Study of Mechanical and Durability properties of Geopolymer concrete Incorporated Waste Brick Powder as Fine Aggregate

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Abstract - *In this research, an experimental program has been proposed to study the strength behavior of fly ash slag based geopolymer concrete prepared with waste brick powder by replacing natural sand. For the geo-polymerization reaction to take place, the fly ash and GGBFS utilized as the binder were being activated by the alkali solution made with a fixed molar concentration of sodium hydroxide and solution binder ratio for trial mixes also ratio of concentration for sodium hydroxide to sodium silicate is kept constant. Tests were conducted to assess physical properties of materials and Mechanical properties and durability of prepared GP concrete. Test reveals solution binder ratio has a strong impact over every sample where the strength also varies with the replacement of waste brick powder with natural sand at different proportions.*

Key Words: S/b, GP, GPC, Geo-polymerization, Alkali solution, WBP, NS and NSWBP.

1. INTRODUCTION

In the construction sector, concrete is the most powerful material. Engineers and manufacturers are challenged by the steadily rising demand for concrete to improve its dependability and suitability regarding the environment and natural resources. Ordinary Portland cement is produced by calcining limestone (calcium carbonate) and silico-aluminous material at extremely high temperatures, resulting in 1 metric tonne of cement is produced for every 1 metric tonne of CO_2. The degradation of the atmosphere occurs when cement consumption rises. The cement industry is one of the greatest industrial pollutants of the environment. To overcome and limit the demand of natural resources many came with idea of replacing natural resources with artificial resources which can be obtained from almost every industrial sector and all are accepting to preserve nature for our future generation and make earth a better place to live. As a result, the need of geopolymer, an alternative material represented in Figure1., emerged as an eco-friendly alternative material with low carbon dioxide emissions, evolved. Reusing such waste material can lowers the cost of building and reduces environmental harm.

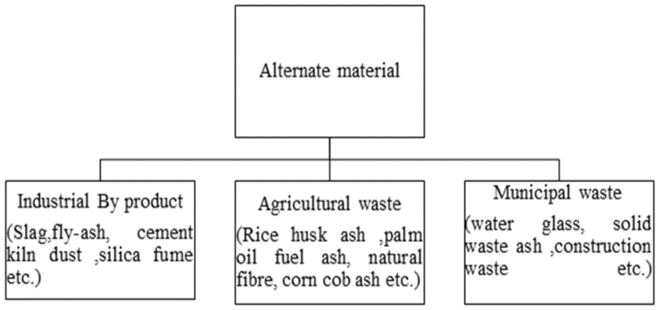

Fig-1 Waste Material

1.1. Geopolymer

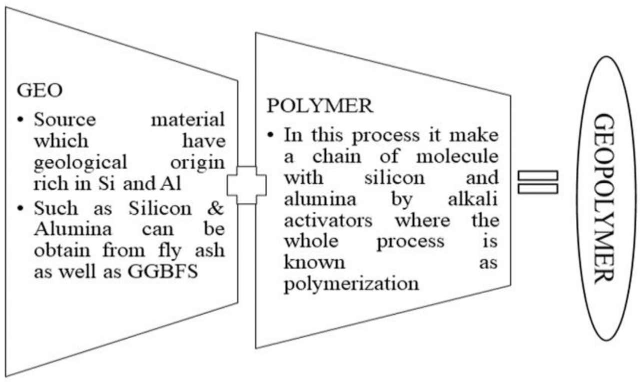

Fig-1.1 Constituent of Geopolymer concrete

The Joseph Davidovits used the term "geopolymer" in 1978 to describe polymers with an inorganic composition. Utilizing waste products like fly ash (trash from thermal power plants) and (GGBFS) Ground Granulated Blast Furnace Slag (waste from iron manufacturing) as a full replacement for cement, geopolymer cement is created as shown above in Figure 1.1 following the chain of geo-polymerization gel below in Figure 1.2. Geopolymer cement has a large amount of potential because of its enhanced durability, chemical and thermal resistance to heat, and early age strength. To increase the dependability and durability of geopolymer concrete, researchers are conducting several studies on its workability.

The Global Change Institute at the university of Queensland has built the first building ever made of geopolymer concrete (GCI). It is a four story structure where 33% of the panels used in the GCI's floor plates is the largest application used in world.

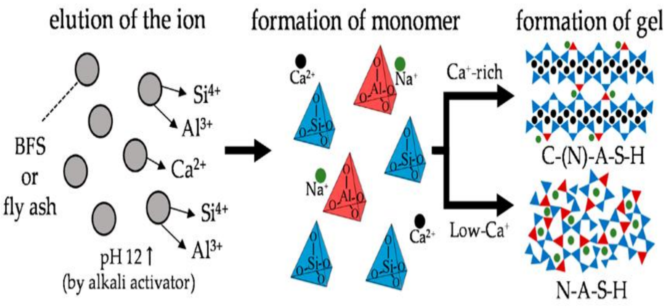

Fig-1.2 Chain of geo-polymerization gel

1.2. Constituents

a) Binders

Cement works as the binder of concrete used in building construction. Various binder material that can be used are fly ash, GGBFS, metakaolin, rice husk ash, corn cob ash, Bagasse ash, and Ultra fine Slag. The majority of GGBS is used as a partial replacement for cement, whereas most of the fly ash is used as additive in the cement industry, for the construction of roads and embankments, and for the manufacture of bricks. The potential for using these industrial by-products as stabilizing agents is quite high. Abundant content of Si and Al can be used as raw material for manufacturing geopolymer concrete where metakaolin, fly ash, and crushed granulated blast slag are among the principal sources of raw materials for production of geopolymer concrete that are using today.

