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An Experimental Study on Alccofine-based Geopolymer Concrete Deep Beams

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Geopolymer concrete; Strut-and-tie model; Deep beam failure; Reinforcement ratios; Alccofine replacement; Shear span to depth ratio; Static Loading.

Abstract

An experimental investigation is carried out to examine the behaviour of alccofine based geopolymer concrete (GPC) deep beams compared with conventional concrete (CC) deep beams with varying reinforcement ratios (0.4% & 0.9%) under static loading conditions. The combination of low calcium fly ash-based GPC with the optimum amount of alccofine was utilized. Various criteria are taken into accounts, such as load-bearing capacity, deflection, energy absorption, and modes of failure were determined and the results were discussed in detail for twelve numbers of deep beams. From the test findings, it is revealed that GPC deep beams have enhanced performance than CC.

Disciplinary: Civil Engineering & Construction Technology (Construction Materials, Structural Engineering).

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1 Introduction

The threat that greenhouse gases represent to the environment is a major source of worry for scientists today. Cement manufacture emits roughly 7% of CO2 into the environment, forcing researchers to create an alternative construction material to cement concrete based on industrial waste. Geopolymer is a word coined by French scientist Davidovits to describe an inorganic polymer formed through geopolymerization (Davidovits, 1994; Gartner, 2004; Radlinski, M; Harris, N, J; and Moncarz, 2011). The concrete building sector has been put under further pressure as a result of these findings. Furthermore, the disposal of industrial wastes necessitates enormous amounts of usable land, which has a significant influence on the environment and land use (Sivagamasundari & Kumaran, 2008). Researchers have recently focused on the creation of replacement binder materials to overcome these problems. The alkali activation of silica and alumina-rich compounds, known as geopolymer concrete (GPC) or Earth-friendly concrete, is one such material that has risen to prominence (Parveen et al., 2018).

As the need for high-rise buildings with high-performance constructions has grown, deep beams in megastructures have recently been utilized (Swaminathan & Kumaran, 2020). Many researchers have presented their experimental/analytical work to examine structural behaviors and propose design approaches for deep beams since classical flexural beam theory cannot be used to comprehend the structural behaviors of deep beams (Kim et al., 2011). Deep beam structural behavior and strength are affected by vertical and horizontal web reinforcement, as well as the shear span-to-depth ratio. According to their findings, vertical web reinforcement increases ultimate shear strength, but horizontal web reinforcement has little or no effect on ultimate shear strength (Lafta & Ye, 2016). The ACI 318-02 and Euro codes-2 (Part-1) give guidelines for designing deep beams that take shear behavior into account. Initial flexural cracking, initial diagonal cracking, initial longitudinal reinforcement yield, and failure of RC deep beams were investigated by using the ACI building code (Pranata et al., 2020). In strut-and-tie mechanism, web reinforcement has been shown to improve deep beam behavior, the researcher's findings suggest that the optimal quantity of web reinforcement for efficient deep beam behavior must be chosen (Kong & Sharp, 1977; Kong, 1990; Menon, 2002; Saravanan & Kumaran, 2010; Zhang & Tan, 2007). The quantity of web reinforced may be estimated by taking into account concrete strength, span-depth ratio, and tensile main reinforcement ratio(Swaminathan & Kumaran, 2020). Deep beams are currently being employed extensively in high-rise buildings with massive constructions.

Hence the present work has been proposed to study the behaviour of conventional concrete (CC) deep beams compared with geopolymer concrete (GPC) deep beams with different steel ratios at the tension zone. The beam design was carried out as per IS:456-2000 codal provisions. There were no such studies carried out in deep beam with alccofine mixed geopolymer concrete. Therefore there is a need for a study to eliminate OPC concrete to predict the environment from CO_2 emission by using GPC in deep beams in high-rise buildings. Increment of steel ratio 0.4%, and 0.9%, was maintained in both CC and GPC.

