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Flexural and Disc Bending Test of Geopolymer Concrete

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***Abstract*:- Geopolymer concrete is one of the more popular building materials in recent years due to the fact that it is significantly more environmentally friendly than standard concrete. Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with slag activator basically sodium silicate and sodium hydroxide. Geopolymer concrete using high influence of waste materials such as fly ash or slag from iron and metal production are used, which helps lead to a cleaner environment. This is because the waste material is actually encapsulated within the concrete and it also does not have to be disposed of as it is being used. Geopolymer concrete is does not require heat to make it and it does not produce carbon dioxide. Standard Portland cement based concrete requires both heat and carbon dioxide. Super plasticizer is a chemical added to Geopolymer concrete mix that makes the concrete more workable and it can be placed easily. The aim of this project is to study the various parameters such as compressive strength, flexural strength, split tensile strength, diametric strength and tensile strength by disc bending test. For experiment Geopolymer concrete G30 has to be prepared and characteristics strength such as tensile strength, compressive strength and flexural strength have to be achieved. In this project also effect of super plasticizer with various percentage such as 0.6% to 1.2% by weight of cement is to be considered.**

Keywords: Compressive strength, disc bending test, flexural strength, Geopolymer concrete (G30), Super plasticizer.

I. INTRODUCTION

In concrete technology indirect methods of testing are available to check tensile strength of concrete. There are two methods are available namely split cylinder test and flexural test to check tensile strength of concrete. In this paper disc bending test is to be used to check the tensile strength of Geopolymer concrete. Disc bending test on normal M40 concrete with admixture is to be done by me previously. In this work, fly ash-based geopolymer concrete is to be used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. Geopolymer concrete is an innovative eco-friendly construction material which is used as replacement of ordinary Portland cement concrete. In Geopolymer concrete cement is not to be used as binding material. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.

II. EXPERIMENTAL PROGRAM

Geopolymer Materials

Geopolymers are inorganic polymeric binding materials. Joseph Davidovits, coined the term “geopolymer” in 1978 to classify the newly discovered geosynthesis that produces inorganic polymeric materials. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Geopolymer material with sodium hydroxide and cured at elevated temperature will attributed more stable cross-linked alumino silicate polymer structure. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines.

Materials

The material used in present investigation were locally available in Bihta, Dist- Patna(Bihar) and physical properties were found through various laboratory tests conducted in Concrete technology lab, NSIT Bihta.

Fine aggregate

Ordinary sand available in Bihta, Patna (Falgu river sand) having the following characteristics has been used.
Specific gravity : 2.66
Fineness modulus : 2.41
Unit weight : 1.675 gm/cc
Water absorption : 0.43%
Bulking : 25%
Sand after sieve analysis confirm to zone – II as per IS 383-1970.

Coarse aggregate

Locally available black crushed stone (Pakur stone) in Bihta with maximum nominal size of 20 mm and 10 mm have been used as coarse aggregate. The physical properties for the coarse aggregate as found through laboratory test according to IS 2386-1963 is resulted as:
Aggregate crushing value = 24%
Aggregate impact value = 29%
Specific gravity = 2.64
Water absorption = 0.94%
Unit weight = 1.60gm/cc
Fineness Modulus = 6.15

Fly ash

Low calcium fly ash samples taken from National Thermal Power corporation Barh, Patna(Bihar) were used in this study. This fly ash was of average quality formed with the combustion of lignite and bituminous coal. The colour of the fly ash was light grey. The sample satisfied the requirements of IS 3812(Part I). The chemical property of the fly ash has been presumed based on the data made available from National Thermal Power Corporation, Barh (Bihar).

Chemical Solution

A combination of sodium hydroxide solution and sodium silicate solution was chosen as the alkaline liquid. Potassium-based solutions were not chosen because they were costlier than Sodium-based solutions. Both were commercially available in market.The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids for 97% purity was measured as 260 grams per kg of NaOH solution of 8M concentration. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10M: 314 grams, 12M: 361 grams, 14M: 404 grams, and 16M: 444 grams. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water is the major component. Further through literature review it was strongly recommended that the sodium hydroxide solution must be prepared 24 hours prior to use as it terminates to semi solid liquid state after 36 hours. The same recommendation was adopted in the present work. Sodium silicate Sodium Silicate was available in semisolid form. The sodium silicate solution (Na2O= 14.7%, SiO2=29.4%, and water=55.9% by mass) was purchased from a local supplier in bulk.

