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Research Paper

Flexural and Shear Performance of the Reinforced Beams made of Geopolymer Concrete: A review

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ABSTRACT

Geopolymer is known to have many structural and nonstructural benefits, but the attractive characteristic of this novel material is that it depends essentially on a byproduct from different industries, and the use of Portland cement is absent. This concrete is an environmentally friendly product and is essential as the sustainability issue is considered. Compared with the material properties, the behavior of reinforced concrete members made of geopolymer has gained less importance by past researchers. Therefore, this review paper aims to summarize the evidence of the structural behavior of geopolymer concrete beams to provide a better understanding of the characteristics of reinforced geopolymer beams. A total of sixteen published works on geopolymer beams reinforced with steel rebar have been reviewed, and it found that there are 83 beams tested in flexure and 29 beams tested to highlight the shear behavior. For comparison, some researchers have tested control beams made of Portland cement concrete (PCC). It is noted that geopolymer concrete (GPC) beams have a performance, in general, better than that of PCC beams in terms of strength and ductility. Design proposals for PCC beams could be safely used for GPC beams, and the software based on the finite element method accurately predicts the load-deflection response. However, further study is recommended to provide more detailed and cost-effective design methodologies for the potential use of GPC in large-scale field applications.

1 Introduction

Different kinds of concrete are used for structural and nonstructural purposes, and this construction material is essentially based on Portland cement as a binder. However, there are problems related to cement production, mainly because of releasing a large amount of greenhouse gas (CO₂) into the atmosphere during manufacturing. The cement industry contributes roughly 5% of global carbon dioxide emissions. Therefore, experts have been actively trying to

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overcome these issues by using alternative materials for construction. On the other hand, different kinds of byproduct wastes are produced worldwide and growing with time. Nowadays, using environmentally friendly construction materials is welcomed to stop pollution because of CO₂ emissions related to cement manufacturing.

Recently, geopolymer concrete (GPC), a binder for concrete manufacturing that is not dependent on cement, has increased in popularity in research studies since the new technology reduces the need for cement. In comparison to using cement, it was stated that using geopolymer might reduce overall carbon dioxide emissions by almost 60% [1]. Byproduct waste materials such as fly ash obtained from industry were introduced to replace the hydraulic Portland cement to produce a new kind of concrete that was essentially different from normal concrete in terms of material constituents. Geopolymer is declared as a binder to replace ordinary Portland cement (OPC), and it seems that it is one of the main construction materials worldwide. An alkaline liquid could be used to react with silicon (Si) and aluminum (Al) in an original source or in by product materials to generate binders, which is what the word "Geopolymer" refers to [2]. By means of activation by an alkaline liquid solution, aluminosilicate materials such as fly ash (FA), rice husk ash (RHA), metakaolin (MK), and slag (SG) can be formed into geopolymer concrete. The alkaline liquids are usually sodium or potassium based. Sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na₂SiO₃) or potassium silicate are the most often used alkaline liquids used in polymerization (K₂SiO₃). As a result, both the types of source materials and the alkaline liquid solution (activators) are essential for geopolymer concrete production efficiency [3]. The behavior of geopolymer concrete as an alternative to cement concrete has recently been the focus of research on both the micro- and macro-scales. Reinforced concrete structural members are the essential concrete used in construction. Geopolymer concrete is being studied widely and demonstrates promise as an alternative to Portland cement concrete. Many geopolymer studies have significantly increased in this field since 2016 [4]. Despite extensive research in this area, geopolymer concrete still needs to be widely adopted as a building material. The crucial concerns concerning geopolymer applications can be briefed as follows: (a) the production cost of geopolymer concrete requests to be practically competitive to that of cement, (b) a wide-ranging and reliable database is required on the possibility of geopolymer concrete in structural members, and (c) It is appropriate to establish new design guidelines for mixture and reinforced geopolymer concrete structures [4]. Most research on geopolymer concrete has been on microscale material investigation; lately, a small number of researchers have expanded the use of geopolymer concrete to examine the structural behavior of reinforced geopolymer concrete elements, including beams, columns, slabs, and panels [5]. To evaluate the viability of utilizing cement concrete-based design codes for geopolymer concrete elements and the suitability of structural design engineers, the behavior of reinforced geopolymer concrete members should be determined with existing design codes. Regarding the importance of GPC in reinforced concrete structures, article analyzes highlights the results of studies on geopolymer concrete beams that have been published. This study analyzes previous investigations on geopolymer concrete beams subjected to flexure and shear. The tests attempted included studying the performance of concrete beams under loading increment, deflection, cracking behavior, and failure mode. This attempt may be a valuable source for the accurate design of reinforced concrete beams subjected to different kinds of loading, in addition to the preparation of state-of-art reports on geopolymer concrete beams in the future.

2 Beams reinforced with steel rebar

Many studies have clarified the flexural and shear behavior of geopolymer concrete beams and compared their behavior with reinforced concrete beams made of ordinary Portland cement. In the following paragraph, a total of 25 past studies will be presented and focus on the most important findings of the researchers. Table (1) shows the number and dimensions of the beams prepared in each study and the characteristics of those beams.