2 Experimental Program

2.1 Material Properties

2.1.1 Constitutions of Geopolymer Concrete

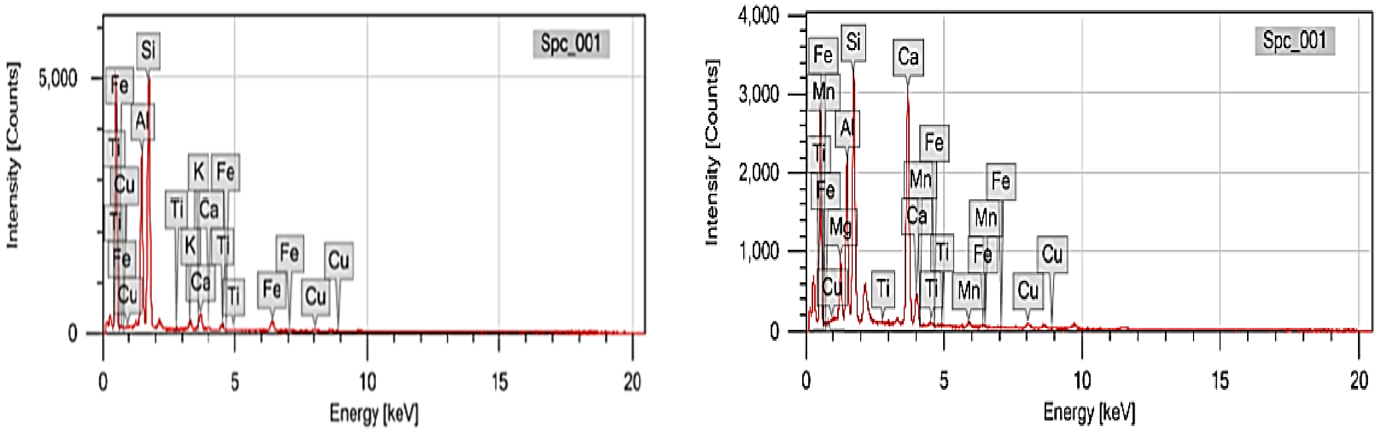
The chemical and physical characteristics of fly ash (FA) and Alccofine (AF) was determined in Table 1 and 2. Low calcium Class F fly ash from the Mettur power plant in Tamilnadu, India was employed as an aluminosilicate source, with a specific gravity of 2.10 and 96% passing through a 45-micron sieve, as per (BIS: 3812 (Part-1), 2003). Alccofine is a low calcium silicate microfine material made from blast furnace slag that has high reactivity and is obtained from Ambuja Cement Ltd, Goa. Alccofine added GPC increases its workability and reduces the porosity. Because of its high calcium oxide concentration, alccofine speeds up the polymerization process, improving the mechanical strength of GPC.

Table 1: Chemical composition of fly ash and Alccofine

Chemical Compound	Mass Percentage	
	Fly ash	Alccofine
SiO_2	52.96	27.53
Al_2O_3	26.23	16.26
Fe_2O_3	11.02	0.59
SO_3	1.28	0.13
CaO	1.02	43.92
MgO	0.38	5.82
TiO_2	2.54	0.81
Na_2O	0.51	-
K_2O	2.82	-
LOI	0.52	-

Table 2: Physical properties

Description	fly ash	Alccofine
Specific gravity	2.1	2.72
Bulk Density [kg/m^3]	820	680
Specific surface area m^2/kg	321.68	1200



(a) (b)

Figure 1: EDS for a) fly ash b) Alccofine 1203.

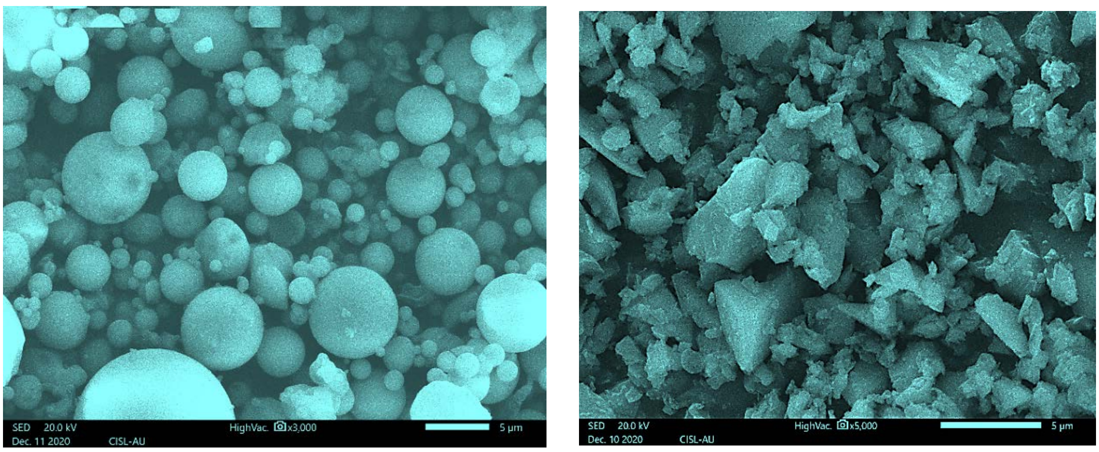

(a) (b)

