Application of Mount Pinatubo lahar sand as fine aggregate in controlled low-strength materials

A R Alzona¹, K M Matriano¹, A J Galarosa¹, A J Malabanan¹, M S Mortel¹, R J Somera¹, M A Taguba¹, M S Delos Santos¹, C M Vahdanipour¹ and F D Santos¹

¹Department of Civil Engineering, National University-Manila, Manila, Philippines

E-mail: aralzona@national-u.edu.ph (A R Alzona);
michaeljohn.delossantos01@yahoo.com (M S Delos Santos)

Abstract. Fine aggregates are key components of controlled low-strength materials (CLSM). These act as structural fillers that are integrally held together by cement paste controlling the mechanical properties and strength. In general, natural sand is the most common material used in the production of CLSM. Despite their low minimum compressive strength, CLSMs are used in highway construction as an alternative to compacted backfill. However, sand supply to road and infrastructure projects may not be sustainable. Meanwhile, in the low lying areas surrounding Mount Pinatubo in Philippines, huge volumes of pyroclastic material and ashes were deposited due to the mountain’s cataclysmic eruption on 1991. To this date, the lahar washed down by the rains to the lowland municipalities and towns induce hazards during extreme rainfall events. Therefore, this study investigated the feasibility of lahar sand as fine aggregate in CLSM. Characterization of the controlled mixtures was performed via flowability, setting time, and compressive strength. Two controlled parameters (water-to-solid and cement-to-water ratios) were defined to show the statistical relationship among investigated properties with the different mixture proportions. Empirical results show acceptable characteristic values for the CLSM’s hardened state, making lahar sand be suitable as fine aggregates. The recommended water-to-solid and cement-to-water ratios for the CLSM mixture should be both 0.30.

1. Introduction

Controlled low-strength material (CLSM) is a self-compacting, low-strength cementitious material having compressive strength at 28th day of 8.3 MPa or less [1]. Primarily, CLSM is used as an alternative material to backfill especially when the available earth on site cannot be qualified by the engineer as “engineered backfill”, or ultimately, there is inadequate supply of earth at all. Bases, sub-bases and subgrade for road and highway constructions, trench or void filler for excavated volume, and backfill for earth-retaining structures like retaining walls are some of the typical applications of CLSM in construction. Utilizing CLSM lists a lot of advantages over conventional earth making it an excellent construction material in view of value engineering. Furthermore, given that CLSM is a low strength concrete, unconfined compressive strength requirement of 0.30 to 2.10 MPa for long-term purpose allows future excavation of the material [1].

Fine aggregate is one of the key construction materials that make up CLSM. These act as structural fillers that are integrally held together by cement paste producing its mechanical properties and strength. Generally, natural sand is the most common fine aggregate used in the production of CLSM; however, many researches have already studied several non-standard materials to determine their acceptability in
CLSM mixture. The production of this type of aggregate for backfilling activities is becoming unsustainable due to its environmental impact and implementing rules and regulations of conservation policies [2]. Wu and Lee conducted a study of recycling construction surplus clay in CLSM mixture [3]. Based on their findings, the proposed clayey materials used for the production of clay-based CLSM are acceptable; however, the results of the study are site-specific and limited the validity of the mixtures with their local materials. Recently, Raghavendra et al. utilized bagasse ash and fly ash in their study regarding CLSM and showed that CLSM mixtures with bagasse ash resulted in comparatively lower strengths than that with fly ash due to lesser pozzolanic property [4]. Nevertheless, the ACI Committee report on CLSM admitted the lack of a unified code on the design of CLSM. In US, each state has its own set of guidelines on the mixing and placement of CLSM. The variability of constituent material’s properties makes CLSM hard to generalize. Trial-and-error in mix proportioning is performed until the appropriate mix proportions based on the intended construction application are achieved.

In 1991, the Mount Pinatubo dormant volcano in Philippines has devastated the entire low lying surrounding areas when it erupted. Today, huge volume of lahar and pyroclastic materials are still deposited along the riverside and slopes of the volcano, posing even more detrimental effect on communities living within the area especially during La Niña season. On the other hand, lahar sand is one of the pyroclastic materials that are released from the volcano. Many a number of chemical analyses were conducted by various researchers and has concluded that the silt composing lahar sand is pozzolanic, and several experimental researches done to exhaust the viability of this material in the construction industry. By fundamental composition, lahar sand largely composed of silicon earth and aluminium earth, making it potentially an alternative aggregate [5]. Lejano et al. have developed a modular panel for low-cost housing utilizing mostly lahar sand. Department of Public Works and Highways on the other hand, made several studies utilizing lahar sand as aggregates and sand as road base and asphalt mix.

