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ENVIRONMENTAL ASPECTS OF INFRASTRUCTURE MATERIALS (CASE STUDY: ALKALI ACTIVATED MATERIAL VERSUS CEMENT BASED MATERIAL)

Partogi H Simatupang*

Civil Engineering Department, Faculty of Science and Engineering, Universitas Nusa Cendana, Kupang

ABSTRACT

Civil engineering infrastructure using cement-based materials is very dominant in Indonesia. The use of cement-based material is much more than the use of steel, asphalt and wood. Although the use of cement-based materials is very dominant, however, it is necessary to find similar materials that can replace the cement-based material. One of the candidate materials is Alkali Activated Material (AAM). AAM is a solid material obtained by activating a silica-alumina-rich material with an alkaline activator. This paper presents a study of environmental aspects of cement and AAM based materials. Environmental aspects compared were: (1) CO_2 emissions, (2) toxic immobilization and (3) solid waste utilization. The amount of CO_2 emissions was obtained by multiplying the CO_2 coefficients of raw materials against the amount of base materials for the similar compressive strength of those materials. Toxic immobilization was assessed by comparing the values of TCLP (Toxic Characteristic Leaching Procedure) obtained by using AAS (Atomic Absorption Spectrometry). Solid waste utilization was determined by how much compressive strength obtained if the fine aggregate of mortar replaced by mining waste (tailing). The mining waste used was tailing of copper and gold mining from PT. Newmont Nusa Tenggara in Sumbawa, Indonesia. Based on this research, the results were obtained, i.e., (1) CO_2 emissions generated AAM mortar lower about 33% compared to CO_2 emissions generated PC/Portland Cement mortar; (2) the toxic immobilization of AAM mortar on toxic elements of Boron (B) and Chromium (Cr) was much better than that of PC mortar and (3) the use of tailings in lieu of fine aggregates yields greater compressive strength in AAM mortar than mortar PC. The results show that Alkali Activated Material has eco-friendly material characteristics that can be compared with cement-based material.

Keywords: environmental aspects; alkali activated material; cement based material

1. INTRODUCTION

World population growth was very high in the last century. World population was about 1.5 billion people in the early 21^{st} century and increased to 6 billion people by the end of the 21^{st} century. The increase of population made the increase of urbanization. In the early 21^{st} century, about 10% of the population lived in urban areas, but increased to 50% by the end of the 21^{st} century (Mehta 2002). Because of that, the need for infrastructure was also increasing. As a consequence, the need for materials to make the infrastructure was also increasing. According to Mehta (2001), about two centuries ago where the Industrial Revolution began until the middle of the 21^{st} century, the problem of environmental conservation was less attention because of the abundant natural resources and the healthy environment. Now, however, environmental conservation is a

*Corresponding author: E-mail: partogihsimatupang@gmail.com

very important issue in all aspects of human life including in infrastructure materials. The above conditions become a dilemma for Civil Engineering because the most commonly used material for infrastructure was cement based material.

It is now estimated that global concrete needs exceed 13 billion tonnes per year (Portland Cement/PC demand ranges from 0.91 to 1.95 billion tonnes). Meanwhile, cement consumption in Indonesia is almost 85 million tonnes. Cement is only about 7-15% of PC concrete. However, cement can most significantly suppress the quality of the environment. Some of the weaknesses of PC cement are: (1) inefficient in raw material usage, because in the manufacture of 1 ton PC clinker takes ± 1.7 ton raw material, (2) high energy consumption to obtain clinker (required heating up to ± 1450^{O}C), (3) less environmentally friendly as production emits large CO_2 emissions (production of 1 ton PC clinker produces 1 ton CO_2), and (4) high susceptibility to durability / endurance problems due to cement hydration products produce easily soluble Ca $(OH)_2$ minerals (Neville 1995, Davidovits 1994, Mehta 1994). This paper presents a comparison of environmental aspects on two manmade stone materials, i.e. cement material and Alkali Activated Material. Environmental aspects reviewed were: (1) CO_2 emissions, (2) toxic immobilization and (3) solid waste utilization. The purpose of this research is to get more environmentally friendly material that can be applied as infrastructure material in Indonesia.