2.1 Beams designed for flexure

Sumajouw et al. [6] started researching the structural behavior of geopolymer concrete beams based on fly ash. Flexural failure tests were performed on six under-reinforced concrete beams with reinforcement ratios ranging from 0.64 to 2.69%. The higher tensile reinforcement ratio leads to an increase in the flexural load-carrying capacity. The examined load/calculated load capacity ratios were between 0.98 and 1.28.

Sumajouw and Rangan [7] tested concrete beams subjected to curing at 60°C for 24 hrs. There was an increase in cracking load with concrete compressive strength, but the effect of longitudinal steel was marginal. The ultimate moment increased significantly with the tension reinforcement increase, while the effect of concrete strength was only marginal.

The ductility index decreased with increasing tensile reinforcement ratio, especially for beams with less than 2%. The test outcomes were generally similar to those observed for reinforced Portland cement concrete beams, as reported. According to tests by Kumaravel and Thirugnanasambandam [8], the performance of GPC beams was better than that of OPC concrete beams in terms of cracking load, service load, yield load, and ultimate load, and the maximum deflection reached was slightly higher for GPC beams. Their load-deflection characteristics for the two kinds of beams were almost similar [9, 10]. The first cracking load of GPC beams is slightly higher when compared to OPC concrete beams. The average service load of GPC beams is 7.9% higher, while the ultimate load is 5.68% higher than the OPC concrete beams. Similar failure modes and crack patterns were observed. The beams failed due to the yielding of the tensile steel, proceeded by concrete crushing in the compression face. Further, they used Finite Element (FE) software ANSYS to predict the load-displacement response of OPC concrete and GPC beams and found accurate predictions for the ultimate load and the associated deflection.

Tests on relatively small-scale beams were performed by [11]. Although the compressive strength of GPC was higher than the companion OPC concrete, beams made of GPC exhibited lower ultimate load capacity and maximum deflection.

Results of testing beams by [12] demonstrated that both ultimate load capacity and maximum deflection of GPC beams are increased with increasing flexural steel ratio. For both the PCC and GPC beams, the deflection at yield varied from 19 to 57% and 32 to 57% at peak load.

Due to their higher flexural strength and elastic modulus, PCC was more serviceable. Also, the patterns and spacing of cracks in the flexural region of GPC beams were similar to that of PCC beams. However, crack width was increased for the same load with increasing fly ash replacement with ground granulated blast slag (GGBS). The cracking and service load moments were marginally lower for GPC beams than for PCC beams. The test beams' cracking, service and ultimate moments were computed using conventional reinforced concrete principles. The strain compatibility approach revealed a good correlation between the test and predicted values. The investigations showed that the computational techniques for assessing the PCC beams' performance parameters at different phases might also be applied to GPC beams. A capacity reduction factor could be required for design purposes because the predictions might not always be conservative in all cases. Fig. 1 shows the load-deflection relationship of PCC, GPC with FA, and GPC with GGB beams. One can find that the ultimate load capacity and the corresponding deflection of GPC beams are higher, indicating better structural performance, but such performance is reduced with increasing GGBS as FA replacement.

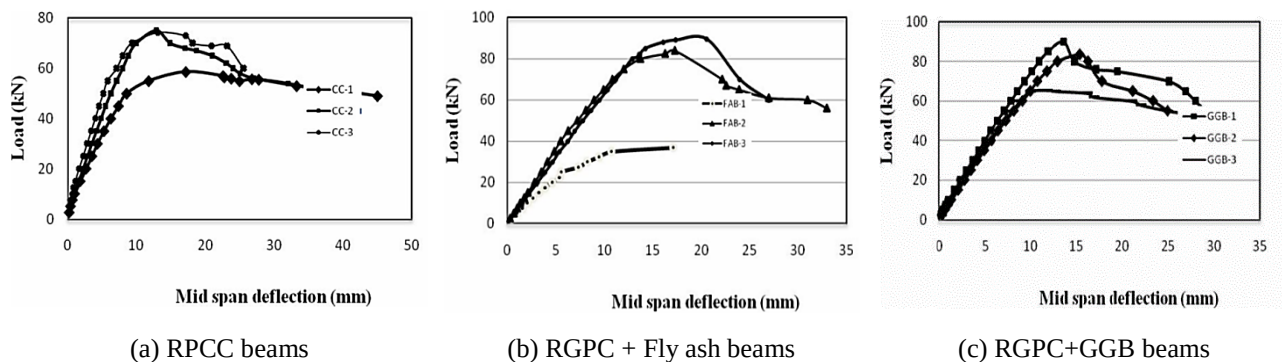


Fig. 1 – Load–deflection curves for the tested beams [12].

[13] worked on modeling GPC beams using eight nodes solid brick elements (Solid 65). They discovered that the theoretical model overestimates the loads in the range of 13 to 15% at different phases of cracking, except for the final crack. The theoretical model, however, slightly underestimates the result for deflection at ultimate load by 3%. But it gives higher results in estimating the deflection in the range of 6 to 14% at various phases of cracking, except for failure. Overall, the model can predict the outcomes for loads at various cracks and deflection at various phases of loading, but there is a need to improve the model so that it can simultaneously meet all the requirements.