Water

Distilled water was used throughout the test procedure to achieve exact molarity.

Mix design of Geopolymer Concrete

As in the case of Portland cement concrete, the coarse aggregates and fine aggregates occupy about 75%-80% mass of Geopolymer concrete. Assuming the aggregates to be in surface saturated dry condition and the unit weight of concrete is 2400 Kg/m3 . Combined aggregates are assumed to consist of 70% coarse aggregate and 30% fine aggregate. The mix proportion for 14 M geopolymer concrete is calculated and the value of different ingradients for one cubic meter concrete by mass is given as:

Fly Ash (Kg)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	NaOH Mass (Kg)	Na2SiO3 (Kg)	Water (Kg)
428	1277	548	17.2	47	85
1	2.99	1.28	0.04	0.11	0.199

3.3 Mixing and casting procedure

The specimen should prepared according to IS 516-1959. The coarse aggregates, fine aggregates and cement were weighed and placed on the mixing floor, moistened in advance and mixed homogeneously. Mixing of all the material were done manually in the laboratory at room temperature. After mixing these ingradient, mix the alkaline solution of sodium hydroxide and sodium silicate and placed on the dry mix. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in colour. Fresh Geopolymer concrete was cast in steel mould and each cube specimen was cast in three layers by compacting manually as well as by using vibration table. Each layer of Geopolymer concrete received 35 strokes of compaction by standard compaction rod, followed by further compaction on the vibration table. The cube specimens of size 150×150×150 mm size were used for compressive strength determination after demoulding at one day, the specimen were cured at 80^{0}C.

3.4 Methodology

The methodology for present work consist of the following points

- Fly ash is to be used as source material to develop Geopolymer concrete.
- Alkaline activator like sodium hydroxide and sodium silicate is to be used to develop the process of making Geopolymer concrete.
- Curing regimens is to be set up for Geopolymer concrete to study the effect on rest period before heat curing.
- Fresh and harden properties of fly ash based Geopolymer concrete is to be observed , mainly its workability compressive strength and tensile strength.
- Effect of superplasticizer on Geopolymer concrete is to be studied.
- Disc bending test is to be used to find the tensile strength of Geopolymer concrete.

IV. TESTING METODOLOGY

Three cubes each was tested for different strength at 7 days and 28 days of curing using testing machines.

4.1 Compressive strength test:- For this it is proposed that 6 (six) cubes of the size 150mm×150mm×150mm have to be cast for each set (i.e. for nominal concrete and with variation of different % of admixtures(0.6% to 1.2%) or super plasticizers),which will be tested after 7 days and 28 days curing separately.

4.2 Determination of tensile strength: - two methods are available for determination of tensile strength (a) direct pull test. (b)Indirect test.

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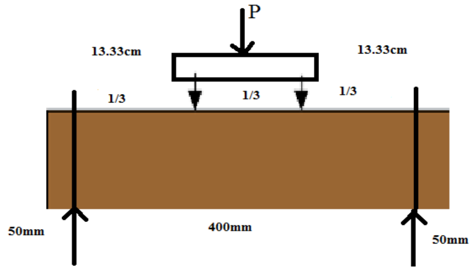
4.2.2 Direct pull test: - The direct pull test is difficult to conduct free of eccentricity and is further complicated by secondary stresses induced by the gripping devices (Davies and boss-1968 and Neville-1977)

4.2.3 Indirect test: - these difficulties gave rise to the use of indirect tensile tests. Two methods are widely used for indirect test namely (I) Modulus of rupture test (ii) Splitting test.

4.3 Modulus of rupture test (ASTMC-78):- In the modulus of rupture test, concrete beams of size of 500mm×100mm×100mm, are subjected to centre point loading or symmetrically two point loading with clear span of 400mm.the tensile stress in the bottom face of the beam at failure (none as modulus of rupture), is calculated by assuming that the stresses across the section is proportional to the distance from the modulus of rupture test is higher than that determined from the direct from the direct tensile test made on concrete from the same batch. The explanation for this was given by (Neville-1977)



The modulus of rupture is determined by the formula,

$f_r = \frac{6M}{bd^2} = \frac{6PL}{bd^2}$

Where, p=applied load.
L=length (clear span of beam).
d=depth of beam. b=width of beam.