2. METHODOLOGY/ EXPERIMENTAL

2.1. Material

The raw materials used to make Portland Cement/PC mortars were: (1) Portland Cement Composite/PCC of Indocement, (2) sand as fine aggregate, and (3) water. While the raw materials used to make AAM mortar were: (1) Class F fly ash of Suralaya Power Plant as precursor, (2) sodium silicate and sodium hydroxide solution (as activator solution) and (3) sand as fine aggregate.

The sand used as a fine aggregate was from Galunggung quarry. The fine aggregate used to make the mortar was aggregate under SSD (Saturated Surface Dry). The fine aggregate distribution was grade No.1 according to SNI 03-2834-1993 (Indonesian Standard). The characteristics of sand are given in Table 1.

Table 1. The characteristics of sand as fine aggregate

Item	Fine Aggregate Ex.Galunggung	
	Trial-1	Trial-2
Apparent Spesifik Gravity	2,50	2,42
Bulk Specific Gravity (dry)	2,21	2,20
Bulk Specific Gravity (SSD)	2,33	2,29
Absorption Percentage (%)	5,26	4,17
Dense Volume Weight (kg/ltr)	1,421	1,435
Loose Weight Volume (kg/ltr)	1,285	1,289

The mining solid waste used was tailing of copper and gold mining from PT. Newmont Nusa Tenggara (PTNNT) in Sumbawa, Indonesia. Tailing taken from the PTNTT was washed and drained. Then, tailing was dried and sieved using sieving No.200. The retained tailing was used as a substitute for fine aggregate as filler in the

AAM mortar phase. Tailing was also in SSD (Saturated Surface Dry) conditions.

Oxide compositions of Class F fly ash and tailing used are given in Table 2. It can be seen that the content of SiO_2 and Al_2O_3 are 78.87% for Class F fly ash and 83.57% for tailing.

Table 2. Chemical Oxide Compositions of Raw Materials As Precursors

Material	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	SO_3	Method
Fly Ash	52,30	26,57	6,00	7,28	1,41	0,70	XRF
Tailing	64,84	18,73	4,49	3,45	2,446	0,01	XRF

Note: XRF = *X-Ray Fluorescence* Testing

2.2. Sample

The specimens used were cubic mortar with size 5 cm x 5 cm x 5 cm. Each variable was provided three specimens. The value shown in the discussion result was the average of three samples.

For a comparison of CO_2 emissions, the mixture of AAM mortar and PC mortar were taken so that the similar compressive strength was obtained. PC Mortar consisted of cement, sand and water. Meanwhile, AAM mortar consisted of sand, fly ash and activator solution. For comparisons of toxic immobilization, AAM mortar and PC mortar used tailing in lieu of 100% sand. The AAM mortar mixture used was the activator : fly ash : sand = 1: 2: 3. Meanwhile, the mixture of PC mortar mixture was water : cement : sand = 1: 2: 3.

2.3. Sample Making

The mortar samples were prepared according to ASTM C 109-92 standard. Mortars made were treated with 2 methods of curing i.e ambient curing and dry curing. Method of mortar making and the procedures of ambient and dry curing refered to Simatupang et al 2015 and Simatupang 2013. Meanwhile, the manufacture of PC mortar was following the SNI (Indonesian) standards.

2.4. Testing

The amount of CO_2 emissions was obtained by multiplying the CO_2 coefficients of the raw material against the amount of raw material for the similar compressive strength of the mortar. The CO_2 coefficients of raw material was referred to Yang et al 2013. Toxic immobilization was assessed by comparing the value of TCLP (Toxic Characteristic Leaching Procedure) obtained by using AAS (Atomic Absorption Spectrometry). Solid waste utilization was determined by how much compressive strength obtained if the fine aggregate of mortar replaced by mining waste (tailing). Testing of mortar compressive strength was performed by using UTM (Universal Testing Machine) testing with loading speed of 0.2 rpm for 20000 kg (20 tons).

3. RESULTS AND DISCUSSION

3.1. CO_2 Emission

The amount of CO_2 emissions of AAM mortar and PC mortar were calculated. Since data of CO_2 emissions of raw material in Indonesia does not exist, coefficient CO_2 stated by Yang et al 2013 was used to calculate CO_2 emissions. AAM mortar and PC mortar which had similar compressive strength about 47 MPa were used. Calculations of CO_2 was made only on the contribution of the raw material as given in Table 3 and

Table 4 below.

