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Behavior of Reinforced Geopolymer Concrete Beams under Repeated Load

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ABSTRACT

Finding an alternative material for building constructions is an essential topic nowadays after the weather pollution which caused by cement protection factories, at the same time, the engineers thinking to find such material from environments wastes to minimize the earth pollutions. Geopolymer is very important material which satisfy such purpose, because it is minimizes the need to concrete production and overcome the environment from many slags. Geopolymer beams were casted and tested under repeated load to study the possibility of using them as structural members exposing to repeated loads. The beams also strengthen by steel fibers and glass fiber reinforced polymer (GFRP) to investigate their effect on such new structural member. It was concluded that, it has been observed that the structural behavior of geo-polymer concrete beams tends to be more flexible when compared to that of ordinary concrete beams. Also, the geopolymer members showed an improvement in strength when using the steel fibers and GFRP, which what was observed on conventional concrete.

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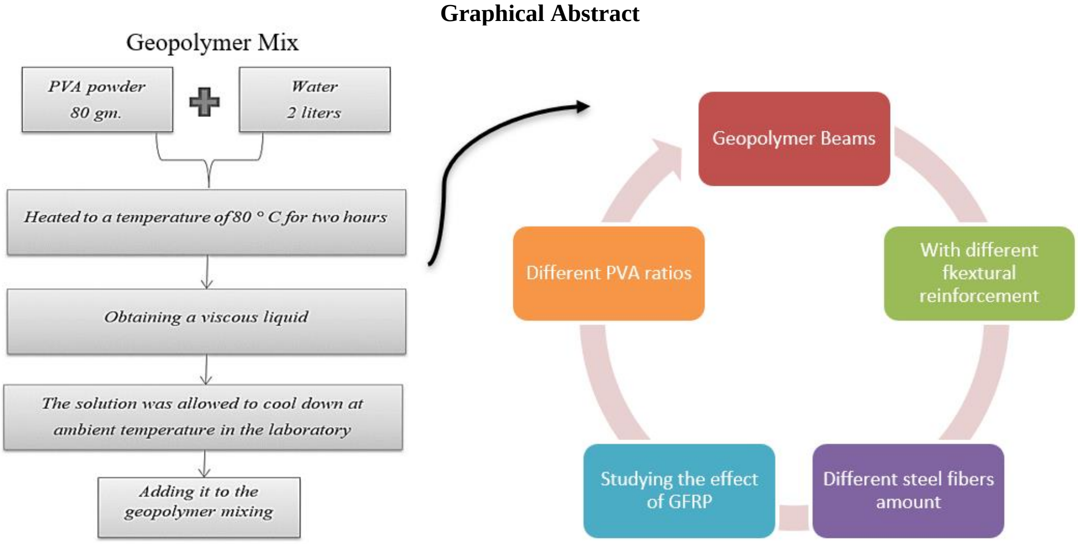
Graphical Abstract



1. INTRODUCTION

Concrete is a broadly used construction material and the construction industry exploit the natural resources (1). Ordinary Portland Cement (OPC) plays a vital function in the production of concrete and the manufacturing of cement involves burning of huge quantities of fuel and breakdown of limestone, which results in large emission

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of carbon dioxide to the atmosphere (2). The production of one ton of Portland cement causes the release of approximately one ton of carbon dioxide into the environment and the consumption of 1.5 tons of raw materials in manufacturing one ton of cement (3). Another essential reason pushed the engineers to look for another construction material which is a catastrophic fires occurs in France in 1973, which led Davidovits to think in another non-flammable and non-combustible material (4). Davidovits (5) prepared the geopolymer to replace OPC by activating active aluminosilicate materials with high alkali solution. Geopolymer can be produced from industrial wastes and geological sources including fly ash (FA), blast furnace slag, bottom ash, metakaolin (MK), and so on (6). Both ordinary concrete and geopolymer concrete are weak under tensile stresses and for this reason; the concrete in tension is neglected in many international codes and depends in totally on the strength of steel reinforcement to resist the tensile strength in structural members. While plain concrete tensile strength enhanced significantly by adding steel fibers to the concrete mix (7). The use of geopolymer cement can reduce carbon dioxide emissions by 44-64% compared to Portland cement (8).