Hence, with the urgency of using CLSM and lahar sand due to their versatility, this paper aims to evaluate the feasibility of employing lahar sand exclusively as the aggregate material of CLSM and study the relevant parameters.

2. Materials and Testing Methods

This study aims to replace natural sand commonly used as fine aggregates by lahar sand derived from the riversides and slopes of Mount Pinatubo in making controlled low-strength materials (CLSM). Fundamental properties of the materials used in this study are detailed below.

2.1. Lahar Sand

The lahar sand used in this work was obtained from an international exporter of lahar sand in The Philippines, quarried from the silted river channel of Bucao River, Zambales. It contains 4.57% soil particles finer than 0.075 mm (Sieve No. 200), and 79.24% finer than 0.42 mm (Sieve No. 40). The whole particle size distribution curve of the sand utilized is shown in figure 1. The lahar sand sample has specific gravity of 2.58, and it can be classified as gray fine to coarse sand with pyroclastic materials (SP) in accordance with the Unified Soil Classification System or A-3 in the AASHTO system. In order to examine the physical morphologies of the lahar sand as well as its element compositions, Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS) as shown in table 1. Figure 2 depicts the SEM image of the material, and figure 3 illustrates the pattern of the sand. It can be readily seen that the sample contains high silica content and is low in iron and magnesium, which indicate the characteristics of lahar sand.

| Element | O | Si | C | Na | K | Fe | Ca | Mg | Total |
|---------|---|----|---|----|---|----|----|----|-------|
| Atomic No. | 8 | 14 | 6 | 11 | 19 | 26 | 20 | 12 |       |
| Mass Norm. [%] | 57.85 | 25.02 | 9.08 | 3.37 | 1.56 | 1.16 | 1.11 | 0.84 | 100.00 |
| Atom [%] | 65.36 | 16.10 | 13.66 | 2.65 | 0.72 | 0.38 | 0.50 | 0.62 | 100.00 |
Figure 1. Particle size distribution curve of lahar sand used in this study.

Figure 2. Scanning electron microscopy (SEM) image of lahar sand.

2.2. Cement
Cement paste in CLSM is the structural material that binds all materials that make up the concrete mixture. For this work, type I Portland cement was used. Although fly ash was commonly present in CLSM mixtures for quality improvement, it is not used in this study because it is already considered as a valuable admixture in CLSM. Also, commercial admixtures, like density-reducing agents, are excluded from the design mixes.

2.3 Test methods
CLSM samples produced were analysed in its hydraulic or fresh state and hardened state. During the hydraulic state, laboratory tests were conducted to determine the proper design mixes following the criteria of flowability and setting time. Prior to the obtained results, design mixes that met the acceptable range values for flowability and setting time are subjected to unconfined compressive strength test during its hardened state. Furthermore, to investigate the effects and correlation of cement, lahar sand, and water to the properties of CLSM mixture, a series of C/W and W/S ratios were applied for the mix
design as two controlled parameters ranging from 0.3-0.9 and 0.1-0.9, respectively. Thirty-six fresh CLSM samples were initially prepared during the first phase of the study.

![Figure 3. SEM spectra of lahar sand.](image)

**2.3.1 Flowability.** Flowability test was conducted in compliance with ASTM D 6103; this work utilized a 75 mm by 150 mm open-ended cylinder placed on a flat, level surface and filled with fresh CLSM. The cylinder was then raised quickly so the CLSM will flow into a patty. Two measurements of the spread diameter perpendicular to each other were recorded. The average measured diameter of the patties was determined and compared to established requirement ranging from 200 to 300 mm.

**2.3.2 Setting time.** The setting time range for the actual mix proportions was determined using the Gillmore Apparatus. Each specimen needed to reach a penetration resistance equal to 0.30 and 5.00 MPa as the initial and final setting time, respectively. The objective is to verify whether the actual setting times determined agree with the 3-5 h (180-300 min) range of acceptable setting time for CLSM. The samples subjected to this test were the samples which satisfied the requirement for flowability test.

**2.3.3 Compressive strength.** CLSM samples gradually hardened and achieved strength through the hydration of cement. The unconfined compressive strengths of hardened composites were recorded after curing them for 7, 21, and 28 days, and examined as per ASTM D 4832 standards and further fitted to a linear model.