Table 1 – Test variables attempted by the researchers

N°	Reference	No. of specimens	Concrete strength (MPa)	Binder	Beam dimensions* (mm)	Steel reinforcement	Type of test	Property studied ⁺
1	[7]	12	37-76	Class F FA	200×300×3000	0.64-2.69%	Flexure	M_{cr} , M_u , Δ_y , Δ_u , μ_d
2	[8]	4	59	OPC, Class F FA	125×250×3000	2#16 and 1#12	Flexure	P_{cr} , P_s , P_y , P_u , Δ_u
3	[11]	4	24, 31	FA	50×100×700	4#4	Flexure	M_u , Δ_u
4	[12]	9	17-63	OPC, FA & GGBS	100×150×1350	1.82-3.33%	Flexure	P_{cr} , P_s , P_y , P_u , Δ_u , ω_c
5	[13]	1	34-35.62	FA	150×230×1500	#16 mm	Flexure	P_{cr} , Δ_{cr} , P_u , Δ_u
6	[14]	6	14.297, 14.339	Class C FA	100×150×1300	#8 mm	Flexure	P_{cr} , P_u , Δ_u
7	[15]	18	33,40,60.2	OPC, Class F FA	150×150×525	13 mm	Flexure	P_u
8	[16]	3		Class F FA	100×200×1500	2#10 mm	Flexure	P - Δ
9	[17]	9	28-70.16	OPC, FA & GGBS	125×200×1100	#10 and #12	Flexure	P_{cr} , P_s , P_y , P_u , Δ_u
10	[18]	6	40-88	OPC, GGBS	150×150×1000	#12 mm	Flexure	P_{cr} , P_u , Δ_u
11	[19]	9	M20	OPC, FA, GGBS	100×200×1000	2#10 mm	Flexure	
12	[20]	2	50.6, 55.1	OPC, GP cement	120×250×2150	2#16mm	Flexure	P - Δ , μ_d
13	[21]	9	M30, M40, M50	OPC, FA	150×150×2000	#8 and #10	Flexure	P - Δ
14	[22]	12	Not mentioned	Metakaolin GGBS, OPC	150×150×700	#8, #10 and #12	Flexure	P - Δ , P_{cr} , P_s , P_y , P_u , M_u
15	[23]	18	37-54.4	FA	-	-	Flexure	M_u
16	[24]	6	12.80-35.45	POFA, FA and OPC	150×200×2000	#8, #10 and #12	Flexure	M_{cr} , M_u , Δ_u
17	[25]	9	44-56	Class F FA	200×300×1680	1.74, 2.32, 3.14%	Shear*	P - Δ , V_{cr}
18	[26]	6	26.9-43.4	OPC, Class F FA	203×305×2438	0.71 and 1.57%	Shear**	P - Δ , Strains, V_{cr}
19	[27]	8	21-33	Class F FA	200×250×2100, 200×200×2100, 200×300×2600	2#16 mm	Shear ⁺	P - Δ , V_{sl}
20	[28]	6	-	PC, FA	305×152×1524	3#16, 3#19, 5#22	Shear ⁺⁺	P - Δ , V_{sl}
21	[29]	16	40	GGBS, FA, OPC	100×150×1350	#6, #12	Shear ⁺⁺⁺	P - Δ , P_{cr} , P_s , P_u , M_{cr} , M_s , M_u
22	[30]	12	-	GGBS, FA, OPC+ silica fume	125×250×2000	2#8, 2#10, 4#12	Shear ⁺⁺⁺⁺	P_u , V_u
23	[31]	2	23.6, 27.87	FA and OPC	120×240×3000	2#13 mm, 2#16 mm	Shear ⁺⁺⁺	P - Δ , Strains, P_{cr} , V_u
24	[32]	18	43-56	Class F FA and GGBS	100×150×1200	#8, #10 and #12	Shear	V_c , V_{sl} , Δ_u

* Width × depth × span. + M_{cr} = cracking moment, M_u = ultimate moment, Δ_y = deflection at yield, Δ_u = maximum deflection, μ_d = ductility index, P_{cr} = cracking load, P_s = service load, P_y = yield load, P_u = ultimate load, ω_c = crack width. P - Δ = load-deflection relationship, V_{cr} = shear cracking load, V_{sl} = shear force at failure, τ_{max} = shear friction capacity, * Stirrups ratio = 0.1, 0.13 and 0.17%. ** Stirrups: No stirrups, #10 at 254 mm, #10 at 191 mm. + Without stirrups. ++ #13 stirrups at 152 mm. +++ #6 stirrups at 100 mm. ++++ #8 stirrups at 150 mm, 200mm, and 230mm.

[14] studied flexural strength, deformation, and cracking of GPC beams subjected to two different curing regimes: continuous room temperature between 30–32°C for series II test (3 beams), while series I beam (3 beams) were transported to the seashore and placed in a splashing zone area, to experience cycles of wet and drying due to tide cycles. Cracking and ultimate loads for series I and II testing are shown in Fig. 2. for series I, the cracking load was 275% higher than the cracking load for the series II test. This could be explained by splitting tensile testing, where the ratio of tensile strength to compressive strength is around twice that of normal concrete. Additionally, the results demonstrate that the series I test's ultimate load was 15% greater than the series II test's ultimate load. According to the loading test, the crack pattern for series I and II testing was also quite similar.

