EVALUATION ON ENGINEERING PROPERTIES OF GEOPOLYMERS FROM BOTTOM ASH AND RICE HUSK ASH

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ABSTRACT

Geopolymerization is the process of reactions among alumino-silicate resources in high alkaline conditions developed by Joseph Davidovits in 1970s. The reactions form chains and rings of alumino-silicate networks in geopolymeric structures. The raw materials used for geopolymerization normally contain high SiO_2 and Al_2O_3 in the chemical compositions such as meta-kaoline, rice husk ash, fly ash, bottom ash, blast furnace slag, red mud, and others. The geopolymer-based material has potentials to replace Ordinary Portland Cement (OPC)-based materials in the future because of its lower energy consumption, minimal CO_2 emissions and lower production cost as it utilizes industrial waste resources. Moreover, in this paper, coal bottom ash (CBA) and rice husk ash (RHA), which are industrial and agricultural wastes, were used as raw materials with high alumino-silicate resources. Both CBA and RHA were mixed with sodium silicate (water glass) solution for 20 minutes to form geopolymer materials. The specimens were molded in 5-cm cube molds according to ASTM C109/C109M 99, and then cured at room temperature. These products were then tested for engineering properties such as compressive strength (MPa) and volumetric weight (kg/m^3), and water absorption (kg/m^3). The results indicated that the material can be considered lightweight with volumetric weight from 1394 kg/m^3 to 1655 kg/m^3; compressive strength at 28 days is in the range of 2.38 MPa to 17.41 MPa; and water absorption is at 259.94 kg/m^3.

Keywords: Coal bottom ash, geopolymers, rice husk ash, industrial waste, engineering properties.

1. INTRODUCTION

Geopolymer is inorganic polymer material based on alumino-silicate networks which are products of reactions among alumino silicate resources in high alkaline condition. Geopolymer has been recently gaining attention as an alternative binder for Ordinary Portland cement (OPC) due to its low energy and CO_2 burden [1-3]. This binder is also referred by other researchers as alkali-activated pozzolan cements [4] or alkaline activated materials [5] to describe the alkali activation of the solid alumino-silicate raw materials in a strongly alkaline environment. It has been estimated that the use of such geopolymer cement can reduce about 80% of the CO_2 emissions associated with the cement production [3, 6]. In addition, its reported advantage over OPC in terms of material performance includes longer life and durability, higher heat and fire resistance, and better resistance against chemical attack [3, 7-10]. Unlike Portland cement, the solid component of such binder, which is the main source of reactive alumino-silicates, can be sourced out entirely from industrial waste materials such as blast furnace slag, fly ash, bottom ash, rice husk ash, and red mud [10-15].

This research presents the utilization of coal bottom ash and rice husk ash as raw materials to produce a geopolymer-based material. These raw materials constitute the blend of the alkali-activated binder in this study. CBA was used as the primary source of reactive alumina and silicate. It is an industrial waste of coal-fired power plants, which is estimated to be over 125 Mt/year worldwide [16-18]. Rice husk ash was used as the primary source of reactive silica. It is a by-product of burning agri-waste particularly rice husk, with an estimated generation rate of over 20 million metric tons per year worldwide [19-21]. It is highly porous, lightweight material with very good pozzolanic properties which is used to produce cheap insulating refractory materials (e.g., see [22]).

2. MATERIALS AND METHODS

2.1. Materials

In this paper, the CBA waste was obtained from the Tan Rai Power Plant (Lam Dong, Viet Nam). The CBA after being dried for 24 hours were ground in 4 hours by a ball miller and then sieved using a 90 µm-mesh. On the other hand, the rice husk ash (RHA) was produced from the burning of rice husk at 650 ºC for one hour in the furnace. The rice husk was obtained from the agricultural waste in Dong Thap province, a local of the Mekong Delta, Vietnam. The burned rice husks were also ground in 30 minutes and sieved afterwards to produce RHA. Water glass solution (WGS) was from Bien Hoa Chemical Factory, Dong Nai province, Viet Nam.