Figure 2. SEM Image a) Fly ash b) Alccofine.

EDS and SEM analysis of fly ash and alccofine is shown in Figures 1&2. Fly ash has a distinct sharp peak and particles are spherical in shape. The crystalline phases in the fly ash sample are mostly Alumina silica, which has a high peak. Amorphous silica and alumina are also found in the amorphous phase of fly ash. Because of no crystalline phase and the ultrafine particle size is small, the alccofine possesses a high degree of reactivity (Jindal et al., 2017). As an activator in the preparation of geopolymer sodium hydroxide pellets with 98 percent, purity and sodium silicate solution with SiO_2/Na_2O ranges between 2 adopted in the local market and of 1.39 g/cm^3 was used in this research, the most commonly used alkaline solution comprising a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) is used.

2.1.2 Preparation of GPC Specimens

Alkali solution 10 Molarity (10M) was made and it was kept at room temperature for 24 hours. To get the best ratio, $Na_2SiO_3/NaOH = 2.5$ was used (Pawar, M S; Saoji, 2013). To lower the amount of water required and increase the workability of the fresh geopolymer mix, a Naphthalene sulphonate-based high range water reducer was added to the alkaline solution at a rate of 2% by weight of total binder content before combining with dry materials. The GPC was mixed according to the requirements (BIS: 516, 1979). The liquid component, i.e., premixed alkaline activator solution, a dosage of superplasticizer, and additional water, was progressively added to the pan mixture for about 4 to 5 minutes after the concrete mixture was formed in a rotating pan mixer. Table 4 shows the mixing proportions of geopolymer specimens with various fly ash and alccofine concentrations. Six GPC deep beams were made with varying percentages of Fly ash and Alccofine. Each of the three specimens has distinctive molarity, for 10M GPC concrete 319.06 kg/m^3 fly ash and 35.45 kg/m^3 alccofine with water/geopolymer solid ratio 0.43 was finalized by cube compression test. The average of each three cube results was taken to finalize the deep beam casting shown in Table 4. The mass of geopolymer solids includes the mass of fly ash, alkaline solution (Water $+NaOH+Na_2SiO_3$), and any excess free water. These solids are referred to as geopolymer solids because they aid in the process of polymerization (Jindal et al., 2018).

2.1.3 Concrete

The deep beam specimens are made of M30 grade concrete shown in Table 3. The CC is prepared using Ultratech OPC 53 grade was compared with alccofine added fly ash-based geopolymer concrete.

Table 3:CC M30-Normal grade concrete

Material/m^3	M30 grade of concrete	Ratio
Cement	340 kg	1:1.92:3.85
Alccofine	-	
Fine aggregate	654.29 kg	
Coarse aggregate	1308.58 kg	
Water/cement ratio	0.43	
Superplasticizer	1.7kg	
Average compressive strength of concrete cubes	42 MPa	

The Various percentage of fly ash and alccofine 10M, and 12M were tried in this experiment. From that different percentage of fine aggregate and alccofine in various molarities, 10M of 90% FA

& 10% AF satisfies the M30 target strength in CC. Therefore in this research work, the optimum Molarities 10M was taken and narrated in Table 4.

Table 4: Constituents of GPCwith Alccofine.

Mix	Fine Agg. Kg/m^3	Coarse Agg. Kg/m^3	Fly ash Kg/m^3	Alccofine Kg/m^3	Molarity NaOH	Alkaline solution Kg/m^3	NaOH Kg/m^3	Na_2SiO_3 Kg/m^3	Extra Water Kg/m^3	SP Kg/m^3	AVG Comp. Strength (MPa)
GPC10M	654.29	1308.58	319.06	35.45	10	132.18	18.23	113.95	27	3.55	43

Locally available coarse aggregates of a maximum 20mm size and river sand as fine aggregates were utilized to make both GPC and CC. The concrete mix proportions are calculated according to Indian standards (BIS: 10262, 2019), and the average compressive strengths are determined by laboratory tests.

