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Preparation and tests for workability, compressive and bond strength of ultra-fine slag based geopolymer as concrete repairing agent

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HIGHLIGHTS

- Prepared ultra-fine blast furnace slag based geopolymer for use as concrete repairing agent.
- Workability, compressive and bond strength tests are conducted.
- 1 day strength of geopolymer concrete is about 60% of 28 days strength.
- Addition of flyash and superplasticizer at low dosage level shows satisfactory results.
- Bond of geopolymer concrete with rebar and old concrete shows promising results.

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ABSTRACT

In modern era, there is a need to develop sustainable concrete repairing material. This study aimed to develop ultra-fine blast furnace slag based geopolymer as concrete repairing agent. Sodium hydroxide activated geopolymer concrete mixes with various admixtures were prepared and tested to study fresh and hardened state properties including bond strength. The 1 day strength of ultra-fine blast furnace slag based geopolymer concrete was found to be about 60% of that at 28 days. Addition of flyash up to certain quantity level contributed towards achieving satisfactory workability, compressive and bond strength of the geopolymer concrete. Similar improvement in fresh and hardened state properties was also observed due to addition of superplasticizer at low dosage level. High alkali activator concentration led to loss of workability and strength of the geopolymer concrete.

1. Introduction

Blast furnace slag (BFS) based geopolymer concrete (GPC) has the potential of replacing the conventional Portland cement concrete (PCC) in the construction industry. Its use can reduce the CO_2 emission that otherwise results due to manufacturing of Portland cement (PC), the prime component in any construction project. The speciality of BFS based GPC is that unlike flyash (FA) based GPC, it can gain strength even when cured at ambient temperature [1,2]. Of late, numerous researchers have dedicated their attention towards the study of fresh and hardened state properties of BFS based GPC [3–6].

Many researchers in the past have tried to use geopolymer mortar (GPM) and GPC as concrete repairing agent. Hu et al. [7] investigated the compressive, bond strength and abrasion resistance of metakaolin (MK) based concrete repairing geopolymer pastes. The geopolymer pastes possessed high early strength. The mechanical properties were found to be better than PC based pastes. Addition of steel slag to the geopolymer pastes improved the performance. Phoo-ngernkham et al. [8] attempted to develop concrete repairing mortar using high calcium FA. Satisfactory bond strength was observed in the GPM compared to the commercial repair binders. On adding PC to the GPM, the bonding behaviour tended to improve. Vasconcelos et al. [9] used MK based GPM for repairing concrete beams and found it to be effective as repairing layer than as adhesive material for applying carbon fibre reinforced polymer strips on the beams. Investigation on the mechanical properties of ambient temperature cured blended and unblended FA and slag based GPC was carried out by Manjunatha et al. [10]. GPC consisting of only slag exhibited superior performance among others including conventional PCC. Increase in slag content in the mixes progressively increased the strength and improved bonding.

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Zanotti et al. [11] prepared and tested MK based geopolymer for using as repair mortar. Significant strength was achieved by curing the specimens at elevated temperature. Addition of polyvinyl alcohol fibers to the geopolymer improved its cohesion with the substrate. MK based geopolymer was also employed for preparing PCC pavement repair mortar. The 3 days strength of MK based GPM was found to be as high as 80% of its 28 days strength. It also outperformed the other commercial materials available for concrete repairing [12]. Duan et al. [13] prepared a novel concrete repairing agent using MK based geopolymer. It possessed properties such as water resistance, fast setting, hydrophobic surface, high compressive and bond strength. Sarker [14] found that compared to PCC, GPC shows better bonding capacity with rebars. The cracking patterns of GPC specimens under the bond test were similar to that of PCC specimens.

Increase in fineness of binding material leads to early strength gain in GPM and GPC. Early age strength is a desirable property of concrete repairing agent [15]. Collins and Sanjayan [3] prepared slag based geopolymer concrete specimens by replacing 10% of slag by ultra-fine FA (UFA), ultra-fine slag (UFS) and condensed silica fume (CSF). From test results, it was observed that remarkable improvement in workability occurred due to addition of UFA. Notable improvement in strength occurred even at early ages due to addition of UFS and CSF. Enhanced ultimate strength of BFS based GPM was observed by Oner et al. [16] due to increase in fineness of binder. Finer binder contributes to accelerated strength gain and improved durability of the geopolymeric systems [4,17,18]. However, increase in fineness of the binder leads to accelerated setting and low workability of mortar or concrete compared to that with same binder of lower fineness [3]. In case of ultra-fine ground granulated blast furnace slag (UGGBS) based geopolymer mixes, high fineness and angular shape of slag particles contribute towards loss in setting time and workability of the mixes.

In this study, the authors attempted to develop UGGBS based GPC possessing such fresh and hardened state properties that make the GPC advantageous to be used as concrete repairing agent. Admixtures such as FA and superplasticizer (SP) were added to the GPC to alter the properties and arrive at satisfactory workability, compressive and bond strength. Effect of variation of alkali activator concentration and time of addition of SP in GPC have also been noted. Slump, compressive strength, rebar pull-out and slant shear tests were performed on total 21 numbers of mixes in this study.

2. Experimental program

2.1. Materials

Table 1 presents the physical and chemical properties of UGGBS and FA. UGGBS was the primary binding agent in the GPC. Class F FA obtained from thermal power plant at Farakka, India was used as an additive. Hereafter, UGGBS and FA are together referred as total binding agent. The median particle size and specific surface area of UGGBS and FA were evaluated by Laser Particle Size Analyzer and specific gravity by laboratory experiment as per IS 1727 1967 [19]. The oxide composition was determined by X-ray Fluorescence Spectrometer (XRF).

