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Aluminium hydroxide waste based geopolymer composed of fly ash for sustainable cement materials

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HIGHLIGHTS

- Aluminium hydroxide waste (Al-waste) was firstly used as a source material for producing geopolymer.
- Fly ash (FA) and Al-waste were used in different contents for the geopolymers cured at room temperature, 60 °C and 80 °C.
- Effect of activator concentration on the geopolymer samples were investigated.
- When higher Al-waste amount was added, it was appeared to have denser structures with high strength and low porosity.

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ABSTRACT

This report is the first to describe the reuse of aluminium hydroxide waste (Al-waste) for geopolymers. For cement materials, both Al-waste and fly ash (FA) were mixed at different Al-waste contents of 10–60 wt%. The mass ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) solution was fixed at 2.5. Here, the NaOH concentrations of 5, 10, and 15 M were used as alkaline activators for geopolymerization. Slurry properties for the geopolymers were evaluated using viscoelasticity measurements, which demonstrated that slurry containing higher alumina has a higher elastic modulus and that the setting time is greater than that for pure FA. Then, cured at room temperature for a week and also in an oven at 60 °C and 80 °C for 24 h, the geopolymerization was increased with increasing concentration of NaOH. After curing, the mechanical properties, microstructure, bonding, and phases of the resultant geopolymers were ascertained. The contents of the Al-waste in the geopolymer influenced the geopolymer strength when NaOH concentration was changed at different curing temperatures. The Al-waste content in the resultant geopolymer at 40 wt% cured at 80 °C showed the highest compressive strength of about 40 MPa and also the highest bulk density of about 2.8 g/cm^3. Furthermore, X-ray CT scanning results indicated that the geopolymer with Al-waste content at 40 wt% cured at 80 °C exhibited a dense structure, supporting the results obtained for mechanical strength.

1. Introduction

Every year, aluminium consumption is increasing for many applications such as anodizing processes for producing decorative and protective films on aluminium and alloys. The first step of anodizing processes is pre-treatment of the metal. The second step is etching the surface of the aluminium metal in pre-treatment before sealing and colouring. This step, which most often uses NaOH in warm solution, gives the metal surface a light grey satin finish. After etching, Al-waste in gibbsite phase ($Al(OH)_3$) is wasted: typically about 360 tons/year from various industries are discarded in landfills [1–3]. Consumption of fossil fuels in power plants for energy production is increasing, leaving fly ash waste. About 3 million tons/year of such industrial waste are produced by large and small power plants. For fly ash, pozzolanic materials are normally reused in cement and concrete industries [4]. Therefore, these wastes should be regenerated to produce novel materials. If people can do this, then such materials can become sustainable products that provide environmental, social, and economic benefits. Especially, as renewable resources of both aluminium hydroxide waste and fly ash, these seem to be applicable for reuse in concrete materials. Approximately 13,500 million tons of Portland cement are manufactured annually using processes

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Table 1
Chemical composition of fly ash and aluminium hydroxide waste.

Chemical compound	Fly ash (%)	Aluminium waste (%)
SiO_2	31.94	0.18
Al_2O_3	18.37	63.28
Fe_2O_3	17.39	–
CaO	19.84	0.01
MgO	1.86	0.31
SO_3	5.13	<0.01
Na_2O	1.20	–
K_2O	3.05	0.05
MnO	0.07	2.05
P_2O_5	0.16	0.01
TiO_2	0.40	0.01
L.O.I	1.47	34.02

Table 2
Mixture proportions.

Series	Symbol*	Mix proportion by weight (g per 100 g)					
		FA	Al-waste	Na_2SiO_3	NaOH		
					5 M	10 M	15 M
1	0 Al 5 M 2.5	65	–	25	10		
	10 Al 5 M 2.5	58.5	6.5	25	10		
	20 Al 5 M 2.5	52	13	25	10		
	40 Al 5 M 2.5	39	26	25	10		
	60 Al 5 M 2.5	26	39	25	10		
2	0 Al 10 M 2.5	65	–	25		10	
	10 Al 10 M 2.5	58.5	6.5	25		10	
	20 Al 10 M 2.5	52	13	25		10	
	40 Al 10 M 2.5	39	26	25		10	
	60 Al 10 M 2.5	26	39	25		10	
3	0 Al 15 M 2.5	65	–	25			10
	10 Al 15 M 2.5	58.5	6.5	25			10
	20 Al 15 M 2.5	52	13	25			10
	40 Al 15 M 2.5	39	26	25			10
	60 Al 15 M 2.5	26	39	25			10

* *yy*Al *zz*Mn: *yy* = % of aluminium hydroxide waste in solid fraction, *zz* = molarities of NaOH and *n* = Na_2SiO_3/NaOH ratio.

that incorporate high heating energy of 1400–1600 °C for calcining raw materials [5].