2.2. Mix proportion and experimental process

Through some preliminary investigations of changes in the ratio of CBA/RHA (e.g. 1/0; 0.75/0.25; 0.5/0.5 (or 1/1); 0.25/0.75 and 1/0), most of these ratios did not meet the technical requirements, except for the ratio of 1/1. Therefore, this ratio was chosen for all following experiments. In detail, a mixture of solid powder with 50% CBA and 50% RHA was mixed with WGS concentration from 10 to 28% (in weight of liquid powder per solid solution). **Table 1** showed the mix proportions and WGS solution using for doing experiments in this research. The effects of WGS proportions were investigated through engineering properties of the geopolymer specimens after cured at room condition for 28 days.

Table 1. Mix proportions used in the design of experiments

Mixture (Sample)	Proportion of solid powders (% in wt)		Concentration of WGS (% in wt, liquid/solid)
	CBA	*RHA*	
G10	50	50	10
G16	50	50	16
G22	50	50	22
G28	50	50	28

The powdered raw materials were prepared according to the designed proportion and then mixed with 10 to 28% (by weight of the powdered solid) water glass solution for 20 minutes using a laboratory cement mixer [23]. Water is also added to adjust the pH value of the paste mixture to around 12. The fresh geopolymer paste was molded to a standard cubic size (50 mm x 50 mm x 50 mm) and cured at room temperature condition (30^{o}C, 80% humidity) for 28 days. After curing, these specimens were tested for engineering properties. At least three cured specimens were prepared prior to each test. Figure 1 depicts the flow of the experimental process. The mixing process and specimen preparation are then repeated for all mix proportions.

Compressive strength (MPa) and volumetric weight (kg/m^3) tests were performed for the 50-mm cube specimens according to ASTM C109/C109M [24]. On the other hand, water absorption test specified by ASTM C140 was also performed [25].