Table 1
Chemical composition and physical properties of UGGBS and FA.

Chemical composition (% mass)	UGGBS	FA
Silicon dioxide (SiO_2)	33.6	55.47
Aluminium oxide (Al_2O_3)	22.5	25.37
Ferric oxide (Fe_2O_3)	1.3	6.2
Calcium oxide (CaO)	34.0	6.24
Magnesium oxide (MgO)	6.8	1.55
Sulphur oxide (SO_3)	0.15	0.9
Physical properties		
Specific gravity	2.84	2.42
Median particle sized d50(μm)	3.579	26.33
Specific surface area (cm^2/g)	30100	8940

Sodium hydroxide (SH) pellets having 97–98% purity were used to prepare the alkali activator solution. SH solution of required concentration was prepared by mixing SH pellets with distilled water 24 h before the casting of specimens. Alluvial sand conforming to zone III of IS 383 1970 [20] having specific gravity of 2.69 and water absorption of 1.7% was used as fine aggregate. Well-graded crushed coarse aggregate of maximum 20 mm size having aggregate crushing value of 17.63, specific gravity of 2.61 and water absorption of 0.7% was used. Both sulfonated naphthalene (SN) based SP namely Conplast SP430SRV having specific gravity of 1.260 and polycarboxylate ether (PE) based SP namely Structuro 201 having specific gravity of 1.090 were used. SPs were supplied by Fosroc Chemicals (India). Rebar of size 16 mm diameter having yield stress, f_y of 547.40 MPa was used for preparing specimens for performing pull-out test. OPC 43 grade [21] was used for preparation of the PCC substrate for preparing specimens to perform slant shear test.

2.2. Mix proportions

Mix proportion of the UGGBS based GPC is presented in Table 2. Constant alkali activator solution/total binding agent (a/b) ratio of 0.66 was maintained in GPC throughout the study. The mixes were prepared to study the effect of addition of FA of amounts of 20, 30, 40 and 50% by weight of total binding agent; addition of SP of amounts of 0.5, 1.5 and 3% by weight of total binding agent; variation of SH concentrations of 8, 10, 12 and 14 M (M); and variation in the time of addition of SP on workability, compressive strength and bond strength of GPC. SH as the alkali activator, the lower and upper limits of FA and SP content; and SH concentrations were set based on the study of past works by various authors in the same field of research mentioned elsewhere [22]. SP of both SN and PE types were added to the GPC in following three types:-

Type I: SP added after the addition of SH to the mix.
Type II: SP was mixed with SH and then added to the mix.
Type III: SP added before the addition of SH to the mix.

The difference in all the three types lies in the time of SP addition. In Type I, the SP was added to the wet mix which consisted of UGGBS, FA, fine and coarse aggregates; and SH solution. After the addition of SP to the wet mix, it was blended thoroughly so that the SP gets homogenously distributed. In Type II, SP was added to the SH solution and stirred properly. Later, the SP contained SH solution was added to the dry mix. In Type III, SP was added to the dry mix prior to the addition of SH solution. On addition of the SP, it was thoroughly mixed for homogenous distribution. SH solution was added to the mix at the end of this step of SP addition.

PCC substrates for preparing slant shear test specimens were cast using cement of amount of 380 kg/m^3, fine aggregate of 662 kg/m^3, coarse aggregate of 1146 kg/m^3 and water/cement ratio of 0.5. The maximum size of coarse aggregate was restricted to 16 mm. The compressive strength of PCC substrate at 28 days was 31.78 MPa.

2.3. Specimen preparation and curing

For preparing UGGBS based GPC, initially dry mix was manually composed by thoroughly mixing UGGBS, FA, fine and coarse aggregates for 2 min. To this dry mix, SH was added and the mixing processes was further continued for 3 min. SP was added to the mix by either of Type I, Type II or Type III method. On completion, the fresh GPC was placed into the respective moulds for compressive strength, pull-out and slant shear tests as per the codal provisions [23–25]. The moulds were kept at ambient temperature of 20 ± 2 °C. After 24 h of casting, the specimens were demolded and submerged inside water tank, maintaining temperature of 20 ± 2 °C and stored till the arrival of test day.

The size of cube specimens for compressive strength and pull-out test was 150 mm. Fig. 1 shows the special arrangements that were made for casting of the specimens for pull-out test. Provisions mentioned in IS 2770 1967 [24] were followed for the preparation of the specimens. The size of the rebar in each specimen was of 16 mm diameter. The embedded length of rebar inside the cube was 50 mm. The remaining part of the rebar inside the cube was covered using plastic tube to break the contact between the GPC and debonded length of the rebar.

For the slant shear test, the GPC constituted half of the specimen volume. The other half, i.e. the substrate was prepared using PCC (see Fig. 2). The PCC substrates were prepared with the help of dummy specimens which were cast, cured for 28 days and hand finished to give the perfect shape and slant angle of 30° along the surface 'ab' as shown in Fig. 2. The volume of each dummy specimen was half of that of cylindrical mould of size 75 mm diameter and 150 mm height [25]. Prior to the casting of the PCC substrate for slant shear test, the dummy specimens were placed into the cylindrical moulds with the surface 'ab' covered with polyvinyl sheet which acted as debonding media between the PCC substrates and dummy specimens. The fresh concrete for PCC substrate was prepared and placed into the moulds such that it occupied the other half of volume of the mould and kept for 24 h at temperature of 20 ± 2 °C. The size of the moulds were taken as 75 mm diameter and 150 mm height to economize the cost of the experimental study.