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Improving Durability and Flexural Behaviour of Bottom ASH Geopolymer Concrete

Prof. Harsh Gupta[1], Trilochan Prasad Saket[2]

[1]Professor & Head of Civil Engineering Department, JNCT Rewa M.P. 486001 India

[2]Scholar, Civil Engineering Department, JNCT Rewa M.P. 486001 India

ABSTRACT:

Ordinary Portland cement concrete has its incredible strength, solidness qualities and additionally overall acknowledged composite materials for the development business. Fixings expected for assembling this substantial is cover concrete and filler total. Both filler and folio materials are extricated from the regular assets. Additionally in India, hurried development of land, framework advancement and savvy urbancommunities' improvement require tremendous amount of concrete cement. In the mean-time, India is the second biggest concrete maker on the planet. Along these lines, the interest for concrete is expanding each year. Simultaneously, the nation is delivering more than the interest. Issue is concrete assembling industry is answerable for 7% of worldwide CO2 emanation. During assembling one ton of concrete, clinker development, burning of petroleum derivative and transportation process discharges 1 ton of CO2 to the climate and it will cause an unnatural weather change moreover. On the other hand, there is scarcity of new innovative, pollution free and sustainable material in the construction industry. In spite of this and with the hard work of the many researchers, geopolymer concrete was discovered. Geopolymer concrete has the mixture of source materials, aggregates, and alkaline liquids. Source materials of this geopolymer must have pozzolanic characteristics like medium of silica and alumina. Fly ash geopolymer concrete was successfully experimented and commercialized in all parts of the country.

1.INTRODUCTION:

Portland cement is a very popular binding material in concrete due to its strength and durability. Cement, as such has been well recognized for its rapid strength enrichment. Since cement manufacturing especially involves huge consumption of virgin raw materials, high energy consumption, and greenhouse gas issues etc. it has certain negative environmental impacts during production. Raw materials for cement are calcium carbonate lime stone and clay and these materials are non renewable resources. In fact, cement industries are responsible for 7% of carbon dioxide emission into the atmosphere (Malhotra 2002). Kumar Mehta (2001) acknowledged that one tonne of Portland cement clinker production has been releasing an equal quantity of CO2 into the atmosphere. In this century, human beings consume Portland cement next to water. Moreover, India emerged second in world cement production only next to China.Hence a need is intensely felt to make new binder which is environmentally sustainable. This led to several research and studies which have been undertaken to replace cement partially with industrial by-products. Though industrial wastes are produced abundantly every year, only less quantity is being utilized in construction applications whereas most are discarded into the land fills.

1.1 GEOPOLYMER

In the year 1978, Davidovits coined the term "Geopolymer" andfound kaolinite aluminosilicate polymers hassimilar chemical characteristicof natural rock forming materials such as zeolites, feldspathoids and feldspars.Amorphousmineraladmixtureshavingoxidesofaluminosilicatereactedwithalkalipolysilicatestoproducesemi-crystallineSi–O–Albonds.Polysialate(-Si-O-Al-O-),polysialate-silaxo(-Si-O-Al-O-Si-O-),andpolysialate-disilaxo (-Si-O-Al-O-Si-O-Si-O-) are the three major oligomericstructures resulted during polymerization reaction (Davidovits 1991).

1.2GEOPOLYMERCONCRETE

Like cement concrete, geopolymer concrete has inert aggregates,source materials and water. In cement concrete, cement is being used as thebinder while the geopolymer binder consists ofsource materials andalkalineliquids. The source materials for geopolymers should be rich in silicon (Si)andaluminium(Al)anditmaybenaturalmineralsorindustrialby-products.

1.3 CURING

Curing is a process of keeping moisture inside the cement concrete to complete the heat of hydration. Water curing is used for control concrete. Ambient curing and heat curing methods are used for geopolymer concrete. After the demoulding, all the geopolymer specimens are kept in roomtemperature for ambient curing. In heat curing, specimens are kept inside the heat curing chamber for particular duration and temperature, normally at 60˚C for 24 hours. After 24 hours, the heat specimens are being kept at ambient temperature up to the curing ages.

