Performance of lightweight cement board using coconut coir fiber and expanded polystyrene foam waste

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Abstract. Lightweight cement hybrid materials based on expanded polystyrene (EPS) foam waste and coconut coir fiber (CF) have been developed as an effective method for industrial and agricultural wastes management. The purpose of this study is to investigate the effects of CF and EPS foam as cement replacements at various proportions of EPS foam and CF at various lengths of CF on the properties of cement composites. The mixtures containing partial replacement of cement by 1, 2 and 3% CF with three different CF lengths (1, 2 and 3 cm) and 1, 2 and 3% EPS foam were prepared. The physical and mechanical properties of the specimens were determined after 28 days of hydration. The flexural strength and impact strength of the composites increased with CF content. Meanwhile, the bulk density clearly decreased along with the addition of EPS foam. The cement composites containing 3% CF and 1% EPS as well as 2% CF and 2% EPS at 2 cm fiber length showed acceptable strengths and density for structural lightweight cement. The results indicated that EPS foam and CF can be used as replacements for cement and asbestos in the production of fiber board cement to obtain inexpensive, lightweight and strong product.

1. Introduction

Nowadays, cement board is one of the most widely used construction materials. The most common type of fiber cement is asbestos cement. The major attractions of asbestos cement products to the users are durability and cost-effectiveness. However, asbestos fibers are carcinogenic. Alternatively, there are other types of organic or inorganic fibers, which are safer to human health [1]. The rapid growth of urbanization and industrialization has generated huge amounts of industrial and agricultural wastes. A circular economy in recycling and waste management is a systematic approach to minimize the problem. In this regard, the use of industrial and agricultural wastes should be considered in attempt to develop new cement board composites. Many researchers have shown several advantages in using natural fibers in cement composites: increased impact strength, increased flexural strength, and decreased bulk density [2-3]. Coconut fiber has one of the highest lignin contents, making it stronger than other natural fibers [2]. For industrial wastes, EPS is mainly used as an insulating or packaging material in various industrial fields. A large number of EPS is consumed, and is disposed as a waste, whilst the availability of mechanical test results will extend EPS geofoam to geotechnical applications, contributing to decreasing the amount of EPS ending up in landfills and more sustainable infrastructure systems [4]. The natural fiber reinforced concrete and EPS concrete have been separately studied in previous works; but until
now, the study is carried out with combination of CF and EPS in cement board. Therefore, the current study presented herein is an attempt to develop lightweight EPS/CF/cement composite with considerable flexural and impact strengths. The influence of EPS foam from waste material in packaging industry and CF as cement and asbestos replacements at different weight contents of EPS foam and CF at different CF lengths on the physical and mechanical properties of fiber cement board was investigated.

2. Experimental

2.1. Materials and specimen preparation
Type I Portland cement satisfying the requirements of ASTM C150 was supplied by Siam Cement Group Company. In this work, CF was brown fiber obtained from Suphan Buri, Thailand. The raw materials were washed with distilled water to remove impurities and then dried at 60°C for 24 h. The cleaned CF with 0.14 mm diameter were then cut into 1, 2 and 3 cm length. Recycled EPS waste from electronics packaging was used. The cleaned EPS waste was ground to reduce the particle size to < 3 mm. All specimens test setup was developed with acrylic mold dimension of 12 cm in length, 5 cm in width and 5 mm in depth. The specimens were removed from the mold after 24 h and then kept in water for 28 days before the test date. In this study, various mixtures were produced by substituting cement with 1, 2 and 3% CF with three different fiber lengths (1, 2 and 3 cm) and/or 1, 2 and 3% EPS foam. The sample name was abbreviated as CxyEz, where the wt% of CF, the fiber length of CF (cm), and the wt% of EPS were denoted as x, y, z, respectively. Meanwhile, CF and EPS were given notation as C and E in the sample name.

2.2 Characterization and testing method
The tests were undertaken in accordance with BS EN 12467:2012 (Fibre-cement flat sheets—Product specification and test methods). The bending test was performed to investigate flexural behaviour of the specimens using the Instron 5965 50kN universal testing machine by the three-point bending tests, whose displacement control rate and span were 2 mm/min and 75 mm, respectively. An Instron CEAST 9050 impact pendulum machine was used to evaluate the impact behaviour of the specimens. The bulk density of the specimens was measured using a density kit (Mettler Toledo) mounted on a precision balance. The morphology of CF, EPS raw materials and the composites was characterized using a Hitachi TM3030 SEM.

