Performance of controlled low strength material made using industrial by-products

Vinay Kumar Singh¹ and Sarat Kumar Das²

¹Department of civil engineering, Indian Institute of Technology Delhi, 110016, India.
²Department of civil engineering, Indian Institute of Technology Dhanbad, 826004, India.

E-mail: ¹shashivinaysingh@gmail.com, ²saratdas@rediffmail.com.

Abstract. Controlled low strength materials (CLSM) are the materials which are flowable and self-compacting in nature. These materials are used in various civil engineering applications such as backfill in trenches abutments and retaining walls; void fills in abandoned structures and cavities, conduit bedding, and many more. The strength of these materials is less than 8.3 MPa. CLSM is generally made of Portland cement, fine aggregate, fly ash, and water. Many researchers have studied the performance of CLSM using different industrial by-products such as quarry dust, foundry dust, shredded rubber tire, and many others. In this study, various mix proportions made up of red mud, crusher dust, fly ash, and Portland cement is used to study the engineering properties of CLSM. Considering flow value as one of the important parameters of CLSM, firstly, the amount of water content required for the desired flow value (0.15-0.3 m) was determined. After finding the water contents, each mix proportion was tested for other engineering properties such as unconfined compressive strength, bleeding, density, and durability. The results primarily show that these geomaterials can be used as a CLSM material with further study of its environmental impact on the surrounding soil.

Keywords: CLSM, red mud, crusher dust, flow value, unconfined compressive strength, bleeding.

1. Introduction
American Concrete Institute (ACI 229R) [1] defines CLSM as flowable self-compacting cementitious material having a compressive strength minimum of 0.3 MPa and a maximum of 8.3 MPa at the age of 28 days. Considering re-excavation in the future, the strength of CLSM is restricted to 2.1 MPa. Flowable fill, unshrinkable fill, self-compacting, soil-cement slurry, self-leveilling, controlled density fill are the various other nomenclatures used for CLSM material. CLSM has the same principle that of self-compacting concrete but has different material compositions. Initially, the basic material used in CLSM is soil, fly ash, cement, and water [1].

CLSM has wide applications in civil engineering works such as trench backfill and utility lines in highway projects, backfill materials of retaining wall and abutments, filling of abandoned underground structures, voids, and cavities. Flowable nature makes its handy material in terms of labour and equipment requirements. Due to less availability of natural geomaterials, various researchers [2,3,4] have studied the use of recycled aggregate, blast furnace slag, quarry dust, cement kiln dust, foundry sand, shredded rubber tire as one of the constituent materials of CLSM. To make CLSM...
more environment-friendly [5] made alkali-activated cement less CLSM. There are various other materials that have high pozzolanic content, which can be effectively used as a CLSM material such as red mud and phosphogypsum, which are used in brick and concrete making. Some researchers [6,7] studied the use of red mud as the replacement of natural aggregate in self-compacting concrete and CLSM. There is some flue gas desulfurization (FGD) materials which have good shear strength and light in weight as well. [8] studied the potential use of dry and wet FGD materials in flowable fill and found to be suitable. The steel industry is at the boom, and every industry leads to some waste. Stainless steel reducing slag (SSRS) is one of the byproducts from the steel industry. It contains metal oxides such as CaO, SiO$_2$, and Al$_2$O$_3$ therefore [9] studied the use of SSRS as a CLSM material. Sometimes during excavation for construction of various types of structures, we encounter high-plastic clay soil which cannot be used again for refilling so [10] studied the use of these clayey soil as a CLSM material and used it for the refilling of the excavated portion. CLSM mainly contains cement as the binder material and water quality has a significant effect on the strength of the cement. [11] studied the performance of CLSM material with different types of industrial wastewater and found not much difference in the physical properties.

In this study, the performance of CLSM made up of different mix proportions of red mud, crusher dust, fly ash, Ordinary Portland cement, and water are evaluated. The performance of it is examined based on various key properties of CLSM, like flow value, compressive strength, bleeding, and density.

2. Materials used
In this study, red mud and crusher dust along with the traditional CLSM material fly ash, cement and water are used. Before finding CLSM engineering properties, geotechnical characterization of these materials is done as per Indian standard code (IS 2720).