Twelve geopolymer and six traditional concrete beams were tested by [15] and were subjected to an accelerated corrosion test in natural seawater. These beams underwent flexural load testing following the corrosion test. The bending test showed that the average flexural strengths for the 8- and 14-M specimens (GPC beams) were 4.88 and 5.22 MPa, respectively, higher than the average flexural strength of OPC, which was only 2.1 MPa.

[16] tested three GPC beams, which were analyzed using ABAQUS/CAE software. The measured and predicted load-deflection curves were quite similar.

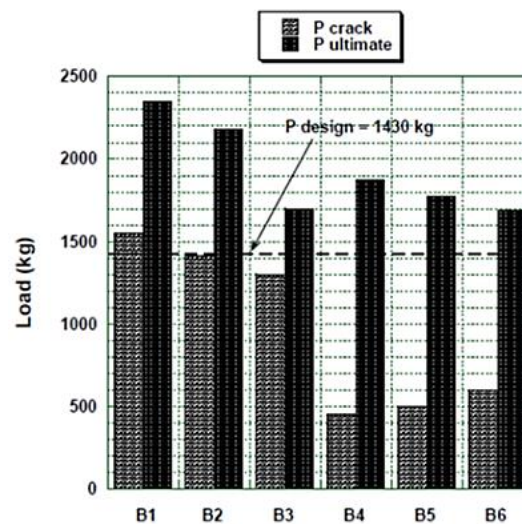


Fig. 2 – Ultimate and Cracking load of series I and II tests [14].

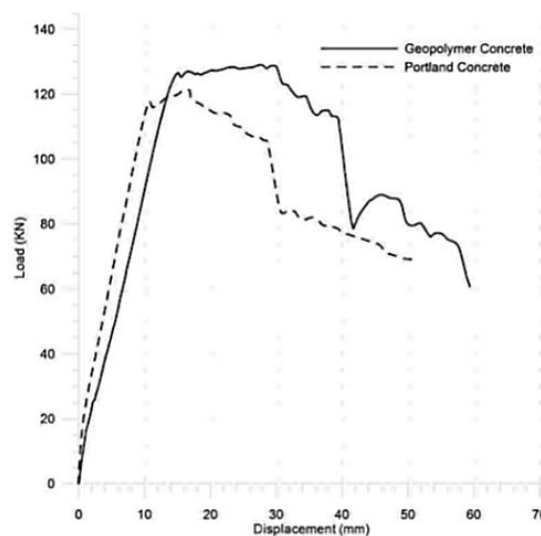


Fig. 3 – Load versus displacement of the beams obtained [20].

Test results by [17] showed that cracking load, service load, yield load, and ultimate of beams made of GPC with or without recycled waste glass as fine aggregate were larger than that of Portland cement concrete beam (PCC). However, most tested beams' ductility ratio was lower than that of PCC beams. They observed that predicted loads by the ANSYS program were slightly lower than the measured loads for all tested beams.

[18] found that the load-carrying capacity of the GPC beams increases as the sodium hydroxide concentration increases in molarity. The ultimate load capacity for all GPC beams (GPC with different molarities) was more significant than that of the PCC beam.

Experimental tests by [19] showed that regardless of replacing FA with GGBS binder, the cracking load and ultimate load capacity of GPC beams were appreciably larger than those of PCC beams. Also, the maximum deflection for GPC beams was 5.28–8.34 mm larger than that of PCC beams (3.85–5.5 mm).

[20] concluded that the GPC beam is more ductile, with a ductility coefficient of 1.92 compared with 1.59 for the OPCC beam. Also, the GPC beam reached a higher maximum failure load and toughness than the OPCC beam (see Fig. 3). They determined that the results of the finite element model created using the mechanical characterisation of the GPC were realistic.

[12] conducted an experimental study investigating the flexural behavior of reinforced geopolymer concrete beams made from different grades of concrete (M-30, M-40, and M-50) with the adoption of three different reinforcement ratios (0.55, 1.1, and 1.65) for each designed mix. The results of the study demonstrated that fly ash can be used to make a geopolymer binder phase. Deflection and ultimate load of the geopolymer beams were found to increase as the reinforcement ratio increased, as shown in figure 4.