a) Coal b) Thermal plants c) (Fly ash) Residue from thermal plants after burning of coal

Fig-1.3 Production of fly ash

b) Aggregates

Coarse aggregates and fine aggregates are the main constituent of geo-polymer concrete that would be used in natural as well as artificial form with appropriate quantity to obtain maximum strength. Rock dug from natural deposits is utilized to produce coarse aggregates, which are used in construction. These ground deposits include, for instance, river gravel, crushed stone from rock quarries and old concrete. Sand, gravel, or crushed stone are example of inert granular materials that are used in combination as a binding agent, such as water, bitumen, Portland cement, lime, etc. mix together to create compound materials.

Waste brick powder/Surkhi is that type of waste that, when dumped, not only occupies space but also causes environmental issues. This waste will be taken from brick kilns (where the bricks are produced). So, to reduce the waste material by reusing waste brick powder as an artificial fine aggregate.

c) Alkali Activators

Over the past ten year or so there has emerged a large amount of interest in alkali activated binders, especially the substances known as "geopolymers." The geopolymers are produced by reacting an alkaline activator, which is generally a concentration solution of alkaline hydroxide, silicon, calcium, or sulphate., using an aluminosilicate, which is frequently available in powder as an industrial by-product or other low cost material. Report of Provis [11] explained the behaviour of alkali activated binders or geopolymer binders as hardened compounds which acquire their strength and other properties by chemical reaction such as geo-polymerization between an alkaline soluble source and aluminate rich raw materials as shown in figure 1.4 below:

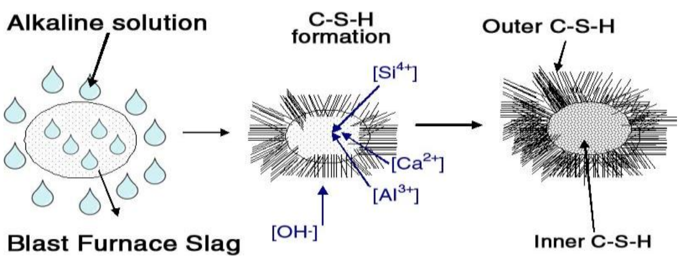

Fig-1.4 Reaction mechanism in an alkali activated slag particle

1.3. CATEGORIES OF GEOPOLYMER CONCRETE

Geopolymer concrete based on industrial byproducts with high early strength, minimal shrinkage, dehydration resistance, sulfate resistance, and resistance to corrosion are categorized [3] in Table 1 below:

Table 1: Categories of geopolymer by Joseph davidovits

1. Slag based geopolymer concrete.
2. Rock based geopolymer concrete.
3. Fly ash slag based geo polymer concrete.
4. Ferro-silicate based geo polymer concrete

2. OBJECTIVES

The following goals are pursued with this research project: -

1. To study the workability of geopolymer concrete containing waste brick powder /surkhi.
2. To study the mechanical properties such as compressive strength, flexural strength, and split tensile strength of prepared geopolymer concrete incorporated WBP.
3. To study the influence of carbonation on geo polymer concrete incorporated waste brick powder /surkhi.

3. EXPERIMENTAL PROGRAM

A flowchart depicting a high level overview of the program given below in Figure 3:

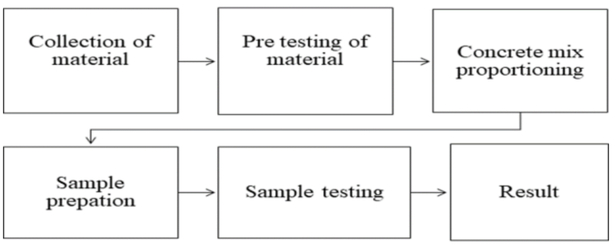

Fig- 3: Flow Chart of work

3.1. Constituent materials and their testing

3.1.1. Binder

The GGBFS. and fly ash was used in the current study as the alumina silicate source material to create the geopolymer specimens. Binder contained 70 percent of high class 'F' fly ash and 30 percent of GGBFS manufactured by Akarsh earth power solution and JSW Cement Ltd. Their physical properties shown in Figure 3.1 and Table 3 such as specific gravity are assessed using processes outlined in Bureau of Indian Standard 8112-2013.

a) 70% fly ash 30 % GGBFS b) specific gravity

Fig-3.1: Fly ash and ground granulated blast furnace slag as Binder

Table 3: Physical Properties of Binder

GGBFS	Fly ash Class F	Specific gravity
30 %	70 %	2.79

2.1.2. Coarse Aggregate

In this experiment, coarse aggregate consists of a mixture of material with nominal sizes of 20 mm and 10 mm. Both types of coarse aggregate came from nearby sources. The techniques described in the Bureau of Indian Standards criteria, as indicated in Tables below. Both types of coarse aggregate's specific gravities were determined using the water basket method.

