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Using bottom ash from the domestic waste incinerator to make building materials

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ABSTRACT

This paper researched the use of ash from domestic waste incinerators to generate electricity and blast furnace slag for civil construction materials. Due to the presence of heavy metal elements in the ash from the domestic waste incinerator and the blast furnace slag, its use is limited. This study focused on the field of manufacturing adhesive materials based on the ash from the incinerator for power generation and blast furnace slag by activated alkaline solution and investigating the heavy metal migration into the environment. The study showed that the compressive strength of the adhesive from the ash of the electric generating incinerator - blast furnace slag (BFS) activated by alkaline solution had a compressive strength 19.98 MPa when cured at normal conditions. Ash from domestic waste incinerator (DWS) - BFS binder activated alkaline had the ability to fix heavy metals and can be used in construction works.

Introduction

Present and future, waste generated from industries and households is a major concern for the environment and human health. Taking advantage of waste sources generated from industries to recycle them as input materials for other industries is interested in the world and Vietnam. In which recycling industrial and domestic wastes to make construction materials is a possible solution that reduces environmental pollution and creates economic value for the construction field. Geopolymer is an amorphous aluminosilicate cement material with properties similar to natural mineral substances based on silicate and aluminosilicate materials [1].

Materials created on the basis of geopolymers such as geopolymer concrete have higher mechanical strength and fire resistance, environmental resistance than

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normal concrete. Research on using industrial waste such as fly ash, blast furnace slag, domestic waste incinerator slag, bottom ash, steel slag, glass powder to make construction materials such as concrete, unburnt bricks, fireproof materials are being applied more popular [2-4].

Currently, the process of urbanization, along with rapid economic and population growth, has been generating a large amount of waste in Vietnam. The forecasted growth rate of domestic solid waste is about 8.4 %/year for urban areas and about 5 %/year. The total amount of waste in the country is estimated at 54 million tons. In the National Strategy on Solid Waste Management, Vietnam has committed to collect and treat 100 % of non-household waste by 2025 and 85 % of household waste by 2025 in urban areas. Incineration of domestic waste to generate electricity is being concerned and put into use. Domestic waste incineration technology brings benefits such as recovering energy to produce electricity, reducing landfill volume, and reducing wastewater by garbage and landfill gas. However, incineration technology can cause secondary impacts on the environment due to the emission of exhaust gases and ash after incineration.

Currently, a number of domestic waste incineration plants have operated, such as in Hanoi, Can Tho, Thai Binh, Bac Ninh, Ha Nam. In the process of burning waste to generate electricity, a large amount of ash and slag is generated with a rate ranging from 15 to 25 % [5]. Yiquan Liu studied the fabrication of geopolymers based on ash and slag from power plants and blast furnace slag and evaluated the migration of heavy metals into the environment [6]. The study showed that the content of heavy metal leached by geopolymer materials after 64 days of soaking and extracting was much lower than those of the permitted construction materials standards. Some authors studied the characteristics of the bottom ash of the domestic waste incinerator and evaluated the possibility of heavy metal contamination into the environment.

The author realized that the bottom ash could use to make roads and as building materials [7-9]. The use of ash from waste incineration plants for power generation has controverted due to the presence of heavy metals remaining in the ash (especially bottom ash).[10] Therefore, the assessment of heavy metal migration into the environment of geopolymer materials manufactured from incinerator ash and blast furnace slag activated by alkaline solution should be studied.

In this paper, some research results on making geopolymers from bottom ash of domestic waste incinerators and blast furnace slag and evaluating the possibility of heavy metal contamination into the environment were concerned.

Experimental

Materials and method

Blast furnace slag (BFS) was taken at Viet - Trung steel factory in Tang Loong industrial zone with a density of 2.95 tons/m^3, average particle size 1.5-3.5 µm. Ash was taken at a domestic waste incinerator (DWS) in Ha Nam province with a particle size less than 0.66 mm and a density of 2.25 tons/m^3. The chemical composition of the main elements in BFS and DWS determined by X-ray fluorescence spectroscopy (XRF) were shown in Table 1.