2.1.4 Tensile strength and Density of Reinforcement

The tensile strength of conventional steel reinforcement is tested using a universal testing machine and the typical tension test as per (BIS: 1786, 1985). An automated Universal Testing Machine with a capacity of 500 kN and a computer is used to determine elongation, stress, and strains during the tensile test properties are mentioned in Table 5. The specimens are loaded at a rate of roughly 250 MPa/min. The test is repeated until the specimen breaks down, not only at the anchorages. The test results for specimens in which free-length Failure is valid for measuring tensile strength.

Table 5: Tensile properties of steel reinforcements

Properties	Steel Fe 550 rod (Fe)
Tensile strength (MPa)	583
Longitudinal Elastic modulus (GPa)	210
Strain	0.002
Poisson’s ratio	0.3

The steel reinforcement density was determined using the volumetric displacement technique. The density of Fe 550 steel used in this research was 7520.6 kg/m^3.

3 Experimental Test Setup for Deep Beams

3.1 Test Specimens

All test specimens are developed and cast using M30 grade concrete compared to GPC of the same strength with minimum and maximum percentage of steel ratios at the bottom longitudinal reinforcement as per Indian standards (BIS: 456, 2000). A total of twelve deep beams with a span of 1000 mm are used in this experiment. Each of the three beams has the same numbers of tensile reinforcement was placed and tested.

