Nexo Revista Científica
Vol. 36, No. 06, pp. 1049-1061/Diciembre 2023

ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v36i06.17462

Flexural behavior of steel fiber reinforced slag- based geopolymer concrete beams

Comportamiento a la flexión de vigas de hormigón geopolímeras a base de escoria reforzadas con fibras de acero

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(recibido/received: 30-agosto-2023; aceptado/accepted: 25-noviembre-2023)

ABSTRACT

This study includes tested nine reinforced concrete beams. It's designed to fail in flexural under two-point load. All beams are classified according to the type of concrete and the percentage of PVA into three groups. The first group including four reinforced geopolymer concrete beams with percent of PVA was 0.2 %; second group including four reinforced geopolymer concrete beams with percent of PVA was 0.75 % and third group including one reinforced normal concrete beam. The results showed when comparing the geopolymer concrete beam with the normal concrete beam, noticed that the ultimate strength is equivalent to many times the normal concrete. The best percentage for improving the ultimate load for beam NO.6 (GSSB10) where the percentage of increase was 132% this beam is reinforced by steel bars 2ϕ12mm at top and 2ϕ16mm at bottom. As for the other beams, the percentage increase in ultimate load was for beam NO.1 (46%), beam NO.2 (99%), beam NO.3 (13%), beam NO.4 (60%), beam NO.5 (58%), beam NO.7 (32%) and beam NO.8 (66%). The maximum deflection in all samples was high compared with the normal concrete, where the ultimate deflection reached 30 mm, while in the normal concrete it was 9.65 mm.

Keywords: Geopolymer; GFRP; PVA Alcohol; Steel fiber.

RESUMEN

Este estudio incluye nueve vigas de hormigón armado ensayadas. Está diseñado para fallar en flexión bajo carga de dos puntos. Todas las vigas se clasifican según el tipo de hormigón y el porcentaje de PVA en tres grupos. El primer grupo que incluye cuatro vigas de hormigón armado con geopolímero con un porcentaje de PVA fue del 0,2 %; el segundo grupo incluía cuatro vigas de hormigón armado con geopolímero con un porcentaje de PVA de 0,75 % y el tercer grupo incluía una viga de hormigón armado normal. Los resultados mostraron que al comparar la viga de hormigón geopolímero con la viga de hormigón normal, se observó que la resistencia última es equivalente a muchas veces la del hormigón normal. El mejor porcentaje para mejorar la carga última para la viga NO.6 (GSSB10), donde el porcentaje de aumento fue del 132%, esta viga está reforzada con barras de acero de 2ϕ12 mm en la parte superior y 2ϕ16 mm en la parte inferior. En cuanto a las otras vigas, el aumento porcentual en la carga última fue para la viga NO.1 (46%), viga NO.2 (99%), viga NO.3 (13%), viga NO.4 (60%), viga NO.5 (58%), viga NO.7 (32%) y viga NO.8 (66%). La deflexión máxima en todas las muestras fue alta en

comparación con el hormigón normal, donde la deflexión máxima alcanzó los 30 mm, mientras que en el hormigón normal fue de 9,65 mm.

Palabras claves: Geopolímero; PRFV; Alcohol PVA; Fibra de acero.

1. INTRODUCTION

Reinforced concrete (RC) is one of the most commonly used composite materials in the construction of roads, bridges, buildings, and other civil infrastructures. The demand for this material is expected to increase in the future owing to the rise of infrastructure needs in many developing and industrialized countries. In fact, it is estimated that the total global infrastructure demand amounts to USD 4.0 trillion with a gap of at least USD 1.0 trillion per year (Ascione et al., 2014). Due to the serviceability and economic issues owing to the costly repair and rehabilitation of damaged RC structures caused by the corrosion of the steel bars and the sustainability issue owing to the extremely resource- and energy-intensive process of producing steel and cement materials, however, many engineers and researchers have sought viable alternatives. Among the solutions that are currently being employed are replacing cement-based concrete with geopolymer concrete and replacing steel bars with fibre-reinforced polymer (FRP) bars. Neither, however, can solve the issues altogether (Hardjito et al., 2004).