Geopolymer concrete (GPC) is environmentally friendly, is energy saving, and also has similar or better mechanical properties than OPC concrete (OPCC) [10]. Compared to OPCC, GPC has better bond strength under similar compressive strength, higher early strength, and faster speed of strength development (9). Besides, the fire resistance of GPC is much better than the traditional concrete. As a result, GPC can be used in repairing and strengthening of existing structures, such as bridge structures, pavement structures, building structures, and so on. The rapid repaired strength can be obtained.

Geopolymer concrete have an enhanced mechanical and chemical properties when comparing with the normal conventional concretes, such as higher compressive, tensile and flexural strengths (10), faster hardening (10), longer durability (10), resistance to fire, and high temperature (11).

Many researchers studied the effect of concrete beam under repeated loads (12-14), but there is no research in the literature studied the behavior of Geopolymer beams under repeated loads. So, it is a novelty to investigate such topic for filling up the gap of literature for such essential case.

It was concluded that, from the previous research, a magnitude of residual deflection formed at the final of each loading stage after the unloading cycle due to the microcracks merging and the residual applied stresses. Also, the concrete beam which exposed to repeated load losses a magniude of its failure load capacity when comparing with the static load due to the multi repeating cycles of loading and unloading stages (12, 15).

Repeated load may be subjected on structural members by a periodic of series loads which may cause due to vehicle passing on bridges. These repeating loads causing deflections in each single passing on the beam and may cracked the beam with several micro cracks, or helps the creep and shrinkage cracks to be matching and developing after a period of time till cause failure. This phenomenon called as fatigue, the capacity of beam to overcome the repeated load after several periodic loadings.

Loads which applied on any structure classified into three basic categories, which are: static, dynamic and the repeated load. The static loads neither accelerates the beam nor effects on the velocity of it, so the first two items from the dynamic load equations (Equation 1) were neglected at static loading. In contrast to the the dynamic loading, which effects on beam velocity and acceleration so all items in the equation will be considered. But in the case of repeated load, and since the load is too slow, the inertia effect ignored (has no effect on the mass) (16-18). The study investegated the behaviour of Geopolymer beams under the effect of fatiage loading.

$$m\ddot{u} + c\dot{u} + ku = F(t) \quad (1)$$

2. EXPERIMENTAL WORK

Nine reinforced concrete beams designed to fail by flexural stresses were casted and test under repeated loads. Nine beams casted by geo-polymer concrete, and one beam made of normal concrete to compare with the geo-polymer concrete. The difference between the geopolymer beams relenting to the geopolymer mixture itself are shown in Tables 1 and 2. The first group includes four reinforced geo-polymer concrete beams made of the first mix, the second group includes four reinforced geo-polymer concrete beams made of the second mix, and the third group includes a reinforced concrete beam made of normal concrete has a w/c ratio equals 0.42. The difference between the first and second mixture is the percentage of PVA content.

All beams have the same dimension 1600 mm length, 250mm depth, and 150 mm width as shown in Figure 1. The beams denoted by mixture type, type of fiber which used, reinforcement presence, and the amount of fibers which used, as explain in Figure 2.

The beams were subjected to a successive cycle of loading and unloading (repeated loading) (7). Through this type of loading, as shown in Figure 3.