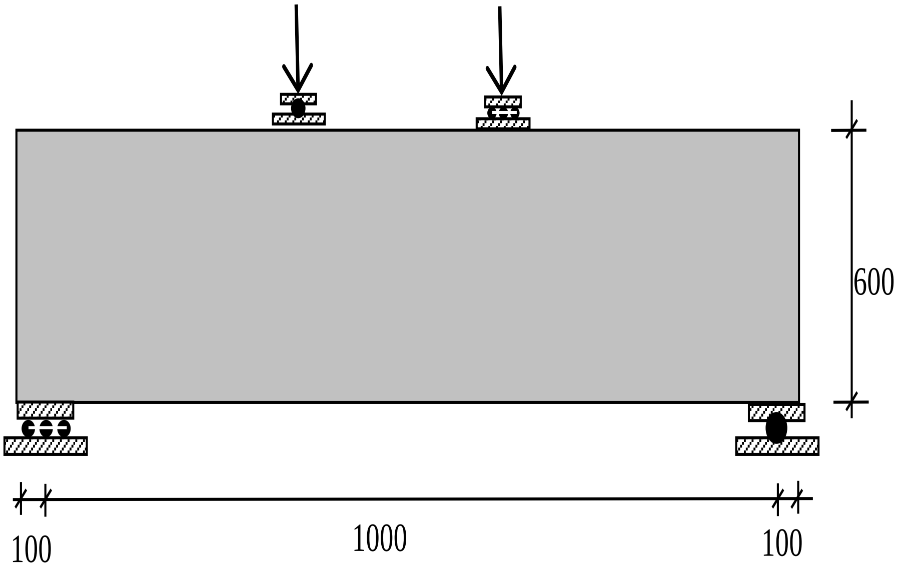


Figure 3: Schematic diagram of test specimens

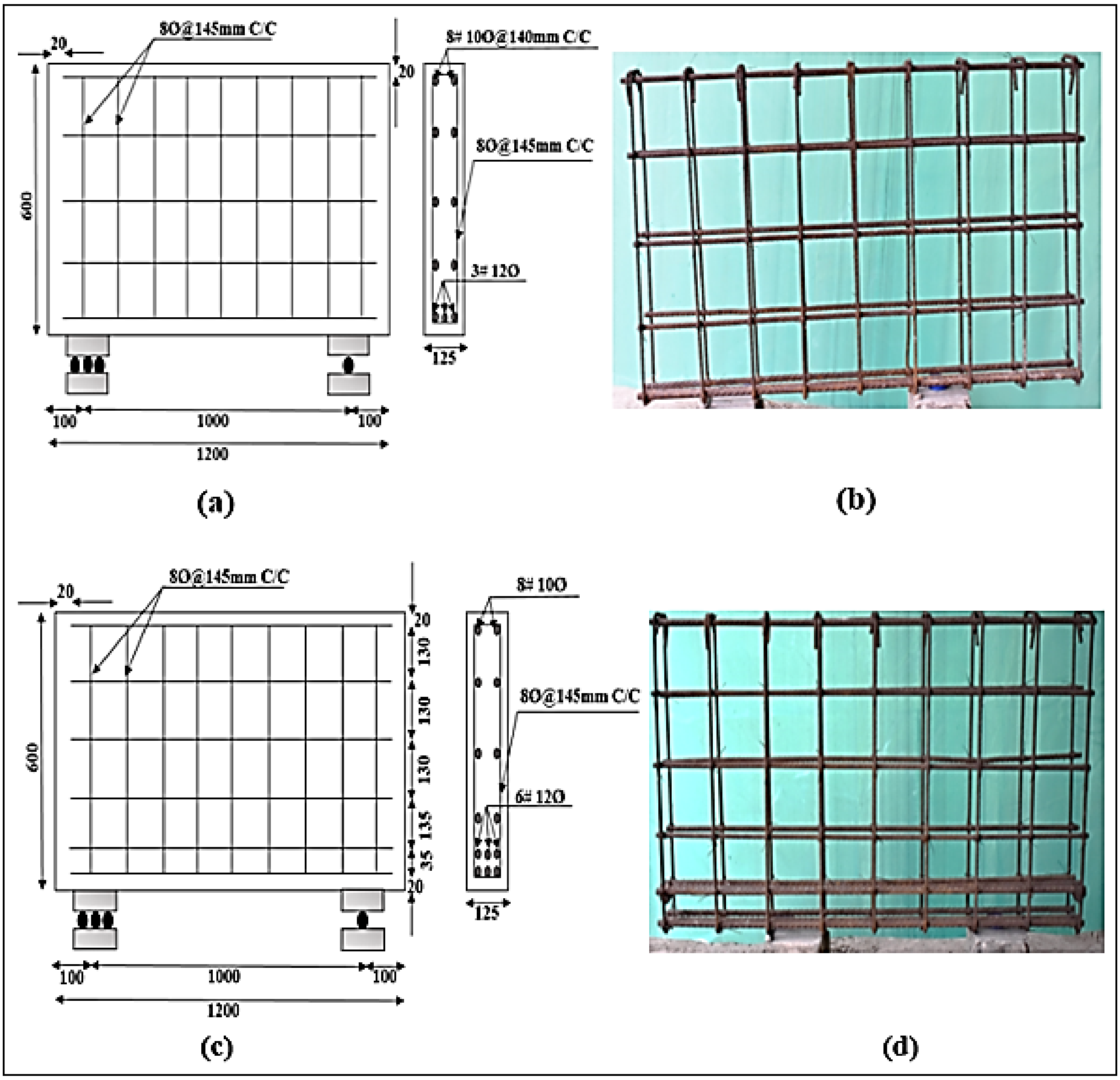


Figure 4: Reinforcement details (a & c) Line diagram of 0.4% and 0.9% of reinforcement ratio (b & d) skeleton of reinforcement before casting

Table 6 lists the various parameters investigated in this study, along with their appropriate designations. For the static load test, all twelve deep beams are employed. Figure 3 shows a schematic representation of the test specimen.

Table6: Different parameters considered in deep beams

S.No.	Beam Designation	Details
1	CDB1a	Conventional Deep Beam M30 Reinforcement 0.4%
2	CDB1b	Conventional Deep Beam M30 Reinforcement 0.9%
3	GDBM10a	Geopolymer Deep Beam 10 Molarity Reinforcement 0.4%
4	GDBM10b	Geopolymer Deep Beam 10 Molarity Reinforcement 0.9%

- **Comparison 1**: Molarity10 and M30 grade concrete with longitudinal minimum bottom reinforcement of three numbers of 12mm dia bars($\rho = 0.4\%$) (where ρ is steel ratio);
- **Comparison 2**: Molarity10 and M30 grade concrete with longitudinal maximum bottom reinforcement of six numbers of 12mm dia bars ($\rho = 0.9\%$).

