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Effect of waste foundry sand addition on strength, permeability and microstructure of ambient cured geopolymer concrete

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Abstract. Increasing urbanization and industrialization is raising burden on existing natural resources used in construction industry which is leading to severe environmental issues. Using industrial waste materials in construction can be one alternative to curb this problem. Geopolymer concrete (GPC), known as the next generation of concrete, is more durable and environment friendly as compared to conventional concrete. The current investigation presents the effect of waste foundry sand (WFS), a by-product of foundry industries; on low-calcium fly ash based GPC. The WFS was replaced by natural sand in the range of 0% to 100%. Tests on hardened concretes, such as, compressive strength, split tensile strength and sorptivity were conducted to evaluate the strength as well as permeability of ambient cured geopolymer concrete. Results indicate consistent decrease in workability of concrete with increase in WFS content but its inclusion improved the strength as well as decreased the sorptivity of concrete upto 60% replacement level of WFS. Maximum enhancement of approximate 43% in compressive strength was achieved in the GPC with 60% replacement by WFS. The results are validated by conducting SEM study.

1. Introduction

Concrete is one of the most widely used construction material in the world. Each one of these primary constituents of concrete, to a different extent, has an environmental impact and gives rise to different sustainability issues. In order to address the environmental effect associated with OPC, there is need to use other binders for production of concrete. One of the efforts to make environment friendly concrete is the development of inorganic alumina-silicate polymer, called geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that are rich in silicon and aluminium [1,2]. The geopolymer technology proposed by Davidovits shows considerable promise for application in concrete industry as an alternative binder to the OPC. Geopolymer is an excellent alternative which transform industrial waste products like GGBS and fly ash into binder for concrete. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, but to date its utilization is limited. As the need for power increases, the volume of fly ash would also increase so as the problem of its disposal will increase. The utilization of fly ash in concrete may also solve the problem of its disposal.

Heat cured low calcium fly as based geopolymer concretes (GPC) have shown superior strength and durability properties than conventional concrete [3]. However, heat curing requirement restricts the use of GPC in construction practice. Development and study of properties of ambient cured concrete has now gained the interest of researchers worldwide [4].

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Furthermore, the restriction in the extraction of sand from the river increases the price of sand and has severely affected the stability of the construction industry [5]. Waste foundry sand (WFS) is one promising material which needs to be studied extensively as substitute of sand in concrete. It is a major by-product from the metal alloys casting industry with high silica content [6]. Inclusion of WFS as partial replacement to natural sand by 20-30% has been found to improve the mechanical as well durability properties of conventional as well as special concretes such as SCC and geopolymer concretes [7-10]. Few authors have reported improvement in strength upto 50-60% replacement level of WFS as well [11,12,]. Upto 70% of strength was achievable even at 80% replacement by WFS [13]. Studies on use of WFS in geopolymer concrete are very limited. The objective of this study is to study the strength, sorptivity and microstructure of ambient cured GPC concretes when WFS partially to fully replaces NA.

2. Experimental

2.1. Materials

A range of geopolymer concrete specimens were cast with varying the composition of WFS as partial to full replacement of natural sand (NA). Mix of strength 40 MPa was designed based on mix design parameters for low calcium fly ash GPC reported in study by Junaid et al. (2015) [14]. All the mixes were dry ambient cured in laboratory conditions. Testing included compressive strength, split tensile strength and sorptivity test. In addition, Scanning electron microscopy (SEM) analysis of the concrete was also undertaken.

2.1.1. Source Material. Low calcium fly ash (ASTM Class F) was used in the research as aluminosilicate source material, procured from Ambuja Cement plant at Darlaghat, Solan (H.P.). Chemical composition of fly ash (FA) is shown in **table-1**. Along with FA, ordinary Portland cement (OPC) of 43 grade was also used for preparation of GPC mixes as 10% of total powder material. OPC was added in the concrete to achieve strength gain at early age of concrete in ambient lab condition. Specific gravity of FA was 2.23 whereas for OPC it was 3.14. Blaine's specific surface area of fly ash was 260 m^2/kg.

2.1.2. Alkaline activators. A combination of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) solutions was chosen as the activator solutions. Sodium Hydroxide of desired concentration was prepared by mixing 98% pure NaOH pellets with normal tap water. The concentration of NaOH solution was kept constant as 14 Molar with the mass of NaOH solids per kg of solution was measured as 404g. Sodium Silicate was clear colourless viscous solution with SiO_2 to Na_2O mass ratio of 2.1 and water content of 52%. Both were procured from local dealer. The ratio of Na_2SiO_3 to NaOH solution was kept constant as 2.3 for all the concrete mixes.

