. It has been reported that 0.81 kg of cement production produces CO2 1 kg on average [14]. Carbon dioxide emission from cement production is a result of processing steps, including 7% from quarrying, 5% from clinker grinding, 3% transportation. Calcination of the clinker is accounted for 85% of carbon dioxide emission [15]. The Natural Resources and Environmental Policy and Planning of Thailand reported that cement industry is responsible for carbon dioxide emission of more than 12 million tons per year [16].

Solution combustion technique is a powder synthesis technique capable of producing fine ceramic powders with controlled chemical composition. The technique involves self-propagating exothermic reaction. In addition to high-quality powder production, this method offers advantages in terms of low fossil fuel consumption and minimal processing time [17]. Since combustion reaction is initiated at the temperature lower than 400°C, and low calcination temperature of 900°C is required for production of cement-like material, considerably lower fuel consumption and diminished carbon dioxide emission is substantially evident.

For practical applications, lightweight cement blocks are required to maintain compressive strength following industrial standards. Thai Industrial Standards Institute (TISI) type C12 demands minimum compressive strength of 2.5 MPa [18]. In addition to adequate strength, high durability and good integrity of the cement blocks are desired. Poor installation of construction component, excessive stress, and environmental factors often cause disintegration of the materials. Flaking and pitting are commonly observed. With addition of fiber reinforcement, alleviation of spalling is possible. Fiber reinforcement can generally enhance mechanical properties of materials through crack abridgement. It has been reported that jute fiber is an effective reinforcing material to improve ductility, compressive strength, flexural strength, and tensile strengths in concrete [19, 20].

This research aims at utilizing waste in synthesis of eco-friendly cement-like materials. Properties of fiber-reinforced light-weight cement blocks prepared from the cement-like materials were also examined.

2. Experimental procedures

2.1. Preparation of Cement-like Material

An initial step to synthesis of cement-like material involves preparation of wastes. To obtain fine particle, with sizes smaller than 45 micrometers, rice husk ash (DhebKaset Industrial Co., Ltd) was ground by ball milling for 2 hours and screened through a 325-mesh sieve. Eggshells and cockleshells were collected from local markets in Bangkok, calcined at 900°C for 3 hours and ball milled.

Solution combustion technique was employed in synthesis cement-like material, consisting of di-calcium silicate (C_2S), tri-calcium silicate (C_3S), tri-calcium aluminate (C_3A), and tetra-calcium alumino ferrite (C_4AF). Di-calcium silicate (C_2S) and tri-calcium silicate (C_3S) were produced by dissolving cockleshells or eggshells and rice husk ash (RHA) in nitric acid 70% (HNO_3, RCI Labscan) with the weight ratio of cockleshell:RHA equal to 0.84 : 0.41. For preparation of C_2S and C_3S using eggshells, the weight ratio of eggshell:RHA of 0.85 : 0.41 was used. Glycine ($C_2H_5NO_2$, Daejung) and deionized water was added to the mixture to obtain aqueous solution with concentration close to 0.2 M, which was subsequently heated at 400°C. Combustion reaction was initiated and resulted in as-synthesized powders. The powder was collected and calcined at 900°C for 3 hours.

C3A and C4AF powders were prepared in a similar approach. For C3A, cockleshells or eggshells were mixed with aluminium nitrate nonahydrate ($Al(NO_3)_3$, Daejung) at weight ratio close to 0.73 : 2.77. C4AF was attained by preparing mixture of cockleshells or eggshells, aluminium nitrate nonahydrate, and 95% ferric oxide red (Fe_2O_3, Lobachemie) at ratio of 0.81 : 2.36 : 0.51 by weight.

To obtain chemical compositions similar to those of the OPC, the synthesized powder of tri-calcium silicate(C_3S) and di-calcium silicate(C_3S), tri-calcium aluminate (C_3A), tetra-calcium alumino ferrite (C_3AF) and gypsum were mixed together with weight ratio of $CS : C_3A : C_4AF :$ gypsum equal to 0.75 : 0.12 : 0.1 : 0.03, as shown in Table 1.

