DAMPING CAPACITY OF FLY ASH-BASED GEOPOLYMER

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1 Introduction

Ordinary Portland cement (OPC) is unquestionably the primary cementitious material used in construction nowadays. To manufacture Portland cement, however, large amount of CO_2 is released. It is estimated that the manufacture of one ton of cement approximately 0.8 tones of CO_2 are emitted into the atmosphere. This contributes substantial global air pollution, and for the cement industry accounts for 5-8% of worldwide CO_2 emissions [1]. Meanwhile, around one billion tones of fly ash are produced annually world-wide in coal-fired steam power plants. In the best-case scenario this waste is stockpiled, but more often than not it is simply dumped. In either case, it constitutes a serious environmental and economic problem for which a solution is yet to be found. One option to eliminate this ash in an ecologically sensitive manner is to reuse it. In line with this view, one of solutions is to partially replace the amount of OPC in concrete with fly ash. An important achievement in this regard is the development of high-volume fly ash concrete that uses only approximately 40% of OPC, and yet possesses excellent mechanical properties with enhanced durability performance [2]. Another effort in this regard is the development of inorganic alumino-silicate polymer, called geopolymer, which can be used as a binder to produce concrete, instead of the cement paste.

Geopolymer is ceramic material that is produced by alkali activation of aluminosilicate raw material (e.g. fly ash), which is transformed into reaction product by polymerization in a high pH environment and hydrothermal conditions at relatively low temperatures (60 °C) [3]. With regard to matrix formation, geopolymer is totally different from Portland cement. The geopolymer contains aluminum and silicon species that are soluble in highly alkaline solutions. The dissolved species then undergo polycondensation to produce materials with desirable mechanical properties. While Portland cement generally depends on the presence of calcium, geopolymer does not utilize the formation of calcium-silica-hydrates (CSH) for matrix formation and strength. These structural differences give geopolymer certain advantages, such as particularly resistant to aggressive acids and the aggregate-alkali reaction [4].

Initial research has shown that compressive strength of geopolymer is easily developed to the level specified by design code (25-65 MPa) [5]. Although geopolymer exhibits a moderate modulus of elasticity, the splitting tensile strength and flexural strength of geopolymer is generally higher than that of OPC counterparts [6]. Moreover, geopolymer is found to have better ability to bond to the reinforcing steel in comparison with OPC [7].

Whereas the engineering properties of geopolymer have been extensively studied in a static state, the dynamic response such as damping capacity has received less attention. The damping capacity is important in analysis and design of concrete sleeper because of the nature of dynamic loading on railway track [8]. It is noted that geopolymer concrete has been used to manufacture railway sleeper. Palomo et al [9] found that the geopolymer concrete sleeper could easily be produced using the existing current concrete technology without any significant changes. The strength of this concrete can be developed over a short time, and the drying shrinkage was small. However, the damping capacity has not been investigated in their research.

In order to fill this knowledge gap, the damping capacity of geopolymer is investigated by using free vibration method. For the purpose of benchmarking and comparisons, OPC counterpart was also prepared and tested. Further, the mechanism for damping capacity is discussed in term of different moisture content between two materials.

2 Experimental Program

Ordinary Portland cement, conforming to the requirements of ASTM Type I was used for making OPC concrete. Fly ash used for making geopolymers in the investigation was dry ASTM Type F (low calcium) fly ash. The chemical composition of the binders, as determined by X-ray fluorescence (XRF) analysis, are summarized in Table 1.

Table 1 Chemical composition of binders

	OPC	Fly ash
LOI	3.0	1.7
Al_2O_3	4.7	30.5
SiO_2	19.9	48.3
CaO	63.9	2.8
Fe_2O_3	3.4	12.1
K_2O	0.5	0.4
MgO	1.3	1.2
Na_2O	0.2	0.2
SO_3	2.6	0.3

The alkaline liquid used in geopolymers consisted of a mixture of commercially available sodium silicate solution grade D with a specific gravity of 1.53 and a modulus ratio (Ms) equal to 2 (where Ms = SiO_2/Na_2O, Na_2O = 14.7% and SiO_2 = 29.4% by mass), and sodium hydroxide solution. The sodium hydroxide solution was prepared by dissolving the commercial grade sodium hydroxide (NaOH) pellets with 98% purity in distilled water. Both alkaline solutions were prepared and mixed together one day prior to usage.