A large number of research, has been studied on the behavior of GFRP strengthened of geopolymer beams (Ahmed, 2014; Al-Husseinawi et al., 2022; Kumaravel et al., 2022; Sharath et al., 2018; Zeini et al., 2023; Zhang et al., 2021).

2. EXPERIMENTAL WORK

The experimental work included casting nine reinforced beams. It is designed to fail in flexural under two point loads based on (ACI 318R-05) (Guide et al., n.d.). All beams are classified according to the type of concrete and the percentage of PVA into three mixing. All beams have the same dimension (1600mm*150mm*250mm).

2.1. Materials properties

2.1.1 Ground Granulated Blast Furnace Slag (GGBS):

Properties of Ground Granulated Blast Furnace Slag that used was shown in Table 1.

Table 1. Properties of Ground Granulated Blast Furnace Slag

Model Number:	S95
SLAG:	Hot
Type:	Powder
COLOR:	Light Grey
FINENESS:	490-510 M2/kg

2.1.2 Steel Fibers:

Hooked end by (length 30 mm, diameter 0.51mm) were used in this study and the properties of the steel fiber shown in Table (2).

Table 2. The properties of the steel fiber.

Property	Specifications
Appearance	Bright and clean wire
Diameter	0.51 mm
Length	30.2 mm
Density (kg/m3)	7800 kg/m3
Tensile strength (MPa)	1200
Aspect ratio (L/d)	60

2.1.2 Reinforced Bars:

Two type of longitudinal reinforced bars that used, steel bars and GFRP bars(Glass Fiber Reinforced Polymer). With different diameter for steel bars used 12mm and 16mm, for GFRP bars used 10mm and 14mm. all beams design for minimum steel and GFRP bars. For transverse reinforced used 10mm @100mm for all beams. Table (3) showed the properties of steel and GFRP bars.

Table 3. The properties of steel and GFRP bars.

No.	Nominal Bar Diameter	Bar Type	Description of bar	Yield Stress (MPa)	Ultimate Stress (MPa)	The bending result is at 180°
1	10 mm	Steel	Deformed	508	635	successful
2	12 mm	Steel	Deformed	524	655	successful
3	16 mm	Steel	Deformed	560	659	successful
No.	Nominal Bar Diameter	Bar Type	Description of bar	Tensile strength (MPa)		The bending result is at 180°
4	10 mm	GFRP	Deformed	895		Not successful
5	14 mm	GFRP	Deformed	1169		Not successful

2.2 Preparation Alkaline Solution for Geopolymer and Poly(vinyl alcohol) (PVA):

In this study, an 8 molar of NaOH was used, and the Table (4) shows the amount used for 1kg. Flaky sodium hydroxide (Hallensleben, 2000) was added to the sodium silicate solution to produce an alkali activator solution. The Flaky sodium hydroxide is mixed with water 24 hours before it is mixed with the Na2SiO3, and after 24 hours have passed, it is mixed with the Na2SiO3 and waited for at least an hour before adding it to the geopolymer mixing.

Table 4. Amounts of NaOH Solids for 1 Kg of Solution

Molarity (mole/L)	Weight NaOH Flakes (g)	Weight of Water (g)
8 mol.	262	738

The PVA powder is mixed with water to obtain a solution saturated with water and added to the mixture. Where 80 gm of powder is added to 2 liters of water and heated to a temperature of 80 ° C for two hours with continuous stirring of the mixture until it is homogeneous, obtaining a viscous liquid. After the powder was dissolved, the solution was allowed to cool down at ambient temperature in the laboratory.

2.3 The mixing proportion and casting of samples:

From the 1st beam to the 4th beam using 1st mixing, From the 5th beam to the 8th beam using 2nd mixing and 9th beam using 3rd mixing. The mixing proportion for all beams as shown in Table (5), the mixing is done by using concrete mixture. For each beam two concrete cube samples (100mm*100mm*100 mm), two concrete cylinder samples (100mm*200mm) and one prism (100mm*100 mm*500 mm) were made at the time of casting beams and were kept 28 days for curing. Figure1 and Table 6 showed description and details of tested beam specimens.