Usually, in the laboratories works, the designers tested the beam to loading equals the service load (70% of the ultimate service load (Ps)) and then unloaded it to get a repeated load cycle. Two cycles exposing quarter the service load, then two cycles of exposing half of the service load, the next three cycles applying the third-quarter service load and the final next cycles applying

TABLE 1. The mixing proportion for three mixing

The mixing proportion 1st mixing.							
Type of concrete	**Slag**	**Sand**	**Glass Sand**	**NaoH (8 mol)**	**Na2Sio3**	**Steel Fiber**	**PVA 0.2%**
Geopolymer	520	962	78	119	297	60	2.6
The mixing proportion 2nd mixing							
Type of concrete	**Slag**	**Sand**	**Glass Sand**	**NaoH (8 mol)**	**Na2Sio3**	**Steel Fiber**	**PVA 0.75%**
Geopolymer	520	962	78	119	297	60	9.75

The mixing proportion 3rd mixing					
Type of concrete	**Cement**	**Sand**	**Gravel**	**Water**	**Sp N211**
Normal concrete	390	515	1185	235	1.1

TABLE 2. The steel proportion for beams

No.	Symbol	Type mixing	Type of longitudinal reinforcement	Top reinforcement	Bottom reinforcement
1st	GSRA5	1st	steel	2ϕ12	2ϕ12
2nd	GSRB6	1st	steel	2ϕ12	2ϕ16
3rd	GGRA7	1st	GFRP	2ϕ10	2ϕ10
4th	GGRB8	1st	GFRP	2ϕ10	2ϕ14
5th	GSRA13	2nd	steel	2ϕ12	2ϕ12
6th	GSRB14	2nd	steel	2ϕ12	2ϕ16
7th	GGRA15	2nd	GFRP	2ϕ10	2ϕ10
8th	GGRB16	2nd	GFRP	2ϕ10	2ϕ14
9th	RCR18	3rd	Steel	2ϕ12	2ϕ12

fully service load. Such increment in the applied load is called a rainfall style of repeating load, as explain in Figure 3.

3. MATERICAL PROPERTIES

The steel Fibers used is hooked end with a length of 30 mm and a diameter of 0.51mm and its specifications are Bright and clean wire, the density is 7800 kg/m^3, the Tensile strength is 1200 MPa and aspect ratio (L/d) is 60.

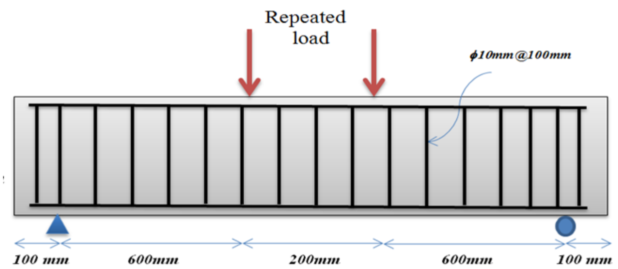

Figure 1. Beam Specimens

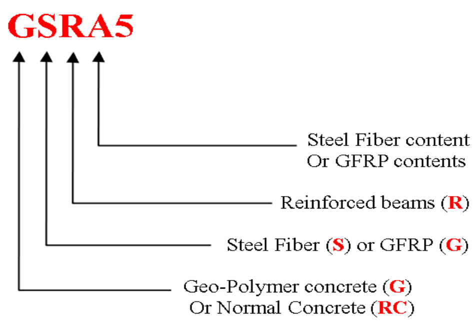

Figure 2. Bems symbol definations

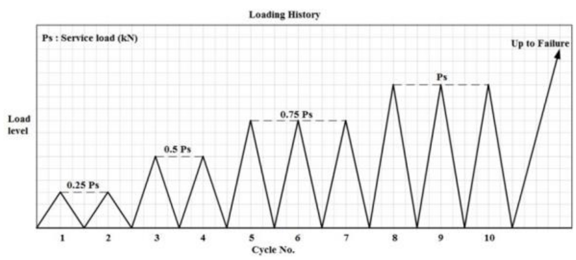

Figure 3. Proposed Repeated Loading History of Specimens

The tested properites of concrete and geopolymer were listed in Figure 6.

3. 1. Cement Portland cement (Al-Jeser) was used in the experimental study. It complies with the Iraqi Standard (I.Q.S) NO.5 of 1984.