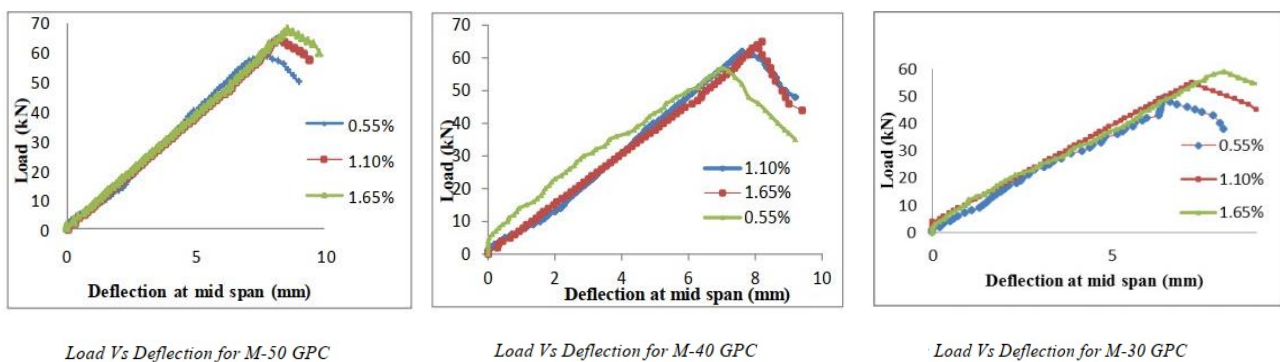


Fig. 4 – Load versus vertical displacement curves [21].

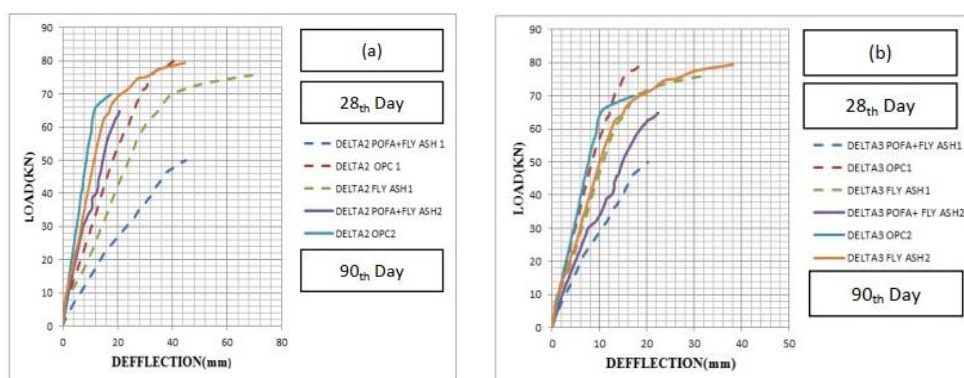


Fig. 5 – Load versus displacement (a) at mid-span (b) one-third span [24].

Comparing the flexural behavior of reinforced geopolymer concrete beams made of combination (GGBS and Metakaolin) with reinforced concrete beams made of Ordinary Portland cement (OPC) was the aim of the study conducted by [22]. (12) reinforced concrete beams were prepared using different percentages of (GGBS and Metakaolin) while

keeping one beam made of (OPC). The results exposed that the maximum moment of the geopolymer concrete beams is higher than beams based on (OPC), and it was also recognized that the failure patterns of the (GPS) and (OPC) beams were not different, and the crack pattern was almost identical for both types of beams in the different stages.

[23] discovered that the standard codes' design parameters are unsuitable for use with Fly ash based Geopolymer Concrete. They also found that the modulus of elasticity model used for ordinary Portland cement concrete is not suitable for fly ash based geopolymer concrete beams; therefore, they conducted a study to obtain relationships between stress-strain and modeling the modulus of elasticity and design parameters of the equivalent stress block. The study's results proved a good agreement with the experimental results of previous studies.

[24] conducted an experimental study investigating the effect of using (Palm Oil Fuel Ash & Fly ash) as substitute materials for cement on the flexural, deflection, and cracking behavior of reinforced concrete beams and comparing their behavior with reinforced concrete beams made of (OPC). The results appeared that the beams containing (POFA-Fly ash) have cracking and the ultimate moment is almost similar to the beams made of (OPC) at 90 days, as presented in figure 5. It was also demonstrated that these beams had better resistance to acids than (OPC) beams.

2.2 Beams designed for shear

Shear reinforcement ratio, Dowel action, concrete strength, shear span-to-effective depth ratio, and aggregate interlock are the main factors that influence shear strength. Concrete strength plays a significant role in the contribution to shear load-carrying capacity in the structures. The shear strength of reinforced geopolymer concrete has been reported in some papers, and the essential results are given below and discussed.

[25] tested nine beams of different longitudinal reinforced ratios (see Table 1) and #4 mm stirrups arranged at 125, 100, and 75 mm spacings, designed to fail in shear. According to the findings, cracking load rises as transverse and longitudinal reinforcing ratios rise. At the same compressive strength of geopolymer concrete, the beam S2-1 (longitudinal reinforcement ratio=2.32%) achieved 80 kN, whereas the beam S3-3 (longitudinal reinforcement ratio=3.14%) acquired 112 kN. It was reported that the failure modes and crack patterns are similar to those observed in reinforced Portland cement concrete beams. They stated that the shear strength of reinforced geopolymer concrete beams could be calculated using the same code provisions utilized in the design of reinforced normal concrete beams. Fig. 6 shows the load-deflection relationship for Beam S1-1, reinforced with 1.74% flexural reinforcement and stirrups at 125 mm spacing.

