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The influences of chemical treatment on recycled rejected fiber cement used as fillers in the fiber cement products

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Abstract

Fiber cement products (FC) are globally used in the constructions of houses and commercial buildings. The recycling of rejected FC as fillers is an important way to contribute to a sustainable material flow. However, several negative effects regarding the extremely high water content from the FC forming (Hatschek process) and the limited reuse of rejected FC instead of natural fillers can be explained by the negative influences on setting and hardening behaviors of FC. Both mentioned inferiors significantly decrease the cement hydration mechanism, leading to remarkable reductions of set and hardened performances of FC. Hence, chemical treatment (CT) was applied to drive the hydration kinetic, and the properties achieved were characterized via the relevance of higher heat of hydration. Moreover, scanning electron microscope (SEM) was used to reveal the favorable effects of appropriate chemical and mineral additives through the microstructures of treated reject-FC.

1. Introduction

Fiber cement products (FC) are widely used in the constructions of house and commercial building as ceiling, floor, door, wall and other decorative products due to their high strength, durability and toughness with good appearance [1]. In addition, FC are also fire and water resistant. The mixture for producing FC consists of Portland cement type1 (OPC), fine sand, kraft pulp, and natural filler such as gypsum. The mixture was mixed and molded to the semi-finished products by Hatschek process. Generally, in addition to the aforementioned raw materials, the natural filler such as gypsum was added to the mixture to facilitate molding process [2]. After that, the molded FC was cured under hydrothermal condition by using an autoclave. Under hydrothermal condition (HT) in the autoclave, the hydration reaction is accelerated, which the curing time can be reduced from 28 days to only 1 day, and the crystalline C-S-H phases such as tobermorite ($5CaO•6SiO2•5H2O$) is formed [3-6]. This crystalline phase enhances FC properties [7]. Moreover, for the natural filler, it will transform to anhydrous ($CaSO_4$) under hydrothermal condition [8-9]. This anhydrous will fill the space between the crystalline C-S-H phases such as tobermorite crystal. Then the density and the workability of FC products are improved.

Each year, as shown in Figure 1, there are several tons of rejected FC generated either from just after the manufacturing process or from the construction sites. Some of these FC waste may be reused as furniture, plant pot, decorative items and pallet; the sustainable management of these FC wastes is still necessary. According to Fenyvesi et al [10], the autoclaved products could be recycled as the lightweight aggregate [11]. However, it was found that the C-S-H phase could influence the hydration reaction [12-14].

Figure 1. The rejected FC at the dump site of a waste management company.

Beside several negative effects regarding the extremely high water content from the FC forming (Hatschek process), it was found that using these recycled FC as the filler for FC could cause the greater negative impact, resulting in the remarkable reductions of set and hardened performances of FC. According to Gopala Krishna Sastry et al [15], some treatment can be applied in order to alleviate this obstacle on using recycled FC.

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Therefore, the aim of this work was to apply the chemical treatment (CT) on the recycled fiber-cement products (Re-FC) in order to accelerate the hydration kinetics of the mixture containing Portland cement and Re-FC. The properties were characterized via the relevance of higher heat of hydration.

2. Experimental

2.1 Material preparation

The recycled fiber-cement products (Re-FC) was prepared by grinding the rejected FC which was supplied by Shera Public Company Limited, using hammer mill and dried at 100°C for a day. Then, 700 g of dried ground FC was mixed with 2,300 g of water and further ground by ball milling for 15 h. After ball milling, the slurry was screened by 18-mesh sieve and then dried at 150°C. Finally, this dried cluster was powdered and used as a raw material in this work and characterized for the heat of hydration and morphology.

The chemical used for the chemical treatment of Re-FC was the dissolving agent (DA), which could dissolve cementitious materials to the aqueous phase. This DA was used to weaken the surface of cementitious particles which enhanced the kinetics of hydration reaction and improve the rheology of Re-FC added mixtures instead of natural filler. The DA was the proprietary blend of citric acid together with thickening and wetting agent. The DA was initiated and developed under technology licensing agreement of Shera Public Company Limited. The licensor, SHERA®, did agree to reveal only the mixing ratio of thickening and wetting agents, not that their chemical details. The potential ratio of both chemicals was 1:2.