1.4 BOTTOMASH

Bottomashisanindustrialby-productcomingfromcoal-firedelectricutilitygeneratingstations.During the combustion of coal,somequantityofashescapesfromchimneyandtheremainingnoncombustible residue remains at the bottom of furnace. The amount of the ashwhich escapes the chimney or stack is called fly ash. This non combustibleresidue isreferredas thebottom ash.The portion of fly ash is about 80%while bottom ash is about 20% in the combustion of coal.Bottom ash is adark grey, granular and porous material. It is predominantly comprised ofcoarserashparticles.In construction industry, it is generally used as structural fill andmay also be used as fine aggregate, lightweight aggregate and lightweightconcrete blocks(Geetha & Ramamurthy 2013). The chemical property ofbottom ash is almost similar to fly ash and is rich in silicon and aluminum likeflyash.

2. LITERATURE REVIEW

1.Lloyd &Rangan (2010)studied the influence of strength propertiesof fly ash geopolymer concrete and also methodology for making geopolymerandshorttermandlongtermstrengthpropertiesofgeopolymerconcrete.Itisclearthatresultsof geopolymerconcreteshowedexcellentstrengthpropertiesand issuitableforprecastreinforcedconcreteelements.

2.Deepandra kumar*et al.* (2013)compiled a study with regard tostrength properties of fly ash, bottom ash and GGBS blended geopolymerconcrete. It was noted that alkaline liquid comprised of sodium silicate andsodium hydroxide with silica to alumina ratio of 2 to 3. It is reported thatsodium hydroxide of molarity 4 to 8was used and all the samples weresubjected to heat curing at 60˚C for 24 hours. It has been found that thestrength properties ofblended geopolymer concrete increased with curingtemperatureandage.

3.Prasanna Venkatesan &PazhaniKandukalpattiChinnaraj (2015)studied the effect of strength and durability of GGBS and Black rice husk ashbased geopolymer concrete andused sodium basedalkaline activator andalkaline liquid ratio of2.5 for all the mixes. Rice husk ash up to 20 %replacementwasidentifiedasoptimummixproportionformakinggeopolymer concrete. Also, addition of more than 10% rice husk ash delaysthe setting time of concrete. According to strength and durability studies,geopolymerconcretemadewithGGBSandRicehuskashhaspotentialapplication.

4.Djwantoro Hardjito*et al.* (2005) reported that in most of the cases,flyash was utilized as a partial replacement material for cement.Butgeopolymerconcretewasa‘new’binderintheabsenceofordinaryPortlandcementinconcrete.Thepozzolanicfly ashmixedwithalkalineliquidresultsineco-friendlybindertoproducegeopolymerconcrete.Further, the suitable mix proportions for making geopolymer concrete wasidentified and recommended and due to higher compressive strength it can beusedforstructuralapplications.

5.Chindaprasirt *et al.* (2007)investigated the strength and workabilitypropertiesofgeopolymermortarsmade with high calcium fly ash.Theoptimalsodiumhydroxidetosodiumsilicateratiowasnoticedas0.67 to 1.0.Concentration of sodium hydroxide molarity was in the range of10 M to 20 M to produce fly ash geopolymer mortar. The fly ash geopolymermortar strength mainly depends on the concentration of sodium hydroxide andalsoheatcuringmethod.