2.2. Casting of Eco-friendly Lightweight Cement Blocks

In order to utilize high content of waste and to minimize usage of OPC, lightweight cement blocks con-

Components of light-weight cement blocks				
Content of fiber [%w/v]	Cement-like [wt%]	OPC [wt%]	RHA [wt%]	Water to binder ratio
1	20	20	60	0.8, 0.9, 1, 1.1, 1.2
1	25	25	50	0.8, 0.9, 1, 1.1, 1.2
1.5	20	20	60	0.8, 0.9, 1, 1.1, 1.2
1.5	25	25	50	0.8, 0.9, 1, 1.1, 1.2
2	20	20	60	0.8, 0.9, 1, 1.1, 1.2
2	25	25	50	0.8, 0.9, 1, 1.1, 1.2

TABLE 2. Components of light-weight cement blocks consisting of cement-like material, OPC, rice husk ash and natural jute fiber with water to binder ratio of 0.8 to 1.2 and autoclaving 6 hours after curing in water 7 days.

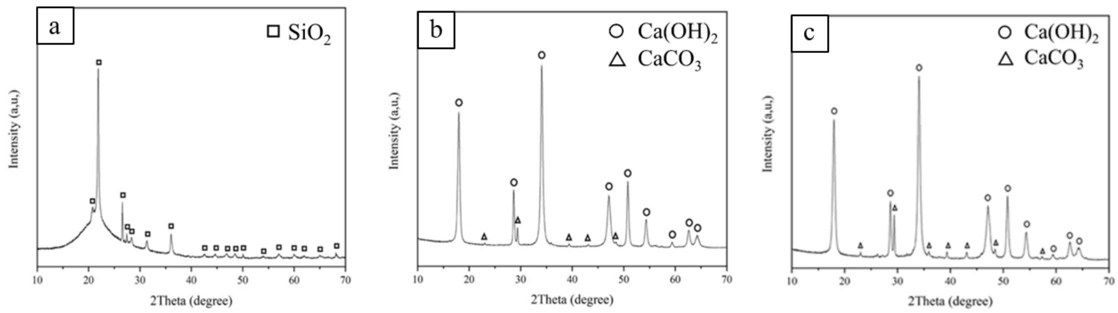

FIGURE 1. a) X-ray diffraction pattern of rice husk ash, b) X-ray diffraction pattern of cockleshells, c) X-ray diffraction pattern of eggshells

taining 50 – 60 wt% of RHA were fabricated. The mixtures containing cement-like material, OPC, RHA at weight ratio of cement-like material:OPC:RHA equal to 25 : 25 : 50 and 20 : 20 : 60, respectively, were prepared. To examine optimal water content, the mixtures were mixed with water at the water to binder ratio (W/B) of 0.8, 0.9, 1, 1.1 and 1.2. To examine effects of fiber reinforcement, 1 cm-long jute fibers were added to the mixtures at the content of 1, 1.5 and 2% w/v. The mixtures were casted in a $2.5 \times 2.5 \times 2.5$ cm acrylic mold, cured in water for 7 days and autoclaved for 6 hours. Components of the fiber-reinforced cement blocks are shown in Table 2.

2.3. CHARACTERIZATION

The examination of chemical composition and phase identification of the raw waste materials, such as rice husk ash, cockleshells, and eggshells, as well as the cement-like material, were conducted by x-ray diffraction (Philips, XPert). Compressive strength of the lightweight cement blocks was determined by using a universal testing machine (Hounsfield, H50KS), whereas optical micrographs were obtained from the optical microscope (Lica, DM2700M).