Table 5. 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	

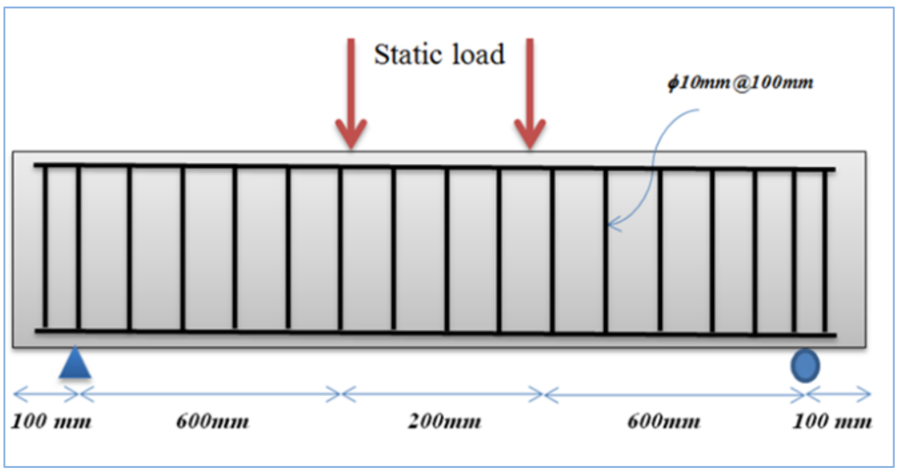
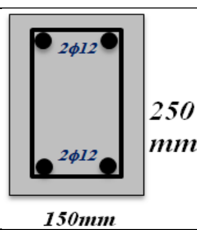
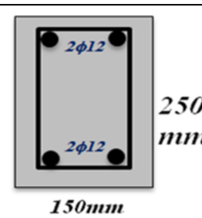


Figure 1. tested beam specimens.

Table 6. showed description and details of tested beam specimens.

1st mixing. (geopolymer)			2nd mixing. (geopolymer)		
Beam Symbol	Type of longitudinal reinforcement	Section	Beam Symbol	Type of longitudinal reinforcement	Section
1-GSSA1	steel		5-GSSA9	steel	

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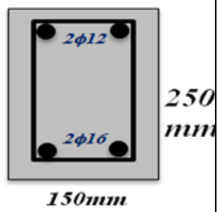
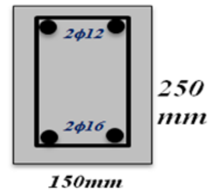
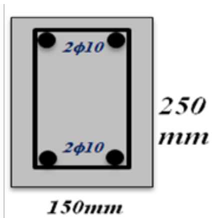
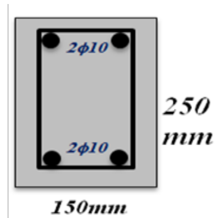
<tr><td>2-
GSSB2</td><td>steel</td><td>
</td><td>6-
GSSB10</td><td>steel</td><td>
</td></tr>
<tr><td>3-
GGSA3</td><td>GFRP</td><td>
</td><td>7-
GGSA11</td><td>GFRP</td><td>
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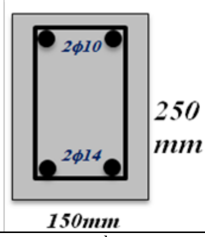
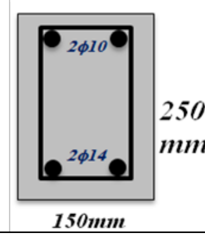
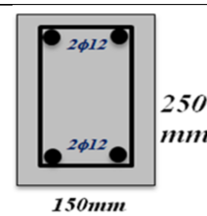
GGSB4</td><td>GFRP</td><td>
</td><td>8-
GGSB12</td><td>GFRP</td><td>
</td></tr>
<tr><td colspan="6">3rd mixing. (Normal concrete)</td></tr>
<tr><td colspan="2">Beam Symbol</td><td colspan="2">Type of longitudinal reinforcement</td><td colspan="2">Section</td></tr>
<tr><td colspan="2">9-
RCS16</td><td colspan="2">Steel</td><td colspan="2">
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3. EXPERIMENTAL RESULTS

Experimental results including mechanical properties of mixtures and results from tested beam specimens which including ultimate load, crack patterns, first crack and load-deflection curve.

