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Mechanical Properties Enhancement of the Cement Mortar by Synthetic Zeolite Polymer Composites

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Abstract

The performance of cement mortar can be improved with additives based on waste by-products. Synthetic zeolite polymer composites (referred as SZPC) produced from the combination of solid waste ashes with a selective acrylic compound was used as a cement mortar additive. The effect of SZPC as an additive on hydration reaction of ordinary Portland cement (referred as OPC) at different amounts of SZPC, from 1-4% of OPC weight, as well as microstructure and mechanical behavior of the cement mortar are determined. The results from the hydration reaction rate test showed that the optimum amount of SZPC as the additive was 2% of OPC weight. Compressive strength and flexural strength of the cement mortar after 1, 7, 14 and 28 days of curing increased, with the largest increases at the early stage. Additions of SZPC, synthesized by a waste by-product, improved mechanical behavior of cement mortars supporting sustainable development and the circular economy.

Keywords: Cement mortar, Zeolite, Pozzolan, Ettringite

1. Introduction

The principles of sustainable development and the circular economy have gathered more attention in recent years. Numerous countries embrace the concepts of efficient energy conservation, greenhouse-gas emission reduction, and efficient commodities improvements (Velenturf & Purnell, 2021). To comply with these concepts, it is necessary to consider how high-performance products can be utilized to lengthen the lifetime of the current products and reduce the manufacturing requirements. In the concrete industry, every ton of manufactured cement generates 0.85 tons of CO_2 emissions. Moreover, 5-7% of worldwide greenhouse gas emissions are produced by the cement production sector (Devi, Lakshmi, & Alakanandana, 2018).

Cement mortar is a cement-based material prepared from ordinary Portland cement (referred as OPC), sand, and water (Parveen Kumar & Radhakrishna, 2015). Commonly, cement mortar is used for adhering construction bricks and blocks, plaster for building interior walls, as well as many other constructions uses. Many have studied improving the performance of cement mortar, for example. Gbekou, Benzarti, Boudenne, Eddhahak and Duc (2022) found that there was a reduction in density and improvement of the thermal properties of Shicement mortar when microencapsulated phase change materials were added. However, the mechanical strength of cement mortar diminished, and porosity also increased. According to Jiang, Li, Liu, He and Hernandez (2022) using recycled concrete powder as a sand replacement for cement mortar decreased the bulk density of the mortar while the mechanical properties were slightly improved.

Another method to improve the mechanical properties is the use of nanomaterials. He et al. (2022)

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found that using graphene as an additive could significantly improve the flexural strength and compressive strength of cement mortar. Shi et al. (2022), added carbon-nanofibers that improved both flexural strength and the modulus of elasticity of the cement mortar significantly. Moreover, Zhang et al. (2021) used nanocomposites to improve the early strength of cement mortar.

Alumino-silicate is a chemical additive that can improve the early strength and reduce the setting time of the concrete due to its pozzolanic property (Zhang & Malhotra, 1995). Synthetic zeolite is an alumino-silicate compound manufactured by a thermal process (Zhao, 2010). Moreover, synthetic zeolite can be synthesized from the waste by-product of AlF_3 production. As a concrete additive, synthetic zeolite can improve the performance of concrete; for example, increased strength and freeze-thaw resistance (Girskas, Skripkiūnas, Šahmenko, & Korjakins, 2016).

To promote the mega trend following the circular economy, the improvement of the properties of the related cement product is inspired to expand the time of consumption by the cement additives, especially, the treated waste additives. Synthetic zeolite polymer composites (referred as SZPC) produced from the combination of solid waste ashes with a selective acrylic compound is used as a cement mortar additive. The influences of SZPC on the mechanical properties and microstructure of the cement mortar are observed.

2. Materials and Methods

2.1 Materials

The raw materials are ordinary Portland cement (OPC), sea sand (particle size -325 mesh), with the additive SZPC. These materials were supplied by Shera Public Company Limited. Chemical composition of the raw materials was determined from pressed powders by x-ray fluorescence spectrometer (XRF, Panalytical-Minipal 4) with results provided in Table 1.

Table 1. Chemical composition of raw materials.

Compound	**Sample (wt%)**		
	Sand	**OPC**	**SZPC**
SiO_2	97.06	20.01	40.60
Al_2O_3	1.10	6.25	37.44
Na_2O	0.00	0.00	21.05
K2O	0.00	0.30	0.03
CaO	0.24	64.32	0.07
Fe_2O_3	0.00	3.25	0.02
MgO	0.0	1.02	0.00
SO_3	0.00	2.33	0.77
Others	1.35	2.52	0.02

2.2 Hydration reaction rate test

The effect of SZPC on the hydration reaction of OPC is determined from the temperature change due to the heat released from the reaction. The dry mixtures consisting of OPC and SZPC (0 to 4% of OPC weight) were mixed with water to create a slurry using the water-to-cement ratio of 0.3. The slurry was kept in the chamber as shown in Figure 1. The heat generated within the chamber because of the hydration reaction was measured by the thermocouple every 30 s until the temperature inside the chamber was constant. The test was carried out based on the method described in ASTM standard C95/95M. (Pahuswanno, Chakartnarodom, Ineure, & Prakaypan, 2019; Sonprasarn, Chakartnarodom, Ineure, & Prakaypan, 2019).