Table 3. Calculation of CO_2 emissions on PC mortar (fc_{28}=47,12 MPa)

Item	CO_2-gr/gr	Amount of Material	Unit	Amount of CO_2	Unit
PC	0,944	682,8	gr	644,56	gr
Sand	0,0026	955,9	gr	2,49	gr
Water	0,000196	341,4	gr	0,07	gr
			TOTAL	**647,12**	**gr**

Table 4. Calculation of CO_2 emissions on AAM mortar (fc_7=47,5 MPa)

Item	CO_2-gr/gr	Amount of Material	Unit	Amount of CO_2	Unit
Sand	0,0266	945	gr	2,46	gr
Fly Ash	0,0196	630	gr	12,35	gr
Activator	1,232	315	gr	388,08	gr
Dry Curing	0,0385	gr/cm3 with volume of sampel = 750 cm3		28,88	gr
			TOTAL	**431,76**	**gr**

Based on Table 3 and Table 4, it appears that CO_2 emissions on AAM mortar is 33% lower than that of PC mortar. If compared with the results obtained Yang et al. 2013 where CO_2 emission reductions can reach 55% -75% reduction for concrete phase, 33% reduction in CO_2 emissions in the mortar phase seems rational because the number of binders (largest contributor of CO_2 emissions in AAM mortar components) required on mortar phase was greater than concrete phase.

3.2. Toxic Immobilization

The comparison of Toxic Characteristic Leaching Procedure (TCLP) values of AAM mortar and PC mortar which used tailing as a sand substitution is given in Table 5 or Figure 1. According to Table 5, it is shown that TCLP values of both mortars are lower than the standard of TCLP values (Indonesian standard). If we look at the ratio of the number of toxic elements as shown in Figure 1, it is generally seen that AAM binders are effective on toxic immobilization especially for Boron (B) and Chromium (Cr). However, toxic immobilization for toxic elements such as Silver (Ag) and Zinc (Zn) in AAM mortar were less effective.

Table 5. Comparison of TCLP values between Class F fly ash based AAM and Portland Cement mortar which equally used PTNTT tailings as 100% substitution of sand

Parameter	TCLP (mg/L)		
	Mortar PC-*Tailing*	**Mortar AAM -*Tailing***	**Indonesian Standard PP18/99 Jo PP85/99**
Arsen (As)	0,009	0,009	5
Barium (Ba)	7,412	4,662	100
Boron (B)	2,195	1,048	500
Cadmium (Cd)	0,031	0,031	1
Chromium (Cr)	0,154	0,001	5
Copper (Cu)	0,017	0,014	10
Lead (Pb)	0,391	0,167	5
Mercury (Hg)	0,0011	0,0008	0,2
Selenium (Se)	0,015	0,013	1
Silver (Ag)	0,001	0,007	5
Zinc (Zn)	0,015	0,145	50

While based on research Zhang et al. 2008, Class F fly ash based AAM binder effectively immobilized toxic Cr, Cd and Pb which were in the form of nitrate and chromate salts. It was also characterized as unchanged elements (very small changes) in the AAM structure. This confirms the results of this study as given in Table 5. Other research, which specifically examined the immobilization of Mercury toxic elements (Hg) in Class F fly ash based AAM pastes, also concluded the ability of AAM binders to immobilize these elements (Donatello et al. 2012).