3.1 Mechanical properties:

After curing the samples in standard conditions (cubes, cylinders and prisms), and after a 28 day has passed, the mechanical properties are tested, which includes compressive strength, tensile strength and flexural strength as shown in Table 7 and Figure 2.

Table 7. mechanical properties.

No.	Mixing type	Compressive strength (MPa)	Split tensile (MPa)	Flexure test (MPa)
1	1st mixing (geopolymer 0.2% PVA)	47	4.7	4.92
2	2nd mixing (geopolymer 0.75% PVA)	40	4.5	3.207
3	3rd mixing (normal concrete)	38	2.3	3.1

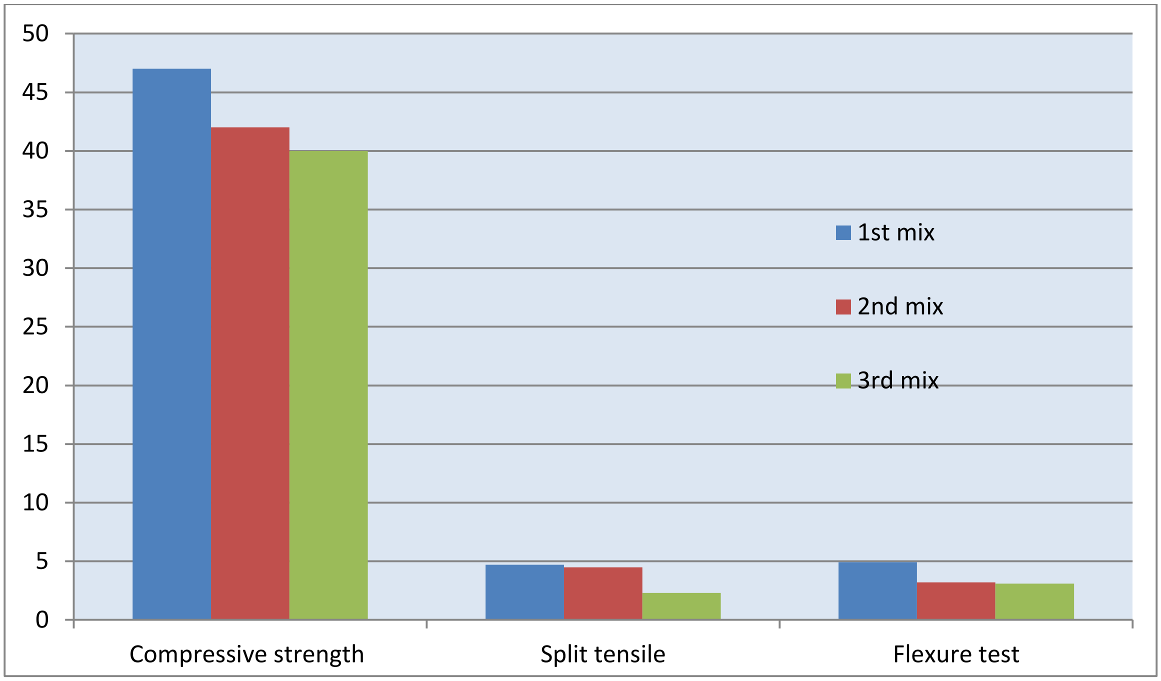


Figure 2. mechanical properties of mixtures.

The results from the mechanical properties showed that:

- The increase in the compressive strength of the first mixture was 24% compared to the normal concrete and 5% compared to the second mixture.
- In terms of tensile strength, the increase in the first mixture was 104% compared to normal concrete and 96% compared to the second mixture.
- -For the flexural test of the prism, the increase in the flexural strength of the first mixture was 59 % compared to the normal concrete and 3% compared to the second mixture.
- The increase in the percentage of PVA from 0.2% to 0.75% led to a decrease in compressive strength, so the optimal ratio in this mixture represents 0.2 %.