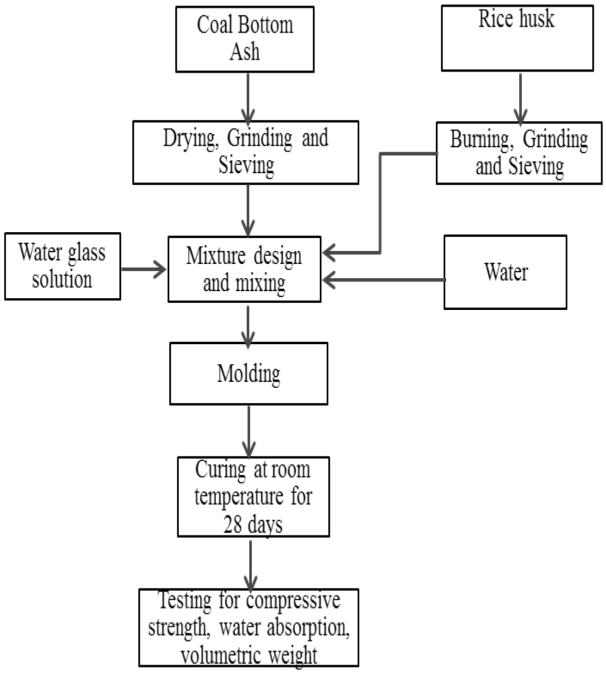

Figure 1. The flow chart of experimental process

3. RESULTS AND DISCUSSION

3.1. Properties of raw materials

Table 2 summarizes the chemical composition of these alumino-silicate raw materials. RHA contains high silica with 83.2% of SiO_2 and low loss on ignition (LOI) value at 4.6%. The LOI value is an important parameter in material engineering. It shows the completeness of the burning process to obtain the RHA with high silica and activity. Therefore, it is necessary to have a proper heating regime to get RHA with high quality CBA has 20.85% of Al_2O_3, 52.63% of SiO_2, 9.08% of Fe_2O_3 in its chemical composition. As indicated in XRD patterns of these materials (see Figure 2), the raw materials contain both amorphous alumina and silica [26-27] suitable for geopolymerization reaction at high alkaline condition. For mineral compositions, CBA has quartz (SiO_2) and aluminum silicate oxide (Al_2SiO_5) in its crystal phases, RHA contains only cristobalite (SiO_2) in the crystal structure. As for the alkaline activator, water glass or sodium silicate solution (32% SiO_2, 12.5% Na_2O and 55% H_2O) with a silica modulus of 2.5 was used. Volumetric weight of CBA is at 1378 kg/m^3 and bulk density of CBA is at 2560 kg/m^3.

Table 2. Chemical composition (% in weight) of CBA and RHA.

Oxides	*CBA*	*RHA*	*WGS*
Al_2O_3	20.85	0.37	-
SiO_2	52.63	83.20	32.00
Fe_2O_3	9.08	1.70	-
Na_2O	0.22	-	12.50
K_2O	4.75	6.60	-
Others	3.86	2.93	-
L.O.I	8.61	4.60	-
Moisture content (%)	2.66	0.23	55.50

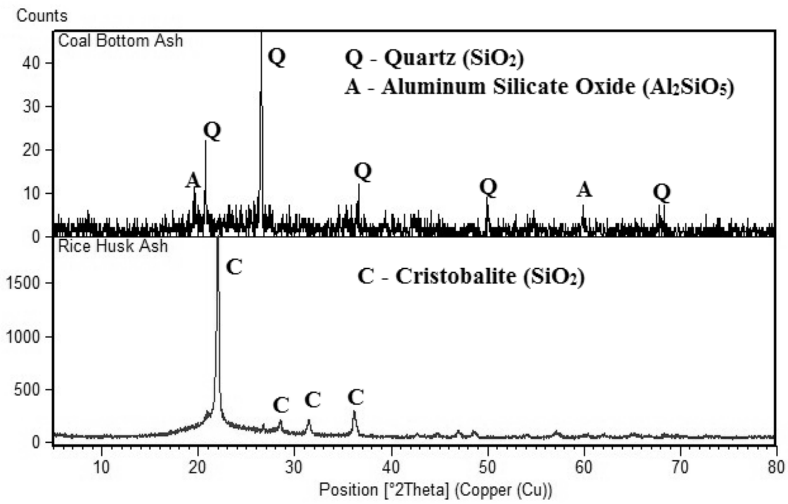

Figure 2. XRD patterns of CBA and RHA [26-27]

3.2. Engineering properties of geopolymer products

Table 3 summarizes the results of the experimental test done on the geopolymer specimens. All geopolymer specimens after 28 days were having low volumetric weight. These values range from 1394 to 1655 kg/m^3 which are less than the prescribed volumetric weight (1680 kg/m^3) for a lightweight concrete brick in ASTM C55-99 and ASTM C90-99a [28-29].

Table 3. Engineering properties of the geopolymer specimens.

Samples	*Volumetric weight (kg/m^3)*	*Compressive strength (MPa)*	*Water absorption (kg/m^3)*
G10	1394	2.38	394.10
G16	1472	6.23	367.61
G22	1546	14.10	334.79
G28	1655	17.41	259.94

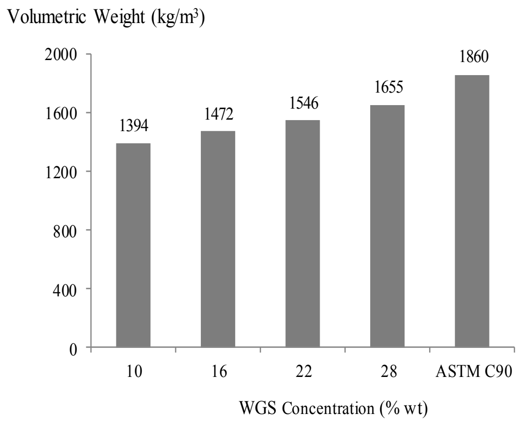

Figure 3. The lower values of volumetric weight compared with ASTM C90 for lightweight concrete brick