Table 3.1: Physical properties of Coarse aggregate

Fineness Modulus	Specific gravity	Water absorption
6.8	2.13	1.07 %

Table 3.2: Sieve analysis

IS Sieves	Weight Retained [gm]	Weight Retained (%)	Cumulative Percentage Retained	Passing Percentage [%]	Limits as per IS 383-2016 [%]
40 mm	0	0	0	100	100
20 mm	52	1.04	1.04	98.96	85-100
10 mm	4367	87.34	88.38	11.62	0-20
4.75 mm	546	10.92	99.3	0.7	0-5
Pan	35	0.7	-	-	-
Total	5000 grams		Σ 188.72		

3.1.3. Natural Sand

The physical characteristics of natural sand are examined using the procedures indicated in Bureau of Indian Norms standards, such as sieve analysis at Table 3.3, specific gravity, water absorption, and silt content as results are shown in Table 3.4. In accordance with BIS 2386(Part1):1988, natural sand was passed through a series of sieves to obtain sieve analysis, which was then compared to BIS 383:1970 criteria. In accordance with BIS 383:1970, the fineness modulus was calculated, the sand zone was identified, and the results were provided in Table 3.4. The process described in employed the pycnometer method to calculate the specific gravity of natural sand and its capacity to absorb water.

Table 3.3: Physical properties of Natural Sand

Fineness Modulus	Specific Gravity	Water absorption	Silt content	Grading Zone
2.11	2.51	1.9 %	5 %	III

Table 3.4: Sieve Analysis

IS Sieves	Weight, Retained [gm]	Weight, Retained [%]	Cumulative [% Age], Retained	Passing Percentage, [%]	Limits as per IS 383-2016 [%]
10 mm	0	0	0	100	100
4.75mm	18	1.8	1.8	98.2	90-100
2.36 mm	42	4.2	6	94	85-100
1.18mm	120	12	18	82	75-100
600 µ	55	5.5	23.5	76.5	60-79
300 µ	429	42.9	66.4	33.6	12-40
150 µ	242	24.2	90.6	9.4	0-10
Pan	94	9.4	4.7	-	-
Total	1000		Σ 211		

a) Specific gravity b) Silt content

Fig-3.2: Natural Sand

3.1.4. Waste Brick Powder

Surkhi other name of waste brick powder which is a collected waste from the brick kilns and has no further use. It is obtained during the process of making brick, a layer of sand and clayey soil was used over unburned brick to make a cover in the mold. Same procedure has been followed to check the physical properties of waste brick powder as for natural sand shown in Table 3.5 and 3.6.

a) Waste brick powder b) Silt content

Fig-3.3: Waste brick powder

Table 3.5: Properties of Waste brick powder

Fineness Modulus	Specific Gravity	Water absorption	Silt content	Grading Zone
2.63	2.35	2.8 %	6 %	IV

Table 3.6: Sieve analysis

IS Sieves	Weight Retained [gm]	Weight Retained [%]	Cumulative % Age Retained	Passing Percentage [%]	Limits as per IS 383-2016 [%]
4.75 mm	0	0	-	-	
2.36 mm	14	4.2	10	80	85-100
1.18 mm	40	12	25	82	75-100
600 µ	20	5.5	24.5	76.5	60-79
300 µ	48	42.9	69.4	33.6	12-40
150 µ	172	24.2	100	10	0-10
Pan	206	9.4	-	-	-
Total	500		Σ 263		

3.1.5. Water

For the mixing of concrete, water is required. In addition to water, the alkali solution was made with it. Potable water was procured from GNDEC, Ludhiana, and was used throughout the research.

3.1.6. Alkali Solution

The alkaline activator for Fly Ash and GGBS activation was a solution of NaOH and sodium Na_2SiO_3. In the presence of NaOH, more silicate and aluminate monomers develop, and Sodium-based activators were chosen because they are less expensive than potassium based activators. The sodium hydroxide used was in the form of flakes. In the process of making the sodium hydroxide solution, the flakes or pellets were dissolved in water. The molarity of 12 were used in this study. Shivas Chemicals, Ludhiana, provided the material for the alkali activator solution, which was 97 percent pure. According to the previous literature, the ratio of Na_2SiO_3 to NaOH is kept 2.5 [1].

3.2. Mix Proportion

In the beginning f-or the pro-duction of geopolymer concrete solution t o binder ratio is taken as a constant 0.48 in all the mixes to check the 3-day behavior of compressive strength, the following assumptions are used to perform trial mix for achieving maximum strength.