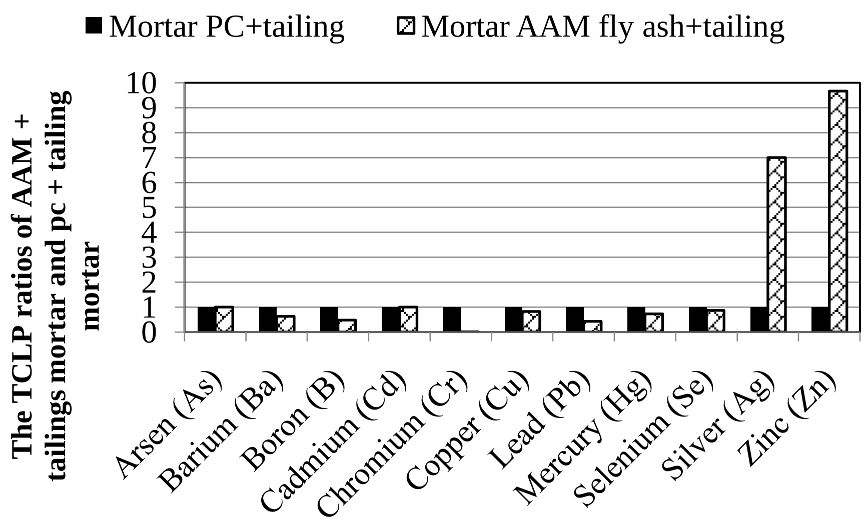

Figure 1. The TCLP ratios of AAM + tailing mortar and pc + tailing mortar

Meanwhile, according to Pandey et al. 2012, Class F fly ash based binder more effectively immobilized toxic elements Zinc (Zn) compared to portland cement binders. This was characterized by smaller toxic element content in the AAM binder than in the portland cement binder. But their leaching test was SPLP (Synthetic Precipitation Leaching Procedure). Therefore, the comparison of toxic Zinc (Zn) content of the results in Table 5 above cannot be directly asserted because the different leaching test methods used. This was confirmed by Provis 2009 in Provis and van Deventer (2009) which stated that immobilization of Zinc (Zn) element on AAM material was good but not uniform. The condition of toxic content ratio of Silver (Ag) element in Fig. 1 cannot yet be justified because there was no literature related to the immobilization of this Toxic Silver (Ag) element. However, based on the discussion in this sub-section, in general, the ability of AAM binders to immobilize toxic elements is better than that of Portland cement binder.

3.3. Solid Waste Utilization

Comparison of Class F fly ash based AAM mortar using PT Newmont Nusa Tenggara (PTNNT) tailing as 100% substitution of sand with Portland Cement mortar using the same tailing as 100% substitution of sand for two compaction levels is given in Table 6. To see the solid waste utilization, it was reviewed the development of mortar compressive strength against the compressive strength of control mortar of each material. Control mortar was mortar for both types of materials that used sand as fine aggregate. Comparison of mortar compressive strength using PTNNT tailings as a 100% sand substitution is given in Table 6 and Figure 2.

Table 6. Comparison of strength of AAM Mortar and PC Mortar against the use of tailings as a 100% sand substitution

	Compressive strength of Mortar at 28 days (MPa)	
	Control Mortar	Tailing Mortar
Mortar AAM with less compaction	18	36,9
Mortar AAM with perfect compaction	45,1	45,3
Mortar PC	28,69	12,8

Note: Mortar Control is a mortar that uses sand as a fine aggregate

Based on Table 6 and Figure 2, it appears that the use of tailing as a 100% sand substitution on PC mortar will result lower strength about more than 50%. This is due primarily to the fineness of the tailings so that the mixture of PC mortar requires more water, especially to get good compaction.