The hydration reaction rate, represented by the average rate of temperature change from the initial temperature to the maximum temperature, is calculated by (Chakartnarodom, Wanpen, Prakaypan, Laitila, & Kongkajun, 2022; Sonprasarn et al., 2019):

$$r = \frac{T_{max} - T_i}{t} \quad (1)$$

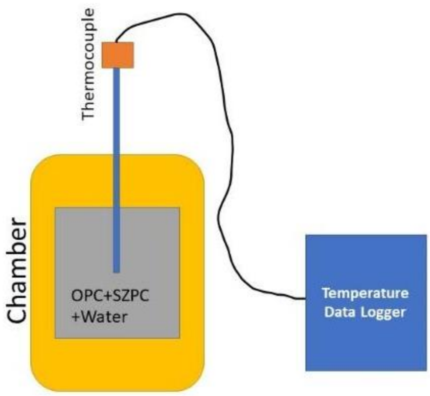

Figure 1. The schematic drawing of the instrument used for hydration reaction rate test.

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2.3 Sample preparation and testing

Cube-shaped samples (5 cm × 5 cm ×5 cm) and rectangle-shaped samples (4 cm × 4 cm × 16 cm) were casted based on the formulas listed in Table 2. The dry mixtures in Table 2 were mixed with water using a water-to-cement ratio of 0.45. A SZPC amount of 2% of OPC weight was determined from the hydration reaction test (section 3.1). After 1, 7, 14 and 28 days of curing, the compressive strength is determined on the cube-shaped samples while the flexural strength is determined on the rectangle-shaped samples. The mechanical testing was carried out based on ASTM standard C90: standard specification for load-bearing concrete masonry unit, using a universal testing machine (UTM, Instron machine 3300). Five samples from the same formulas were used for each test. Additionally, the microstructure of the samples was characterized by a scanning electron microscope (SEM).

Table 2. Formulas for sample preparation.

Formula	OPC (wt%)	Sand (wt%)	SZPC (% of OPC weight)
REF	75	25	-
HSZ2	75	25	2

3. Results and Discussion

3.1 Rate of hydration reaction

The effect of the SZPC concentrations ranging from 1-4% of OPC weight on the hydration reaction rate of OPC are presented in Figure 2 and Table 3. The initial temperature for the test was about 28°C.

Based on the reaction rate calculation, Table 3, the reaction rate is improved by 25% with the addition of SZPC at 2% of OPC weight. This improved reaction rate should be from the pozzolanic reaction between SiO_2 and Al_2O_3 in SZPC with $Ca(OH)_2$, a product from the hydration reaction, which produces calcium silicate hydrate (C-S-H) and calcium aluminosilicates hydrate (C-A-S-H) as shown in equation (2) and (3) (Tran, Lee, Kumar, Kim, & Lee, 2019):

$$2SiO_2 + 3Ca(OH)_2 \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O \quad (2)$$

$$Al_2O_3 + 3Ca(OH)_2 \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O \quad (3)$$

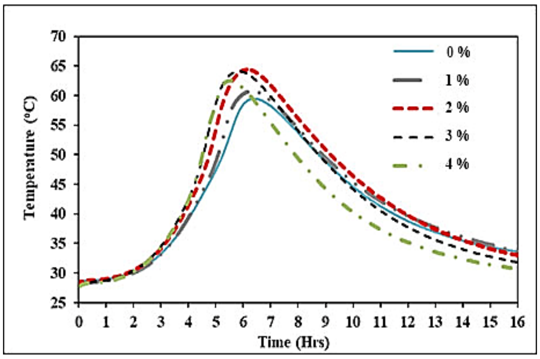


Figure 2. Results from hydration reaction rate test.

Table 3. Hydration temperatures, times, and reaction rates of SZPC on OPC.

SZPC concentration (% of OPC weight)	Max Temp. (°C)	Time (hr:min)	Reaction Rate (°C /min)
0 (Control)	59.0	6:28	0.08
1	60.7	6:11	0.09
2	64.4	6:13	0.10
3	64.1	5:55	0.10
4	62.6	5:33	0.10

Additions of SZPC over 2% of OPC weight does not have any further effect on the reaction rate. According to Marchon and Flatt (2016) and the hydration products, such as C-S-H, will nucleate and grow over the surface of cement particles and other seeding particles. However, thickening of C-S-H layer, and particle impingement during the growth of C-S-H layer could reduce the hydration rate (Chakartnarodom et al., 2022; Zhou, Duan, Tang, Chen, & Hanif, 2019). Therefore, based on this work, the optimum amount of the SZPC is 2% of OPC weight.