The liquids-to-solids ratio was fixed to 0.5 for both OPC and geopolymer pastes. The mixture of geopolymer was formulated with the molar oxide ratios SiO_2/Al_2O_3 = 3.21, Na_2O/Al_2O_3 = 0.41 and H_2O/Na_2O = 12.88. The mixing procedures used in the manufacturing OPC and geopolymer pastes are similar. The binders (cement or fly ash) and the liquid component (water or alkaline liquid) were mixed in a conventional pan mixer for 5 min. The mixture was poured into moulds in three equal layers. Each layer was vibrated for 15 to 30 seconds on a vibration table. Curing for OPC and geopolymer-based materials was done in different ways. OPC specimens were cured under polyethylene sheets for 24 hours in a laboratory environment. Specimens were then removed from the moulds and transferred to tank of saturated limewater at 23 ± 2°C as the moist-curing regime to satisfy ASTM C 192 requirements. Specimens were cured for 28 days. After casting, geopolymer specimens were kept in the moulds and covered by polyethylene sheet and placed immediately in a preheated oven. The specimens were cured at 60°C for 24 hours. After curing, the specimens were demoulded. Both OPC and geopolymer specimens after curing were stored in a controlled environment kept at 50 ± 3 percent RH and 23 ± 2°C. This environment meets the International Organization Standardization (ISO) requirements as a standard atmosphere for conditioning and testing of materials known to be sensitive to variations in temperature or relative humidity.

The compression tests were performed on 100 X 200 mm cylinders in accordance with AS1012.9. All compression specimens were sulphur-capped to satisfy ASTM C 617 requirements. Specimens were tested after 28 days.

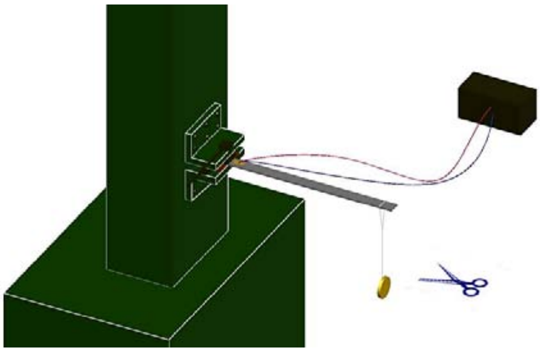

Fig.1 Scheme for test set-up

The damping capacity of a material is an intrinsic property which causes vibrations in a specimen to decrease in amplitude even when the specimen is isolated from all sources of energy loss. The most common way of expressing the damping capacity is in terms of logarithmic decrement, which corresponds to the measure of the decrease in amplitudes of successive oscillations in the damped sine wave produced by the decay of free vibrations of a specimen [10]. The test set up is shown in Fig.1. The specimen attached to the test was set free after it deviated slightly from the balanced situation. The cantilever beam was in free vibration, which damped in the course of time. These vibrations were recorded by TDAS PRO SIM data recorder. In this study, the damping was based on the damping curves obtained from test specimens, and values of amplitude in the successive 10 periods were gauged. According to these values, logarithmic decrement and critical damping were calculated as follows [11]:

$$\Delta = [1/(n-1)]\ln(X_1 / X_n) \qquad (1)$$

$$D \cong \Delta / 2\pi \qquad (2)$$

where Δ is the logarithmic decrement, X_1 is a amplitude in the first period, X_n is amplitude in the nth period, and D is critical damping value. The sample size for damping test was taken as 5 X 15 X 160 mm.

The TGA (thermogravimetric analysis) was conducted in a TG92-Setaram, with the temperature of the furnace programmed to rise at constant heating rate of 5°C/min up to 800°C, under air flow.