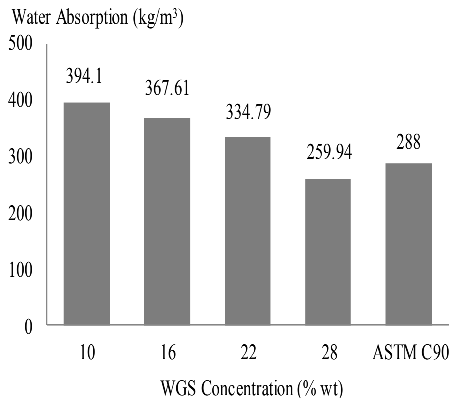

Figure 4. Water absorption of the ash geopolymer compared with lightweight concrete brick in ASTM C90

As for water absorption, the G28 specimen has the lowest value (259.94 kg/m^3) whereas G10 has the highest value (394.10 kg/m^3). Nevertheless, the water absorption value of the geopolymer (sample G28) was still lower than 288 kg/m^3 which is the prescribed limit according to ASTM C55 or C90 [28-29] requirements for lightweight concrete brick material.

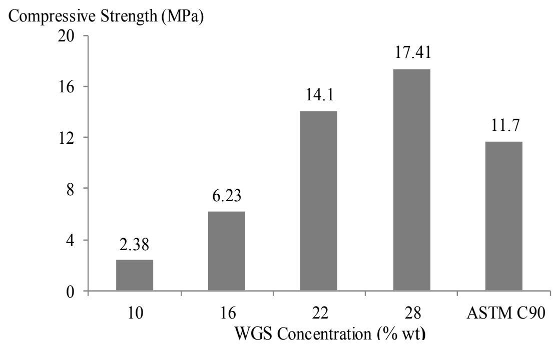

Figure 5. Compressive strength of geopolymer with 22-28% WGS is higher than the lower limits of ASTM C90

The 28-day compressive strength of the specimens ranges from 2.38 to 17.41 MPa. Specimens G22 and G28 were above 11.7 MPa, which is the prescribed strength for concrete brick according to ASTM C55 and C90-99a standards.

4. CONCLUSIONS

This paper presents an experimental study to produce and optimize a light-weight geopolymer-based material from a blend of coal bottom ash waste and rice husk ash. The ash-geopolymer based materials with a solid powder mix of 50% CBA and 50% RHA and alkaline-activated with 28% (by weight of solids) of water glass (silica modulus of 2.5) produced geopolymers with an average 28-day compressive strength of 17.4 MPa, water absorption of 259.9 kg/m^3, volumetric weight of 1655 kg/m^3. These values were in good agreement with the required values of the ASTM C55 and C90 for lightweight concrete brick. The ternary-blended geopolymer can thus be potentially used as lightweight material for masonry walls or partitions. Future studies will consider chemical resistance of the material and other thermal properties such as thermal conductivities, thermal expansion coefficient. Microstructure of these geopolymers will also be studied further to understand the relationship among composition, microstructure and macroscopic properties of such materials.