3. 2. Fine and Course Aggregat In concrete mix used naturally sand and gravel. This sand was tested according to Iraqi Standard Specification (I.Q.S NO 45 of 1984), and gravel was tested according to Iraqi Standard Specification (I.Q.S NO 45 of 1984).

3. 3. Reinforced Bars As explained in Table 3, the samples were reinforced with two types of longitudinal reinforcement, steel and GFRP, with different diameters:

- STEEL bars: a diameter of 12 mm was used where the yield stress was 524 Mpa while ultimate stress was 655 Mpa, and a steel bar with a diameter of 16 mm where the yield stress was 560 Mpa while ultimate stress was 659 Mpa.
- GFRP bars: a diameter of 10 mm was used where the tensile strength was 895 Mpa and a steel bar with a diameter of 14 mm where the tensile strength was 1169 Mpa.

For transverse reinforced a diameter of steel bar 10 mm was used for all beams where the yield stress was 508 Mpa while ultimate stress was 635 Mpa.

3. 4. Preparation Alkaline Solution for Geopolymer and Poly (Vinyl Alcohol) (PVA) Preparation of alkaline solution for geopolymer is shown in Figure 4, and preparation of PVA is shown in Figure 5. The tested mechanical properties are illustrated in Figure 6.

TABLE 3. Reinforcment properties

No	Normal Bar Diameter (mm)	Bar Type	Description of bar	Yeild stress (MPa)	Ultimate Stress (MPa)	Bending result at 180°
1	10	Steel	Deformed	508	635	Successful
2	12	Steel	Deformed	524	655	Successful
3	16	Steel	Deformed	560	659	
No.	Normal bar Diameter	Bar Type	Description of bar	Tensile strength (MPa)		Bending result at 180°
4	10	GFRP	Deformed	895		Successful
5	14	GFRP	Deformed	1169		Successful

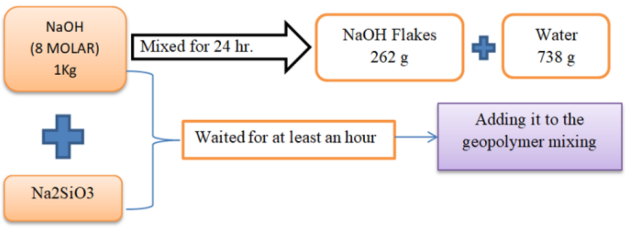

Figure 4. Preparation Of Alkaline Solution For Geopolymer

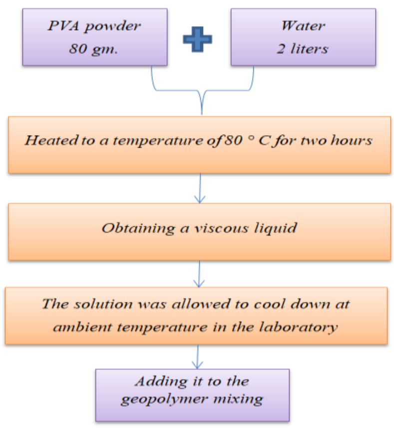

Figure 5. Preparation Of PVA

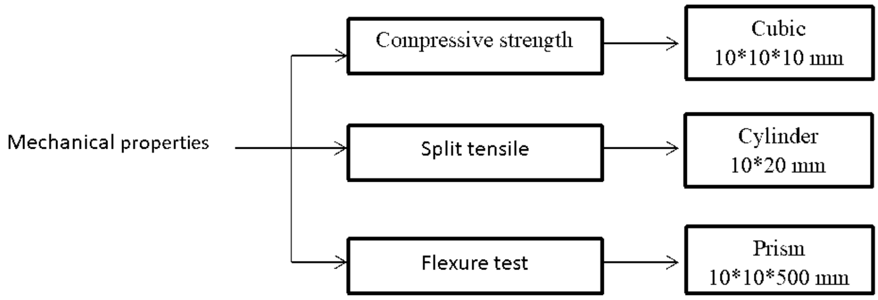

Figure 6. Mechanical Properties.