The contents of heavy metals in the waste slag sample were determined by the ICP method. – MS results and shown in table 2.

Table 1: Main chemical compositions of BFS and DWS

Compositions (%)	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3
BFS	2.38	38.2	12.2	33.6	6.02	0.35	0.16	0.68	1.36
DWS	6.63	5.66	21.2	6.31	1.19	0.72	4.15	0.76	1.26

Table 2: Heavy element contents in BFS and DWS

Contents (mg/kg)	As	Cd	Cr	Cu	Ni	Pb	Zn	Hg
BFS	3.73	0.44	208	1914	46.3	31.1	551	0.296
DWS	4.87	6.63	162	824	89.7	137	1949	0.088

Table 1 showed that the compositions of waste ash, including SiO_2, Al_2O_3, CaO, had the ability to create geopolymer materials in the presence of alkaline solution.

Table 2 showed that the slag of BFS and DWS contained many heavy metals that affected the environment if they were leaked.

The activated alkali solution made from 10M NaOH (dissolved by pure NaOH ≥ 98 %) was mixed by liquid glass water with SiO_2 content from 26.80 to 18.30 %; Na_2O from 6.88 to 8.78 %. The research samples have changed the ratio between BFS and DWS, the concentration of NaOH 10M, and the $NaOH/Na_2SiO_3$ ratio was 0.36, denoted as in table 3 and figure 1. Samples of geopolymer materials were made by mixing BFS and DWS materials for about 3-5 minutes, then slowly added activated alkaline solution (90 ml NaOH 10 M and 250 ml of sodium silicate solution in 1000 g of waste ash).

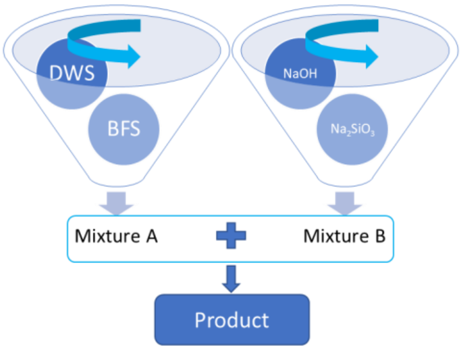

Figure 1: Diagram for the preparation of geopolymer materials

Table 3: Ratio and contents of samples

Label	DWS (g)	BFS (g)	NaOH 10M (ml)	Na_2SiO_3 (ml)
M41	800	200	90	250
M73	700	300	90	250
M32	600	400	90	250
M23	400	600	90	250
M37	300	700	90	250
M14	200	800	90	250

The geopolymer mixture was stirred for 2-3 minutes by a stirrer, then molded with 160 × 40 × 40 mm dimensions, then placed on a vibrating shaker for 30 minutes, removed, and cured in normal conditions. After 14 days of curing, the samples were determined compressive strength, and after 28 days, heavy metal contamination was assessed according to EA NEN 7375 (Netherlands Standard).

Methods for determining material characterizations

Sample compositions of BFS and DWS were determined by Xray fluorescent spectra (XRF - 1800) Shimadzu (Japan);

Specific density analysis of the material was followed by TCVN 4195:2012;

Compressive strength analysis was followed TCVN 7570-2006: Raw materials for concrete and mortar - Technical requirements;

Quality check of geopolymer samples was taken by stereo microscope SZM7045T - B1 (China) with magnification 40 times;

ICP-MS atomic plasma mass spectrometry method of Shimadzu (Japan) was used to analyze heavy metal compositions in raw material samples and extracting solutions.