3 Results and discussion

Test results show that OPC paste had strength of 48.5 MPa and geopolymer had strength of 57.2 MPa. The similar strength was achieved by deliberately manipulate curing regime of geopolymer. As a result, effect of strength on damping characteristics could be reduced to a great extent although this effect is not conclusively in the reported literature for cement-based materials. Sri Ravindrarajah and Tam [12] suggested an inverse relationship between strength and damping while the results obtained by Swamy and Rigby [13] show no such direct relationship. Further, they stated that there is no fundamental reason why the logarithmic decrement should be related to compressive strength

Table 2 Damping test results (%)

Specimen no.	OPC	Geopolymer
1	3.14	2.37
2	2.88	2.11
3	2.93	2.09

Damping tests were conducted on three samples for each material. Critical damping values of these samples are given in Table 2, and typical damping curves of OPC and geopolymer are given in Fig. 2. For all the samples, the OPC sample showed higher damping capacity than the geopolymer sample. When compared to OPC paste, geopolymer showed a decrease of damping capacity by approximately 27%. This difference in damping capacity is similar to that reported between concrete made with recycled aggregate and concrete made with normal aggregate [12].

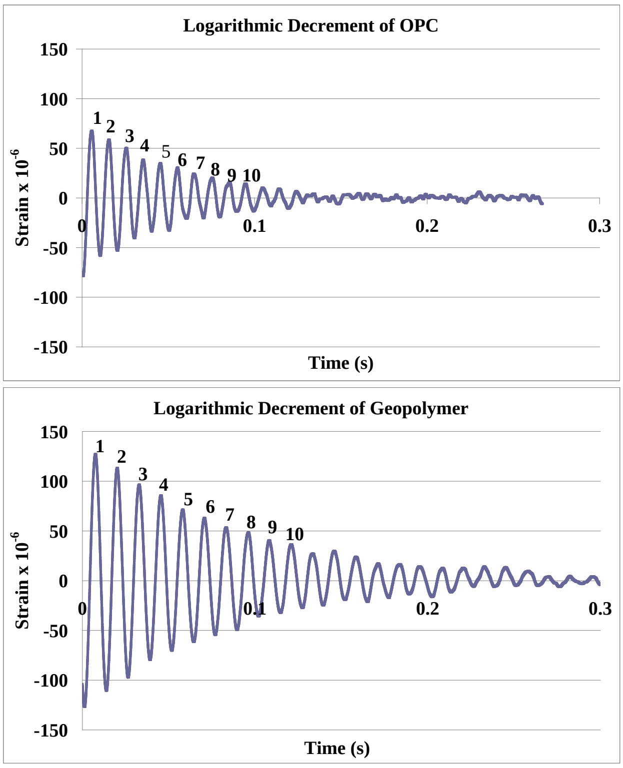

Fig.2 Damping curves of OPC and geopolymer

It is well established that the damping properties of cementitious materials increase with moisture content [12, 13]. The moisture content of two materials was characterized by TGA test. Fig.3

shows the TGA results for the geopolymer and OPC pastes. Both materials experienced mass loss with the increase of temperature. However, there was more moisture within the OPC system compared to the geopolymer system. A total mass reduction of 30% after temperature exposures was recorded for the OPC paste, which was significantly higher than that of geopolymer paste. A high rate of weight loss was observed between room temperature and approximately 300^{o}C in OPC paste. This mass reduction can be attributed to evaporation of free pore water and was also observed in geopolymer paste. Above 300^{o}C, there was a continuous loss of weight in OPC paste up to 800^{o}C while there was little change in the percentage of geopolymer mass remaining. The different behavior of weight loss in this temperature range indicates that the OPC system contains more chemically bound water compared to geopolymer system. Based on TGA results, it is thus speculated that the high moisture in OPC paste is a major contributor to a higher damping capacity compared to geopolymer.

