Mechanical Strength of Trass as Supplementary Cementing Material

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Abstract: *The suitability of trass in Indonesia as a supplementary cementing material was investigated and studied. Mechanical properties of pozzolanic–lime obtained from trass reacting with lime were evaluated according to procedure ASTM C-593. Compressive strength of mortar was measured at ages of 2, 3, 7, 14 and 28 days. In addition to the compressive strength, pozzolanic reaction of trass and lime was also evaluated by Thermal Activity Measurement (TAM) Air Calorimeter. Results showed that increasing of fineness until 9000 Blaine resulted strength of 60 kg cm^{-2} at age of 2 days. Further increase in compressive strength of 90 kg cm^{-2} at the age of 2 days was obtained by the addition of 2.71 wt. % Na_2SO_4. Results of TAM Air Calorimeter of pozzolanic reaction showed that heat released followed a linear and exponential correlations for increasing fineness and addition of Na_2SO_4, respectively.*

Keywords: trass, pozzolanic reaction, supplementary cementing material

1. INTRODUCTION

Nowadays, pozzolanic materials are widely used as supplementary cementing material in Portland cements and may replace part of the clinker in order to enhance the performance of the hydrated cement. Such composite or blended cements are employed for their economic, ecological and technological benefits. Energy consumption as well as CO_2 emission is reduced. Supplementary cementing materials reduce lime content in hydrated Portland cements and replace it with pore-filling cement hydrates, which are known to improve the ultimate strength, impermeability and durability to chemical attack of cement.[1] Different types of additions are used such as pozzolanic (natural pozzolan, low calcium fly ash and silica fume), auto pozzolanic (high calcium fly ash and blast furnace slag) and crystalline (generally known as filler). Pozzolanic activity or hydraulicity of pozzolanic material is mainly associated with their vitreous and/or amorphous structure.[2]

The slow chemical reaction between pozzolan and calcium hydroxide, lime (CH) in water (H) is called the pozzolanic and leads to the formation of calcium silicates (C-S-H) and calcium aluminate hydrates (C-A-H). However, the C-A-H usually have higher crystallinity and their composition is usually easier to determine than the composition of C-S-H. Because pozzolan are usually low in CaO, this component must be added in stoichiometric quantity and added as lime or, in composite cement, provided by the lime formed during cement hydration. The consumption of lime, followed by the precipitation of hydrated cement minerals with lower density is very efficient in filling up capillary pore space thereby decreasing porosity. This lime consuming process and the associated pore refinement process lead to increase strength, impermeability, durability and chemical resistance of pozzolan cement.[1]

Mechanical activation is a mechanical physical method to improve the degree of fineness through method of pulverization, and thus increase the surface area and surface energy greatly so as to enhance volcanic ash reaction activity. There are many reports about this subject. Pulverization breaks the vitreous body and increases their surface, resulting in higher activity.[3]

Chemical activation is widely used to excite the activity of pulverized fuel ash. Chemicals used may include alkaline reagents such as $Ca(OH)_2$ and NaOH[4] which can break the Si-O and Al-O in the vitreous body of pulverized ash, and accelerate the dissolution of Si^{4+} and Al^{3+}. Other chemicals are alkali salts such as silicates, sulfate and carbonates. The hydrate of $NaSiO_3$ could maintain the concentration of alkali in solution, but when it loses water, its product in the form of silica gel would change to gel having solid properties. This gelatinization is the process of transformation from linear to reticular structure. $CaSO_4$ and Na_2SO_4 are sulfates, which in alkaline condition reacts with Al_2O_3 to produce hydrated calcium sulfate crystal. The continuous reaction accelerates the hydration of pulverized fuel ash which makes the activity fully exploited.[4]

Study on activation of slag indicates that the commonly used activators are sulfates, sodium silicate, calcium hydroxide, and in rare caustic soda. The majority of these activators contain alkali metal (e.g. Li, Na, K) so they are called alkali activators. The activator will accelerate the strength development and increase the 28 days strength. Some of the activators can be taken simply as catalyst, because they are highly soluble and can hardly react with the oxides in slag to form solid products. NaOH solution is a typical example.[3]