Therefore, in 1978 Davitdovits introduced the word "geopolymer" to describe the replacement of Portland cement which has cementitious materials and properties similar to those of ceramics [6–8]. Such geopolymers have several attractive properties of high strength, low permeability, excellent adherence to aggregates, high acid resistance, hazardous materials, and immobilisation of toxic materials [9–11]. Generally, geopolymers are made from alumino-silicate materials such as slag [12], metakaolin [13], and fly ash [14] mixed with alkaline solution. Then, the paste slurry can form and transform quickly into a rigid geopolymer. Sufficient strength at low temperatures can be gained [15–17]. For geopolymer synthesis, raw materials containing silica and alumina and alkaline liquor are necessary [18–20]. Generally, geopolymers are prepared from an alkaline solution. For example, sodium or potassium hydroxide is necessary for dissolving silicon and aluminium atoms from raw materials of natural minerals or industrial waste. The silicate alkaline solution includes a binder, alkaline activator, and a dispersant or plasticizer [7,11,21]. The basic forms of structure have silicon-aluminate 3D structures with cross-linked chain bonds together in the geopolymer matrix [22]. The reaction of geopolymers was greatly slowed at room temperature [23]. At elevated temperatures of 40–95 °C, geopolymerization is known to improve the strength of specimens [24–27].

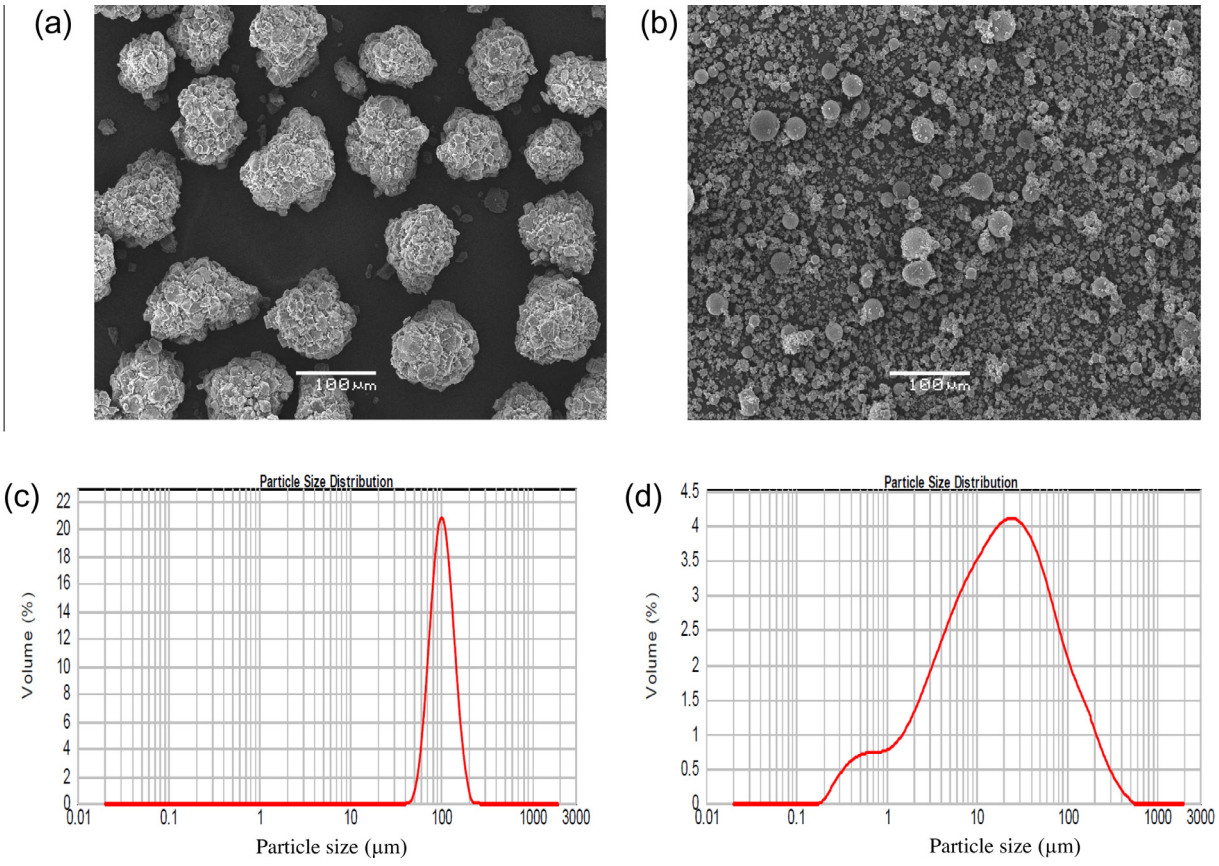

Fig. 1. SEM micrograph of (a) fly ash and (b) aluminium hydroxide waste and particle size distribution of (c) fly ash and (d) aluminium hydroxide waste.