*2.1.3. Aggregates***.** Locally available crushed sand (NA) was used as fine aggregate along with waste foundry sand (WFS) as its partial replacement. Waste foundry sand was procured from one local ferrous foundry. The NA lies in zone-2 whereas WFS falls under zone-4 as per IS-383 (1970). Besides, locally available crushed stone aggregate, angular in shape, with maximum size 12.5 mm was used as coarse aggregate. Physical properties of fine and coarse aggregate are shown in **table2**.

2.2. Methodology

2.2.1. Mix details

The GPC mixes were proportioned to investigate the effect of inclusion of WFS as partial to replacement of regular sand (NA) on strength and durability of geopolymer concrete. Since there are no codal provisions available for the mix design of geopolymer concrete, the density of Geopolymer concrete was assumed as 2430 Kg/m^3 and other calculations were made based on the density of concrete as per the mix design procedure given by Junaid et al. (2015) [14]. The combined total weight occupied by the coarse and fine aggregates was assumed to be 76%. The alkaline liquid to binder ratio was taken as 0.45. Target strength of 40 MPa was fixed considering as a regular strength concrete. The mix proportions of the constituents are shown in **table 3**.

A total of 11 mixes were cast and tested. Details of concrete mixes are shown in **table 4**. Cube specimens of size 100 mm x 100 mm x 100 mm were cast for obtaining compressive strength and cylinders of 100 mm diameter and 200 mm height were cast for testing Sorptivity

Table 1. Chemical composition of Fly Ash and OPC

Constituent	Fly ash (%)	OPC (%)
SiO_2	59.87	20.1
Al_2O_3	23.96	6.80
CaO	5.06	61.3
Fe_2O_3	3.70	4.30
MgO	0.48	2.6
Na_2O	0.17	0.26
SO_3	0.16	1.3
K_2O	1.20	0.23
TiO_2	1.27	-
P_2O_5	0.28	-
LOI	2	1.2

2.3. Testing
The casting of the specimens was done under laboratory conditions using standard equipments. Each batch consisted of three standard cubes for compressive strength test and three cylinders for testing split tensile strength and one cylinder for sorptivity . All the tests on the mixes were tested at the age of 28 days.

First of all, the aggregates in saturated surface dry condition were mixed in with FA and OPC for 2 min. After that the alkaline solutions, super plasticiser and extra water were added to the dry materials and mixed for 3-5 min. Sodium hydroxide solution was prepared 24 h prior to casting [15]. Alkaline solutions were mixed together 30 minutes prior to casting. After mixing the concrete was cast in moulds. Moulds were then covered with plastic sheets to prevent moisture loss. The specimens were then demoulded after 24 hours and were left in the laboratory ambient conditions until specified testing ages.

Table 2. Properties of fine and coarse aggregates.

Property	Fine aggregate		Coarse aggregate
	NA	WFS	
Specific Gravity	2.65	2.18	2.74
Fineness modulus	2.50	1.80	6.93

Although GPC can set at ambient temperatures, application of heat to the specimen greatly increases the compressive strength. It has been found that the temperature of curing as well as the curing time play a significant role in the final strength of GPC mix [16]. But it can have wider application if concrete can be cured at ambient temperature. So, in the current investigation the

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concrete specimens were left to dry cure in ambient lab conditions. The slump test was undertaken in accordance with IS-1199-1959 to assess the workability of fresh geopolymer concrete. Concrete specimens of size 100mm×100mm×100mm were cast for compressive strength test, whereas, cylinders of size 100mm diameter and 200 mm height were cast for testing split tensile strength as well as for sorptivity of concretes. All the tests were conducted at the age of 28 days.

Sorptivity test is conducted to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. This test was done as per ASTM standard C 1585–04 [17].

Table 3. Mix design proportions for all constituents of GPC.

Grade of GPC	(kg/m^3)
Fly Ash	360
OPC	40
Fine aggregate	644
Coarse aggregate	1196
NaOH	72
Na_2SiO_3	108
Extra water	10
Super plasticizer	8
Water/Geopolymer solids ratio	0.24

3. Results and Discussion

3.1. Workability and Strength

Workability of fresh concrete was assessed by conducting slump cone test. Sulphonated Naphthalene based superplasticizer was added in the range of 1-3% by weight of powdered binder (fly ash + OPC). With increase in the replacement level of foundry sand, decrease in slump of concrete was observed. This decrease in workability is probably due to the presence of water absorbing finer particles i.e. clay-type fine materials, ashes and impurities etc. in WFS, which are responsible for decreasing the fluidity of the fresh concrete and increasing the water demand [18-20]. Increase in water demand further increases the demand of superplasticizer. Upto 60% replacement level of WFS mixes lied in medium workability range but beyond 60% the mixes were very harsh and lied in very low workability range.

