Enhanced mechanical performance of cement board composite reinforced with coconut coir fiber and tire rubber waste

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Abstract. This work aimed to study the use of tire rubber waste (TW) and coconut coir fiber (CF) as the recycled material and partial replacement of cement and asbestos to produce cement board composite and obtain optimal replacement level. The amounts of TW and CF were the variables in this experimental study. Various mixtures were produced by partial replacement of cement with TW at different percentages (2.5, 5.0, 7.5 and 10%) and with CF at different percentages (1, 2 and 4%) using a fiber length of 3 cm. The mechanical and physical properties of the cement boards were evaluated. Both the flexural and impact strengths of the cement boards increased with an increase in the content of TW and CF. The mechanical properties of the cement composites based on the combination of TW and CF were significantly better due to the synergy of TW and CF additions. Moreover, the results also showed that the density decreased with increasing in TW and CF. Therefore, TW and CF can be utilized as a good replacement of cement for cheap, lightweight and eco-friendly reinforced cement boards.

1. Introduction
Composite materials with both economic and environmental benefits are being considered for applications in the building and construction industries. After banning asbestos fibers because of its hazardous impacts on human health, developing low-cost, strong, and durable cement board remains one of the greatest challenges [1]. In present, there are many waste materials for cement board production to achieve desired properties or reduce the cost of the final products [2]. Management of TW has caused an environmental crisis due to the large volume of waste generated from automobile industry and increasing use of car. In considering the reuse of recycled rubber in concrete, extensive researches have been carried out on tire-based concretes. These results have revealed that rubberized concrete mixtures provide a decreased density, higher impact resistance, lower compressive and tensile strength, and better sound insulation [3]. However, some observations have suggested that the loss in strength might be minimized by incorporating natural fibers [4]. CF was found to be one of the most effective fibers and widely available. Large quantities of coconut waste are generated from agroindustry that when discarded or burnt can cause environmental problems. Therefore, it is imperative to reduce the volume of TW and CF waste burned or dumped to landfill through modern recycling processes, without harming the environment. Using TW and CF in cement as a partial replacement of some components is one of
the possible recycling approaches currently being explored. In order to solve the above problem, this study replaced part of cement and asbestos with TW powder and CF, which was then mixed into cement composites. We tested the physical and mechanical properties (density, impact and flexural strengths) of cement composites based on different weight percentages of added TW (2.5, 5, 7.5 and 10%) and CF (1, 2 and 4%) to find out the optimal replacement level.

2. Experimental

2.1. Materials and composite preparation
Type I Portland cement conformed to ASTM C150 specifications and two types of replaced cementitious materials; TW and CF; were used in this work. Type I Portland cement was purchased from the Siam Cement Group Company. Brown CF was obtained from Suphan Buri (Thailand). Prior to use, CF was washed with distilled water and then dried for 24 h at 70°C, followed by cutting into 3 cm length. The TW powder was produced by the KKI Recycle factory. The TW powder is sized less than 1 mm. The mixtures were cast in acrylic molds (5 mm in height, 12 cm in length and 5 cm in width). After casting, the specimens were cured at room temperature for 24 h. Then the samples were demolded and soaked in water for 28 days before testing. In this study, the mixtures include partial replacement of cement weight with 2.5, 5.0, 7.5 and 10% TW and/or 1, 2 and 4% CF with 3 cm fiber length. The material name was designated as TW-xCF-y, where x and y indicate the wt% of TW and CF in cement, respectively.

2.2. Experimental method
The fractured surface morphology of the composites was studied by SEM using a Hitachi TM3030 electron microscope. All the mechanical properties were performed in accordance with BS EN 12467:2012 (Fibre-cement flat sheets Product specification and test methods) to determine the optimal TW and CF contents of fiber cement composites. Flexural behaviour of the specimens was analyzed under a three-point load system. The three-point bending tests were done under displacement control (cross-head feed rate of 2 mm/min and span of 75 mm) using a universal testing machine (Instron 5965), with a 50 kN load cell. The impact resistance test was carried out using an Instron CEAST 9050 impact pendulum machine and a pendulum of 1 J. The specimen density was measured using a top-loading electronic balance, equipped with a Mettler Toledo accessory density kit.