Other study on natural pozzolan-lime system showed that Na_2SO_4 is more effective as an activator compared to Na_2CO_3, NaOH, $CaCl_2.2H_2O$ and ordinary Portland cement clinker. Addition of 6% Na_2SO_4 in the system of lime:pozzolan ratio 30%:70% increased the compressive strength of two folds compared with the mixture without pozzolan at the age of 90 days. Morphology of the paste showed the similar porosity as the cement paste without activator at the age of 50 days.[6]

In this paper, preliminary study on natural pozzolan in Indonesia, trass was performed to identify the reactivity in relation to mechanical strength gained by mechanical and chemical activation treatment.

2. EXPERIMENTAL

Chemical compositions and mineralogy of 65 samples of trass from various deposits in Java Island, Indonesia were investigated by X-Ray fluorescence and diffraction method. One sample was selected to determine its activity as supplementary cementing material. Activation was carried out by pulverizing the sample to finer particles and addition of inorganic salt, Na_2SO_4 as chemical activator.

Pulverization was performed by grinding sample into various particle size distributions represented by the specific surface area, Blaine. Particle size distribution was measured by Malvern, Laser Particle Size Analyzer. In accordance with the standard specification for pozzolanic materials, ASTM C-593, pozzolans for supplementary cementing material, shall have minimum 66% of particle size less than 45 μm or 34% retained on 45 μm sieve.

In this experiment, particle sizes of trass were varied from 2462 until 9100 $cm^2\ g^{-1}$ Blaine, but activation by Na_2SO_4 applied only to the extreme low and high Blaine samples. Dosage of 2.71 wt. % Na_2SO_4 by weight of binder was used and applied to both coarse and fine samples.

To measure the mechanical strength gained, trass samples mixed with lime (trass:lime = 70%:30%) to form slurries with water/binder ratio of 0.62, the ratio which slurry is workable. Slurries then poured into cubes mould of 4 x 4 x 4 cm, referring to procedure in ASTM C-593. For measurements at ages of 2, 3, 7, 14 and 28 days, each 3 cubes were prepared making the total of 15. Cubes were cured for 7 days in moist cabinet with relative humidity of 50% and temperature of 50^{o}C. After 7 days, the cubes were then moved to a moist cabinet of 23^{o}C and kept for 28 days. On each age of curing, compressive strength of cube was measured.

Pozzolanic reaction was monitored by TAM Air Calorimeter. Heat released during reaction of trass–lime system was measured as heat flow in mW and converted to $J\ g^{-1}$.

3. RESULTS AND DISCUSSION

3.1 Typical Oxides and Mineral Compositions of Trass

Trass is an alumino silicates compound with major oxides SiO_2, Al_2O_3, Fe_2O_3 and some others CaO, K_2O, Na_2O in minor amounts. While the oxide composition of trass can vary from one deposit to another, the trass from one deposit remains relatively consistent. Chemical compositions of a number of trass samples from various locations in Java Island, Indonesia, consisting of 65 samples, are shown in Table 1 showing SiO_2 and Al_2O_3 as main oxides.

Trass suitable for cement production mainly contains glassy phase silicates, while Portland cement generally contains crystalline calcium silicates. The high glassy phase silicates content and its metastable nature are the important source of activation energy during its hydration. However, trass as natural pozzolan mainly contains crystalline minerals which are inactive. Mineral compositions of samples in this experiment contain mineral groups of feldspar and kaolinite. Typical crystalline minerals found in trass sample are listed in Table 2. The glassy phase content is not determined and discussed in this experiment.

Table 1: Chemical compositions of 65 trass samples from Java Island, Indonesia.