Compressive strength test results of all the mixes as obtained in this investigation are shown in **table 4**. There was consistent increase in the compressive strength of mixes with increase in NA replacement by WFS upto 60%. Mix with 40%NA+60%WFS showed the highest compressive strength i.e. approximately 60 MPa which is approximately 43% more than the strength of control mix at 28 days of curing age. Moreover, significant increase in strength was seen beyond 30% replacement of NA by WFS. At 100% replacement of NA by WFS, the achieved strength was 47% of the strength of control mix.

Split tensile results of concretes were in correlation with compressive strength results. Results of concretes at 28 days age at both heated as well ambient conditions are also shown in **table 4**. Alike compressive strength results, maximum tensile strength was achieved by mix with 60% WFS.

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3.2. Sorptivity

Uptake of water (and therefore ions) by unsaturated, hardened concrete may be characterized by the sorptivity. Graph between cumulative water absorption against the square root of time for first 6 hours gives the initial rate of absorption (IRA). For all the specimens tested, this duration of time produced linear relationships which gave correlation coefficients greater than 0.90. The mean slopes of such plots for all mixes, i.e. average initial rate of absorption, for all the concrete mixes investigated at 28 days of curing age are shown in **table 5**. It was observed that with increase in WFS content there was consistent decrease in IRA values of the mixes with lowest value of IRA was shown by mix with 40%NA+60%WFS i.e. 0.0188.

Table 4. Compressive strength of geopolymer concrete mixes.

S.no.	Mix No.	Description	Compressive strength 28 Day, MPa	Split tensile strength 28 Day, MPa
1	GM0	100% NA (Control mix)	34.0	4.02
2	GM1	90% NA+10% WFS	37.4	4.23
3	GM2	80% NA+20% WFS	39.1	4.45
4	GM3	70% NA+30% WFS	40.3	4.62
5	GM4	60% NA+40% WFS	47.2	4.75
6	GM5	50% NA+50% WFS	48.1	4.8
7	GM6	40% NA+60% WFS	48.5	4.82
8	GM7	30% NA+70% WFS	27.0	3.54
9	GM8	20% NA+80% WFS	20.0	3.05
10	GM9	10% NA+90% WFS	19.5	2.97
11	GM10	10% NA+90% WFS	15.9	2.65

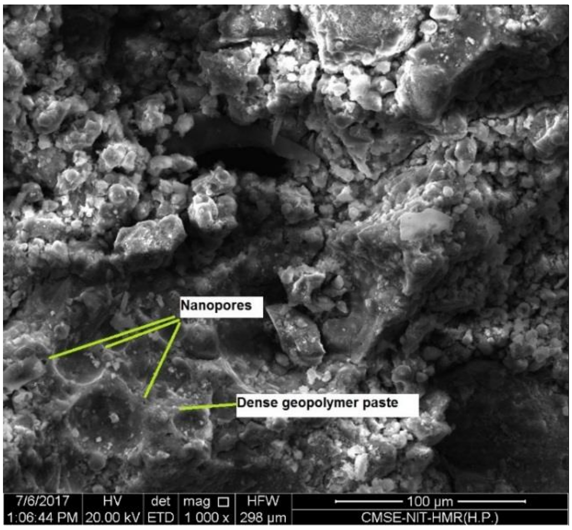
Table 5. Variation in IRA values of different geopolymer concrete mixes.

S.no.	Mix no.	Description	Average IRA (mm/Sec$^{1/2}$)
			28 Day
1	GM0	100% NA+0%WFS	0.0362
2	GM1	90% NA+10% WFS	0.0354
3	GM2	80% NA+20% WFS	0.0325
4	GM3	70% NA+30% WFS	0.0261
5	GM4	60% NA+40% WFS	0.0217
6	GM5	50% NA+50% WFS	0.0203
7	GM6	40% NA+60% WFS	0.0188
8	GM7	30% NA+70% WFS	0.0297
9	GM8	20% NA+80% WFS	0.0358
10	GM9	10% NA+90% WFS	0.0380
11	GM10	0% NA+100% WFS	0.0391