3. RESULTS AND DISCUSSION

3.1. PHASE IDENTIFICATION OF RAW WASTE MATERIALS

X-ray diffraction was employed in phase identification of rice husk ash, cockleshells, eggshells. According to x-ray diffraction patterns shown in Figure 1, rice husk ash contained a single phase of silica (SiO_2, JCPDS 01-074-9378). Observations from this study was consistent with numerous researches [21–23]. The x-ray diffraction patterns of cockleshells and eggshells were similar in nature. The patterns, as shown in Figure 1, contained prominent peaks corresponding to calcium hydroxide ($Ca(OH)_2$, JCPDS 01-084-1263) and calcium carbonate ($CaCO_3$, JCPDS 01-085-1108).

With high silica content and high calcium content, rice husk ash, cockleshells and eggshells had great potential for usage as raw materials for producing cement constituents such as tri-calcium silicate (C_3S) and di-calcium silicate(C_2S), tri-calcium aluminate (C_3A) and tetra-calcium alumino ferrite (C_4AF).

3.2. PHASE IDENTIFICATION OF CEMENT AND CEMENT-LIKE MATERIAL

As mentioned in the previous section, high silica content and high calcium content facilitate the use of rice husk ash and cockleshells in the production of C_3S, C2S, C_3A, and C_4AF. In this section, x-ray diffraction was also employed in phase identification of the synthesized powders. X-ray diffraction pattern of the synthesized powders revealed prominent peaks corresponding to tri-calcium silicate (Ca3SiO5, JCPDS 00-031-0301), di-calcium silicate (Ca2SiO4, JCPDS 00-029-0369), tri-calcium aluminate ($Ca_3Al_2O_6$, JCPDS 00-008-0005) and tetra-calcium alumino ferrite ($Ca_4Al_2Fe_2O_10$, JCPDS 00-011-0124). The pattern, as showed in Figure 2, was also similar to the diffraction pattern obtained from

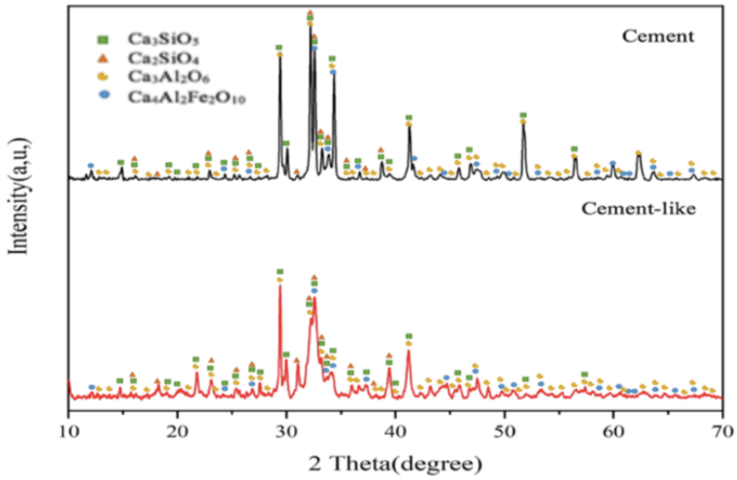

Figure 2. X-ray diffraction pattern of the ordinary Portland cement (OPC) and cement-like material containing tri-calcium silicate (Ca_3SiO_5), di-calcium silicate (Ca_2SiO_4), tri-calcium aluminate ($Ca_3Al_2O_6$) and tetra-calcium alumino ferrite ($Ca_4Al_2Fe_2O_10$)