4. EXPERIMENTAL TEST RESULTS

Experimental results including mechanical properties of mixtures and results from tested beam specimens. The mechanical properties including compressive strength, tensile strength and flexural strength. are shown in Figures 7 to 11, Tables 4 and 5. It can be concluding that, increasing PVA within the mix deteriorated the concrete compressive strength because it is working on incrementing the water amount in the mix. The same behavior was observed for the flexural strength and there is no significant influence observed for the tensile strength.

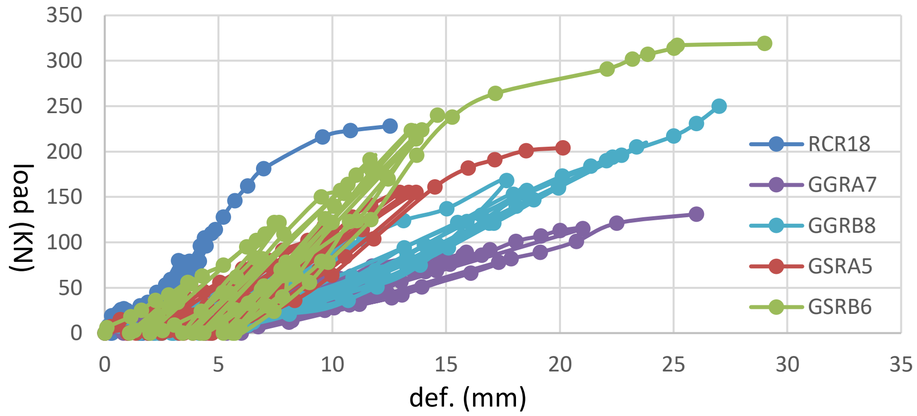

Figure 7. Comparison The Load-Deflection Curve Between Beams In The 1st & 3rd Group

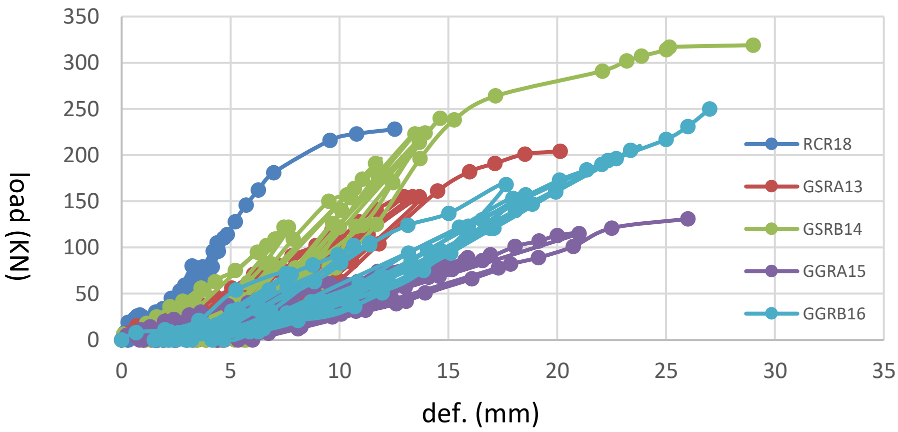

Figure 8. Comparison The Load-Deflection Curve Between Beams In The 2nd & 3rd Group