1. Different binder content from 350 to 400 kg per meter cube, where the binder content with a combination of 70 % fly ash and 30 % G G B F S was kept same for all mixes.
2. Ratio of sodium silicate to sodium hydroxide is kept 2.5 with a molarity of 12 Molar.
3. Waste brick powder was used as fully replaced fine aggregate.
4. Varying ratio of coarse and fine aggregate from 55:45 (%) to 70:30 (%) at an interval of five.

3.2.1. Trial for Mix Proportion

The proposed mixes were used to attain maximum compressive strength at 3-day with all the supposition was further carried as shown in Table 3.7. Where total 36 are casted and tested for three Mix 1, Mix 2, and Mix 3.

Table 3.7: Coarse to Fine aggregate ratio for varying binder content

MIX	Binder Content (Kg/m3)	CA: FA (%)	CA: FA (%)	CA: FA (%)	CA: FA (%)	S/B
MIX 1	350	55:45	60:40	65:35	70:30	0.48
MIX 2	375					
MIX 3	400					

3.2.2. Result for Trial Mix

From the above mentioned trial mixes, mix which achieved the maximum compressive strength at 3-day were selected for fulfilment of objectives. Result for trail mix presented in Table 3.8 and figure 3.4.

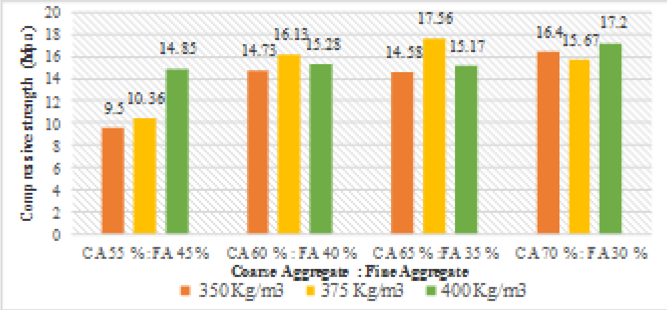

Fig-3.4: Variation in compressive strength at 3-day ambient curing for 0.48 s/b.

Table 3.8: Compressive strength at 3-day for trial mix

Binder (Kg/m³)	(CA55%: FA 45%)	(CA60%: FA40%)	(CA 65 %: FA 35 %)	(CA 70%: FA 30 %)
	(MPa)	(MPa)	(MPa)	(MPa)
350	9.42	14.94	14.96	16.69
	9.6	14.7	14.8	16.4
	9.5	14.5	14	16.12
Avg.	9.5	14.73	14.58	16.4
375	10.4	16.11	17.7	15.71
	10.37	16	17.6	15.5
	10.33	16.3	17.4	15.8
Avg.	10.36	16.13	17.56	15.67
400	14.93	15.04	15.42	17.52
	14.8	15.6	15	17.2
	14.75	15.2	15.1	17.1
Avg.	14.85	15.28	15.17	17.2

Considering the behavior for 0.48 solution binder ratio is found good as shown in Figure 3.6. than it proceeds for further examination of strength with fixed 0.48 solution, 375 kg/m³ binder content, 65 % coarse aggregate and 35 % fine aggregates.

3.3. Elected Mix Proportion of Geopolymer Concrete

Based on the above mix assumptions, an all-in aggregate percentage of coarse and fine aggregate was determined, with a maximum compressive strength of 3 days, to be utilized in calculating coarse and fine aggregate amounts at the time of mix design where the particle packing theory [17]. The quantity of aggregate was estimated based on weight of aggregate in concrete and the proportion was selected from trial mix as represented in Table 3.9 and 3.10.

The SSD condition was used to compute coarse and fine aggregate quantities. As a result, the adequate water corrections are made based on the aggregate's moisture content during casting. Geopolymer concrete blends with waste brick powder proportions mixes with replacement of natural sand from 0%, 50% and 100 % where waste brick powder was designated as WBP0, WBP50 and WBP100, respectively.

Table 3.9: Proportioning of materials

MIX	CA: FA (%)	WBP (%)	NS (%)	S/B
MIX 2	65:35	0	100	0.48
		50	50	
		100	0	

Table 3.10: Mix proportion

Binder Content (Kg/m³)	Coarse Aggregate (Kg/m³)	Fine Aggregate (Kg/m³)	Alkali Solution (Kg/m³)	Extra water
375	1020.612	647.60	180	5 % of Alkali solution
1: 1.72: 2.72				

4. Mixing and Casting

4.1. Mixing of Materials

a) Dry mixing

In dry mixing material containing coarse and fine aggregate as in the form of SSD condition were mixed with binder for a calculated quantity.

b) Preparation of alkali solution

Alkali solution was prepared with NaOH and sodium silicate Na_2SiO_3 as shown below in Figure 4.1. Where 12 molar concentration of sodium hydroxide is mixed with sodium silicate i.e., 2.5 times of sodium hydroxide for example if we have to prepare 12 molar per liter solution for NaOH then 12 x 40 = 480 gm and $Na_2SiO_3$1480 x 2.5=3700 gm, represents its weight with concentration of 12 molarity, during the preparation of solution it must be prepared prior to its usage when mixed in wet mixing due to its exothermic reaction during mixing of chemicals together. Precautions should be taken such as before collection or touching of chemicals.