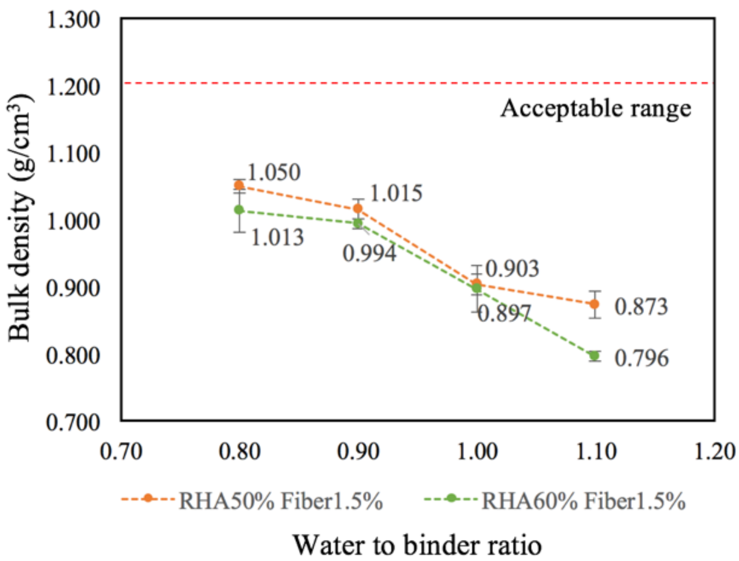

Figure 3. A relationship between bulk density and W/B ratio of jute fiber-reinforced cement blocks containing RHA50% and RHA60%.

OPC. The results suggested that the cement-like material synthesized by solution combustion technique might be alternative materials used for substitution of ordinary cement.

3.3. Effects of Water Content on Density of Lightweight Cement Blocks

Water-to-binder ratio (W/B) is one of the most critical parameters influencing properties of construction components containing cement, specifically workability, strength, and durability. Determination of the W/B is therefore crucial for quality control during lightweight cement blocks production and general quality assurance purposes [24, 25].

In this study, the mixture containing synthesized cement-like material, OPC, rice husk ash, and jute fibers were mixed with water at the W/B ratios ranging from 0.8 to 1.1, and cast into cement blocks. After 7 days of curing in water and autoclave, the cement blocks were tested for their density.

The results, as shown in Figure 3, revealed density values ranging from 0.873 to 1.050 g/cm^3 and from 0.796 to 1.013 g/cm^3 in the fiber-reinforced cement blocks containing 50 and 60 wt% rice husk ash, respectively. High water content diminished bulk density. This is attributed to formation of capillary water from excessive water content. The water subsequently evaporates and leads to formation of capillary pores. It was also found that the cement blocks containing high RHA yielded lower density. This is attributed to low bulk density of rice husk ash (Dhe-

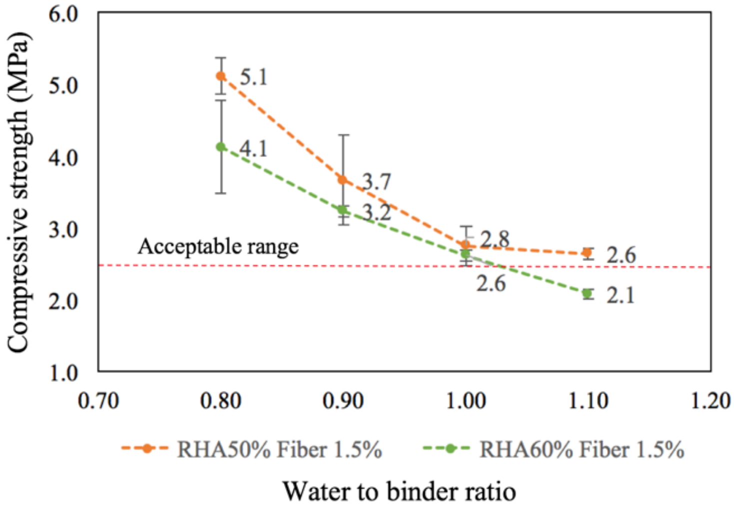

FIGURE 4. A relationship between water to binder ratio and compressive strength of jute fiber-reinforced cement blocks containing RHA50% and RHA60%.