2.2 Effect of chemical treatment on the heat of hydration

The mixtures consisting of ordinary Portland cement (OPC), gypsum, Re-FC, and DA were prepared based on the details shown in Table 1. Formula G0 was used as the reference formula. As mentioned previously, gypsum is a common non-toxic natural filler used in the mixture for producing FC that assists the molding process, however, gypsum mining could cause the negative environmental impact. To reduce the utilization of natural material in construction material industry and promoting the recycling of industrial waste, in this work, Re-FC was used as the substitute for gypsum in the Formula G0. This formula of Re-FC substituted was R0. The dissolving agent (DA) was added to the mixture based on the weight of OPC in the mixture. For example, from formula R1, the amount of DA was 1.5% of the total weight of OPC in the mix. Then, 650 g of the mixture from each formula was mixed with 270 g of water to form the slurry by Hobart mixer. The slurry was kept in the chamber of the instrument as shown in Figure 2. The amount of heat released during the hydration reaction was represented by the temperature change within the chamber. The temperature within the chamber were recorded every 30 sec. The temperature measurement was carried out for 16 h. The process for monitoring the heat of hydration was based on ASTM C186 [16]. The chemical treatment on Re-FC was carried out during the hydration reaction of the slurry in the chamber.

Table 1. The formulas of samples for heat of hydration analysis.

Formula	Composition (wt%)			DA (% of OPC weight in the mixture)
	OPC	Gypsum	Re-FC	
G0	75	25	-	-
R0	75	-	25	-
R1	75	-	25	1.5
R2	75	-	25	3
R3	75	-	25	4.5

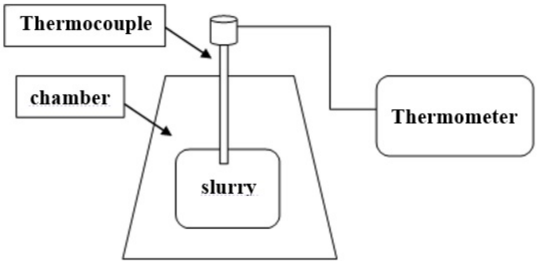

Figure 2. Schematic diagram of the instrument for heat of hydration analysis.

2.3 Materials characterization

Both gypsum and Re-Fc were characterized for their composition, average particle size, and loss on ignition (LOI). The composition and the average particle sizes were determined by X-Ray Fluorescence (XRF) spectrometer (Panalytical, Minipal 4), and laser particle size analyzer (Sympatec, HELOS/BR + QUIXEL), respectively. For loss on ignition (LOI), it was determined by the method based on ASTM C114, in which the raw materials were heated at 900°C for 1 h and LOI was calculated by [17];

$$\mathrm{LOI}(\%) = \frac{W_1 - W_2}{W_2} \times 100 \qquad (1)$$

where W_1 and W_2 are the sample weight before and after heating, respectively

To study the effect of chemical treatment on the morphology of Re-FC, the samples of chemically treated Re-FC were prepared by mixing 10 g of Re-FC with 5.5 g of water, and DA at 0, 1.5, 3.0, and 4.5% of the weight of Re-FC (0, 0.15, 0.3, and 0.45 g). Then, Re-FC was kept in the solution for 24 h and dried at 60°C. After that, the morphology of the chemically treated Re-FC was observed by scanning electron microscope (SEM).

3. Results and discussion

Table 2 showed the average particle size, the LOI, and the chemical compositions of the raw materials which were gypsum and Re-FC. Obviously, the average particle size and LOI of Re-FC were lower than gypsum. For the composition, Re-FC primarily consists of CaO, SO_3, and SiO_2, while gypsum primarily consists of CaO and SO_3. Figure 3 showed the particle-size distribution curves for Re-FC and gypsum, including the density distribution (Figure 3 (a)) and the cumulative distribution (Figure 3 (b)).