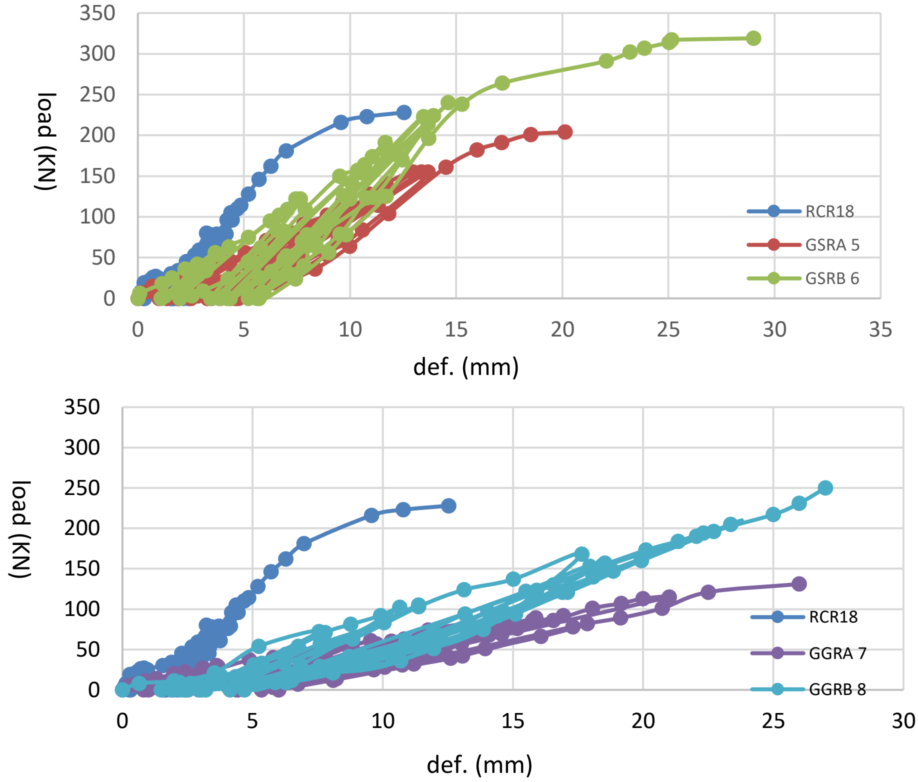

Figure 9. Comparison The Load-Deflection Curve in 1st Group Between Beams Which Have The Same Properties

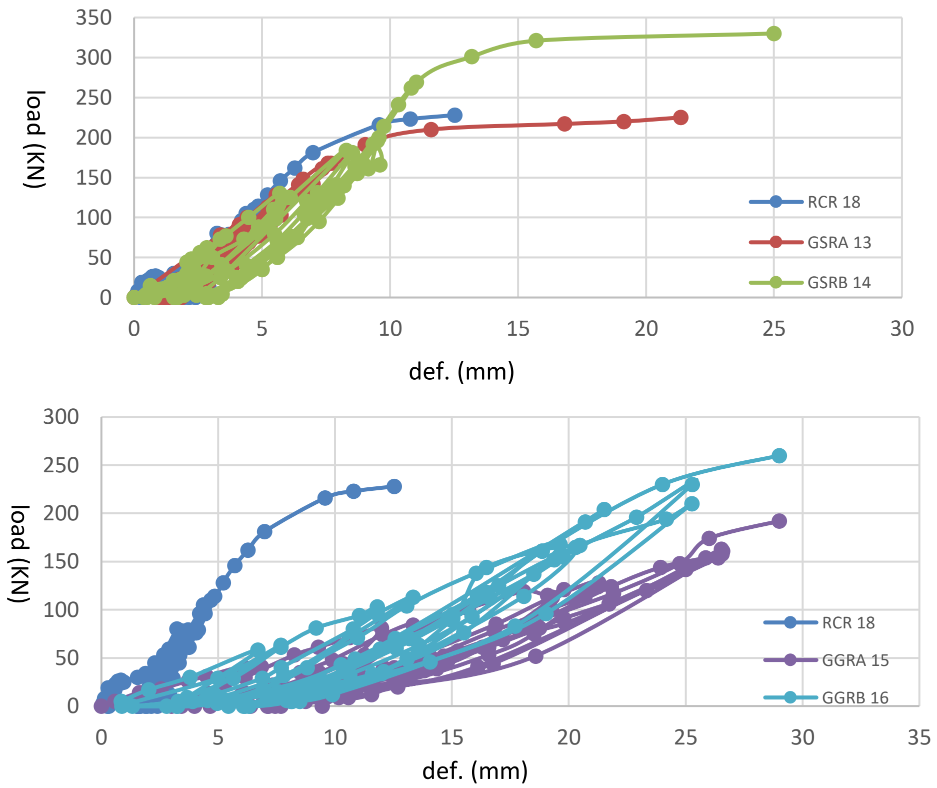

Figure 10. Comparison The Load-Deflection Curve in 2nd Group Between Beams Which Have The Same Properties