3. Results and discussion
The SEM images of EPS and CF wastes are presented in Figures 1(a) and (b), respectively. The morphology of EPS revealed hollow and closed-cellular foam structure, that plays an important role in its properties. CF showed a rough surface morphology with irregular shape. Figures 1(c)-(f) demonstrate the SEM images of the fractured surface for EPS cement and CF cement composites after impact test. It can be seen that there was a small gap between EPS and cement matrix which means a weak adhesion for 3 wt% EPS. The gap formed was probably caused by incomplete wettability between cement and EPS during the composite fabrication (Figures 1(c)-(d)). This was also reported by other literatures [5]. Meanwhile, a better interfacial bonding is observed between CF and cement for the CF cement composite and thereby found relatively little fiber pull-out with a rough interface and more effectively bridge microcracks within the CF cement composite (Figures 1(e)-(f)). Probably because physical interlocking and hydrogen bonds could form between fiber and cement matrix during the hydration of cement [6]. The results of the physical and mechanical tests of EPS cement and CF cement composites are shown in Figure 2. The bulk density of plain cement ranged from 2.07 to 2.09 g/cm³. Both the composites, particularly EPS cement, have lower density than plain cement (Figure 2(a)). The decrease in bulk density of the composites was mainly due to the substitution of heavier material (cement) by lighter one (CF and EPS). Depending on replacement by EPS or CF, the bulk densities of the composites were decreased by 66% when specimen was dosed with 3 wt% EPS. The EPS cements have the bulk densities ranged between 0.71 to 1.43 g/cm³. Whist a smaller decrease (~11%) in bulk density was
observed after adding 3 wt% CF at all the fiber lengths. The bulk densities of CF cements ranged between 1.85 to 1.95 g/cm³.

**Figure 1.** SEM images of (a) EPS, (b) CF and SEM images of the fractured surface of the composites (c-d) EPS cement and (e-f) CF cement.

The effect of EPS content on the flexural and impact strengths is shown in Figures 2(b) and (c). The flexural and impact strengths of EPS cement decreased as EPS content increased. Moreover, it can be seen that after EPS content exceeding 1 wt%, its effect on the impact strength of EPS cement become insignificant. The results showed that higher EPS content resulted in lower flexural strength, impact strength and density due to higher air-void content and looser structure in EPS composite with lower volume of cement. For the CF cements, the replacement of cement by CF notably improved flexural and impact strengths compared with plain cement (Figures 2(b) and (c)). The improvement rate increased with increasing cement replacement (flexural strength improved by 60-70% for all the CF lengths at 3% replacement). On replacing 3% cement by CF, at the CF lengths of 1, 2 and 3 cm, impact strength increased by 407, 668 and 860%, respectively. This may be because the better interaction between CF and cement and the fracture behavior of high strength composite contains crack bridging and some fiber pull-out (as shown in Figures 1(e)-(f)) that are responsible to resist crack propagation and improve the composite strength [6-8].

**Figure 2.** Effect of CF or EPS content at various CF lengths on (a) density, (b) flexural strength and (c) impact strength.

The combination of CF and EPS in cement replacement seems to improve their flexural and impact strengths and decrease the bulk density for structural lightweight cement board (Figures 3(a)-(c)). The increased flexural and impact strengths resulted from the addition of CF, whereas the existence of EPS is responsible for the reduction of bulk density. It seems that somewhat adverse effect of EPS beads in flexural and impact strengths could be compensated by adding CF to the EPS cement composite. Cement mixed with both CF and EPS showed improvements on increased flexural strength (24%), increased
impact strength (547%) and reduced density (41%) using 3% CF for 3 cm fiber length and 1% EPS. The CF/EPS/cement composite containing 3% CF at 3 cm fiber length and 1% EPS (C33E1) as well as 2% CF at 3 cm fiber length and 2% EPS (C23E2) showed acceptable flexural strength, impact strength and density for structural lightweight cement. According to C33E1, the structural lightweight cement has the average flexural strength of 4.62 MPa, impact strength of 3.35 kJ/m², bulk density of 1.23 g/cm³, and consists entirely of lightweight cement.

**Figure 3.** Effect of replacement level by the mixture of CF and EPS at 3 cm CF length on (a) flexural strength, (b) density and impact strength.

4. Conclusions
In this study, CF and EPS wastes can be used as a reinforcement and replacement of cement in the development of lightweight cement board. Application of CF improved the EPS/CF/cement composite properties including increased flexural and impact strengths and decreased bulk density. Adding EPS into cementitious mixtures significantly decreased the bulk densities of composites. Application of EPS also decreased the strength properties; however, the results showed the potential for producing different strength and lightweight cement composites; in particular satisfactory cement composite can be produced by replacing cement with 3% CF and 1% EPS as well as replacing with 2% CF and 2% EPS for the CF length of 3 cm. In this regard, to some adverse effect of EPS beads in strengths could be compensated by adding CF to the EPS cement composite. The findings of the present study supported acceptable performance in cement based composite materials for low-cost housing applications.

5. References
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