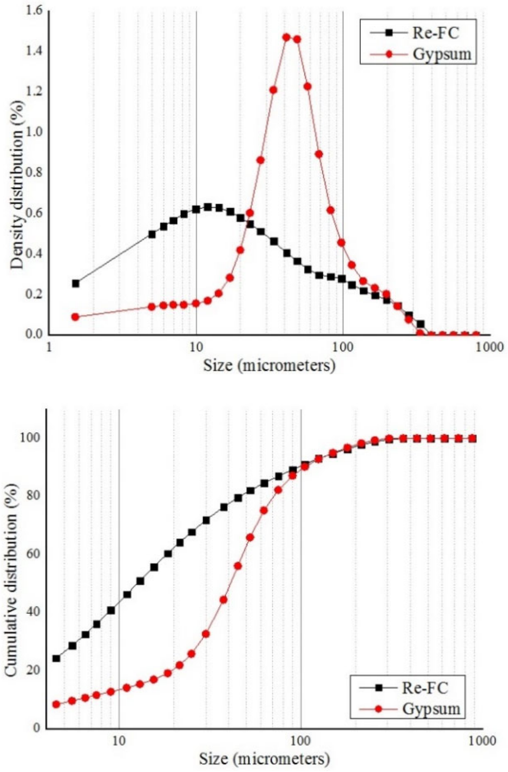

Figure 3. (a) Density distribution and (b) Cumulative size distribution for gypsum and Re-FC particles.

When the heat released from the hydration reaction was considered from Figure 4, the temperature profile of formula R0 was shifted to the left with higher maximum temperature compared to formula G0. This result indicated the improved in hydration kinetics. Gypsum ($CaSO_4 \cdot 2H_2O$) was commonly used to facilitate the molding of fiber-cement products, however, it could retard the hydration reaction. Re-FC substituted for gypsum lessened this retardant effect. In addition, for the C-S-H crystalline phase found in Re-FC, according to Land and Stephan [18], this crystalline phase could act as a hydration accelerator by promoting the cement phase nucleation in the slurry.

According to Land and Stephan [18], large reactive surface area could accelerate the hydration reaction by being the nucleation sites for the crystalline hydration products. By considering the morphology of as-received Re-FC and chemically treated Re-FC in Figure 5, the surface area on Re-FC particles were increased via the increasing surface roughness after DA was added. Moreover, from Figure 5, when the amount of DA was increased from 1.5 to 4.5% of OPC weight in the mixture (formula R1 to R3), the surface roughness of Re-FC was further increased.

Therefore, from Figure 4, compared to formula R0, when DA was added, the temperature curves were shifted to the left with the higher maximum temperature and shorter time to reach the maximum temperature. These results indicated that using chemically treated Re-FC as the substitute for gypsum could enhance the kinetic of hydration due to the increasing of reactive surface area of Re-FC particles by DA. Then, when the amount of DA was increased from 1.5 to 4.5% of OPC weight in the mixture, the roughness was further increased, and the time to reach the maximum temperature was decreased which indicated by the further shifted of the temperature curves.

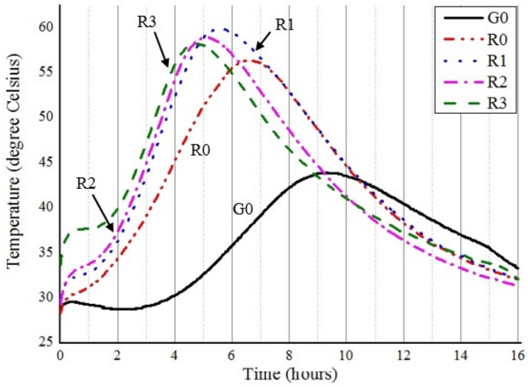

Figure 4. Effect of Re-FC substituted and DA doped on heat of hydration.

Table 2. Average particle size, LOI, and chemical composition of gypsum and Re-FC.