**3. Results and discussion**

**3.1. Flowability**

Flowability is expressed in terms of CLSM sample’s flow diameter. Out of 36 fresh states CLSM tested and assessed, 50% of the samples characterizing W/S of 0.20 passed, 75% with W/S of 0.30 passed, while 25% of the samples with W/S of 0.30 passed. CLSM sample mixtures with W/S less than 0.2 failed the test because they did not flow; it is evident that in this setup water in insufficient to make their hydraulic material to flow. On the other hand, samples having W/S ratio of 0.3 higher resulted to large flow diameter; these exceeded the acceptable value. Thus, 16.67% of all the sampled CLSM mixture passed this test, advancing to the next property test.

Furthermore, figure 4 shows the relationship of flowability for samples with different C/W ratios and W/S ratios that passed the required flow consistency. The result indicated that as the W/S ratio increases with flowability.
3.2. Setting time

Table 2 shows the initial and final setting time of CLSM mixtures ranged from 120 to 210 minutes and from 210 to 280 minutes, respectively. Based on the results, all mixes satisfactorily met the setting limits of CLSM.

| Sample No. | Initial setting time (min) | Final setting time (min) | Remarks |
|------------|---------------------------|--------------------------|---------|
| S25        | 120                       | 240                      | Passed  |
| S27        | 210                       | 280                      | Passed  |
| S33        | 120                       | 210                      | Passed  |
| S35        | 210                       | 280                      | Passed  |
| S37        | 150                       | 255                      | Passed  |
| S43        | 120                       | 225                      | Passed  |

3.3. Compressive strength

Figure 5 indicates the unconfined compressive strength of each mix varied as a function of W/S, C/W and curing time. The evaluated samples are those that passed the requirements of flowability and setting time. The compressive strength values increased with C/W and curing time, but decreased with the increase of W/S thereby indicating their relationships.

The values of compressive strength cured for seven days ranged from 0.30 to 3.55 MPa, 0.65 to 9.26 MPa on the other hand for 21 days, and 1.21 to 10.19 MPa for 28th day strength. The improvement of strength with curing time was more significant for samples with higher W/S and lower C/W ratios. Furthermore, the relationship between improvement of strength and curing period fitted well to linear model with R-squared values of 0.9624 and 0.9842, respectively. It can be seen that the 28-day strength values showed about 2.1 to 4.1 times increase, as compared to those of 7th day. The strength increase became linear with curing time, and the observed overall 28-day strength values were about twice of those cured for 21th day.
4. Conclusions
The fresh and hardened attributes of CLSM with lahar sand as fine aggregates were investigated. The following conclusions can be drawn based on the results obtained in all test results performed.

- The water-to-solid ratio of CLSM mainly affects the flowability. A lower share will produce a granular mixture, while the excessive one yields too much water. The W/S value of 0.30 produces the optimum acceptable value.

- Setting time of all CLSM mixtures that passed the flowability test produced acceptable time values. Setting water/solids ratio constant – as the cement/water ratio increases, the initial and final setting time of CLSM increases. In contrast, decreased cement/water ratio results to reduced initial and final setting times. On the other hand, assigning C/W ratio constant and raising W/S ratio, increase the initial and final setting times of CLSM. Lower W/S ratio results in smaller initial and final setting time values.

- Compressive strength of LSCM varies linearly with curing time. Mixture with water/cement ratio and water/solids ratio of both 0.30 can already provide long term compressive strength of 0.30 MPa at 21-day curing time, equivalent to a well-compacted backfill. However, mixture with C/W exceeding 0.70 and W/S ratio below 0.30 exceeds the maximum permissible strength of 8.30 MPa.

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References
[1] Ramme B W 2005 ACI 229R-99 Controlled Low-Strength Materials 99 (Reapproved) 1-15
[2] Wu J Y and Lee M Z 2011 Beneficial reuse of construction surplus clay in CLSM Int. J. Pavement Res. Tech. 4(5) 293-300
[3] Wu J Y and Tsai M 2009 Feasibility study of a soil-based rubberized CLSM Waste Manage. 29(2) 636-42
[4] Raghavendra T, Sunil M and Udayashankar B 2016 Controlled low-strength materials using bagasse ash and fly ash *ACI Materials Journal* **113** 447-57

[5] Murtazaev S A, Zaurbekov S, Salamanova M and Khadisov V 2016 The impact of finely dispersed micro filling materials of volcanic ash on the concrete properties. *Int. J. Environ. Sci. Educ.* **11**(18) 12681-6