Oxides (%)	Mean	Minimum	Maximum
SiO_2	59.65	48.13	74.93
Al_2O_3	20.64	13.88	28.86
Fe_2O_3	5.51	0.57	10.78
CaO	3.32	0.46	7.23
MgO	1.02	0.11	3.11
SO_3	0.15	0.00	4.27
Na_2O	1.5	0.00	3.8
K_2O	1.64	0.01	4.40

Table 2: Possible crystalline minerals in trass of Java Island, Indonesia.

Main components	Minor components	Seldom components
Andesine	Microline	Biotite
Quartz	Kaolinite	Analcime
Montmorillonite	Anorthite	

3.2 Effect of Fineness and Addition of Inorganic Salt Na_2SO_4 to Compressive Strength

Pulverized trass samples with the specific surface area, Blaine $cm^2\ g^{-1}$ is shown in Figure 1. In this experiment, only samples with Blaine above 4500 $cm^2\ g^{-1}$ have 66% of particle sizes of less than 45 μm, as governed by the standard. Pulverized trass at this fineness can be used as supplementary cementing material requiring no further activation.

Compressive strength obtained is shown in Figures 2 and 3. Figure 2 shows the effect of mechanical activation, where sample with low fineness of 2462 $cm^2\ g^{-1}$ Blaine gives very low strength of 17 to 21 kg cm^2 at the ages of 2 to 28 days. Sample with high fineness of 9190 $cm^2\ g^{-1}$ Blaine (100% of particle sizes less than 45 μm) gives 60 kg cm^{-2} strength at 2 days and increasing to 80 kg cm^{-2} at 28 days age.

The addition of Na_2SO_4 of 2.71 wt. % as activator shown in Figure 3. Trass sample of 2462 $cm^2\ g^{-1}$ Blaine gained strength of 42 kg cm^{-2} at 2 days age but not increasing up to 28 days. Trass sample of 9190 $cm^2\ g^{-1}$ Blaine showed tremendous increase in strength. Strength of 90 kg cm^{-2} was gained at 2 days age and reaching 110 kg cm^{-2} at 28 days.

3.3 Heat Release of Trass–Lime Reaction

Monitoring the pozzolanic reaction occurred between trass and lime was shown in Figures 4 and 5. Figure 4 shows reaction occurred spontaneously after the material mixed. Heat released during the reaction increases as the reaction continued. Finer particles showed higher heat released, which means reaction occurred at a higher portion. This was also proven by higher strength gained at higher fineness as described above. Monitoring was performed up to 7 days and showed an increase of heat released. Maximum heat released by system with 8218 $cm^2\ g^{-1}$ Blaine and achieved about 30 J g^{-1} at 160 h.

Addition of chemical activator Na_2SO_4 at 2.71 wt. % showed higher heat release compare to the one without activator as shown in Figure 5. This proved that Na_2SO_4 worked as activator to accelerate the reaction between lime and trass.[6] About 60 J g^{-1} heat was released during the hydration of mix 9190 $cm^2\ g^{-1}$ Blaine with addition of Na_2SO_4.

Figure 6 shows an equation as an approach to the model reaction of trass–lime system. Mechanical activation showed a linear correlation at a very moderate coefficient which means the value is almost fixed. This data is supported by trend of compressive strength gain in mechanical activation. On the