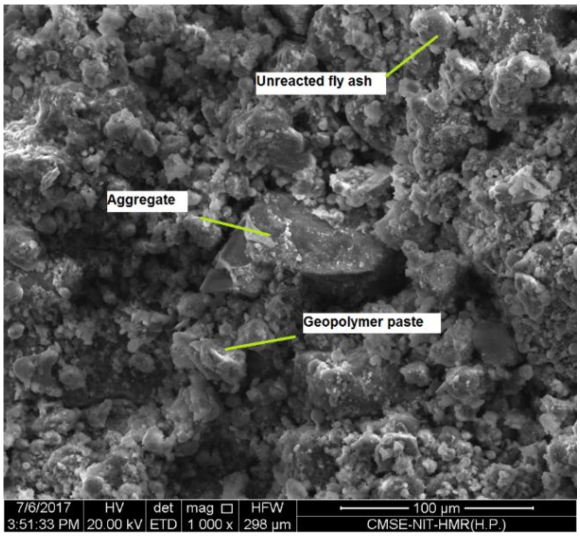
The percentage reduction in IRA values shown by mixes with 10%, 20%, 30%, 40%, 50% and 60% was about 2.23%, 10%, 28%, 40%, 44% and 48%. This could be attributed to pore refinement of the concrete matrix due to finer WFS particles. Beyond 60% replacement there was steep rise in sorptivity values, this could be due to increase in pores due to unimodal grain size of WFS [21].

3.3. SEM Analysis

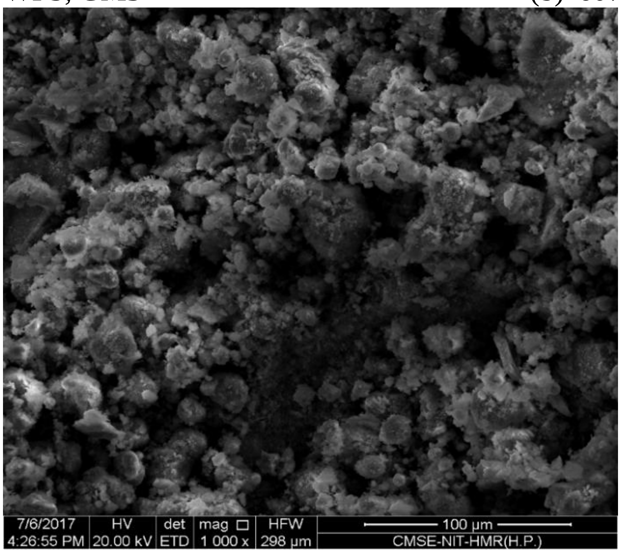
The surface image of mix GM6 observed using SEM is shown in **figure 1(b)**. Typical fly ash geopolymer consists predominantly of aluminosilicate gel or geopolymer paste, unreacted fly ash and voids. The aluminosilicate gel has an irregular shape, and the unreacted fly ash still exists in a spherical form [22]. The reactivity of the system changes the resulted geopolymer paste. Coarser gel indicates a moderate reactivity of the geopolymer. Concrete cured in low temperature or ambient temperature might have coarser microstructure with high porosity gel as visible in **figure 1**. While increased silicate content could increase the reactivity, providing a denser microstructure in the microstructure. The unreacted fly ash, as visible in **figure (a), (b) and (c)**, is unavoidable although high alkaline concentration and even curing temperature are used in the system [23]. Small pores are also visible in the geopolymer, which can influence the water absorption and permeability values. Figure 1(b) displays the aggregate-gel interface of fly ash geopolymer concrete. As can be seen that there is no clear boundary between the geopolymer gel and aggregate such as Interfacial Transition Zone (ITZ) in the OPC system. A strong chemical bonding between the geopolymer gel and aggregate was observed under SEM [23]. It is observed that unreacted fly ash particles are more in GM9 mix as compared to GM3 and GM6.



(a) 30% WFS, GM3



(b) 60% WFS, GM6



(c) 90% WFS, GM9

Figure 1. SEM images of mixes.

4. Conclusions

Based upon the limited scope of the work carried out in this investigation, following conclusions are drawn:

- Addition of WFS into GPC led to decrease in workability of concrete. Keeping superplasticizer dosage between 1-3%, workability of mixes beyond 60% WFS decreased abruptly. This is due to the presence of water absorbing finer particles i.e. clay-type fine materials, ashes and impurities etc. in WFS, which are responsible for decreasing the fluidity of the fresh concrete and increasing the water demand.
- Partial replacement of NA by WFS led to consistent increase in 28 day compressive strength of GPC mixes with increase in replacement level upto 60% WFS. However, at 60% replacement, 28 day compressive strength about 43% more than control concrete was achieved, whereas, at 100% replacement about 47% of the strength of control concrete was achieved.
- Split tensile strength were in line with the compressive strength results.
- Sorptivity results were in good correlation with strength results. Mix with 40%+60% showed minimum IRA value at 28 day curing age i.e 0.0188 mm/Sec$^{1/2}$. There was about 48% decrease in IRA value of this mix w.r.t. the IRA value of control concrete (100% NA).
- Due to ambient curing, coarser geopolymer gel is observed in microstructure of GPC mixes, SEM images shows more coarse gel, due to unreacted fly ash particle, is present in concrete at higher replacements levels of WFS.

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