3.2 The Experimental Test Setup

This study follows the test setup in Figure 5.

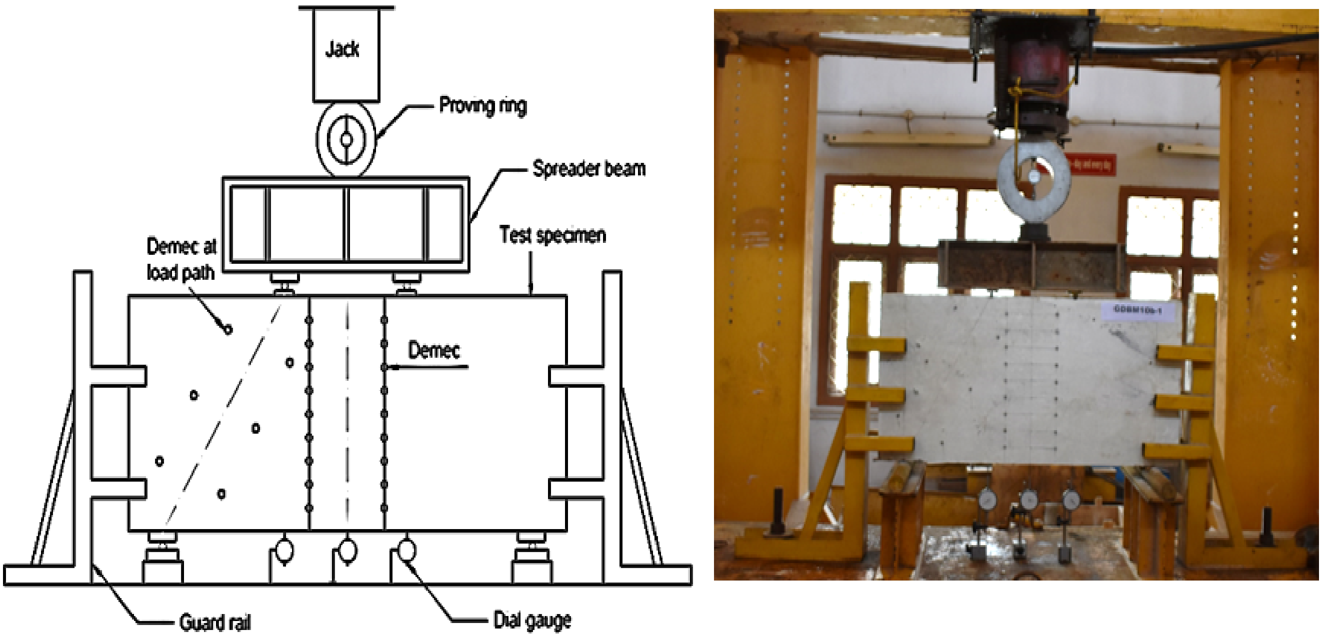


Figure 5: a) Schematic diagram and b) Experimental test setup

3.3 Experimental Observations

The load testing frame is used to test all of the specimens, and the results are recorded. Photographs are used to display the results of the tests. Figures 6 and 7 show the failure and cracks of the tested beams.

(a) (b)

Figure 6: Failure of a) CC and b) GPC deep beams with 0.4%bottom reinforcement (CDB1a and GDBM10a)

(a) (b)

Figure 7: Failure of a) CC and b) GPC deep beams with 0.9% bottom reinforcement (CDB1b and GDBM10b)

4 Result and Discussion

All twelve beams were tested. Each CC and GPC with minimum and maximum steel ratios were compared and an average of each of the three beams results was narrated in Table 7.

Table 7: Experimental test results

S. No	Designation of beams	Initial crack load (kN)	Ultimate Load, Vu (kN)	Ultimate Deflection, Δu (mm)	Absorbed energy (kN mm)	Failure mode
1	CDB1a	180	360	4.01	721.8	Shear
2	GDBM10a	180	380	3.42	649.8	Combined flexural and shear
3	CDB1b	260	430	3.52	756.8	Flexural
4	GDBM10b	190	450	2.89	650.3	Shear

4.1 Response to Load vs Deflection

The yielding of reinforcement in conventional beams causes a bigger rise in deflection with minimal change in load. In terms of geopolymer concrete, deflection has occurred when there was a greater applied load. It was due to alkaline activator solution combined with silica Alumina (fly ash) along with CaO (Alccofine 1203) gives the concrete as a dense packing leads to a higher strength than that of conventional concrete.