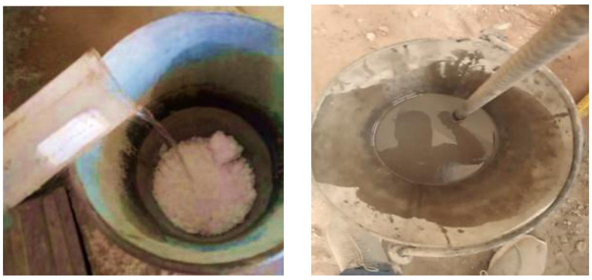

Fig-4.1 Alkali solution

c) Wet mixing

It is final stage of mixing where alkali solution is then added to dry mixing as the whole process is done in the electrically operated mixer shown below in Figure 4.2.

Figure 4.2: Wet mixing in electrically operated drum mixer

After mixing of materials, concrete is filled to lubricated mold. Casting of the prepared geopolymer concrete would be done in cube size 100mm x 100 mm x 100 mm, 150 x 150 x 150 mm, cylinder of size 150 mm x 300 mm and prism 100 mm x 100 mm x 500 mm from the above combinations the total "63" numbers of sample are casted as no. of specimen presented in Table 4.1. and Figure 4.3.

Fig-4.3 Geo polymer concrete specimens

Table 4.1: No. of specimen

Molarity (M)	Solution/ binder S/B	Fly ash: GGBFS (%)	NS (%)	WBP (%)	No. of specimen	
12	0.48	70:30	100	0	(100x100x100) mm	3
			50	50		3
			0	100		3
12	0.48	70:30	100	0	(150x150x150) mm	6
			50	50		6
			0	100		6
12	0.48	70:30	100	0	(100x100x500) mm	6
			50	50		6
			0	100		6
12	0.48	70:30	100	0	(150x300) mm	6
			50	50		6
			0	100		6

5. Test Procedure

Testing of geopolymer concrete is followed as per Indian standards code provision followed by ASTM and ACI.

5.1. Workability

According to IS 1199(Part 2):2018, the slump cone test was used to assess workability. Three layers of material were poured into the hollow cone-shaped mold, which had internal dimensions of 200 mm at the base, 100 mm at the top, and 300 mm in height. Each layer tamped with 25 strokes of the tamping rod. After levelling the surface with the top layer, remove the mold by lifting it vertically upward. The gap between the height of the mold and the highest point of the slumping concrete was measured in millimeters just after the mold was removed. The slump cone test is shown in Figure 5.

Fig-5: Slump cone

5.2. Compressive Strength

Testing of 18 cubes by CT machine at 7-day and 28-day as per IS 516-1959. The blocks were placed under bearing plates preventing any damage and gradually load was applied until crack appeared. Figure 5.1 shows the testing of cubes.

Fig-5.1 : Digital CT Machine

5.3. Flexural Strength

Testing of 18 beams was carried out on UT machine after 7 day and 28 day of ambient curing. Testing of concrete was carried out as per ACI 318 and IS 516:1959 (Method of tests for strength of concrete.

Fig-5.2 : Digital UT Machine

5.4. Split Tensile Strength

It is an indirect method of determining tensile strength of concrete using cylinder which split across the vertical diameter where the test was carried out after curing of 7-day and 28-day Testing of concrete was carried out as per ACI 318 and IS 516:1959 (Method of tests for strength of concrete) represented in Figure 5.3.

Fig-5.3 : Automated CTM

5.5. Carbonation

Carbonation is a test to check the inflow of carbon through accelerated carbonation chamber in which the excess amount of carbon flow is present. Criteria for Carbonation was followed as per IS 1902-12. So as 9 no.'s of specimen (100mm x 100mm x 100mm) was casted. To check the inflow of carbon, the specimens were waxed from the outer four faces for a period of 28 day open air curing, after the curing it was placed in a chamber shown in Figure 5.4 where excess amount of carbon required for another period of 28 days. When all the cubes were taken out of chamber then it was placed for open air curing for some duration

i) Heating of wax

ii) Waxed cube

iii) Cube placed in chamber

Fig-5.4 : Accelerated carbonation tank.

6. RESULTS AND DISCUSSION

This research has been carried out to prepare geo polymer concrete with available literature. In this chapter result obtained from the experimental program are discussed. There are three cases of geo-polymer concrete mix (NS, NSWBP and WBP) for which comparison is produced for its quality production.

6.1. Workability

To see the effect of replacement of natural sand with waste brick powder on workability of concrete and the observations are given in Table 6.

Table 6: Slump value

Mix Designation	Slump (mm)
NS	140
NSWBP	110
WBP	90

The slump for NS and NSWBP concrete mixtures is considerably high other than WBP which is medium because waste brick powder prepared concrete contains harsh substance of burned sand and clayey soil which led to absorb more water even after it was saturated surface dried before using in mix. According to Wong et al. [18] with an increase in waste brick powder, the mixture flowability decreased linearly.