2.1. Red mud
Red mud is the solid waste residue of the Aluminium industry. HINDALCO, Muri, Jharkhand, India is the site from where the red mud is collected for this study. The grain size analysis of red mud shows that it has sand, silt and clay-sized particle in 17, 51 and 32%, respectively. SEM image of red mud shows that the particle is mostly flaky as shown in figure 1. Other geotechnical properties of red mud are listed in Table 1.

| Red mud properties          | Value |
|----------------------------|-------|
| Specific Gravity           | 3.27  |
| Liquid limit, %            | 39.89 |
| Plastic limit, %           | 36.08 |
| Plasticity index           | 3.81  |
| Maximum dry density, kN/m$^3$ | 15.2  |
| Optimum moisture content, % | 31.5  |
2.2. **Crusher dust**
Crusher dust is the aggregate obtained from the crusher industry. The residue left after the crushing of natural rock into specific size aggregate. It is nonplastic in nature. The grain size analysis shows that it contains a 4.57% gravel-sized particle, 72.20% sand-sized particle and 23.21% silt-size particle. Other geotechnical properties of crusher dust are listed in Table 2. SEM image of crusher dust shows that it is flaky in shape, as shown in figure 2.

**Table 2. Geotechnical properties of crusher dust.**

| Crusher dust properties                  | Value |
|-----------------------------------------|-------|
| Specific Gravity                        | 2.74  |
| Maximum dry density, kN/m³              | 17.6  |
| Optimum moisture content, %             | 13.2  |
2.3. Fly ash
Fly ash is a by-product of coal combustion generated from thermal power plants. The fly ash used in the present study was Class F fly ash and was collected from NALCO. The grain size analysis shows NALCO fly ash 22% sand-sized particle and 72% silt-size particle. Other geotechnical properties of the fly are listed in Table 3. SEM image of fly ash shows that it is rounded in shape.

| Table 3. Geotechnical properties of fly ash |
|-------------------------------------------|
| Crusher dust properties | Value |
| Specific Gravity | 2.24 |
| Maximum dry density, kN/m$^3$ | 13.5 |
| Optimum moisture content, % | 24.7 |

3. Experimental methodology
CLSM has different important engineering properties that are determined experimentally following different codes. In this study flow consistency, bleeding, density, and unconfined compressive strength for 7 and 28 days. Various mix proportions of red mud, crusher dust, fly ash, and cement was considered, and then the water content was decided for each mix proportion based on desirable flow value (0.15-0.3 mm) for CLSM material. Table 4 lists the mix proportion and their nomenclature, which will be used further in this paper.

| Table 4. Mix proportions and nomenclature |
|------------------------------------------|
| Nomenclature | Red mud (%) | Crusher Dust (%) | Fly ash (%) | Cement (%) | Water (%) |
| Mix-1 | 70 | 10 | 20 | 10 | 40 |
| Mix-2 | 70 | 10 | 20 | 10 | 45 |
| Mix-3 | 60 | 20 | 20 | 10 | 40 |
| Mix-4 | 60 | 20 | 20 | 10 | 45 |
| Mix-5 | 50 | 30 | 20 | 10 | 45 |
| Mix-6 | 70 | 10 | 20 | 7 | 40 |
| Mix-7 | 70 | 10 | 20 | 7 | 45 |
| Mix-8 | 60 | 20 | 20 | 7 | 40 |
| Mix-9 | 60 | 20 | 20 | 7 | 45 |
| Mix-10 | 50 | 30 | 20 | 7 | 45 |

\(^1\)cement content % is of the mixture containing red mud, fly ash and crusher dust.
\(^2\)water content % is of the mixture containing red mud, fly ash, crusher dust, and cement.

3.1. Flow consistency
Flow consistency is one of the key properties of CLSM. It is measured as per ASTM D6103-04 [12]. For this test, we need a cylindrical mould of 0.150 m height and 0.075 m in diameter. The mould in this study was fabricated from PVC pipe which has a smooth surface as shown in figure 3.
The step followed in the experiment is as follows:

- The cylindrical mould was placed over a smooth impervious fibre plate.
- CLSM mixture was filled into the cylindrical mould without any compaction or vibration.
- Within 5 seconds mould is moved in vertically upward direction so that the CLSM should spread in a circular pattern.
- Immediately after this largest diameter is measured in two perpendicular directions.
- Note: in the entire procedure vibration plate is restricted.

The water content for which flow value was in the acceptable range (0.15-0.3 m) were accepted, and further engineering properties were determined.

3.2. Density

Density is one of the important parameters for the materials to be used as a compact or backfill material. The fresh density of CLSM material helps in analysing the suitability of the material for the particular civil work. The fresh density of the soil is measured as per ASTM D6023-16 [13]. For measuring fresh density measuring cylinder is taken and filled within 5 minutes of CLSM preparation and then the weight and volume of the cylinder is measured to calculate density. The hardened density of the sample at the age of 7 and 28 days is measured from the UCS sample.