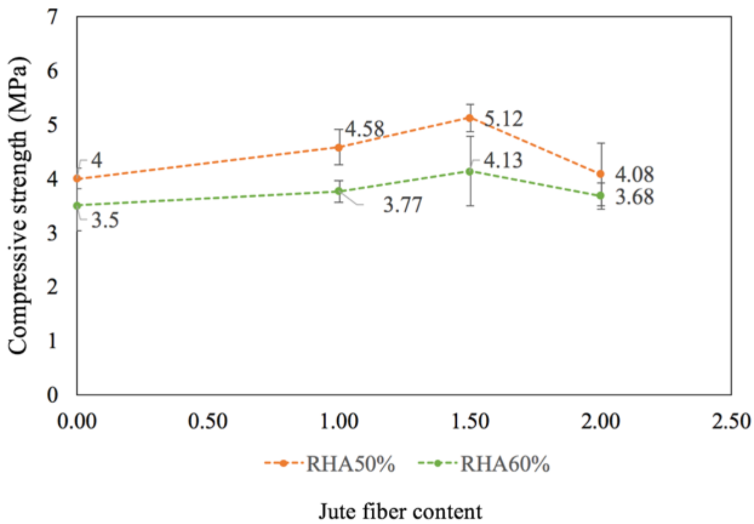

FIGURE 5. A Relationship between compressive strength and jute fiber contents of cement blocks containing RHA50% and RHA60%.

bKaset Industrial Co., Ltd) of 0.33 g/cm^3.

According to Type C12-Thai Industrial Standards Institute (TISI 2601-2556), it is required that the lightweight concrete must have density lower than 1.2 g/cm^3. The overall density values of the cement blocks obtained in this study were in an acceptable range according to TISI 2601-2556.

3.4. Effects of Water Content on Compressive Strength of Lightweight Cement Blocks

The results from compressive strength measurements of the fiber-reinforced cement blocks indicated that the strength values ranging from 2.6 to 5.1 MPa and 2.1 to 4.1 MPa was achieved in the cement blocks containing 50 and 60 wt% rice husk ash, respectively. In this study, the optimal W/B ratio for enhancement of compressive strength was 0.8. With high W/B ratio, compressive strength was diminished. Minimal compressive strength was associated with low density, which was the result of excessively high water content.

In addition, the results, as shown in Figure 4, also revealed that higher content of rice husk ash could result in reduction of compressive strength. With high RHA, content of cement and cement-like material, which play a role as binding materials and reagent for hydration reactions, was minimized. Uneven and discontinuous distribution of the cementitious materials could occur, which possibly cause low compressive strength.

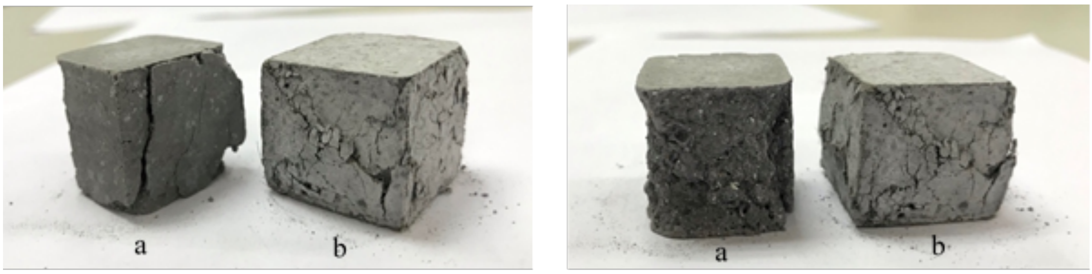

Figure 6. Lightweight Cement Blocks after compression: a) RHA 50% W/B 0.8 autoclaved 6 hours (no jute fiber), b) RHA 50% W/B 0.8 autoclaved 6 hours (with 1.5% jute fibers).