4.4 Splitting test (ASTMC-496)-(IS-5816-99):-Another indirect tensile test method i.e. the splitting test method was proposed by (carneiro and barecllos-1953) in Brazil and developed independently by Akazawa (1953) in Japan.

In this test commonly called Brazilian test. A concrete cylinder specimen of size 30 cm in length and15 cm in dia. is led horizontally between the loading platens of the testing machine and is compressed along a vertical diameter as shown in fig. (2), strips of comparatively soft packing material are placed between the specimen and plates of the machine load are applied until the specimen splits along the vertical diameter.

The Brazilians test namely gives consistent results that lie between those based on other two methods (wrigh-1955). In this method the split tensile strength,

$\sigma_t = \frac{2P}{\pi LD}$

Where, p=applied load.
L= length of cylinder.
D=Dia. of cylinder.

4.5 Disc bending test: - The direct tensile strength is quite difficult to measure with direct axial tension loads because of the problems in gripping test specimen so as to avoid stress concentrations and because of difficulty in aligning the loads. As results of these problems two indirect tests are available to measure concrete tensile strength namely flexural test and split cylinder test.

Some practical difficulties like gripping of specimens, Application of loads, Handling of specimens during the tests, stress concentration of tensile strength of concrete can be minimized up to a great extent utilizing the principle of disc bending test given by (seely and smith-1952) as expressed below.

$$\sigma_t = \frac{3(1+\mu)P}{2\pi t^2}\left[\frac{1}{1+\mu} + \log_e \frac{r_o}{r_d} - \frac{1-\mu}{1+\mu}\frac{r_o^2}{4r_d^2}\right]$$

Where,
σ_t = maximum tensile stress
μ = Poisson's ratio of the material
P = applied load
t = thickness of the disc
r_d = radius of the disc.
r_o = radius of the area under uniform force.
The relationship is valid under the following conditions.

(1) The deflection of plate is relatively small(less than t/2).
(2) The material is ideally elastic
(3) The plates remain flat.

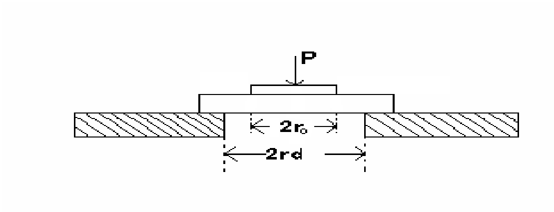


Figure-2 Bending of Disc

4.6 Experimental investigation

The experimental set-up employed for testing the concrete disc comprises of the following components:

1) Mild steel hollow cylinder with required arrangement to provide free circumferential support to concrete disc specimen.
2) Circular splittable mould of mild steel for making of concrete disc specimen.
3) Motorized load frame- strain controlled.
4) Dial gauges and device to hold them.

4.6.1 Mild steel hollow cylinder

To provide free circumferential support to the concrete disc specimen a mild steel hollow cylinder with appropriate edge bearing was fabricated. The clear span i.e., $2r_d$ is kept at 152.4 mm whereas the dimension 177.8mm with circumferential edge bearing of 12.7mm has was provided as the inner diameter of cylinder to accommodate the concrete disc of 177.8mm diameter in order to meet the requirement of free support condition.

4.7 Circular split table mild steel mould

In case of diametral compression test the specimen of 6” diameter and 12”length is used. Keeping this in view concrete disc of 178mm (7”) diameter of various thickness ranging from 25.4mm (1”) to 50.8mm (2”) are proposed for bending test. In order to prepare the sample of the diameter split table mould as shown in plate 3.1 was made. The split table mould was used to get the sample with least disturbances. The mould was fabricated using mild steel plate which consists clamp with nuts and bolts to tie the two halves of the mould firmly.

4.8 Motorized load frame:-

Strain controlled motorized load frame manufactured by AIMIL (as available in lab) is shown in the plate 3.2 and is used to apply the load with a choice of ten constant rate of strain ranging from a maximum of 1.25 mm/minute.