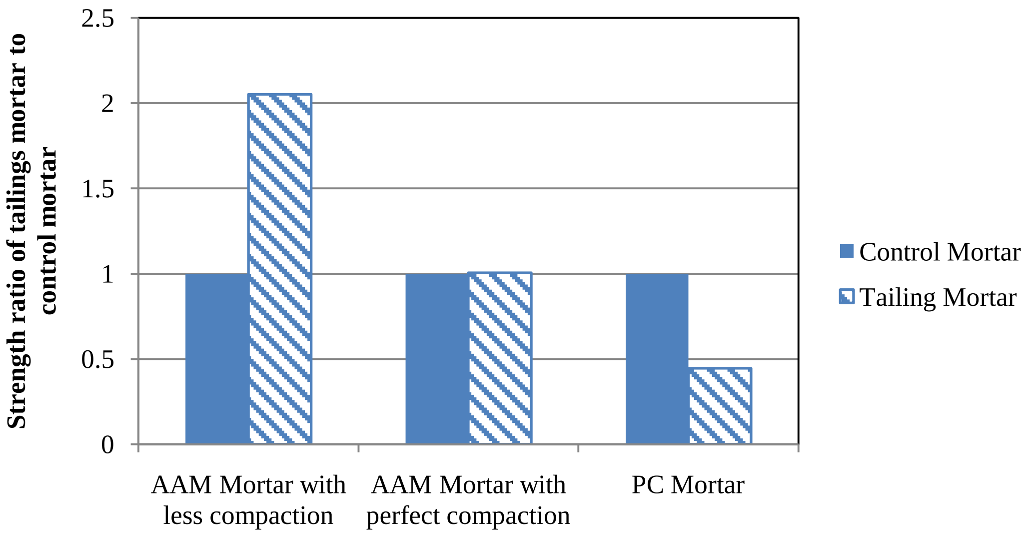

Figure 2. The strength ratio of tailings mortar to control mortar

This extra water requirement should be followed by the addition of Portland Cement. While on AAM mortar, the use of tailing as a sand substitution has 2 (two) advantages: (1) reducing the compaction level and (2) increasing the compressive strength. Therefore, based on this fact, Class F fly ash based AAM has the capability to use tailing more than cement based materials. The results of this study confirmed the results of Imran et al (2011) which states that the optimal use of tailings on the PC mortar by 20% while in the PC concrete by 5%. The use of tailing with an amount greater than the optimal value will result decreasing of strength. Based on this research, the use of tailings as a substitute for 100% fine aggregate can be done on AAM mortar.

4. CONCLUSION

Based on the results of this study, several conclusions can be drawn: (1) the emissions of CO_2 produced by AAM mortar is smaller about 33% compared to CO_2 emissions generated by mortar PC; (2) the toxic immobilization of AAM mortar on toxic elements of Boron (B) and Chromium (Cr) is much better than that of PC mortar and (3) the use of tailings as a substitute of 100% fine aggregate yields greater compressive strength in AAM mortar than with PC mortar. Based on these environmental aspects (CO_2 emissions, toxic immobilization and solid waste utilization), AAM materials have eco-friendly material characteristics that can be compared with portland cement materials. This AAM material can be used to make environmentally friendly materials for infrastructure.

REFERENCES

Davidovits, J., (1994) : High Alkali Cements for 21st Century Concretes, *Proceedings of V.Mohan Malhotra Symposium on Concrete Technology : Past, Present and Future, SP-144, ACI*, Detroit, USA, 383-397

Donatello, S., Fernandez-Jimenez, A., and Palomo, A., (2012) : An assessment of Mercury immobilisation in Alkali Activated *Fly ash* (AAFA) Cements, *Journal of Hazardous Materials*, **213-214**, 207-215

Imran, I., Abduh, M., Gunawan, B., Idiasta, N., Simatupang, P.H., Hardy, Aditya, and Djuarsa, F., (2011) : Study of Tailings Utilization with 3R Principle (Reuse, Recycle and Recovery) PT.Newmot Nusa Tenggara (PTNNT): Utilization of PTNNT Tailings for Acquiring Concrete Materials and Other Building Materials, Research Report, LAPI ITB

Mehta, P.K., (1994) : Concrete Technology at The Crossroads-Problems and Oppurtunities, *Proceedings of V.Mohan Malhotra Symposium on Concrete Technology : Present and Future*, Detroit, USA, 1-30

Mehta P.K (2001). "Reducing The Environmental Impact of Concrete", Concrete International, October. Vol.23 No.10, pp.61-66

Mehta P.K (2002). "Greening of The Concrete Industry for Sustainable Development", Concrete International, July. Vol.24 No.7, pp.23-28

Neville, A.M., (1995) : *Properties of Concrete*, 4th Edition Longman Group Limited, UK, 1-56

Pandey, B., Kinrade, S.D., and Catalan, L.J.J., (2012) : Effects of Carbonation on the Leachablity and compressive Strength of cement-*solid*ified and geopolymer-*solid*ified synthetic metal wastes, *Journal of Environmental Management*, **101**, 59-67

Provis, J.L., and van Deventer, J.S.J., (2009) : *Geopolymers : Structure, Processing and Industrial Applications*, 1st Edition Woodhead Publishing Limited and CRC Press, USA

Simatupang, P.H., (2013) : The Development of Alkali Activated Materials (AAM) to obtain environmentally friendly Infrastructure Materials, Dissertation of Civil Engineering, Bandung Institute of Technology.

Simatupang, P.H., Imran, I., Pane, I., and Sunendar, B., (2015) : On Development of a Nomogram for Alkali Activated Fly Ash Material (AAFAM) Mixtures, *J.Eng.Technol.Sci*, vol 47, No. 3, 231-249

Yang, K-H., Song, J-K., and Song, K-I., (2013) : Assessment of CO2 reduction of Alkali-Activated Concrete, *Journal of Cleaner Production*, **39**, 265-272

Zhang, J., Provis, J.L., Feng, D., and van Deventer, J.S.J., (2008) : Geopolymers for Immobilization of Cr^{6+}, Cd^{2+}, and Pb^{2+}, *Journal of Hazardous Materials*, **157**, 587-598