Results and discussion

The effect of the ratio of BFS and DWS to compressive strength

Geopolymer samples were created according to the ratio of DWS/BFS in table 3, then cured under normal conditions and measured compressive strength after 14 days. Table 4 showed that the compressive strengths of the geopolymer samples depended on the ratio of DWS:BFS when the mixing ratio between DWS:BFS increased. The compressive strengths measured after 14 days of curing were increased from 14.56 to 19.98. These results were similar to the other authors when geopolymer concrete was cured at normal temperature.[13,14] When the ratio of DWS:BFS was increased from 1:4 to 3:2, the compressive strength gradually increased due to the influence of the grain size of DWS, BFS, and Si:Al composition ratio in the sample. When the ratio of DWS:BFS was continued to increase, the ratio of Si:Al was increased, and the compressive strength was decreased. This was affected by the size effect of the compaction of the geopolymer mixture sample. Moreover, the BFS sample had a large amount of CaO to form Ca-Si-H (Calcium-Silicate-Hydrate) gel. This formation was reduced the compressive strength.[15] To demonstrate this, the geopolymer sample was taken the photo at magnification 40x as shown in figure 2.

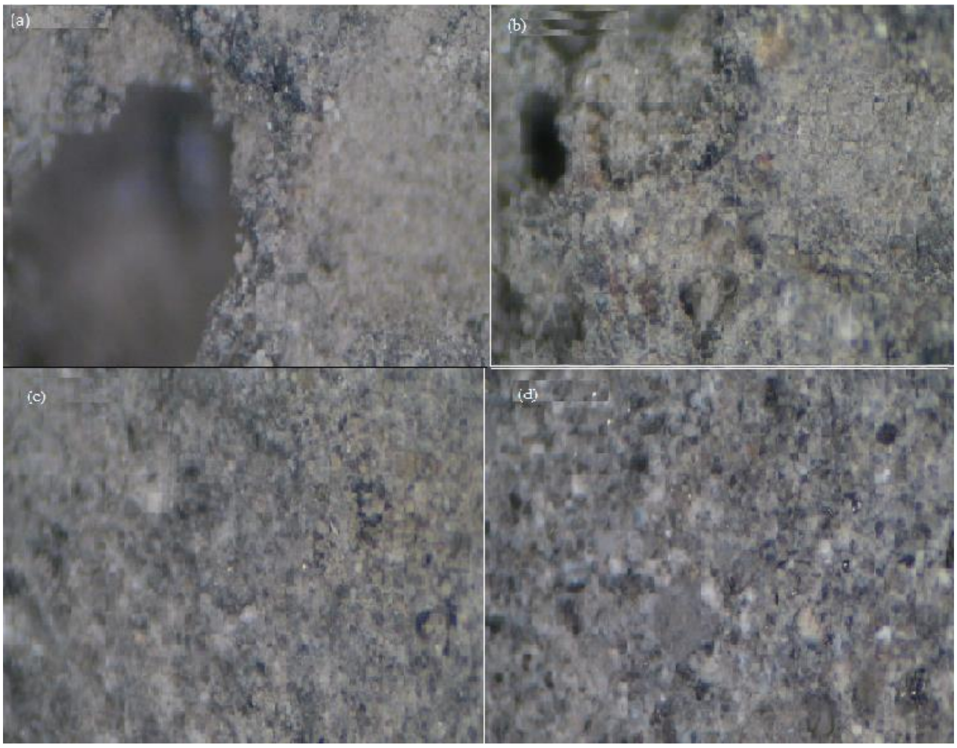

Figure 2: Samples at ratios of DWS:BFS (a) 4:1; (b) 7:3; c (3:2); (d) 2:3 were analyzed by microscope with magnification 40x

Table 4: Effect of ratio of DWS:BFS to compressive strength

Ratio of DWS:BFS	Date	Compressive strength (MPa)
4:1	14	14.6
7:3	14	17.5
3:2	14	19.9
2:3	14	18.2
3:7	14	16.9
1:4	14	12.5

Figure 2 showed that the sample had the phenomenon to create hole defects at the ratio DWS:BFS of 4:1 and 7:3 on the same magnification. Therefore, the compressive strength of the sample was reduced. Samples at the ratio of DWS:BFS = 3:2 and 2:3 had a smooth surface, no defects. However, the sample with the ratio of DWS:BFS = 3:2 had a high Al:Si ratio that led to creating better geopolymers.