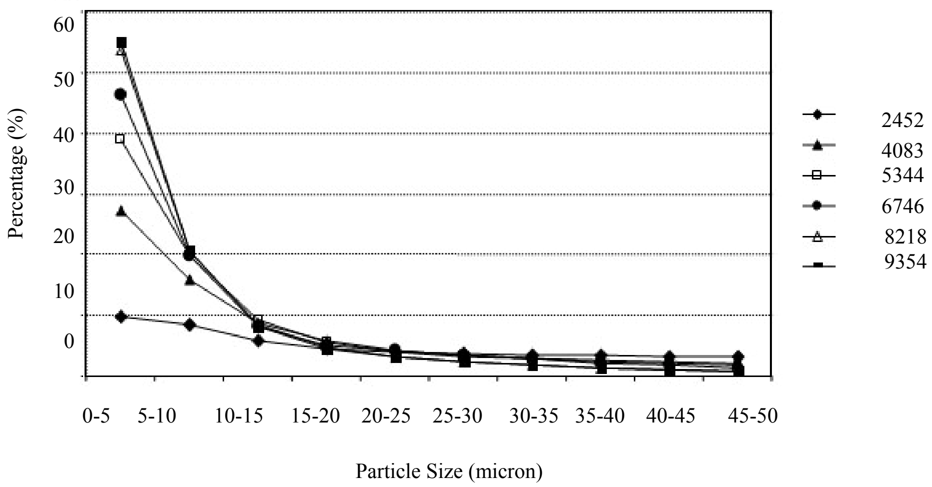

Figure 1: Particle size distribution pulverized trass from Blaine 2462 to 9354 $cm^2\,g^{-1}$.

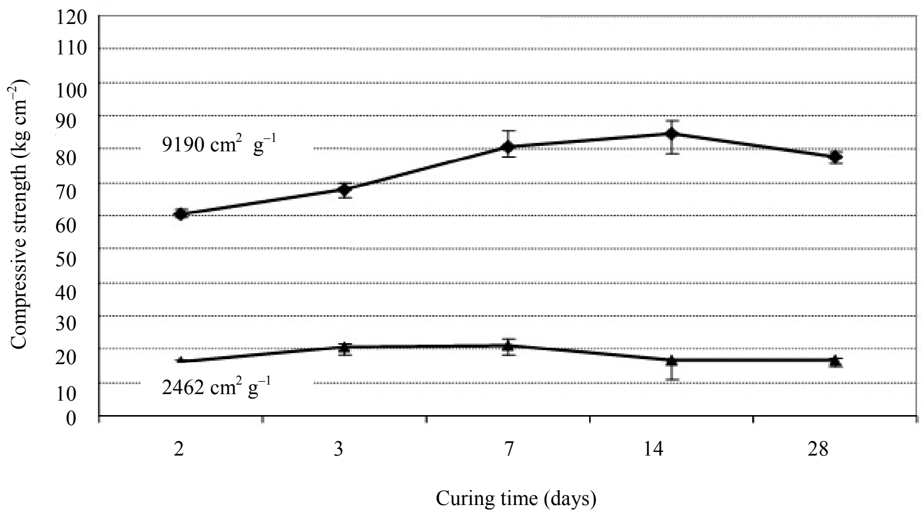

Figure 2: Compressive strength of trass–lime system as function of trass finenesses.

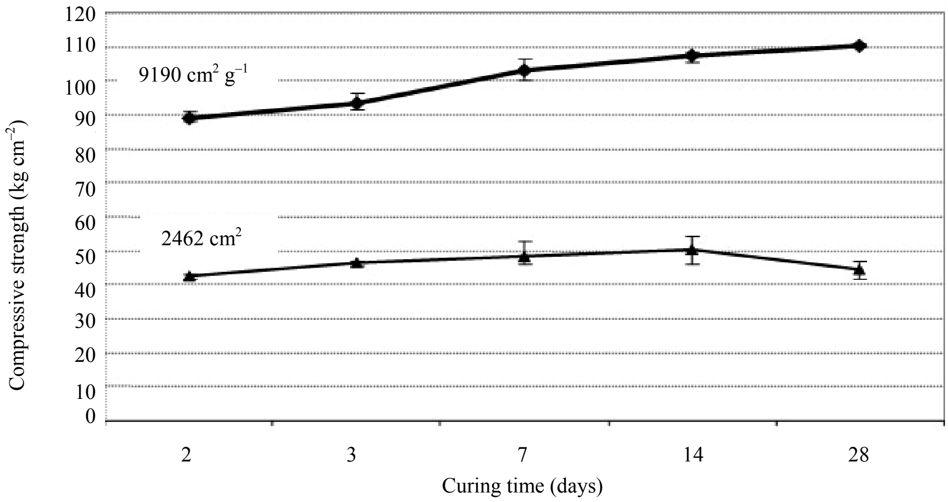

Figure 3: Compressive strength of trass–lime system using 2.71 wt. % Na_2SO_4 as activator.