4.8.1 Operation

Specimen to be tested for bending is placed on the bottom of loading plate in the cylindrical mild steel mould. A proving ring of desired capacity is fixed to the adopter for measuring the load. Loading platen is raised or lowering by operating the hand wheel with the strain rate lever kept at neutral. The proving ring devise to measure the load is brought in to the contact with test specimen with the help of a circular steel ball kept on a circular mild steel plate on the specimen. Being ensure that the proving ring is in contact with the test specimen, loading system is operated by switching on the main supply.

4.8.2 Dial gauges and devices

In order to measure the central deflection of the disc, the arrangement was made to fixed up the dial gauges through clamp to the loading frame and to rest the needle of the dial gauges on mild steel strips attached to the circular mild steel plate which is placed at the centre of the specimen to provide the uniformly distributed load as shown in plate 3.3, the least count of the dial gauge was 0.01 mm.

4.9 Mild steel rectangular, cylindrical and cubical split table mould for beam bending split cylinder and cube test

For beam bending test, mild steel rectangular splittable mould of internal dimension 500mm × 100mm × 100mm, for split cylinder test mild steel splittable mould of internal diameter 150mm and length 300mm and to know the characteristic compressive strength of concrete cube, mould of internal dimension 150mm × 150mm × 150mm were used for casting the specimens.

4.9.1 Universal compression testing machine

For split cylinder and cube test the standard universal testing machine of capacity 1500 KN and constant rate strain loading was used.

4.9.2 Loading frame for flexure test

A standard well established loading frame system consisting of jack for loading and proving ring attached to the jack was used for beam bending test.

4.9.3 Sample preparations and curing of sample

In order to prepare the concrete specimens for test, cement, sand and stone chips were taken by weight in proportion of 1:1.28:2.99.

For preparation of concrete samples for disc bending test, disc of 152.4 mm diameter and 38mm thickness, were prepared with constituent of cement, sand and stone chips were taken by weight in proportion of 1:1.28:2.99. Twelve numbers of samples were prepared in split table mould for each test such as disc bending and diametral test at water

cement ratio 0.33 and with compacting effort of 25 nos. of temping by temping rod of 1” diameter. The samples were also prepared of varying thickness 30mm and 25mm at varying % of admixture (0.6 to 1.2 %) keeping water cement ratio constant for the same test disc bending and diametral test.

In flexural test, beams of 500mm × 100mm × 100mm in 6 numbers for split tensile test of 6 cylinders of 150mm diameter and 300mm length and compressive strength 6 cube of 150mm × 150mm × 150mm size were also prepared from the same batch of mix for the sake of comparison of tensile strength of disc bending test with flexural strength and diametral compression strength and cube strength wherever required. The same process was adopted for different % of admixture.

The specimens of concrete discs, beams, cylinders and cubes after preparation were kept for 7 days and 28 days under water in tank before testing.

4.9.4 Testing Procedure:-

To study the effect of tensile strength in bending, the test set-up as shown in fig. was eused for testing the compacted concrete disc specimens. Before application of load the center of specimen was marked and it the mild steel hollow cylinder in such a way that the free support condition exists.

4.10 Mode of Failure:-

By Visualization of the concrete sample tested in disc bending method, it is found that the samples had failure with the development of cracks at the bottom face of the sample near the centre. The photographic views of some specimen failed are shown in plate. The mode of failure is because of tension.

Most of the failures have taken place due to normal bending of disc which usually occurs inside the ring with the development of radial cracks.

The failure pattern of the concrete disc in the present study is similar to a great extent as earlier reported by jaeger (1967) in case of rocks.

V. RESULTS AND DISCUSSION

The experimental results are presented and discussed in appendix. Each of the strength test data plotted in Table no 1-3, corresponds to the mean value of the strengths.

VI. CONCLUSIONS

In the present study, application of theoretical approach namely Grashof's theory of bending of the plate has been considered. It is based on the similar application as used by Protodyakonov (1961) and Sharma (1997) as an indirect method for obtaining tensile strength of rocks and soil. This method gives the best possible representation of tensile behavior of materials and very useful also in determining their anisotropic strength. In spite of the fact that bending tests usually gives higher values than the direct tensile test, this method may still be useful to determine the tensile strength of concrete an should be termed as the modulus of rupture or flexural strength of concrete. The analysis of results indicate that the sensitivity of experiments depends entirely on certain elemental variation and hence tensile behavior of concrete for any concrete structure covers a broad and extensive field of study because the factors involved are numerous and to a large extent unpredictable analysis even on the most simplified basis under such circumstances. Therefore, it is not possible to make generalized conclusions.

