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Engineering properties of controlled low strength materials using flyash and waste gypsum wall boards

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HIGHLIGHTS

- Proportioning of CLSM using waste gypsum wallboard sheets and quarry dust.
- Ternary binder blend of cement, fly ash and waste gypsum wallboard sheets.
- Reduced compressive strength was observed for all mixes after 28 days.
- Reduction in H_2S emissions at landfills due to drywalls use in CLSM.
- Phenomenological models generated save time and effort to design CLSM mixes.

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ABSTRACT

The discarded gypsum wallboards (drywalls) dumped at landfills, release hydrogen sulfide gas, a harmful substance, to the atmosphere along with the leachate at the landfill. In this paper, the discarded drywalls were utilized as secondary cementitious materials in controlled low strength materials (CLSM) with flyash and cement. Quarry dust, a stone industry waste was used as fine aggregates. CLSM mixes were produced for varying water contents, drywall and flyash to cement ratios by weight. Spread flow, Marsh flow time and fresh density properties at fresh state, and un-confined compressive strength, settlement and density properties at 3, 7, 28 and 56 days for hardened state, were investigated. Reduced compressive strengths at later ages due to use of drywalls were observed. Flow and strength phenomenological models were generated using wide range of experimental data and validated for separate set of experimental data, to encourage production of CLSM using waste drywalls, of required parameters instead of conventional trial and error process.

1. Introduction

Gypsum wallboards or drywalls are widely used in all new constructions for various useful reasons and are contributing in large numbers to Construction and Demolition (C and D) wastes. C and D wastes are the debris generated due to new construction activity, renovation of existing buildings, and demolition of old buildings, roads and bridges. In India about half of the total C and D waste generated is being re-used and recycled while the remaining is dumped at landfills [1]. C and D wastes from buildings are commonly used as recycled concrete aggregates [2]. The wasted pieces of drywalls are usually dumped at construction sites and eventually transported to any nearby landfills. It is reported that these drywalls which are essentially composed of sulfate and calcium, release hydrogen sulfide gas in landfills under certain anaerobic, temperature and moisture conditions, upon reaction with sulfur reducing bacteria's [3–7]. Hence it becomes necessary from public health issues point of view that a recycling solution is required for re-use of these drywall wastes in large quantities. Few researchers explored the possible use of these drywall wastes in fertilizers, concrete, etc. Naik et al. [7], explored the use of drywall wastes in concrete. They were successful in replacing 60% (by weight) of total cement by the blend of drywalls and Class C flyash, and 10% (by weight) of the total binder content by wasted drywall powder. Just 10% (by weight) replacement to binder will only ensure relatively less usage of these drywall wastes; for sustainable growth of concrete industry these drywall wastes should be re-used in large quantities.

Controlled low-strength material (CLSM) has great potential in use of large quantities of waste materials such as ground granulated blast furnace slag, flyash, C and D wastes, etc [8–10]. CLSM may be defined as cementitious flowable slurry, having low

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compressive strengths usually less than 8.3 MPa [11], with little or no cement content and basically used as a backfill in lieu of compacted fill, which is self compacting and does not require curing.

Flyash is very fine material and causes environmental (air, water and soil) pollution, hampering ecological cycles and trigger hazards for environment, and this has been widely used in the production of cement [12,13], CLSM [14], geomaterials [15] and concrete [16,17]. Stone industries greatest concern is stone itself, since large amounts of overburden wastes, wastes due to screening and wastes in sludge and fragments are produced with the final product. It is reported that about 15–78% of the total material quarried is wasted [18,19]. Quarry dust is successfully used in the production of concrete and CLSM [20,21].

In this paper CLSM mixes were prepared with binders and fine aggregates in 1:1 proportion. Binder used was a blend of powdered gypsum wallboard, Class F flyash and cement. Few mixes were prepared using soda ash as an activator, to activate the flyash + gypsum wallboard, and the results were compared with the mixes prepared without the use of soda ash. Quarry dust is used as fine aggregates in total replacement to natural sand. The CLSM mixes proportioned have 74–86.9% (by weight) of total binder content, as the blend of powdered gypsum wallboard + Class F flyash, and 60.86–51.85% (by weight) of total binder content is replaced by powdered gypsum wallboard. It was found that use of activator in the form of soda ash for CLSM mixes have no appreciable impact on the strength results, and the later age strengths reduced after 28 days due to use of gypsum wallboards.