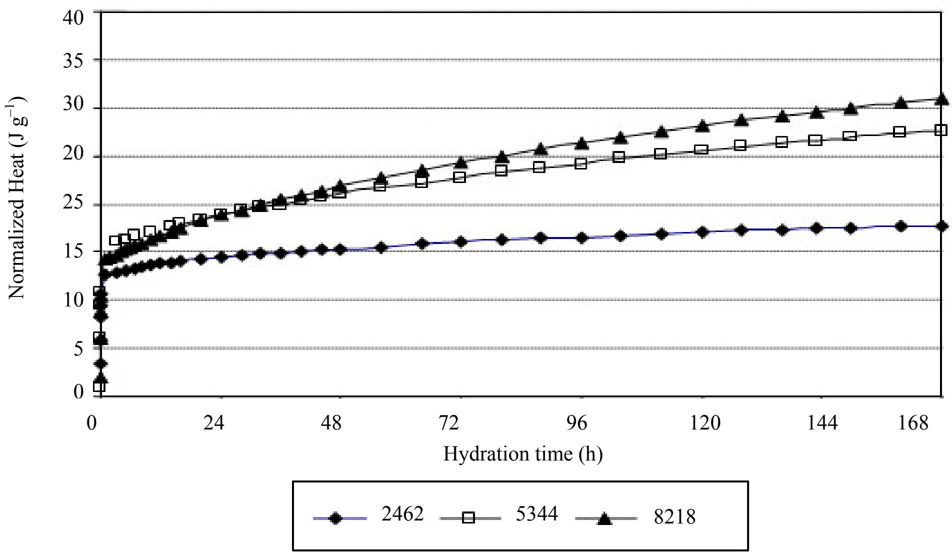

Figure 4: Heat release of pulverized trass–lime reaction as function of time.

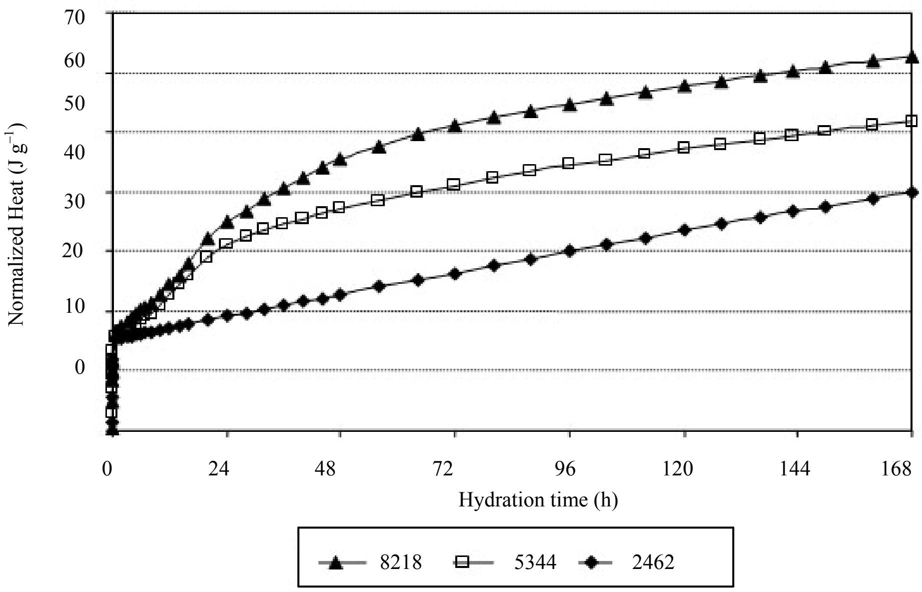

Figure 5: Heat release of trass–lime reaction with addition of 2.71 wt. % Na_2SO_4 on different finenesses of trass.