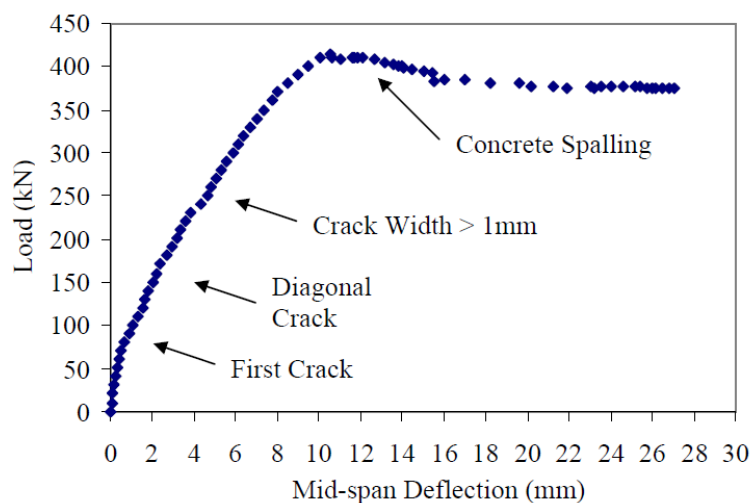


Fig. 6 – Load-Deflection relationship for Beam S1-1 [25].

[26] tested beams consisting of one conventional concrete beam (CL6-2) as control and five geopolymer concrete (GC) beams. Among geopolymer beams, two beams (GN4-2 and GN6-2) had no stirrups with different longitudinal reinforcement ratios (ρ_w), two beams (GL6-2 and GS6-2) had different shear reinforcement ratios (two different stirrup spacing s), and one beam (GL6-2.4) had higher shear span-to-effective depth ratio (a/d). Figure 7 shows the shear load and shear strength obtained from beam tests, from which one can find different ductility behaviors. The area under the load-

deflection curve was used to quantify toughness, and the toughness factor (TF) was derived as the ratio of the modified beam's toughness to that of the reference beam (concrete beam). For GL6-2 and CL6-2 beams, TF was found to be 1.3, indicating that the normal concrete beam is more ductile than the geopolymer concrete beam.

Nevertheless, TF was 1.1 for the beams without shear reinforcement since the failure of both GN4-2 and GN6-2 was brittle and had no ductility. However, due to their ductile flexural failure compared to the control beam, the TF was higher for the beams that failed in flexure-shear (i.e., GL6-2.4 and GS6-2) of 3.8 and 4.2, respectively (GL6-2). It was noted that most of the beams failed in shear except two that failed in flexural-shear mode; one (GL6-2.4) had a higher a/d ratio, and one (GS6-2) had a smaller s . The geopolymer concrete beams were found to have high shear strength when compared to the reference beams, it was established.