6.2. Effect of Strength Over NS, NSWBP AND WBP

6.2.1. Compressive Strength

Total number of 18 cubes were tested on a digital CT machine of capacity 2000 KN after open air curing period of 7 day and 28 days where 3 pair of cubes denoted as NS, NSWBP and WBP contain set of 6 cubes. The test result is shown in Table 6.21and 6.2 with graphical representation in Figure 6 and 6.1.

Table 6.1: 7-day compressive strength of ambient cured specimens for 0.48 s/b

Series	NS (N/mm^2)	NSWBP (N/mm^2)	WBP (N/mm^2)
1.	18.61	17.86	17.58
2.	17.37	18.35	17
3.	18.04	17	17.7
Average	18.01	17.74	17.45

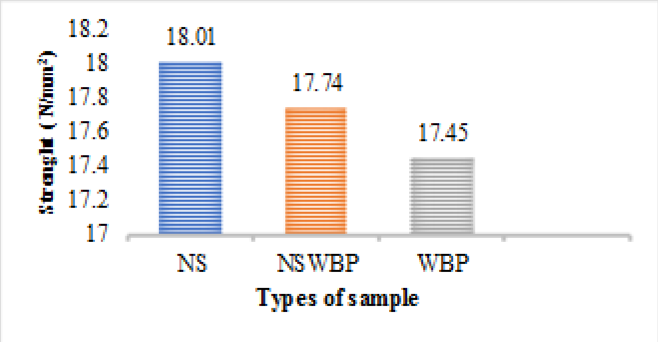

Fig-6 Variation in compressive strength at 7-day ambient curing for 0.48 s/b

Table 6.2: 28-day compressive strength of ambient cured specimens for 0.48 s/b

Series	NS (N/mm²)	NSWBP (N/mm²)	WBP (N/mm²)
1.	22.63	21.83	18.04
2.	21.68	20.54	18
3.	21.89	20.48	18.08

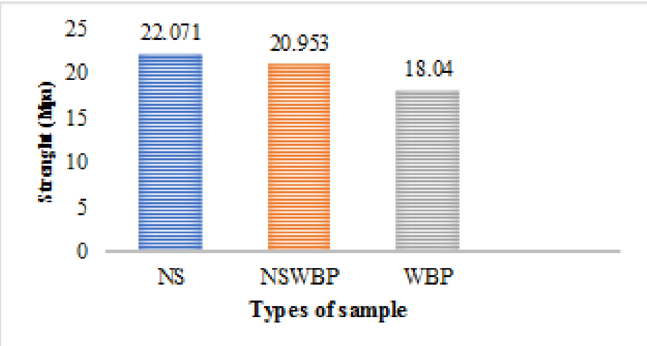

Fig-6.1 Variation in compressive strength at 28-day ambient curing for 0.48 s/b

After 7-day of open-air curing compression test showed the behavior that the rate of hardening is fast for 7 day which increases strength up to 18 MPa. But after 28 days of open-air curing, where the compression test showed behavior in their rate of hardening which is slowed after 7 day and compressive strength is up to 22 MPa.

Rate of percentage in compression for fully natural sand increased by 22.55 % of 18.01 MPa after 7day till 28 days while for NSWBP it was 18.11 % of 17.74 MPa after 7 days till 28 day and for WBP, 3.38 % of 17.45 MPa after 3day till 28-day where after 7day rate till 28 day was 1.92 % of 17.7 MPa.

6.2.1.1 Effect of Increased Solution

In Meantime 3 cube were casted with same quantity of material but increased s/b i.e., 0.55 and then compression was tested. Table 6.3 and Figure 6.2 represents result.

Table 6.3: Variation in compressive strength at 28-day ambient curing for 0.55 s/b

Sample	NSWBP (N/mm²)
1.	27.33
2.	27.11
3.	27.02
Average	27.15

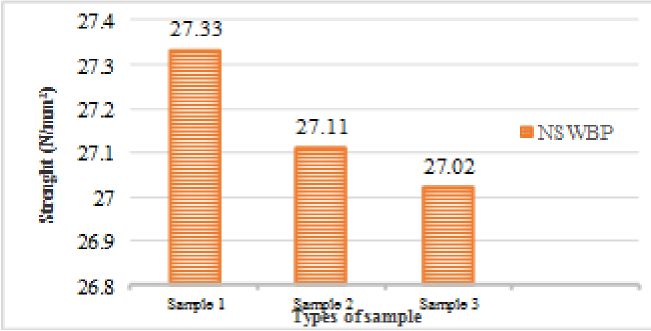

Fig-6.2 Variation in compressive strength for 0.55 s/b at 28-day ambient curing

After testing result has been compared with result of geopolymer concrete prepared by mixing natural sand 50 % and waste brick powder 50 % for 0.48 solution binder at 28 day and found that strength also at the rate of 22.83 % with the 14.28 % increase in solution binder ratio. According to Ding et al [6] with a rise in alkali content compression peak load in tests of specimen all increase.

6.2.2. Split Tensile Strength

18 cylinders were tested over the period of 7 and 28 day on automated CTM with a capacity of 2000 KN as such as 3 pair of cylinder NS, NSWBP, and WBP represents each set of 6 cylinder. Table 6.4 and 6.5, together with Figure 6.3 and 6.4, show the test results.