3. METHODS

3.1 MIXPROPORTIONSOFCONTROLANDGEOPOLYMERCONCRETE.

3.1.1 General

Control concrete (CC) mix design for M40 grade was prepared as per IS: 10262-2009. The bottom ash geopolymer concrete (BAGPC) mix was prepared based on trial and error method (Rangan 2005 & Revathi et al. 2014). The density of the BAGPC was taken as 2400 kg/m3. (Rangan 2005 & Revathi et al. 2014). The total quantity of aggregate was 75% from the density of BAGPC. Outofthat75%,coarseaggregatecomprises of 70% and 30% of fine aggregate.In the case of coarse aggregate,20 mm and 12 mm size aggregates were used in the percentage proportions of60 and 40 respectively. The molarity of sodium hydroxide was taken as 8Mandthesodiumhydroxidesolutionwaspreparedasrecommendedby Rajamane&Jeyalakshmi (2015) and also alkaline liquid to BA ratio was keptas 0.5. Five mixes were proposed such as B1, B2, B3, B4 and B5 with varyingsodiumsilicatetosodiumhydroxideratioof0.5,1,1.5,2and2.5.

Table1Mix proportionsofcontrol concrete

Mix id	Cement Kg/m^3	Fineaggregatekg/m^3	Coarseaggregate kg/m^3	Waterkg/m^3	Superplasticizer kg/m^3
CC	394	629.6	1316.1	157.6	7.9

Table2Mix proportionsofBottomashgeopolymerconcrete

Mixid	Bottomashkg/m^3	Fineaggregatekg/m^3	Coarseaggregatekg/m^3	Sodiumhydroxide(8M) kg/m^3	Sodiumsilicatekg/m^3	Superplasticizerkg/m^3
B1	400	540	1260	133.3	66.7	8
B2	400	540	1260	100	100	8
B3	400	540	1260	80	120	8
B4	400	540	1260	66.7	133.3	8
B5	400	540	1260	57.1	142.9	8

3.1.2 Manufacturingprocess

All the constituents were thoroughly mixed to get homogeneous mix with the help of pan mixer. After mixing both, CC and BAGPC concrete were placed in moulds. The placed concrete were well compacted until the entrapped air escapes. The cast specimen weredemoulded after 24 hours and cured for respective ages. Two curing methods were adopted to cure the geopolymer concrete specimens. In the first category of curing, geopolymer concrete specimens were cured at ambient temperature for 28 days. In the second category, geopolymer concrete specimens were cured using steam curing chamber for 24 hours at 60˚C .Steam cured concrete samples were kept at ambient temperature and tested after 3, 7 and 28 days. Based on the compressive strength results, the optimal ingredient combination was identified. The samples cured at ambient temperature showed better performance. Further, flexural behaviour and durability properties of BAGPC specimens cured at ambient temperature were determined. Control concrete specimens were water cured at room temperature and tested for respective ages.

3.2 TESTSONHARDENEDCONCRETE

In order to determine the mechanical properties of control and geopolymer concrete, compressive strength, split tensile strength, flexural strength, modulus of elasticity and pullout tests were performed.

3.2.1 Compressive Strength Test

Compressive strength of control and geopolymer concrete was determined as per IS: 516-1959 (Reaffirmed 2013) with sample of size 150 mm x 150 mm x 150 mm. Totally, 99 samples were cast and tested for compressive strength. Cast samples were cured at ambient temperature and tested for 3, 7 and 28 days for compressive strength. For compressive strength determination, concrete samples were tested in 2000 kN capacity compression testing machine. Rate of loading of 140 kg/cm2/min was applied until the specimen gets failure.

3.2.2 SplitTensileStrengthTest

Cylindrical concrete specimens of dimension 150 mm x 300 mm were cast and tested for split tensile strength as per IS: 5816-1999 (Reaffirmed 2013). Control and geopolymer concrete samples were cured for 7 and 28 days. The split tensile strength of the cylindrical samples was tested using compression testing machine of 2000 kN capacity. Totally 66 samples were cast and tested for split tensile strength.