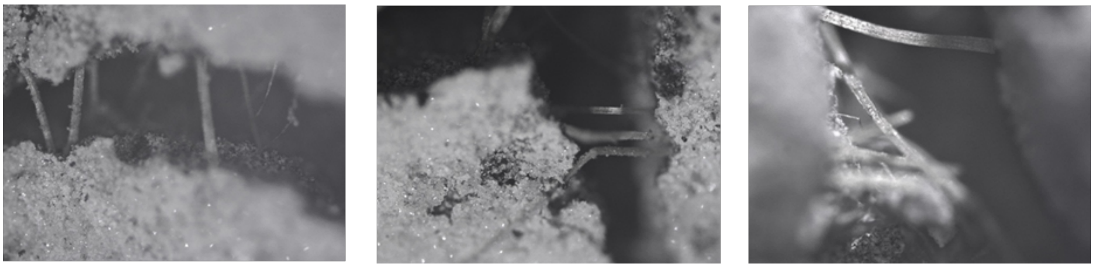

Figure 7. Optical microscographs image (x5) of lightweight cement blocks after compression test.

3.5. Effects of Fiber Contents on Compressive Strength of Lightweight Cement Blocks

In this study, compressive strength of cement blocks with W/B lower than 1.1 were higher than the minimum compressive strength values required by Thai Industrial Standards Institute (TISI 2601-2556)-Type C12. With acceptable range of both density and compressive strength, jute fiber-reinforced cement blocks tended to have great potential for practical utilization.

In the previous sections, it was found that the optimal water to binder ratio to achieve acceptable density while retaining high compressive strength was 0.8. In this section, optimal content of jute fibers for enhancement of compressive strength was examined.

For the cement blocks containing 50 wt% RHA, the minimal and optimal compressive strength was observed in the un-reinforced cement blocks and the reinforced cement blocks with 1.5% jute fiber, respectively. A similar trend was observed in the cement blocks containing 60 wt% RHA, as shown in Figure 5. The results indicated that with an optimal content of fiber reinforcement, compressive strength could increase from 4 to 5.12 MPa and from 3.5 to 4.13 MPa in cement blocks containing 50 and 60 wt% RHA, respectively. An increment of 18 to 28% of compressive strength was consistent with numerous studies [26].

Fibers with high tenacity, such as jute fibers, can be substantially beneficial for improvement of mechanical properties of cement blocks. In addition, high homogeneity mixing of short random fibers can increase the integral adhesion force within the cement blocks, resulting in reduction of spalling in cement blocks when subjected to compression, as showed in Figure 6. Observation from this study was concurrent with S. P. Kundu et al, which revealed that the un-reinforced samples were disintegrated after the maximum load was applied. On the contrary, for the samples with jute fiber reinforcement-cracks appeared without spalling even when the samples were subjected to the maximum load [27–29].

It has been generally accepted that mechanical property enhancement of fiber-reinforced composites can be attributed to crack bridging mechanism. As shown in Figure 7, jute fibers functioned as bridges, joining cement matrix, which consequently resulted in good integrity of the samples subjected to compressive stress.

Despite the aforementioned advantages, excessively high fiber content did not result in improved compressive strength. According to M. Zakaria et al, addition of fiber of more than 2% could lead to fiber ball-up and intermeshing while mixing, and resulted in inferior mechanical strength [19, 30, 31].

4. Conclusion

Eco-friendly fiber-reinforced light-weight cement blocks with acceptable density and compressive strength were successfully fabricated. Cement-like material, an alternative material for OPC which was used as binder for cement block production, was synthesized by solution combustion technique. In addition to utilization of waste, specifically cockleshells, eggshells and rice husk ash, the synthesis technique required low energy consumption, which could be integral part toward sustainable development.

Additionally, effects of processing parameters, including water to binder ratio, rice husk ash content and jute fiber content, were examined. To achieve the optimal compressive strength, water to binder ratio of 0.8 and 50% of rice husk ash were required in this study. By adding jute fiber with the amount of 1.5%, compressive strength enhancement as high as 28% could be achieved.

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