REFERENCES

1. Davidovits, J. - Geopolymers: man-made rock geosynthesis and the resulting development of very early high strength cement, Journal of Materials Education **16** (2&3) (1994) 91-139.
2. Davidovits, J. - 30 years of successes and failures in geopolymer applications. Market trends and potential breakthroughs, Geopolymer 2002 Conference, Melbourne, Australia (2002) 1-16.
3. Davidovits, J., ed. - Geopolymer chemistry and application, 3rd edn, Institut Géopolymère, France, 2011.
4. Shi C., Jinénez, A. F., Palomo A. - New cements for the 21st century: the pursuit of an alternative to Portland cement, Cement and Concrete Research **41** (7) (2011) 750 – 763.
5. Provis J. L. and van Deventer J. S. J. - Alkali activated materials: State of the art report, RILEM-TC244 AAM, Springer Dordrecht Heidelberg, 2014.
6. van Deventer J. S. J., Provis J. L., and Duxson P. - Technical and commercial progress in the adoption of geopolymer cement, Minerals Engineering **29** (2012) 89–104.
7. Bakharev, T. - Resistance of geopolymer materials to acid attack, Cement and Concrete Research **35** (2005) 658 – 670.
8. Kong D. L. Y., Sanjayan J. G. and Sagoe-Crentsil K. - Comparative performance of geopolymers made with metakaolin and fly ash after exposure to elevated temperatures, Cement and Concrete Research **37** (12) (2007) 1583–1589.
9. Kong D. L. Y. and Sanjayan J. G. - Effect of elevated temperatures on geopolymer paste, mortar and concrete, Cement and Concrete Research **40** (2010) 334–339.
10. Petermann J. C., Saeed A. and Hammons M. I. - Alkali-activated geopolymers: A literature review, Air force research laboratory materials and manufacturing directorate, 2010.
11. Xu H. and van Deventer J. S. J. - Effect of source materials on geopolymerization, Industrial & Engineering Chemistry Research **42** (8) (2003) 1698–1706.
12. Kumar S., Kumar R., Bandopadhyay A. and Mehrotra S. P. - Novel geopolymeric building materials through synergistic utilization of industrial waste, International Conference Alkali Activated Materials - Research, Production and Utilization, Agentura Action M (2007) 429 – 446.
13. Dimas D. D., Giannaopoulou I. P. and Panias D. - Utilization of alumina red mud for synthesis of inorganic polymeric materials, Mineral Processing and Extractive Metallurgy Review **30** (2009) 211–239.
14. Zhang G. and He J. - Geopolymerization of red mud and rice husk ash and potentials of the resulting geopolymeric products for civil infrastructure applications, Developments in Strategic Materials and Computational Design II, The American Ceramic Society (2011) 45 – 52.
15. Juenger M. C. G., Winnefeld F., Provis J. L. and Ideker J.H. - Advances in alternative cementitious binders, Cement and Concrete Research **1** (2011) 1232–1243.