The work presented in this thesis is therefore concluded as follows:-

I. The Geopolymer concrete, which is prepared in proportion of 1:1.28:2.99 by weight having fairly good tensile strength.

II. The tensile strength of the Geopolymer concrete increases with an increase in % of admixture up to in the range of 0% to 1.0% and at 1.2% of admixture its value decreases. It is valid for all the cases like compressive strength and the diametral stress and fracture strength too. The tensile strength obtained from bending test (disc bending and beam bending) is higher than the compression test (disc diameteral compression test, split cylinder test and cube test).

III. The tensile strength obtained from disc bending test is higher than the beam bending test.

IV. The tensile strength obtained from disc diameteral compression test is higher than the split cylinder compression test and cube compression test.

V. The value of tensile strength obtained from cube test is lower than the Flexural Strength, Diametral Stress and tensile strength from Disc bending test but it is slightly greater than the tensile strength from split cylindrical test.

VI. It is observed from the test data that % of admixture increase upto 1.0 %. The value of all types of strength of concrete is going to be increased. At the same time flow ability of concrete increases even at 1.2% of addition of admixture.

FURTHER SCOPE OF STUDIES:-

As discussed earlier, there are several factors which affect the tensile behavior of the concrete and it is not possible to include all of them in analysis even on the most simplified basis. However, an effort has been made in the present study to include, major factors and their influence on the tensile behavior of the concrete.

For further work, the effect of the following factors on tensile strength by disc bending method may be studied:

1. Effect of the other methods of compaction.
2. Effect of creep.
3. Effect of stress concentration at surface cracks and flaws.
4. Effect of frictional forces between loading surface and specimen surface.
5. Effect of % of admixtures by considering the various thickness of the disc plate.
6. Effect of the size of aggregates on characteristic strength of G-40 Grades of geopolymer concrete with various % of Admixture can be studies.
7. Studies of characteristic strength of G-40 Grade of geoplymer concrete with different % of Admixture with different types of cement.

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APPENDIX

Table no: 1 Comparative results of % increments' of all data with 0% Admixture for 28 days

Sr.No	% of Admixture	% increments' in compressive strength	% increments' in Split tensile	% increments' in Flexural strength	% increments' in Diametral stress	% increments' in Disc Bending
01	0	------	------	------	-----	-----
02	0.6	3.88	3.43	1.94	1.53	3.32
03	0.8	8.53	7.47	6.79	6.32	7.75
04	1.0	12.49	11.11	12.03	7.85	12.36
05	1.2	5.42	0.80	0.00	3.256 (Decreases)	0.92

Table no: 2 Comparative Results of Deflection in flexural test and disc bending test of different % of admixture at 28 days.

Sr. No.	% of Admixture	In Flexural		In Disc Bending	
		Load in N	Deflection in mm	Load in N	Deflection in mm
01	0%	1.13	0.85	6500	0.69
02	0.6%	1.17	0.75	7250	0.64
03	0.8%	1.38	0.68	8000	0.58
04	1.0%	1.42	0.61	8750	0.50
05	1.2%	1.185	0.92	8133.33	0.77

Table 3. COMPARATIVE RESULTS OF OBSERVATION DATA FOR 28 DAYS

Sr. No	Compressive Strength N/mm2	Split Tensile Strength N/mm2	Flexural Strength N/mm2	Diametral Stress N/mm2	Fracture Strength Fr. $0.7\times\sqrt{fck}$	Disc Bending Test(Tensile Strength) N/mm2
M0	43	4.95	5.15	5.22	4.58	5.42
M1	44.67	5.12	5.25	5.30	4.67	5.60
M2	46.67	5.32	5.50	5.55	4.78	5.84
M3	48.33	5.50	5.77	5.65	4.86	6.09
M4	45.33	4.99	5.15	5.05	4.71	5.5