Figure 11. Crack pattrens for all tested beams

After testing the specimens experimentally, it was observed that, all beams' types failed by flexural stresses in spite of their different types; which may indicate that, the failure criteria of (geopolymer or concrete) beams; still yielding to their theoretical design (which was planned before to be flexural) even it was reinforced by steel fiber, GFRP or even casted by geopolymer material. Ultimate loads, cracking loads and increasing of ultimate load for all beams are provided in Table 5.

From the obtained results, when comparing between the first two geopolymer beams (GSRA5 and GSRB6) it can be concluded that, the increment of steel ratio from (5 to 6) enhance the final capacity of beams by 56.37% , and 90.8% for GFRP samples after increasing the steel ratio from 7% to 8%, all for the same mixes properties (the first mix).

For the second mix, the resistance of beam developed by 46.7% after incrementing the steel ratio from 13% to 14%, while for GFRP samples, the ultimate capacity of beams increased by 32.6% when developing the steel ratio from 15% to 16%, as shown in Table 4.

As a conclusion, it can be stated that, as the steel fiber and EFRB working on developing the concrete strength, it is also effective to enhance the properties of geopolymer mixed against the applied loads and enhance the overall resistance (such as flexural resistance, as well as all the others properties).

The value of the deflection occurring in the geopolymer samples compared to the applied load is higher than the deflection occurring in normal concrete.

By increasing the percentage of reinforcing steel, noticed that a delay in the appearance of the initial crack in all geopolymer beams when comparing the beam of the symbol “A”, which represents the minimum steel percentage, with the beam of symbol “B”, which represents an increase in the steel percentage.

The structural behavior of geo-polymer concrete beams tends to be more flexible when compared to that of ordinary concrete beams .

From Figure 7, in which the results of load versus deflection of the first group specimens were listed. It can be concluded that, the behavior of concrete beam appears more brittleness than the geopolymer samples. The deflection at the same loading stage seems to be larger in geopolymer specimens comparing with the concrete. This case appears again when observing the GFRP specimens at the same Figure 7. The GFRP shows more ductility than the normal concrete and geopolymers beams.

From Figure 8, it can be clearly noticed that, the same behavior involved the ductility of conventional concrete and the brittleness of GFRP was observed .

By following the crack patterns which listed in Figure 11, it can be seen the flexural cracks formed clearly beneath the loaded points, which is described to be vertical passing through the neutral axes of beams.

It can be concluded from Table 6 that, the residual deflection after a cycle of load increases gradually due to micro cracks merging from the previous loadings besides shrinkage cracks. Also, the resigual deflection minimizes when increasing the steel reinforcement ratio.

TABLE 4. Mechanical Properties Results.

Mixing No. (MPa)	First mixing	Second mixing	Third mixing
Compressive strength	47	40	38
Tensile strength	4.7	4.5	2.3
Flexure strength	4.92	3.207	3.1

TABLE 5. Ultimate Loads And Cracking Loads For All Beams

Beams No.	Beams Symbol	First crack loading (KN)	Ultimate deflection (mm)	Ultimate load (KN)
9th	RCR18	45	12.53	228
1st	GSRA5	91	20.13	204
2nd	GSRB6	150	29	319
3rd	GGRA7	80	26	131
4th	GGRB8	142	27	250
5th	GSRA13	95	21.35	225
6th	GSRB14	155	25	330
7th	GGRA15	85	29	196
8th	GGRB16	120	29	260

TABLE 6. Residual deflection at the end of each cycle

Residual deflection (mm)										
Beams \ Cycle	1	2	3	4	5	6	7	8	9	10
G.S.R.A 5	1	1.36	1.9	2.49	3.46	3.87	3.28	4.36	4.72	4.59
G.S.R.B 6	1.09	1.27	1.98	3.42	4.21	3.85	4.35	5.61	5.2	5.71