3.3. Bleeding

For self-compacting material due to its high flowability has the greater chances of segregation. Segregation in the cementitious material leads to lesser strength than the designed one. Segregation is measured in terms of bleeding. ASTM C940-10a [14] is used for measuring bleeding. For measuring this sample is put for 3 hours in measuring cylinder up to 800 to 900 ml. Bleeding is measured as the ratio of the volume of water segregated to the initial volume of the sample taken.

3.4. Unconfined compressive strength

In CLSM 28 days compressive strength is a very important property. For measuring this PVC pipe mould of dimension 0.07 m height and diameter 0.035 m is taken as per ASTM D4832-16 [15]. This mould is sealed from the bottom using cardboard and adhesive plastic tape so that the segregation of water can be prevented. After this the sample is left for 18-24 hours to get hardened and then the PVC mould is removed, and the sample is properly sealed and left for curing. The PVC mould used in this experiment is shown in Figure 4.
4. Results and discussion

4.1. Flow consistency
The mix proportion having flow value in between 0.150 m to 0.3 m is accepted, and others are rejected. The flow values of the various mix proportion are reported in Table 5. From the table, it can be seen that for the same mix proportion as the water content increases the flow value increases which is obvious but for the different mixes have same water content flow value of sample having more crusher dust shows more consistency due to its non-plastic behaviour.

Table 5. Flow consistency

| Mix No. | Flow Value (mm) |
|---------|----------------|
| Mix-1   | 150.75         |
| Mix-2   | 230.25         |
| Mix-3   | 193.75         |
| Mix-4   | 285            |
| Mix-5   | 218.2          |
| Mix-6   | 155.25         |
| Mix-7   | 225.75         |
| Mix-8   | 193.25         |
| Mix-9   | 275.5          |
| Mix-10  | 210.25         |

4.2. Density
Fresh density and hardened density after 7 days and 28 days of the mix proportion is measured and reported in Table 6. From the table, it can be concluded for the same mix having higher water content have a lower density, but for the different mix having the same water content, the mix having more red mud shows higher density. This may be due to the higher specific gravity of red mud.
Table 6. Density

| Mix No. | Fresh density (kN/m³) | 7 days Hardened density (kN/m³) | 28 days Hardened density (kN/m³) |
|---------|------------------------|---------------------------------|---------------------------------|
| Mix-1   | 1.9                    | 1.86                            | 1.8                             |
| Mix-2   | 1.86                   | 1.82                            | 1.77                            |
| Mix-3   | 1.84                   | 1.81                            | 1.76                            |
| Mix-4   | 1.82                   | 1.79                            | 1.74                            |
| Mix-5   | 1.81                   | 1.78                            | 1.73                            |
| Mix-6   | 1.89                   | 1.84                            | 1.79                            |
| Mix-7   | 1.86                   | 1.82                            | 1.77                            |
| Mix-8   | 1.83                   | 1.79                            | 1.73                            |
| Mix-9   | 1.81                   | 1.77                            | 1.72                            |
| Mix-10  | 1.8                    | 1.76                            | 1.72                            |

4.3. Bleeding
Measured bleeding value of the different mixes is reported below in Table 7. From the table, we can see that bleeding % is below 5%, which is acceptable. For the same mix proportion, higher water content has a higher value because of higher water content. For the same water content mix having higher red mud content shows lower bleeding because of plasticity behaviour of red mud.

Table 7. Bleeding (%)

| Mix. No. | Bleeding% |
|----------|-----------|
| Mix-1    | 0         |
| Mix-2    | 0         |
| Mix-3    | 0.15      |
| Mix-4    | 0.34      |
| Mix-5    | 0.44      |
| Mix-6    | 0         |
| Mix-7    | 0         |
| Mix-8    | 0.21      |
| Mix-9    | 0.36      |
| Mix-10   | 0.47      |