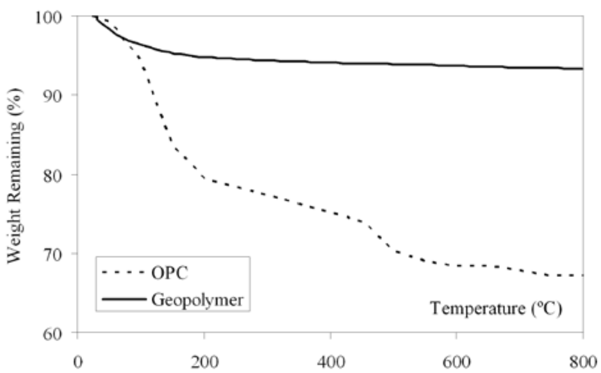

Fig.3 TGA curves

It is noted that the damping in cementitious materials is a complex combination of viscous, solid and friction damping depending upon also the presence of microcracking and interfacial bonding [13]. Therefore, the damping capacity of geopolymer need to be further investigated by considering various fabrication parameters which include steam curing and the change of solvable silicon content in solution.

4 Conclusion

The damping capacity of geopolymer was investigated by measuring logarithmic decrement. It is found that geopolymer exhibit a comparable damping capacity to its OPC counterpart. The low moisture content is believed to have negative influence on its damping capacity.

The damping in geopolymer needs to be further studied by varying the curing regime and solvable silicon content in solution, which is currently in progress.

References

[1] K. L. Scrivener and R. J. Kirkpatrick "Innovation in use and research on cementitious material". *Cement and Concrete Research,* Vol. 38, No. 2, pp 128-136, 2008.

[2] V. M. Malhotra "High-performance high-volume fly ash concrete". *Concrete International,* Vol. 24, No. 7, pp. 30-34, 2002.

[3] J. Davidovits "Geopolymers: Inorganic Polymeric New Materials". *Journal of thermal analysis* Vol. 37, No. 8, pp. 1633-1656, 1991.

[4] A. Fernandez-Jimenez, I. García-Lodeiro and A. Palomo "Durability of alkali-activated fly ash cementitious materials". *Journal of Materials Science,* Vol. 42, No. 9, pp. 3055-3065, 2007.

[5] D. Hardjito, S. E. Wallah, D. M. J. Sumajouw and B. V. Rangan "On the development of fly ash-based geopolymer concrete". *ACI Materials Journal,* Vol. 101, No. 101, pp. 467-472, 2005.

[6] M. Sofi, J. S. J. van Deventer, P. A. Mendis and G. C. Lukey "Engineering properties of inorganic polymer concretes (IPCs)". *Cement and Concrete Research,* Vol. 37, No. 2, pp. 251-257, 2007.

[7] A. Fernandez-Jimenez, A. Palomo and C. Lopez-Hombrados "Engineering properties of alkali-activated fly ash concrete". *ACI Materials Journal,* Vol. 103, No. 2, pp. 106-112, 2006.

[8] S. L. Grassie "Dynamic modelling of concrete railway sleepers". *Journal of Sound and Vibration,* Vol. 187, No. 5, pp. 799-813, 1995.

[9] A. Palomo, A. Fernández-Jiménez, C. López-Hombrados and J. L. Lleyda "Precast elements made of alkali activated fly ash concrete", *8th CANMET/ACI International Conference on fly ash, silica fume, slag and natural pozzolans in concrete,* Las Vegas, pp. 545-558, 2004.

[10] F. L. Joseph and H. P. James "*Significance of tests and properties of concrete and concrete-making materials*", ASTM, 2006.

[11] W. T. Thomson "*Theory of vibration with applications*", Prentice Hall, 1972.

[12] R. Sri Ravindrarajah and C. T. Tam "Properties of concrete made with crushed concrete as coarse aggregate". *Magazine of concrete research*, Vol. 37, No. 130, pp. 29-38, 1985.

[13] N. Swamy and G. Rigby "Dynamic properties of hardened paste, mortar and concrete". *Materials and Structures*, Vol. 4, No. 1, pp. 13-40, 1971.