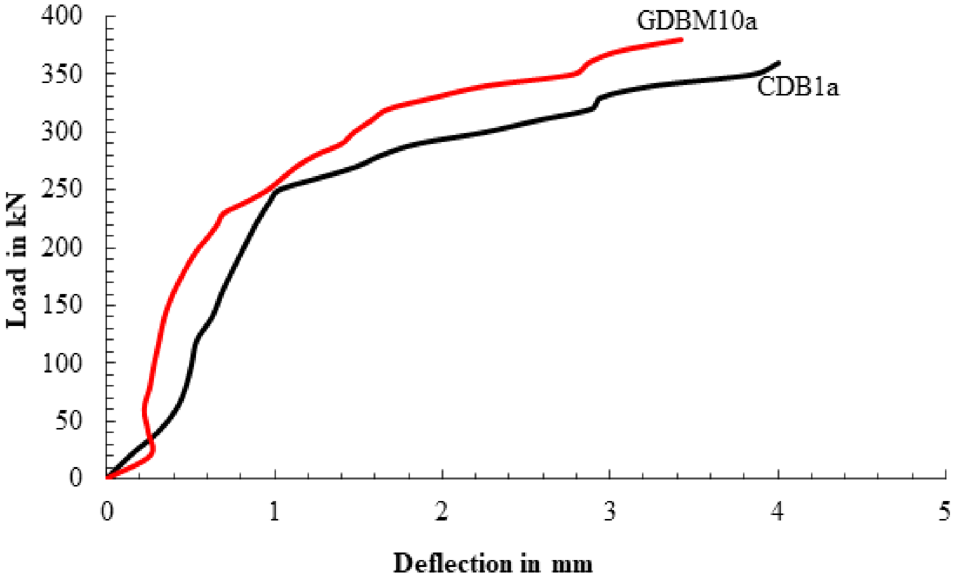


Figure 8: Load-deflection curves for the specimens CDB1a, & GDBM10a

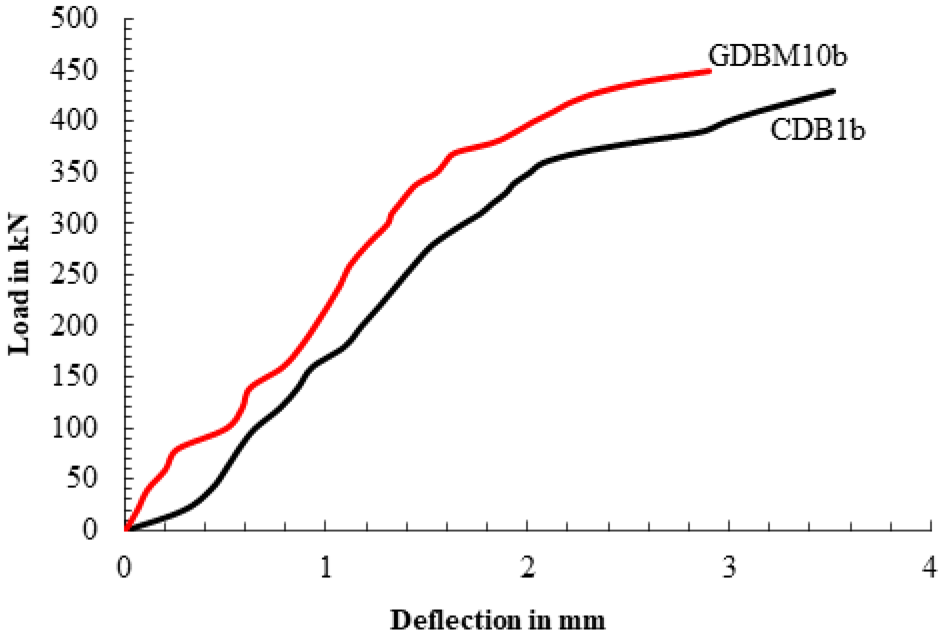


Figure 9: Load-deflection curves for the specimens CDB1b, & GDBM10b

The binder to the aggregate matrix was well defined in the geopolymer concrete. In general, during the time of testing, the maximum load was taken by concrete first after concrete fails the load directly transfers to reinforcement to restrain the beam from failure to take the higher load. The bottom reinforcement was placed as a minimum and maximum and the test was conducted for each grade of concrete. It was noted that the minimum steel reinforcement with GPC takes 10kN extra load as compared to CC. At the same, increasing grade and molarity with maximum steel ratio increasing the load-carrying capacity from 20kN to 30kN extra as compared with CC. Rather than the magnitude of the internal horizontal actions, a change in the lever arm affects the variance in bending moment along the beam span. The fact that the force sustained by the tension reinforcement of a deep beam at its ultimate limit condition is constant across the beam span has been found to cause such behavior(BIS: 456, 2000).

4.2 Deep Beam Strength and Fracture Pattern with Minimal and Maximal Reinforcement

The tensile strength characteristics of the specimens are used to calculate the experimental shear strength of the deep beams. Deep beams, in contrast to shallow beams, transfer shear forces to support via shear stresses rather than bending stresses. Deep beams with diagonal fractures eliminate the willing percept tensile stresses essential for beam action, resulting in a redistribution of internal stresses that causes the beam to behave as a tied arch.

According to the findings, the accurate analysis of GPC concrete deep beam reinforced with various steel ratios yields the predicted results. The strut action due to shear flow occurred from the loading place to the support point. Almost all of the beams have been tested and failed due to diagonal cracking or concrete strut failure. The load is frequently interrupted during the test to monitor flexural as well as shear cracks. The strength of concrete in the region of the routes along which compressive forces are transferred to the supports is related to the load-carrying ability of an RC structural member. A compressive force's route may be seen as a flow of compressive stresses with changing portions perpendicular to the pathway direction and the compressive force, which represents the stress resultant at each section. For specimens with minimal and maximum reinforced GPC, different failure mechanisms are observed. As the failure mode is found, it is not inspired by concrete, but rather by the existence of the percentage of tensile reinforcement at the beam bottom