3. Results and discussion
The mechanical properties and densities of cement composite containing different TW contents are shown in Figure 1. The flexural strength of TW cement composites was not significantly altered with the addition of up to 10% TW (Figure 1(a)). However, the impact strength of TW composites significantly depended on TW content (Figure 1(b)). The results showed that the addition of 2.5, 5, 7.5 and 10% TW resulted in 3.3, 16.3, 23.0 and 34.6% increment in impact strength compared with the reference (plain cement), respectively. This may be because the higher the TW content, the higher tendency to absorb impact energy attributing to higher toughness and ductility of TW particles that is resistant to failure. Similar results were also reported in earlier studies [5]. The effect of TW content on bulk density of the specimens is demonstrated in Figure 1(c). The addition of TW affected the bulk density of cement and as a consequence the TW composites at 2.5, 5, 7.5 and 10% TW replacement revealed about 4.6, 6.4, 8.1 and 9.9% reduction, respectively. A decrease in bulk density resulted from the decreased amount of cement paste required to fill the interstitial space between TW particles. For the CF composites, the addition of CF in TW cement composites leads to the increase in flexural strength and impact strength compared with the reference because of a synergistic effect of TW and CF (Figure 2(a) and (b)). In TW/CF/cement composites, the addition of 1, 2 and 4% CF (TW5CF1, TW5CF2, TW5CF4) in 5% TW composites presented an increase of 90.9, 106.6 and 126.8% in flexural strength, followed by the mixtures with 1, 2 and 4% CF (TW7.5CF1, TW7.5CF2, TW7.5CF4) in 7.5% TW composites were 68.0, 86.2 and 98.3%. The physical-mechanical properties of composites are directly related to the adhesion between CF and cement. The specimens with lower TW content (TW-xCF-y-TW-xCF-y) presented
higher flexural strength than those with higher TW content (TW\textsubscript{7.5}CF\textsubscript{1}-TW\textsubscript{7.5}CF\textsubscript{4}). This fact may have occurred due to higher TW content (TW\textsubscript{7.5}CF\textsubscript{1}-TW\textsubscript{7.5}CF\textsubscript{4}) with lower amount of cement matrix, leading to a decreasing tendency of the adhesion between CF and cement.

Figure 1. Effect of TW content on (a) flexural strength, (b) impact strength and density.

Figure 2. Effect of adding TW and CF on (a) flexural strength, (b) impact strength and (c) density.

Figure 3(b) shows the existence of microcracks (blue circle) in the interface between TW particles and matrix. These cracks are probably because of high elasticity, deformability and also softness of TW with respect to matrix, which consequently results in the loss in strength. Moreover, the irregular shape of TW particles (Figure 3(a)) may cause the presence of microcavities in the matrix (Figure 3(b) (red circle)), resulting in weak bonding between TW particles and matrix. This weak interfacial zone may act as microcrack, leading to crack initiation at the interface between materials accelerating the matrix breakdown. For the addition of CF, the microcrack could be transferred to CF through the interfacial bonding between CF and cement (Figure 3(c)). CF can also restrain the crack propagation and traverse across the cracks to transfer internal force, and CF and cement matrix would bear the load [6-7].

Figure 3. SEM images of (a) tire rubber waste (TW), (b) TW\textsubscript{7.5} and (c) TW\textsubscript{7.5}CF\textsubscript{4}.
The effect of CF content on impact strength is demonstrated in Figure 2(b). The impact strength increased from 0.46 kJ/m$^2$ for TW to 0.76, 0.86 and 1.33 kJ/m$^2$ for TW$_{5}$CF$_1$, TW$_{5}$CF$_2$ and TW$_{5}$CF$_4$, respectively. Whilst the impact strength increased from 0.48 kJ/m$^2$ for TW$_{7.5}$ to 0.85, 0.93, and 2.37 kJ/m$^2$ for TW$_{7.5}$CF$_1$, TW$_{7.5}$CF$_2$ and TW$_{7.5}$CF$_4$, respectively. It is clear that the increased impact strength resulted from adding CF. TW$_{7.5}$CF$_4$ showed higher impact strength than TW$_{5}$CF$_4$ (1.8 times) probably because TW particles have low stiffness which affected the matrix by increasing its flexibility, ability to absorb and transfer energy to CF (Figure 4). TW$_{7.5}$CF$_2$ has lower density than cement and TW$_{5}$CF$_4$ about 14% and 2.3% respectively (Figure 2(c)). Therefore, according to TW$_{7.5}$CF$_4$, the lightweight cement composite has the flexural strength ranged from 7.98-11.63 MPa, impact strength of 1.83-2.91 kJ/m$^2$ and bulk density of 1.75-1.80 g/cm$^3$.

![Figure 4. SEM images of (a) TW$_{5}$CF$_4$ and (b) TW$_{7.5}$CF$_4$.](image)

4. Conclusions
The use of CF and TW showed potential as reinforcement of cement-based composites. The drastic improvement in the flexural strength of the TW/CF/cement composites was observed with adding CF only 1%. According to the mechanical and physical tests on the flexural strength, impact strength, and bulk density, it is verified that the replacement of cement by the combination of TW and CF worked synergistically to reinforce and modify the cement composites. The cement composites reinforced with 4% CF and 7.5% TW (TW$_{7.5}$CF$_4$) presented the optimal average values for flexural strength, impact strength and bulk density. The results of this research proved that the application of TW and CF in cement continues to be an essential part in the process of reducing waste and a promising alternative construction material.

5. References
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Acknowledgement
The authors would like to thank the Department of Materials Science and Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, and the Center of Excellence on Petrochemical and Materials Technology, Chulalongkorn University.