3.2 Mechanical properties of the cement mortar samples

The compressive and flexural strengths of the cement mortar samples are shown in Figure 3 and Figure 4 respectively. Obviously, there is strength development from 1 to 28 days of curing for both the REF and HSZ2 samples. However, the SZPC has a noticeable effect on all the mechanical properties of

HSZ2 samples, especially after 1-day of curing in which the compressive strength and flexural strength of HSZ2 samples are higher than that of REF samples by 68.44% and 27.27% respectively. The significant development of early strength should be from the pozzolanic reaction in the SZPC as described by equation (2) and (3).

The microstructure of the REF sample, Figure 5 (a), is mainly amorphous C-S-H (Chakartnarodom et al., 2022; Harrisson, 2019; Maljaee et al., 2021). Moreover, the REF sample clearly exhibits pores inside its structure, however after adding SZPC as the HSZ2 sample, Figure 5 (b), the replacement of the needle-like crystals is observed by filling those pores. According to Tanasalagul et al. (2019), this crystalline phase is ettringite. According to McCarthy and Dyer (2019), when pozzolan is added to the cement, ettringite will rapidly form and can be observed in the cement for up to 28 days or more. Yu, Qian, Tang, Ji and Fan (2019) determined the formation of the ettringite phase improves the compressive strength of the cement by providing the dense structure and low porosity. Therefore, the decrease in porosity and increase in dense structure of cement mortar due to the presence of ettringite crystals after the addition of SZPC could enhance the compressive and flexural strength of HSZ2 samples.

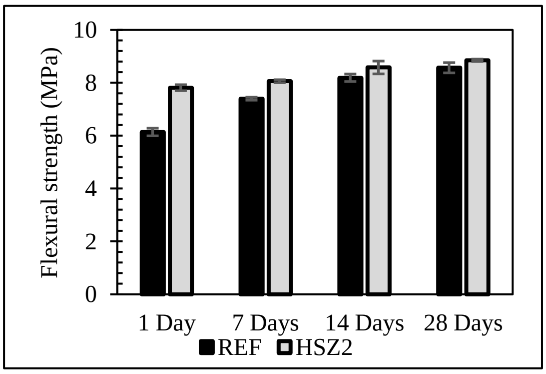


Figure 3. Compressive strength of the samples.

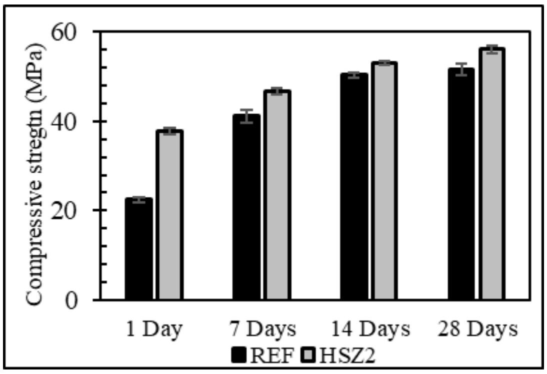
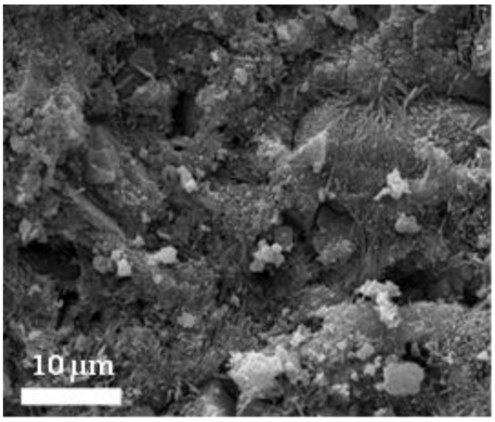
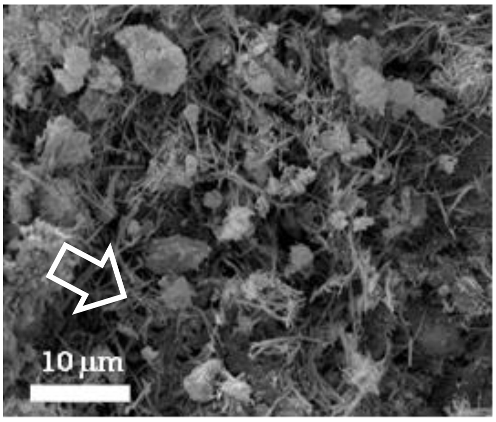


Figure 4. Flexural strength of the samples.



(a)



(b)

Figure 5. Microstructure of the samples after 1 day of curing (a) REF (b) RSZ2.

4. Conclusions

The influences of synthetic zeolite polymer composites (referred as SZPC) on the mechanical properties of cement mortar were investigated. The SZPC was prepared from the solid waste ashes with a selective acrylic compound. The SZPC affected on the increase in the hydration reaction rate of cement by the pozzolanic reaction. Based on the hydration reaction rate test, the optimum amount of SZPC added to the cement mortar samples was 2 wt% of the weight of ordinary Portland cement. By using SZPC, there is improvement of both compressive and flexural strengths, most prominent during the early curing stages due to the change in microstructure by enhancing the existence of ettringite crystals which was provided the dense structure of cement mortar.

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Conflict of Interest

The authors declare no conflict of interest.

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