The specimen with 0.4% of minimum reinforcement provided at the bottom along with a concrete grade of M30 is designated as CDB1a compared with GPC with a designation of GDBM10a as shown in Figure 6. From the results, it was observed that GDBM10a shows 6% higher strength than that of similar strength CDB1a. It is primarily due to the polymerization process that takes place in GPC in addition to that presence of 10% alccofine gives C-S-H gel formation and denser packing of concrete leads to higher strength. The ultimate tensile strength with a maximum strain of minimum bottom reinforcement was 0.002. The ultimate deflection at the mid-span of the specimen CDB1a is 1.26 times higher than that of the average value obtained from GDBM10a mentioned in Figure 8.

Again the beam with the same grade and same molarity of concrete with 0.9% of maximum tensile reinforcement was provided at the bottom. Designated GDBM10b shows a 5% higher strength than that of the CDB1b specimen mentioned in Figure 7. It is more because polymerization process in GPC and the maximum number of reinforcements. Figure 9 denotes that ultimate deflection at the mid-span of the specimen CDB1b is 1.5 times higher than that of the average value of GDBM10b specimens. It was due to larger because of the reality that the modulus of elasticity of GPC is approximately 15% to 20% higher than conventional concrete.

5 Conclusion

All concrete deep beam specimens with minimum and maximum reinforcement using GPC and CC with normal grade concrete (M30, and 10M). From the observations, all the GPC with different reinforcement shows higher strength than conventional concrete. According to the strut-and-tie model, the distance of the tie area ends at 0.2D (D = depth of the beam). Within the range of 0.1-0.2D, the maximum stress zone occurs. The maximum strain in the extreme tension is trending inwards as the percentage of tension reinforcement rises from 0.4 % to 0.9%.

Failure is found to be related to the buildup of tensile stresses in the route area, which can occur for a variety of reasons which are, alterations in the path's direction, the intensity of the compressive stress field varies. At the tip of inclined cracks, stress rises.

Along the strut path, the deep beam exhibits the most compression load. Non-linearity exists in the two-dimensional state of stress and its strain distributions. Nearly 60% of the stresses over the depth of the deep beam at mid-span are under tension, according to the findings. An important design concern is the deflection of a CC and GPC concrete member reinforced with differing reinforcement ratios.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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