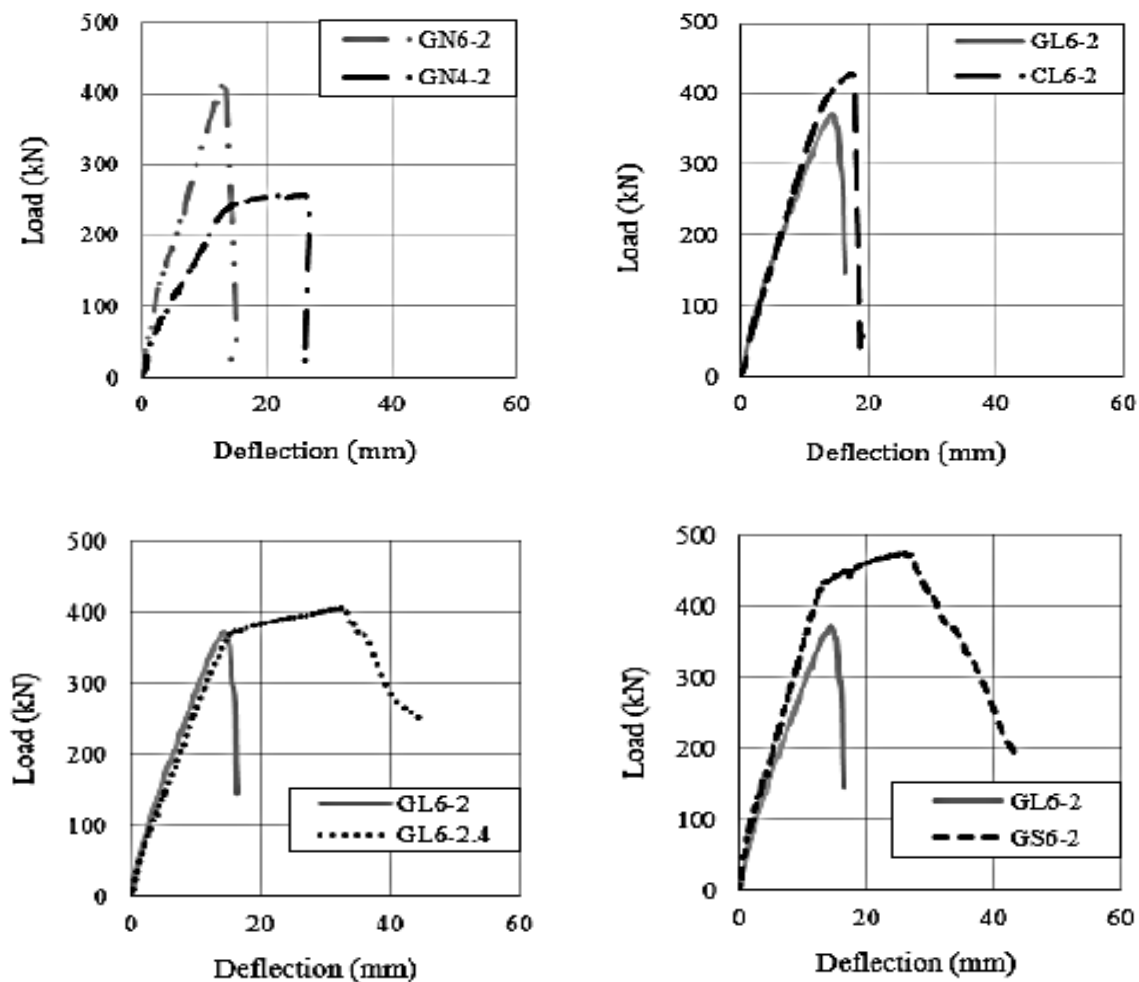


Fig. 7 – Load deflections of tested beams [26].

To predict the shear strength by applying developed mechanics based segmental approach, [27] examined the shear performance and direct shear behavior of reinforced geopolymer concrete beams without stirrups. In this investigation, the test parameters of longitudinal reinforcement ratio and span-to-depth ratio (a/d) were attempted. Figure 8 displays the load-deflection responses for the beams. It can be noted the load increased nearly linearly in all cases until a sudden shear failure occurred along the critical diagonal sliding plane. According to a study, the shear performance of geopolymer concrete is similar to cement concrete. They concluded that the segmental approach can accurately forecast the shear strength of reinforced geopolymer concrete beams. This segmental method can be utilized to develop new design guidelines for reinforced geopolymer concrete beams.

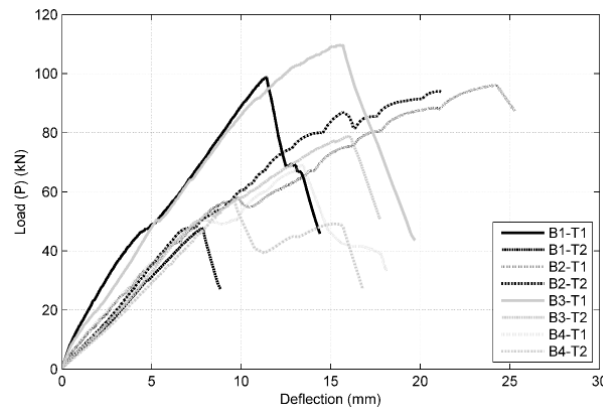


Fig. 8 – Shear load-deflection curves [27].

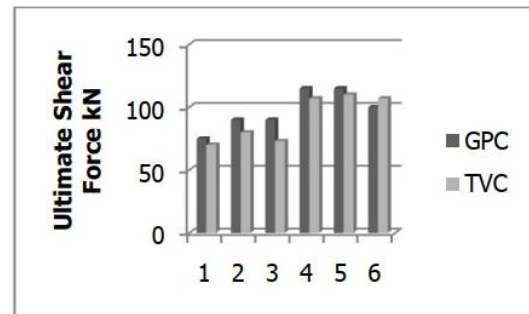
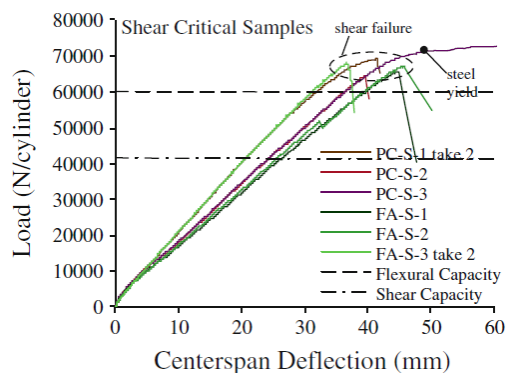


Fig. 9 – Shear load-deflection relationship [28]. **Fig. 10 – Shear Strength of GPC and OPC beams [30].**

The shear behavior of RC beams made of cement and geopolymer concrete was examined by [28]. There are six beams: three are made of Portland cement (PC-S-1, 2, and 3) and the remaining three are formed of concrete with alkali-activated fly ash (FA-S-1,2 and 3). The beams were tested under two-point loads with a shear span of 1524 mm and reinforced with three #16 mm, three #19 mm, and five #22 mm bars for flexure. The response to shear failure is mainly linear for all three PC-S samples and all three FA-S samples, as illustrated in Fig. 9. The measured loads showed a high degree of consistency for all PC-S and FA-S beams. Average shear loads were 69.4 KkN and 67 KkN for PC-S and FA-S beams, respectively. It was observed that geopolymer concrete beams have very similar performance to companion cement concrete beams. Therefore, the same ACI Code recommendations for normal concrete can be used to estimate the shear strength of geopolymer concrete beams.