G.G.R.A 7	0.82	1	2.51	2.4	3	3.4	4.39	4.43	5.34	6
G.G.R.B 8	1.49	1.91	2.22	2.42	3.2	2.93	2.5	4.14	4.69	3.02
G.S.R.A 13	0.85	1.14	1.03	1.2	1.22	1.36	1.81	1.66	1.85	2
G.S.R.B 14	0.49	0.37	0.79	1.68	1.55	2	2.8	2.9	2.89	3.28
G.G.R.A 15	3	3.42	3.98	4.65	6.38	7.1	7.68	7.43	9.45	7.14
G.G.R.B 16	0.88	2.79	3.25	3.22	6.08	6.15	6.31	5.44	4.2	1.33
R.C.R 18	0.31	0.26	1.55	1.52	1.88	1.63	1.67	1.95	2.39	2.13

7. CONCLUSIONS

1. The compressive strength increased by 24% for the first mixture when compared with the third mixture and by 5% when compared with the second mixture.
2. The tensile strength increased by 104% for the first mixture when compared with the third mixture and by 96% when compared with the second mixture.
3. The flexural strength increased by 59% for the first mixture when compared with the third mixture and by 3% when compared with the second mixture.
4. The optimal ratio of PVA in mixture represents 0.2 %.
5. When comparing beams made of geo-polymer concrete with ordinary concrete, the best percentage of increase in ultimate strength was observed for beam NO.6 (GSRB14) (45%) which reinforced by steel bars 2ϕ12mm at top and 2ϕ16mm at bottom.
6. All the beams that were reinforced with the minimum reinforcement gave less resistance than the beam made of concrete under repeated load, which is beam No.1, beam No.3, beam No.5, and beam No.7 where the percentage of decrease was -11%,-43%, -1.3%, and -14% respectively.
7. The percentage of increase in the ultimate strength when compared with ordinary concrete was for beam No. 2 is 40%, beam No.4 is 10% and beam No.8 is 14%.
8. It has been observed that the structural behavior of geo-polymer concrete beams tends to be more flexible when compared to that of ordinary concrete beams.
9. The maximum deflection in all samples was high compared with the normal concrete, where the ultimate deflection reached 29 mm, while in the normal concrete it was 12.53mm.
10. Noticed that the first crack was delayed in appearing in the geopolymer samples compared to the normal concrete, due to the presence of steel fiber and PVA.

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Persian Abstract

چکیده
یافتن مصالح جایگزین برای ساخت و سازهای ساختمانی امروزه پس از آلودگی هوا ناشی از کارخانجات حفاظ سیمان موضوعی ضروری است و در عین حال مهندسان به فکر یافتن چنین موادی از زباله های محیطی برای به حداقل رساندن آلودگی های زمین هستند. ژئوپلیمر ماده بسیار مهمی است که چنین شرایطی را برآورده می‌کند، زیرا نیاز به تولید بتن را به حداقل می‌رساند و از بسیاری از سربارەها بر محیط غلبه می‌کند. تیرهای ژئوپلیمری تحت بارهای مکرر ریخته گری و آزمایش شدند تا امکان استفاده از آنها به عنوان اعضای سازه ای در معرض بارهای مکرر بررسی شود. تیرها همچنین توسط الیاف فولادی و GFRP تقویت می شوند تا تأثیر آنها بر چنین اعضای ساختاری جدیدی بررسی شود. نتیجه گیری شد که مشاهده شده است که رفتار ساختاری تیرهای بتنی ژئوپلیمری در مقایسه با تیرهای بتنی معمولی انعطاف پذیرتر است. همچنین، اعضای ژئوپلیمر در هنگام استفاده از الیاف فولادی و GFRP، بهبود مقاومت را نشان دادند، چیزی که در بتن معمولی مشاهده شد.