3.2 Beams results

Including the results from tested nine reinforced beams failing in flexural and investigate the structural behavior under static load. The results included ultimate load strength, crack patterns, the first crack, and load-deflection curve. According to the different in percentage of PVA and type of concrete the beams classified into three groups:

3.2.1 First group:

Including four reinforced geopolymer concrete beams with percent of PVA was 0.2 %:

- Beam (GSSA1)

Beam GSSA was made from geopolymer concrete with percentage of PVA 0.2% designed with longitudinal steel reinforcement 2ϕ12mm at top and bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 57 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 221 KN. The ultimate deflection in mid span was 11 mm. Figure 3 shown the beam after failure.

Figure 3. Beam GSSA1 after failure.

- Beam (GSSB2)

Beam GSSB was made from geopolymer concrete with percentage of PVA 0.2% designed with longitudinal steel reinforcement 2ϕ12mm at top and 2ϕ16mm at bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 80 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 300 KN. The ultimate deflection in mid span was 20 mm. Figure 4 shown the beam after failure.

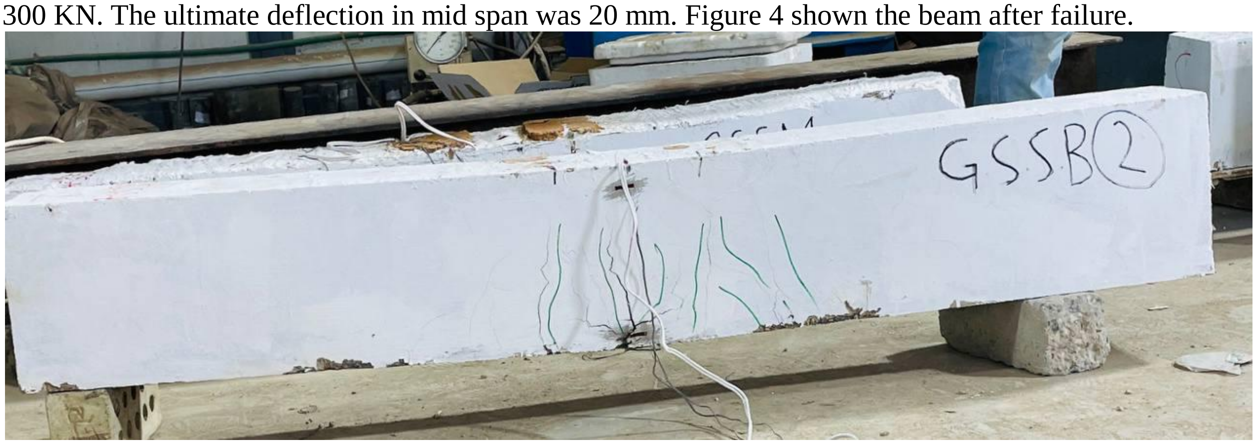


Figure 4. Beam GSSB2 after failure.

- Beam (GGSA3)

Beam GGSA3 was made from geopolymer concrete with percentage of PVA 0.2% designed with longitudinal GFRP reinforcement 2ϕ10mm at top and bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 50 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 170 KN. The ultimate deflection in mid span was 20 mm. Figure 5 shown the beam after failure.