Substance	Average Particle Size (μm)	Loss on Ignition (%)	Chemical Composition (wt%)					
			Al_2O_3	SiO_2	SO_3	CaO	Fe_2O_3	Others
Gypsum	51.81	22.01	0.15	0.14	73.07	24.56	0.10	1.98
Re-FC	33.95	13.05	1.57	22.55	32.28	37.30	2.27	4.03

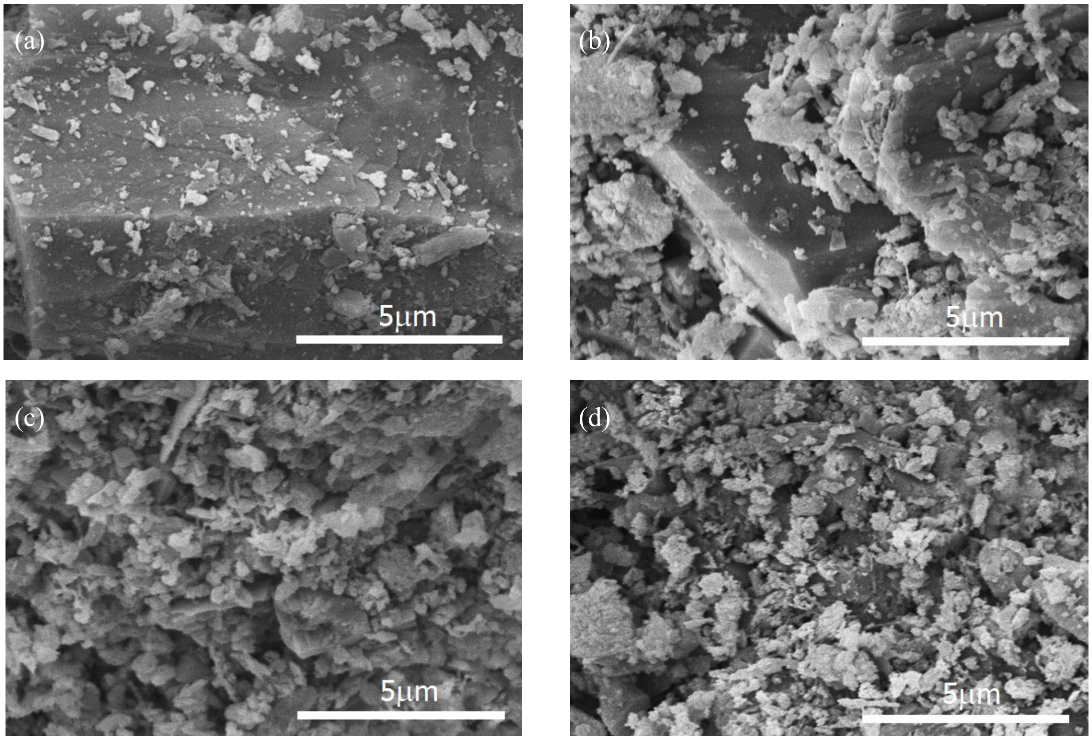

Figure 5. The morphology of (a) Re-FC as receive and chemically treated Re-FC by using DA at (b) 1.5% (c) 3.0% and (d) 4.5% of the weight of Re-FC.

4. Conclusions

The aim of this work was to improve the kinetics of the hydration reaction of the fiber cement products by using the recycled fiber-cement products (Re-FC) which was chemically treated with the dissolving agent (DA) produced from the blending of citric acid with thickening and wetting agents.

The results from the experiment showed that Re-FC could be used as the gypsum substitute for fiber cement production due to the improved hydration kinetic. By using DA, the surface area of Re-FC particles were increased. Then, the increasing of the surface area of Re-FC by DA further improved the hydration kinetics in the fiber cement product.

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References

[1] B. J. Pirie, F. P. Glasser, C. Schmitt-Henco, and S. A. S. Akers, "Durability studies and characterization of the matrix and fibre-cement interface of asbestos-free fibre-cement products," *Cement and Concrete Composites*, vol. 12, pp. 233-244, 1990.