Effect of NaOH content on compressive strength

From the above experimental results, the ratio of DWS:BFS was chosen as 3:2 to study the influence of NaOH concentration on the compressive strength of geopolymer materials. Experiments were carried on NaOH concentration from 8; 10; 12; 14 and 16 M. The compressive strengths of geopolymer materials after 14 days of curing at common conditions were analyzed and shown in figure 3.

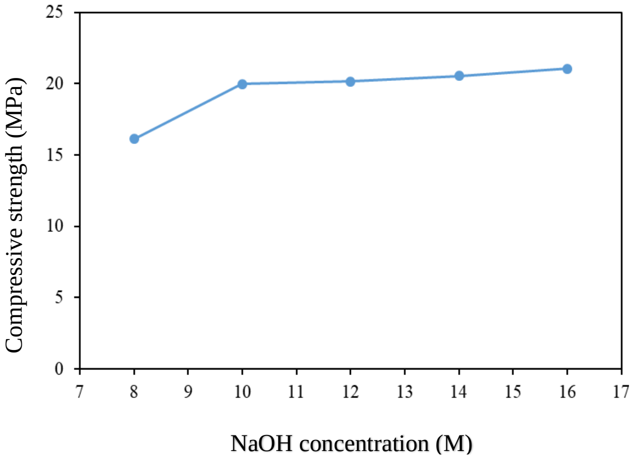

Figure 3: Effect of NaOH content on compressive strength

The obtained results showed that compressive strength increased when NaOH concentration was increased. This was because the high concentration of NaOH enhanced the solubilization of SiO_2 and Al_2O_3 from

DWS and BFS and led to the formation of aluminosilicate gel and thereby increased the compressive strength [15,16]. When the NaOH concentration was high, the compressive strength did not increase much, and there was an excess of alkali on the sample surface after molded. Therefore, a NaOH concentration of 10M was used for further studies.

Effect of ratio of NaOH and Na_2SiO_3 solution on compressive strength

The ratios of NaOH and Na_2SiO_3 solutions studied were 0.28; 0.32; 0.36; 0.40; 0.48 and ratio of DWS:BFS was 3:2. Samples were molded and cured for 14 days under normal conditions. The compressive strengths were analyzed and calculated, shown in figure 4.

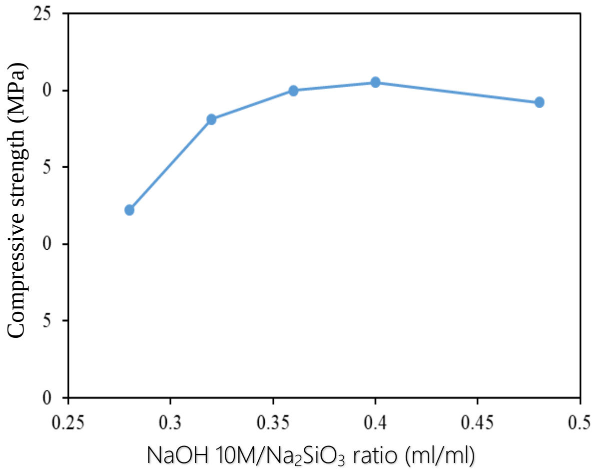

Figure 4: Effect of ratio of NaOH and Na_2SiO_3 solution on compressive strength

The compressive strength of the sample increased when the ratio of NaOH:Na_2SiO_3 solution was increased from 0.28 to 0.36. When the ratio of NaOH:Na_2SiO_3 solution was increased to 0.40, the compressive strength changed insignificantly and decreased at the ratio of NaOH:Na_2SiO_3 solution = 0.48. At the ratio of NaOH:Na_2SiO_3 solution = 0.36, the compressive strength was 19.98 and more suitable because the alkaline solution mixture had a sufficient effect on the ash and slag to create geopolymers and save production cost. This result was similar to the author's.[15] When researching and making geopolymers from bottom ash and blast furnace slag, it was found that when the ratio of NaOH:Na_2SiO_3 was increased, the compressive strength was increased and was the best at the ratio of 0.5. When the ratio of NaOH:Na_2SiO_3 solution was less than 0.36, samples had discrete phenomenon and reaction between NaOH with Si, and Al was unfavorable that led to reducing compressive strength. At a high ratio of NaOH:Na_2SiO_3 solution, excess NaOH led to a longer curing time.