3.2.3 Flexuralstrength Test

Concrete prisms of size 100 mm x 100 mm x 500 mm were cast and tested to determine the flexural strength as per IS: 516-1959 (Reaffirmed 2013). Totally 66 samples were cast and tested for flexural strength at 7, and 28 days. Two point loading was applied to the control andgeopolymer concrete samples using universal testing machine with capacity of 600 kN.

3.2.4 ModulusofElasticity Test

The modulus of elasticity test was carried out for the control and geopolymer concrete samples as per the test procedure specified in IS: 516-1959 (Reaffirmed 2013). Cylindrical concrete specimens of dimension 150 mm x 300 mm were cast and tested for modulus elasticity after 7 and 28 days of curing. Totally 66 samples were selected for test using compression testing machine of capacity 3000 kN. Based on the test results, the stress- strain curve was plotted and modulus of elasticity could be determined.

3.2.5 Pullout Test

Cubical concrete samples of size 100 mm x 100 mm x 100 mm embedded with 12 mm reinforcing bar were used in pull out test. The test was conducted as per the standard procedure mentioned in IS: 2770-1967 (Reaffirmed 2007). Totally 6 specimens were cast and tested to determine the bonding of the embedded steel with concrete and the load required for 0.25mm slip was observed. In order to determine the bonding stress and slip, concrete sample were gradually loaded using 600 kN capacity universal testing machine. The rate of loading, not exceeding 2250 kg/min was mentioned throughout the test.

4. RESULTS AND DISCUSSIONS

In this chapter, the test results of compressive strength, split tensile strength, flexural strength, modulus of elasticity, pull out test and flexural behaviour of bottom ash geopolymer concrete (BAGPC) are discussed and also behavior of BAGP reinforced concrete beams is studied. The durability properties of BAGPC such as acid resistance test, sulphate resistance test, salt resistance test, sorptivity test, water absorption test and accelerated corrosion test are included in this chapter. Further, the microstructure of bottom ash geopolymer has also been incorporated.

4.1 Compressive Strength

The compressive strength test results of ambient, steam cured bottom ash geopolymer concrete and control concrete (CC) are presented in Table3.The compressive strength of steam cured geopolymer concrete mix SB1has reached 27.1 MPa at 28 days and the same mix B1 ambient cured specimens reached 13.2 MPa at 28 days. The test results show that the compressive strength of steam cured mix SB1 is 51.29% higher than ambient cured same mix B1.The 28 days compressive strength of steam cured specimen mix SB2 attained 30.3 MPa and ambient cured same mix B2 accomplished22.7 MPa. It shows that the compressive strength of steam cured SB2 is 25% higher than ambient cured same mix B2 at 28 days.
The mix SB3 yields compressive strength of 33.3 MPa for steam curing and 28.4 MPa for ambient curing at 28 days. The result indicates that the 28 days steam cured SB3 has 14.71 %

higher compressive strength than the ambient cured same mix B3 at 28 days.
The compressive strength of steam cured mix SB4 achieved58.5 MPa at the age of 28 days and the ambient cured same mix B4 achieved50.3 MPa at 28 days. It reveals that the compressive strength of steam cured specimens and mix SB4 reached 14% higher than same specimens cured at ambient mode at 28 days. Similarly the compressive strength of the mix SB5 steam cured specimen shows 6.46 % increase than ambient cured same mix B5 at 28 days.

Table3 Compressive strength of BAGPC and CC

S.No	Mix Id	CompressiveStrength(MPa)		
		3days	7days	28days
1	CC	21.7	28.7	47.6
2	B1	8.4	9.7	13.2
3	B2	10.4	12.8	22.7
4	B3	13.6	16.6	28.4
5	B4	24.1	34.1	50.3
6	B5	15.0	22.2	37.6
7	SB1	15.0	24.5	27.1
8	SB2	18.1	29.1	30.3
9	SB3	23.7	30.9	33.3
10	SB4	35.9	43.7	58.5
11	SB5	32.1	34.3	40.2