16. Wang C., Li J., Sun X., Wang L. and Sun X. - Evaluation of zeolites synthesized from fly ash as potential adsorbents for wastewater containing heavy metals, Journal of Environmental Sciences **21** (2009) 127–136.
17. Kochert S., Ricci D., Sorrenti R. and Bertolino M. - Transforming bottom ash into fly ash in coal fired power stations, 2009 World of Coal Ash (WCA) Conference, May 4-7, 2009, in Lexington KY, USA.
18. Bassetti F., Coppolla D., and Ricci D. - Fully-dry bottom ash removal system for elimination of ponds, 2015 World of Coal Ash (WCA) Conference, May 5-7, 2015, in Nasvhille TN.
19. Zemke N. and Woods E. - Rice husk ash, California Polytechnic State University 2009, 1-12.
20. Bronzeoak Ltd. - Rice husk ash market study, Limited Distribution – UK companies, ETSU U/00/00061/REP - DTI/Pub URN 03/668, 2003.
21. Siddique R. and Khan M. I. - Supplementary cementing materials, Engineering Materials, Springer-Verlag Berlin Heidelberg **5** (2011) 231-281.
22. Kapur P. C. - Thermal insulations from rice husk ash, an agricultural waste, Ceramurgia International **6** (2) (1980) 75-78.
23. Khale D. and Chaudhary R. - Mechanism of geopolymerization and factors influencing its development: a review, Journal of Materials Science **42** (2007) 729-746.
24. ASTM C109/109M - Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens), American Society for Testing and Materials, Philadelphia June 2000. Sec.4, Vol. 04.01.
25. ASTM C140-99b - Standard test methods for sampling and testing concrete masonry units and related units, American Society for Testing and Materials. Philadelphia June 2000. Sec.4, Vol. 04.05.
26. Nguyen H. T., Promentilla M. A. B., Gallardo S. M., Bacani F. T., Hinode H., Do Q. M., Do M. H. and Pham T. K. - Producing geopolymer-based materials from a ternary blend of red mud, rice husk ash and diatomaceous earth, 20th Regional Symposium on Chemical Engineering (RSCE 2013) - Emerging Challenges in Chemical Engineering Research, Education and Industries, Bohol, November 2013, G6.
27. Nguyen H. T., Do Q. M., Do M. H., Dinh T. K. A., Hinode H., Pham T. K., Promentilla M. A. B. - Producing heat resistant geopolymer-based materials from red mud and rice husk ash, 11th International Conference on Ecomaterials (ICEM 11) - Green materials and green technology for green "MONOZUKURI" (Fabrication with heat), Hanoi, November 2013, W08, 82 – 87.
28. ASTM C55-99. - Standard specification for concrete brick, American Society for Testing and Materials, Philadelphia June 2000, Sec.4, Vol. 04.05.
29. ASTM C90-99a. - Standard specification for loadbearing concrete masonry units, American Society for Testing and Materials, Philadelphia June 2000. Sec.4, Vol. 04.05.

TÓM TẮT

ĐÁNH GIÁ CÁC ĐẶC TÍNH KỸ THUẬT CỦA VẬT LIỆU GEOPOLYMER TỪ TRO ĐÁY VÀ TRO TRẤU

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Geopolymer hóa là quá trình phản ứng giữa các nguồn alumino-silicat trong điều kiện kiềm cao do Joseph Davidovits phát triển vào những năm 1970. Các phản ứng hình thành các chuỗi và vòng của mạng alumino-silicate trong các cấu trúc vi mô của nó. Nguyên liệu được sử dụng cho quá trình polymer vô cơ hoá thường chứa SiO_2 và Al_2O_3 cao trong thành phần hóa như meta-kaolin, tro trấu, tro bay, tro đáy, xỉ lò cao, bùn đỏ, và các loại khác. Vật liệu geopolymer có tiềm năng thay thế xi măng truyền thống trong tương lai do tiêu thụ năng lượng thấp hơn, lượng khí thải CO_2 và chi phí sản xuất thấp do sử dụng các nguồn chất thải công nghiệp. Hơn nữa, trong bài báo này, tro đáy của quá trình đốt than (CBA) và tro trấu (RHA), là các chất thải công nghiệp và nông nghiệp, được sử dụng làm nguyên liệu có nguồn alumin silicat cao. Cả CBA và RHA đều được trộn với dung dịch natri silicat (thuỷ tinh lỏng) trong 20 phút để tạo ra vật liệu geopolymer. Các mẫu được đúc theo khuôn lập phương 5 cm theo tiêu chuẩn ASTM C109 / C109M 99, sau đó được bảo dưỡng ở nhiệt độ phòng. Các sản phẩm này sau đó đã được kiểm tra về các tính chất kỹ thuật như độ bền nén (MPa), khối lượng thể tích (kg/m^3), và độ hút nước (kg/m^3). Kết quả chỉ ra rằng các geopolymer là vật liệu nhẹ với trọng lượng thể tích từ 1394 đến 1655 kg/m^3; Cường độ nén tại 28 ngày nằm trong khoảng từ 2,38 đến 17,41 MPa; và độ hút nước là 259,94 kg/m^3.

Từ khóa: Tro đáy, tro trấu, rác thải công nghiệp, geopolymer, đặc tính kỹ thuật.