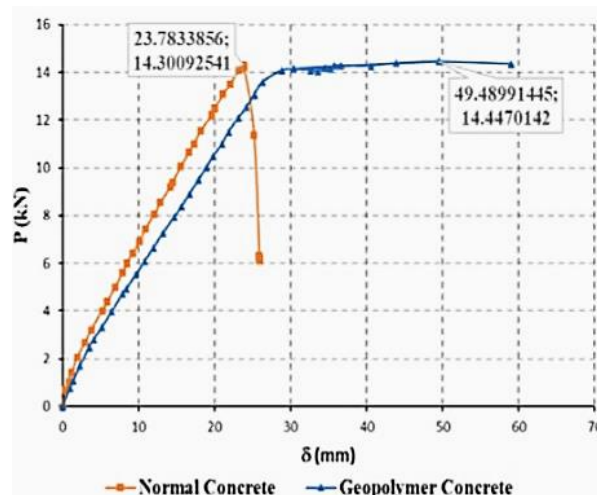


Fig. 11 – load-deflection relationship [31].

The objective of the theoretical and experimental study conducted by [29] is to compare the shear performance of geopolymer reinforced concrete beams made of ground granulated blast slag (GGBS) with the behavior of reinforced concrete beams with OPC. As well as using the ANSYS software to perform a non-linear analysis of the beams to compare the experimental and theoretical results. According to the findings, the load-deflection characteristics of GPC and OPC beams are remarkably similar in mid span of the beams. They also noticed an increase of (15%) in the ultimate load of GPC beams compared with OPC beams. Overall, the outcomes of the theoretical study showed that the deflection, failure patterns, and crack patterns for GPC and OPC beams are in good agreement with experimental data.

[30] conducted an experimental study focusing on the shear behavior of geopolymer reinforced concrete beams using (ground granulated blast slag+ fly ash) and compared it with the behavior of reinforced concrete beams made of cement and silica fume. When the behavior of (12) beams was examined, they discovered that the ultimate load (V_u) of the geopolymer concrete (GPC) beams is greater than the traditional ones, as demonstrated in Fig. 10. Besides, they discovered that employing the American Concrete Institute (ACI) equations to estimate shear values produces better results than the rest of the codes formulas.

The idea of employing bauxite materials as coarse aggregate in geopolymer concrete was investigated by [31]. The researchers prepared two beams with dimensions of (120× 240× 3000 mm), the first of which is a reinforced concrete beam made of ordinary Portland cement (OPC), and the second is a geopolymer reinforced concrete beam made of fly ash. The results showed that the ultimate load of the two beams was similar, but the deflection at the failure of the geopolymer beam was larger than the OPC-based beam, and its failure was more ductile than the OPC-based beam. Fig. 11 displays the relationship between load and displacement for two beams. The researchers also indicated that the first crack of the fly ash-based geopolymer concrete beam occurred at a higher tensile strength than the normal concrete beam; Figure 12 illustrates the pattern of beam shear failure.



Fig. 12 – Failure crack (a) Normal concrete and (b) Geopolymer concrete [31].

[32] examined the impact of adding hybrid fibers (steel fiber + basalt fiber) on the flexural behavior of geopolymer reinforced beams made of (ground granulated blast furnace slag (GGPS) + Fly ash) and compared their behavior with beams made of fly ash only. According to the experimental study conducted on (18) beams with variable proportions of fibers, the results showed, in general, that the behavior of geopolymer beams containing fibers showed more ductile failure than beams without fibers, and the patterns of the cracks are similar to those appear in concrete beams made of (OPC), which contains fibers. The researchers also observed that the first crack load, absorption energy, ductility behavior, and the ultimate load of geopolymer beams based on (GGPS + fly ash) are higher than the beams based (fly ash only) at the same percentage of added fibers.

3 Conclusions

The building sector would become more environmentally friendly and sustainable due to geopolymer, and this innovative concrete can replace Portland cement-based concrete in the future. From this review of flexural and shear behaviors of geopolymer beams reinforced with steel rebar, the following conclusions can be drawn

Most of the structural behaviors of the investigated reinforced geopolymer concrete (GPC) beams, including load-deflection, cracking characteristics, and failure mode, were discovered to be similar to those of the corresponding conventional concrete beams. Based on this fact, most studies recommended that design codes intended for conventional reinforced concrete members, such as AS3600 and ACI 318, are appropriate for GPC beams. Hence, these codes were generally conservative in assessing the strength of the reinforced beams. A more cost-effective structural design for GPC structures could be achieved by creating new codes or making revisions to the existing Portland cement concrete (PCC) based codes, considering the relatively high experimental-to-calculated value ratios.

Since reinforced GPC beams' general behavior and failure mechanism were found to be similar to those of conventional reinforced PCC beams, this should further enhance the usage of existing codes of practices to design structural members utilizing geopolymer concrete.

Further work would be needed on the durability and long-term behavior of reinforced GPC to completely incorporate the concrete for large-scale structural applications in the future.

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