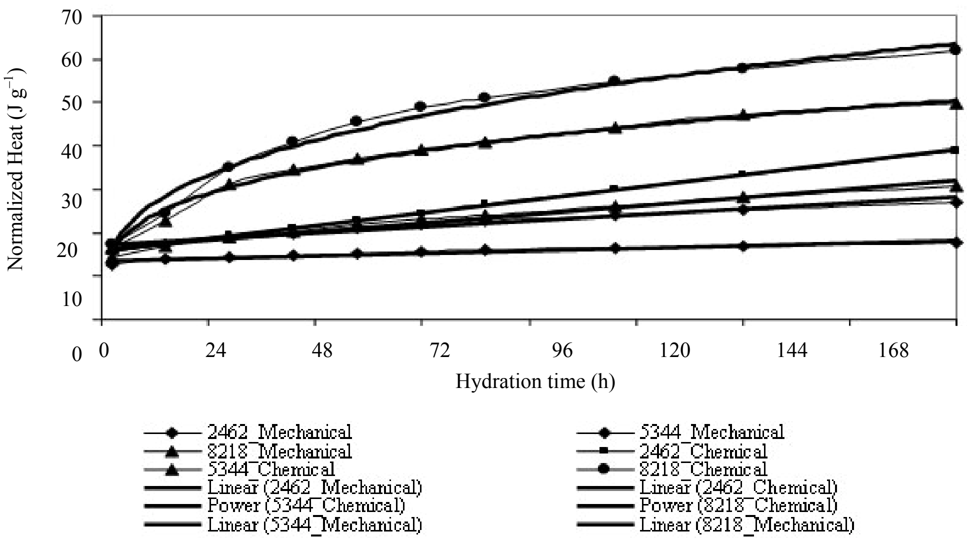

Figure 6: Linear and exponential correlations of heat flow versus hydration time for different mixture.

other hand, samples treated by Na_2SO_4 showed an exponential correlation, with the exception of sample at low Blaine. This also supported by strength development from 2 up to 28 days of samples with high Blaine treated by chemical activation.

4. CONCLUSION

Mechanical strength gained from the mechanical and chemical activations of trass explains and proves that trass could be used as a supplementary cementing material in blended cement. The increase of mechanical strength was also explained by an increase of heat released during pozzolanic reaction. Exponential correlation between the heat release and the reaction time explains the effective activation of trass by means of chemical activation at finenesses above 2500 $cm^2\ g^{-1}$ Blaine. Trass of fineness of 9190 $cm^2\ g^{-1}$ Blaine at trass–lime system (2:1) gives maximum strength of 124 kg cm^{-2} at 28 days with addition of 2.71 wt. % Na_2SO_4.

5. REFERENCES

1. Muller, C.J. (2005). *Pozzolanic activity of natural clay minerals with respect to environmental geotechnics.* Dissertation, Swiss Federal Institute of Technology Zurich, Switzerland.
2. Rahhal, V. & Talero, R. (2005). Early hydration of Portland cement with crystalline mineral additions. *Cement and Concrete Research,* 35, 1285–1291.
3. Chen, W. (2007). *Hydration of slag cement.* Ph. D. Thesis, University of Twente, Netherland.
4. Bao-min, W. & Li-jiu, W. (2004). Development of studies and applications of activation of fly ash. *Proceedings of the International Workshop on Sustainable Development and Concrete Technology,* Beijing, China, 20–21 May, 159–169.
5. Arjunan, P., Silsbee, M.R. & Roy, D.M. (2001). Chemical activation of low calcium fly ash. Part I : Identification of suitable activators and their dosage. *Proceedings of the International Ash Utilization Symposium,* Center for Applied Energy Research, University of Kentucky, 22–24 October, Paper #105.
6. Allahverdi, A. & Ghorbani, J. (2006). Chemical activation and set acceleration of lime–natural pozzolan cement. *Ceramics-Silikaty,* 50(4), 193–199.