Effect of curing time on compressive strength

The research sample was fabricated in the following conditions: ratio of DWS:BFS = 3.2 and 10 M NaOH:Na_2SiO_3 solution = 0.36. The compressive strengths of curing time 7, 14, and 28 days at normal conditions of geopolymer materials were analyzed, calculated, and shown in figure 5.

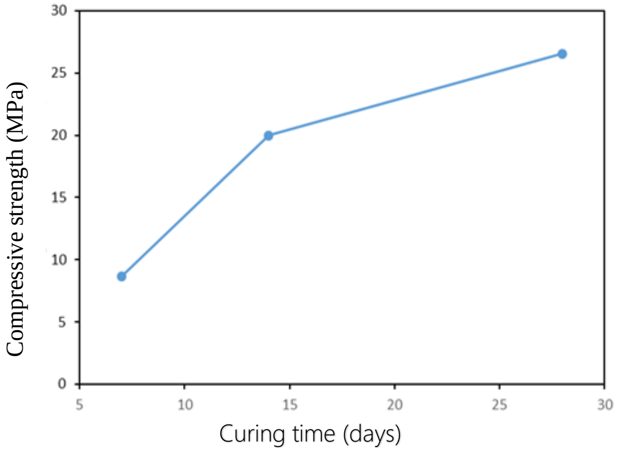

Figure 5: Effect of curing time on compressive strength

The compressive strength of geopolymer samples increased with increasing curing time. At a curing time of seven days, compressive strength only reached 8.68 MPa. When curing time was increased to 14 days, compressive strength reached 19.98 MPa and 26.55 MPa at 28 days. The compressive strength was increased due to forming the polymer gelation reaction between NaOH with Si and Al. The water was slowly released and increased the density and cohesion of the material.[13]

Evaluation of heavy metal migration of geopolymer materials fabricated by BFS and DWS

Geopolymer materials, after cured for 28 days at normal conditions, were extracted with the ratio of material/water equal to 1/10 (kg/l). The results of soaking to assess heavy metal migration into the water environment after 64 days were shown in table 5.

Table 5 showed that the contents of heavy metals in samples made by the ratio of DWS:BFS = 3:2 after 64 days led to water environment were smaller than QCVN 40:2011/BTNMT [17]. The research results were similar to those of the authors [6,18]. Therefore, materials made by DWS and BFS could be used as construction materials without any secondary impact on the environment.

Table 5: Comparison among heavy metals of the soaking solution followed QCVN

Metal	Unit	Soaking concentration	QCVN 40:2011/BTNMT	
			A column	B column
Cr	mg/l	0.04	0.05	0.01
Zn	mg/l	0.32	3.00	3.00
Cu	mg/l	0.27	2.00	2.00
Cd	mg/l	0.01	0.05	0.10
Pb	mg/l	0.02	0.10	0.50
As	mg/l	0.02	0.05	0.10
Ni	mg/l	0.02	0.20	0.50
Hg	mg/l	0.004	0.005	0.01

Conclusions

The geopolymer was successfully manufactured using bottom ash of the power generation incinerator in Ha Nam province and blast furnace slag activated by NaOH solution. With the ratio of DWS:BFS was 3:2 and the ratio of NaOH:Na_2SiO_3 was 0.36, the concrete performed the best compressive strength which was 19.98 MPa when cured at normal conditions.

They were evaluating toxic heavy metal mitigations by soaking according to the QCVN 40:2011/BTNMT. The results showed that DWS - BFS binder activated by alkaline solution had the ability to fix heavy metals. Adhesive materials from DWS-BFS could be used in construction works.

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