Table 6.4: 7-day Split tensile strength of ambient cured specimens for 0.48 s/b

Sample	NS (MPa)	NSWBP (MPa)	WBP (MPa)
1.	1.41	1.27	1.13
2.	1.41	1.23	1.25
3.	1.41	1.32	1.23
Average	1.41	1.27	1.20

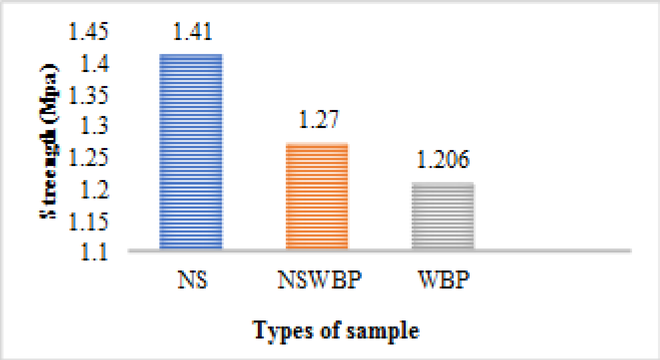

Fig-6.3 Variation in split tensile strength at 7-day ambient curing for 0.48 s/b

The split tensile strength of NS increases by 7.8 % and 14.28 % when compare with NSWBP and WBP at 7-day. With the increase of quantity of waste brick powder, the strength of GP concrete gets decreased.

Table 6.5: 28-day Split tensile strength of ambient cured specimens for 0.48 s/b

Sample	NS (MPa)	NSWBP (MPa)	WBP (MPa)
1.	1.6	1.54	1.37
2.	1.58	1.41	1.32
3.	1.61	1.51	1.34
Average	1.60	1.49	1.34

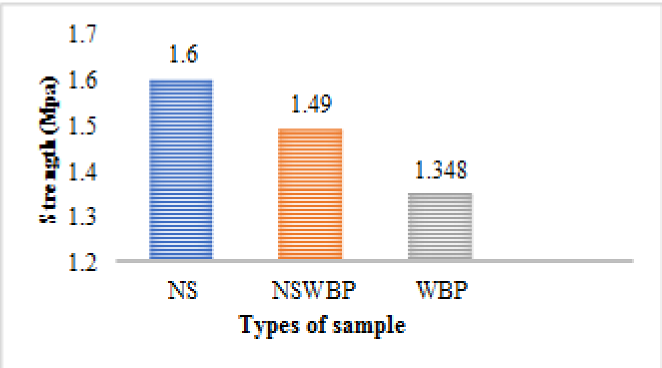

Fig-6.4 Variation in split tensile strength at 28-day ambient curing for 0.48 s/b

The split tensile strength of NS increases by 6.25 % and 18.75 % when compare with NSWBP and WBP at 28-day. With the increase of quantity of waste brick powder, the strength of GP concrete gets decreased. It is safe according to Chowdhury [2] where split tensile strength will achieve 8% to 12 % of compressive strength.

6.2.3. Flexural Strength

Over the period of 7 and 28 days, a total of 18 beams were evaluated on a digital UTM, with 3 pairs of beam NS, NSWBP, and WBP each having a set of 6 beams. The test findings are displayed in Table 6.6, 6.7 and Figure 6.5, 6.6.

Table 6.6: 7- day Flexural strength of ambient cured beam for 0.48 s/b

Sample	NS (kN)	NSWBP (kN)	WBP (kN)
1.	3.1	2.9	2.7
2.	3.2	3	2.5
3.	3.3	2.8	2.6
Average	3.2	2.9	2.6

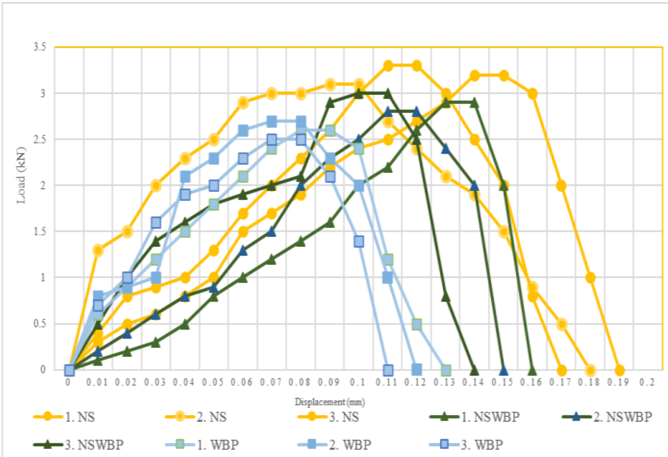

Fig-6.5 Variation in Flexural strength at 7-day ambient curing for 0.48 s/b

Table 6.7: 28- day Flexural strength of ambient cured beam for 0.48 s/b

Sample	NS (kN)	NSWBP (kN)	WBP (kN)
1.	4.4	3.9	3.8
2.	4.3	3.8	3.6
3.	4.5	4	3.7
Average	4.4	3.9	3.7