4.4. Unconfined compressive strength (UCS)
After the curing period of 7 and 28 days, the sample is tested for compressive strength. In CLSM 3 days strength is not significant due to its high flowable nature. UCS obtained value is reported in Table 8. From the results it can be concluded that for the same mix sample the one having lesser water content have more water content while for the different mixes having the same water content the sample with more red mud has more compressive strength. It may be due to more dense mix.
Table 8. UCS value

| Sl. No. | UCS 7 Days (MPa) | UCS 28 Days (MPa) |
|---------|------------------|-------------------|
| Mix-1   | 1.87             | 2.13              |
| Mix-2   | 1.37             | 1.57              |
| Mix-3   | 1.7              | 1.78              |
| Mix-4   | 1.2              | 1.3               |
| Mix-5   | 1.32             | 1.37              |
| Mix-6   | 1.25             | 1.38              |
| Mix-7   | 1.1              | 1.23              |
| Mix-8   | 1.13             | 1.28              |
| Mix-9   | 0.99             | 1.12              |
| Mix-10  | 0.98             | 1.06              |

5. Conclusions
In this study, an attempt has been made to evaluate the usefulness of red mud and crusher dust along with traditional material fly ash, cement and water as a substitute of natural material in making the CLSM. For checking the suitability different experimental test is done to evaluate the engineering properties of CLSM. Based on the experimental values of different tests conducted following conclusion can be drawn:

- The quantity of water required for the flow consistency is inversely proportional to the amount of red mud content, i.e. more the red mud content more the water required. This may be observed due to some plastic behaviour of red mud than crusher dust as due to plasticity it can hold some amount of water.
- The density of the sample depends on the red mud content as it has higher specific gravity due to the presence of metal inside it.
- Bleeding, which is one of the key parameters of CLSM material is not at all a problem as all the values are less than 5%. Increase in crusher dust leads to higher leads to higher bleeding as crusher dust is non-plastic in nature and cannot hold the water.
- UCS values for the mixes of the same composition containing more water is lesser due to water content is more for the mixes containing more red mud. However, the UCS of all the mixes is greater than the required value to be defined as CLSM material.

References
[1] ACI Committee 229, 1999. Controlled Low Strength Materials (CLSM)”, (ACI 229R-99), Farmington Hills, Michigan: American Concrete Institute, p15.
[2] Raghavendra, T., & Udayashankar, B. C. 2013. Flow and strength characteristics of (CLSM) using ground granulated blast furnace slag. Journal of Materials in Civil Engineering, 26(9): 04014050.
[3] Achtemichuk, S., Hubbard, J., Sluce, R., & Shehata, M. H. 2009. The utilization of recycled concrete aggregate to produce controlled low-strength materials without using portland cement. Cement and Concrete Composites, 31(8): 564-569.
[4] Nataraja, M. C., & Nalanda, Y. (2008). Performance of industrial by-products in controlled low-strength materials (CLSM). Waste Management, 28(7): 1168-1181.
[5] Lee, N. K., Kim, H. K., Park, I. S., & Lee, H. K. 2013. Alkali-activated, cementless, controlled low-strength materials (CLSM) utilizing industrial by-products. Construction and Building Materials, 49: 738-746.
[6] Liu, R. X., & Poon, C. S. 2016. Utilization of red mud derived from bauxite in self-compacting
concrete. Journal of Cleaner Production, 112, 384-391.

[7] Do, T. M., & Kim, Y. S. (2016). Engineering properties of controlled low strength material (CLSM) incorporating red mud. International Journal of Geo-Engineering, 7(1), 7.

[8] Butalia, T. S., Wolfe, W. E., Zand, B., & Lee, J. W. (2004). Flowable fill using flue gas desulfurization material. In Innovations in Controlled Low-Strength Material (Flowable Fill). ASTM International.

[9] Sheen, Y. N., Huang, L. J., Wang, H. Y., & Le, D. H. (2014). Experimental study and strength formulation of soil-based controlled low-strength material containing stainless steel reducing slag. Construction and Building Materials, 54, 1-9.

[10] Puppala, A. J., Chittoori, B., & Raavi, A. (2014). Flowability and density characteristics of controlled low-strength material using native high-plasticity clay. Journal of Materials in Civil Engineering, 27(1), 06014026.

[11] Al-Harthy, A. S., Taha, R., Abu-Ashour, J., Al-Jabri, K., & Al-Oraimi, S. (2005). Effect of water quality on the strength of flowable fill mixtures. Cement and concrete Composites, 27(1), 33-39.

[12] ASTM: D6103-04, 2004. Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM), ASTM International, West Conshohocken, PA.

[13] ASTM: D6023-16, 2016. Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low-Strength Material (CLSM), ASTM International, West Conshohocken, PA.

[14] ASTM: C940-10a, 2010. Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory, ASTM International, West Conshohocken, PA.

[15] ASTM: D4832-16, 2016. Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders, ASTM International, West Conshohocken, PA.