This paper examines the fresh and hardened properties of these new CLSM mixes with development of predictive flow and strength models [22], for possible use of these waste materials as secondary cementitious materials (flyash + powdered gypsum wall board) and fine aggregates (quarry dust), in a total of 20 mix combinations, which are not explored in CLSM. The benefit of these predictive models would be saving in time and effort if one has to design the mix for different proportions at any point of time. Preparation of only one trial mix at the reference value is necessary, so that the required flow and strength values may be arrived at a particular value of water content and binder/water ratio (by weight) or vice-versa.

2. Materials and methods

2.1. Experimental investigation

20 CLSM mix proportions were generated. Flow, strength, settlement and density parameters were analyzed and assessed. CLSM mixes were generated for cement mortar 1:1 proportion, using Class F flyash (F) + powdered gypsum wallboard (PGP) as secondary cementitious materials, cement (C) and quarry dust as fine aggregates and named as GF Series. Trial mixes were first prepared to determine water content variations, by measuring spread flow in terms of relative flow area, for different water contents. Table 1 gives the mix proportions for the GF1, GF2, GF3, GF4 and GF5 series with respect to water content, F/C ratio (by weight) and PGP/C ratio (by weight) variations. For each series 80 specimens were casted i.e. 20 specimens were casted for each *B*/*w* (binder/water) ratio (by weight) and tested five specimens each at the age of 3, 7, 28 and 56 days respectively. A total of 400 specimens were cast and tested for GF Series.

The predetermined proportions of materials were collected in a pan and mixed in dry state. Water was added in three parts to the dry mix and uniform mortar mix was prepared using pan mixer. The flowability of fresh CLSM was measured by spread flow test and Marsh cone test. In case of spread flow test, flow was measured using open ended cylinder of 75 mm diameter and 150 mm height, where the diameter of spread CLSM was measured along the six sides and averaged. In case of Marsh cone test, flow was measured using a Marsh cone, where the time required for the certain amount of CLSM to flow through the aperture is measured. The fresh CLSM mortar was cast into cylindrical acrylic moulds (40 mm diameter and 80 mm height). The density of CLSM was measured at fresh state and at increasing ages. At 1 day age, specimens were de-moulded and stored at room temperature for air curing. Unconfined compression strength tests were conducted at 3, 7, 28 and 56 day ages. The settlements of the CLSM specimens were measured by the difference in height of cylindrical specimens at increasing ages with respect to initial height.

2.2. Materials

Ordinary Portland cement (C) of 53 grade was used and its physical properties were determined according to IS: 12269 specifications [23]. Initial setting time and final setting time of cement were found to be 43 min and 218 min, respectively with a specific gravity of 3.09. Class F flyash (F) was used as secondary cementitious material and was procured from Raichur Thermal Power Station, Raichur, Karnataka, India, having a specific gravity of 2.03. Waste gypsum wallboard sheets were used as secondary cementitious material which were sourced from new construction sites and demolition sites in Bangalore, and was crushed manually. Powdered gypsum wallboard passing through 4.75 mm sieve size was used with a specific gravity of 1.76. The specific surface area determined by Blaine's permeability method for cement, Class F flyash, powdered gypsum wall board and quarry dust are 307 m^2/kg, 192 m^2/kg, 169 m^2/kg and 381 m^2/kg, respectively. Figs. 1 and 2 shows the waste pieces of gypsum wallboard sourced and powdered gypsum wallboard collected after the removal of external paper, respectively. Quarry dust was sourced from stone quarry waste dump site at Bidadi, Bangalore, Karnataka, India. Table 2 gives the elemental compositions of powdered gypsum wallboard, flyash and quarry dust, obtained from the Scanning Electron Microscopy (SEM)–Energy Dispersive X-ray Spectroscopy (EDS). SEM image depicting the particle sizes for powdered gypsum wallboard, flyash and quarry dust are given in Figs. 3–5, respectively. The physical characteristics of quarry dust are given in Table 3.

Fig. 1. Waste pieces of gypsum wallboard.

Table 1
Mix proportions of CLSM mixtures.

Mix ID	F/C ratio	PGP/C ratio	Cement (C), g/100g	Powdered gypsum Wall board (PGP), g/100 g	Class F flyash (F), g/100 g	Quarry dust, g/100 g
GF1	2	4.67	6.52	30.43	13.05	50
GF2	1.5	3.5	8.33	29.17	12.50	50
GF3	1.2	2.8	10.00	28.00	12.00	50
GF4	1	2.33	11.54	26.92	11.54	50
GF5	0.86	2	12.96	25.92	11.12	50

Note: 1. Mixes with cement, Class F flyash, powdered gypsum wall board and quarry dust are named as GF series and water content is varied as 45%, 50%, 55% and 60% (by weight of total mixture content), to produce mixes with RFA in the range 5–15.