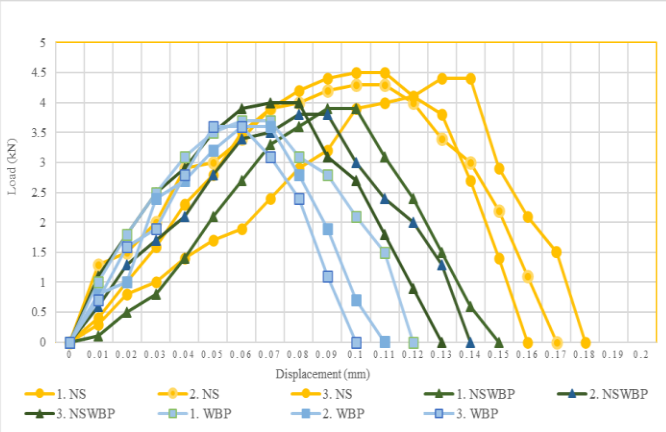

Fig-6.6 Variation in Flexural strength at 28-day ambient curing for 0.48 s/b

Based on the load displacement curve of NS which shows maximum load up to 4.4 kN, for NSWBP it was 3.9 kN and for fully replaced waste brick powder it was 3.7 kN.

Flexural strength at 7 day was 1.91 MPa for NS, 1.7 MPa for NSWBP and 1.56 MPa while at 28 day it was 2.64 MPa which is comparatively higher from Natural sand waste brick powder (2.34 MPa) and Waste brick powder (2.22 MPa).

Rate of strength in percent at 7-day for NS was 10.99 % when compared to NSWBP and 18 % when compared to WBP while at 28-day for NS was 15.9 % with respect to WBP and 11.36 % for NSWBP.

6.2.4 Carbonation

After curing of cubes, it was exposed to air for some duration and then cut into two pieces for applying of phenolphthalein solution over it then left for 1 hour ± 10 minutes. The pieces appeared to purple color after applying solution which indicating non-carbonated region as the colorless region indicates carbonated zone. Colorless region was measured with vernier caliper to check the depth of carbon. Table 6.8 and figure 6.7 represent the result of Carbonation depth. In following reaction (3), which is known as carbonation, calcium hydroxide and carbon dioxide combine to generate insoluble calcium carbonate ($CaCO_3$), which causes concrete to carbonate and result in a lower pH value. According to Pasupathy [12] the durability performance of the geopolymer containing 70% fly ash and 30% GGBFS was comparable to OPC concrete.

$$Ca(OH)_2 + CO_2 \; CaCO_3 + H_2O \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

Fig-6.7 Carbonation depth

Table 4.8: Carbonation depth

S.No.	Series	Sample	Carbonation depth (mm)	Average (mm)
1.	NS	1	10.9	10.86
		2	11.2	
		3	10.5	
2.	NSWBP	1	8.7	8.73
		2	8.5	
		3	9	
3.	WBP	1	7.3	7.06
		2	7.1	
		3	6.8	

Test reveals that with the increased amount of waste brick powder the carbonation depth starts decreasing as compared to NS and NSWBP. Report of Zhuguo [19] represented that the alkaline activator, which is made of sodium silicate and NaOH, has a higher carbonation resistance if more the NaOH content. GP concrete based on FA & BFS are also significantly influenced by curing temperature. Compared to heat curing and ambient curing, at room temperature curing offers less carbonation resistance.

The compressive strength of GP concrete influences as indirectly related to carbonation as higher the carbonation depth is typically associated with stronger concrete. However, other characteristics, such as the type of alkaline activator, may have an impact on the carbonation resistance of GP concrete.

7. CONCLUSION

Binder content with 70 % of fly ash and 30 % of slag for 375 kg/m^3 showed better result with solution binder ratio i.e., 0.48 where coarse to fine aggregate ratio settled at 65% to 35% so as to achieve maximum strength. Due to high water absorption and silt content of waste brick powder results came out less. Also curing condition can impact in geo-polymerization reaction as our study is done at open air curing. For complete geo-polymerization reactions, curing needs to be done at elevated temperatures for minimum solution.

In addition to above statements following are some points observed from the experimental program: -

1. Freshly mixed concrete prepared with 0 % WBP is far better and flowable when prepared with designated alkali solution but in the case of 50% to 100 % waste brick powder mix gets harsh until extra addition of water to get completely mix. Water addition up to 7 % in case of 100 % WBP while in case of NS water addition is up to 5 % which shows concrete is flowable and workable for casting.

2. Split tensile strength of GPC prepared with fully waste brick powder came out lower than those prepared with replacement of natural sand. As flexural strength of GP concrete prepared with 100% and 50 % of waste brick powder was lower while specimen prepared with 100 % natural sand has higher strength.

3. Effect of carbon depth has adverse reflection over compressive strength that larger the depth of carbonation higher the compressive strength. While traces of carbonation depth in GPC concrete for waste brick powder was lower but as on increasing natural sand it starts increasing.

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