4.2 Split Tensile Strength of BAGPC and CC

The split tensile strength of BAGPC and CC mixtures at age of 7and 28 days is given in Table 4. The BAGPC cured at steam mode proportions SB1, SB2, SB3, SB4 and SB5 showed 75.1%, 2.72 %, 18.9%, 18.16% and 13.8% increase in split tensile strength at the age of 28 days when compared with ambient mix B1, B2, B3, B4 and B5 at 28 days.With the bottom ash geopolymer concrete made from alkaline liquid ratio 2, the mix B4 showed a remarkable increase in split tensile strength among all the mixes at 7 and 28 days similar to compressive strength. The mix B4 has resulted in 25.1% and 15% higher split tensile strength than CC at the age of 7 and 28 days respectively.

Table4 Splittensile strength of BAGPC and CC

S.No	Mix Id	Splittensile strength(MPa)	
		7days	28days
1	CC	2.31	4.26
2	B1	0.67	1.41
3	B2	0.76	2.2

4	B3	1.52	2.91
5	B4	1.73	4.9
6	B5	1.18	3.6
7	SB1	1.46	2.47
8	SB2	2.13	2.26
9	SB3	3.17	3.46
10	SB4	3.68	5.79
11	SB5	3.52	4.1

4.3 Flexural Strength of BAGPC and CC

Flexural strength test were conducted on BAGPC at ambient and steam cured mode with varying alkaline liquid ratio mixes and CC as shown in Table 5.The flexural strength of steam cured proportions SB1, SB2, SB3, SB4 and SB5 reached highest flexural strength of 35.27%, 23.21%, 7.87%, 6.73% and 1.32% respectively at 28 days when compared to B1, B2, B3, B4 and B5 ambient cured mixes.After the comparison of BAGPC flexural strength results, B4 yielded 12.32 % higher than CC at 28 days. It is observed that the mix B4 has higher flexural strength at age of 7 days and 28 days in ambient curing mode. The flexural strength of BAGPC increases with increase in compressive strength, as reported by Tianyu Xie & Togay Ozbakkaloglun (2015).

Table.5 Flexural strength of BAGPC and CC

S.No	Mix Id	Modulusofrupture(MPa)	
		7days	28days
1	CC	3.57	4.49
2	B1	2.21	2.75
3	B2	2.7	3.23
4	B3	3.12	3.81
5	B4	4.01	5.05
6	B5	3.61	4.53
7	SB1	3.64	3.72
8	SB2	3.87	3.98
9	SB3	3.96	4.11
10	SB4	4.71	5.39
11	SB5	4.07	4.47

5. CONCLUSION

Efforts made to find the suitable mix proportions of BAGPC under various curing Conditions have been studied in this present work. The experiment son mechanical properties namely compressive strength, split tensile strength, flexural strength and modulus of elasticity of BAGPC were carried out. Further, pullout test and flexural behavior of BAGPC were studied at ambient curing method. Durability studies such as acid resistance test, sulphate resistance test, salt resistance test, accelerated corrosiontest,sorptivity test and water absorption test of BAGPC were undertaken and compared with CC. Further, micro structure of BAGPC was evaluated.

The significant conclusions for the present work are as follows.

i. Among the all mixes, the BAGPC mix B4 exhibited higher compressive strength with alkaline liquid ratio of 2 and was identified as optimum mix proportion of BAGPC.
ii. The compressive strength of steam cured mix SB4 yielded

58.5 MPa at 28 days. However the same mix cured at ambient temperature reached 50.3 MPa at 28 days.

It is evident that mix B4 ambient curing itself showed highercompressivestrength.

iii. The compressive strength ofmix B4 with alkaline liquidratio 2 and sodium hydroxide molarity 8 M was 5.67 %higherthanCCat28days.
iv. The split tensile strength, flexural strength and modulus ofElasticityofmixB4yielded15%,12.32%and1.10%higherthanCCat28days.

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