[2] W. Barbosa, R. D. Ramalho, and K. F. Portella, "Influence of gypsum fineness in the first hours of cement paste: Hydration kinetics and rheological behaviour," *Construction and Building Materials*, vol. 184, pp. 304-310, 2018.

[3] K. Matsui, J. Kikuma, M. Tsunashima, T. Ishikawa, S. Matsuno, A. Ogawa, and M. Sato, "In situ time-resolved X-ray diffraction of tobermorite formation in autoclaved aerated concrete: Influence of silica source reactivity and Al addition," *Cement and Concrete Research*, vol. 41, pp. 510-519, 2011.

[4] M. Chen, L. Lu, S. Wang, P. Zhao, W. Zhang, and S. Zhang, "Investigation on the formation of tobermorite in calcium silicate board and its influence factors under autoclaved curing," *Construction and Building Materials*, vol. 143, pp. 280-288, 2017.

[5] N. B. Winter, *Understanding cement*. United Kingdom: WHD Microanalysis Consultants, Ltd., 2012.

[6] R. J. Kirkpartick, J. L. Yarger, P. F. McMillan, P. Yu, and X. Cong, "Raman spectroscopy of C-S-H, tobermorite, and jennite," *Advanced Cement Based Materials*, vol. 5, pp. 93-99, 1997.

[7] A. Akhavan, J. Catchmark, and F. Rajabipour, "Ductility enhancement of autoclaved cellulose fiber reinforced cement boards manufactured using a laboratory method simulating the Hatschek process," *Construction and Building Materials*, vol. 135, pp. 251-259, 2017.

[8] N. Meller, K. Kyritsis, and C. Hall, "The hydrothermal decomposition of calcium monosulfoaluminate 14-hydrate to katoite hydrogarnet and β-anhydrite: An in-situ synchrotron X-ray diffraction study," *Journal of Solid State Chemistry*, vol. 182, pp. 2743-2747, 2009.

[9] N. B. Singh and B. Middendorf, "Calcium sulphate hemihydrate hydration leading to gypsum crystallization," *Progress in Crystal Growth and Characterization of Materials*, vol. 53, pp. 57-77, 2007.

[10] O. Fenyvesi and B. Jankus, "Opportunities in recycling AAC waste as aggregate for lightweight concrete," *Journal of Silicate Based and Composite Materials*, vol. 67, pp. 66-70, 2015.

[11] T. Suwan and P. Wattanachai, "Properties and Internal Curing of Concrete Containing Recycled Autoclaved Aerated Lightweight Concrete as Aggregate," *Advances in Materials Science and Engineering*, vol. 2017, pp. 1-11, 2017.

[12] E. I. Al-Wakeel, S. A. El-Korashy, S. A. El-Hemaly, and N. Uossef, "Promotion effect of C-S-H-phase nuclei on building calcium silicate hydrate phases," *Cement and Concrete Composites*, vol. 21, pp. 173-180, 1999.

[13] J. J. Thomas, H. M. Jennings, and J. J. Chen, "Influence of Nucleation Seeding on the Hydration Mechanisms of Tricalcium Silicate and Cement," *The Journal of Physical Chemistry C*, vol. 113, pp. 4327-4334, 2009.

[14] M. H. Hubler, J. J. Thomas, and H. M. Jennings, "Influence of nucleation seeding on the hydration kinetics and compressive strength of alkali activated slag paste," *Cement and Concrete Research*, vol. 41, pp. 842-846, 2011.

[15] K. V. S. Gopala Krishna Sastry and P. M. Kumar, "Self-curing concrete with different self-curing agents," in *IOP Conference Series: Materials Science and Engineering*, vol. 330, pp. 1039-1045, 2018.

[16] ASTM C186-05, Standard Test Method for Heat of Hydration of Hydraulic Cement, ASTM International, West Conshohocken, PA, 2005.

[17] ASTM C114-07, Standard Test Methods for Chemical Analysis of Hydraulic Cement, ASTM International, West Conshohocken, PA, 2007.

[18] G. Land and D. Stephan, "Controlling cement hydration with nanoparticles," *Cement and Concrete Composites*, vol. 57, pp. 64-67, 2015.