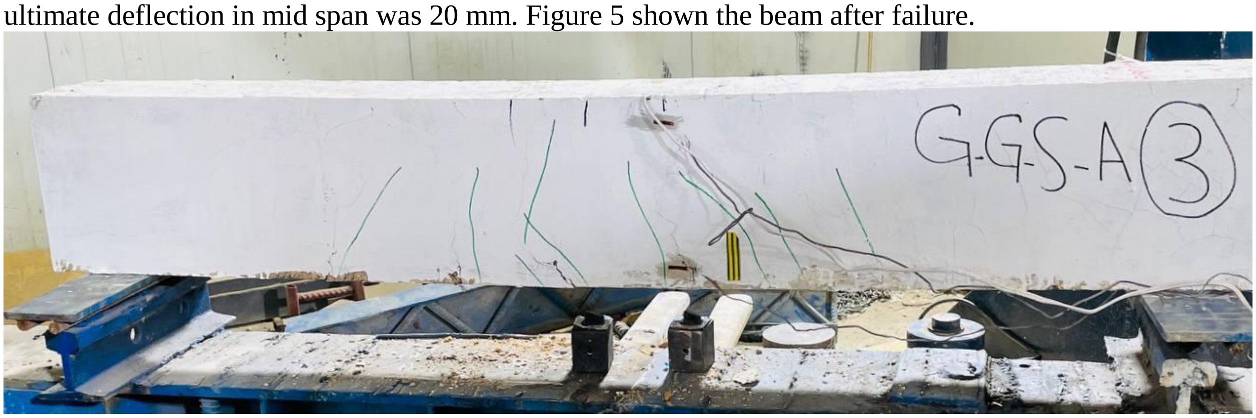


Figure 5. Beam GGSA3 after failure.

- Beam (GGSB4)

Beam GGSB was made from geopolymer concrete with percentage of PVA 0.2% designed with longitudinal GFRP reinforcement 2ϕ10mm at top and 2ϕ14mm at bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 61 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 241 KN. The ultimate deflection in mid span was 24.53 mm. Figure 6 shown the beam after failure.

Figure 6. Beam GGSB4 after failure.

3.2.2 Second group:

Including four reinforced geopolymer concrete beams with percent of PVA was 0.75 %:

- Beam (GSSA9)

Beam GSSA9 was made from geopolymer concrete with percentage of PVA 0.75% designed with longitudinal steel reinforcement 2ϕ12mm at top and bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 53 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 238 KN. The ultimate deflection in mid span was 19.94 mm. Figure 7 shown the beam after failure

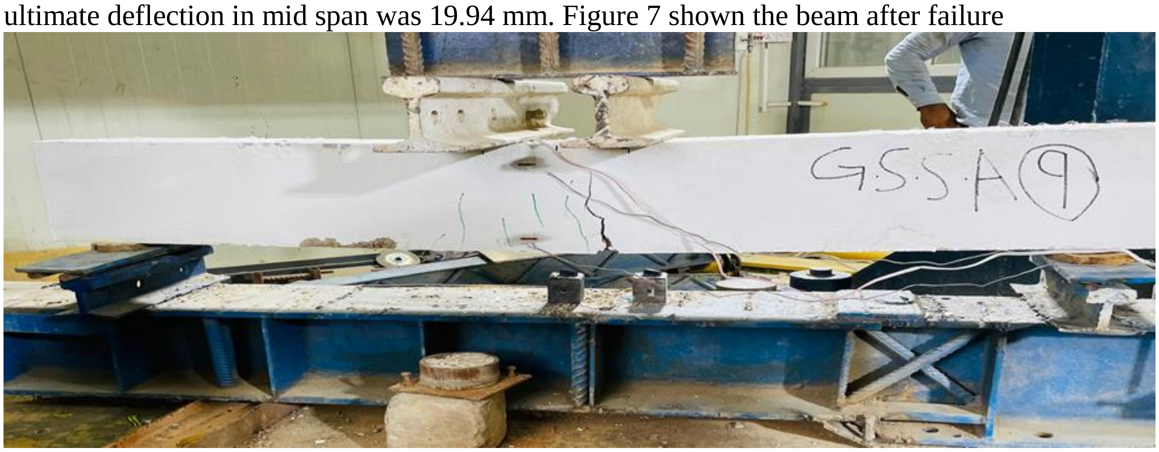


Figure 7. Beam GSSA9 after failure.

- Beam (GSSB10)

Beam GSSB10 was made from geopolymer concrete with percentage of PVA 0.75% designed with longitudinal steel reinforcement 2ϕ12mm at top and 2ϕ16mm at bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 92 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 350 KN. The ultimate deflection in mid span was 24.4 mm. Figure 8 shown the beam after failure.

Figure 8. Beam GSSB10 after failure.

- Beam (GGSA11)

Beam GGSA was made from geopolymer concrete with percentage of PVA 0.75% designed with longitudinal GFRP reinforcement 2ϕ10mm at top and bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 61 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 200 KN. The ultimate deflection in mid span was 29.2 mm. Figure 9 shown the beam after failure.

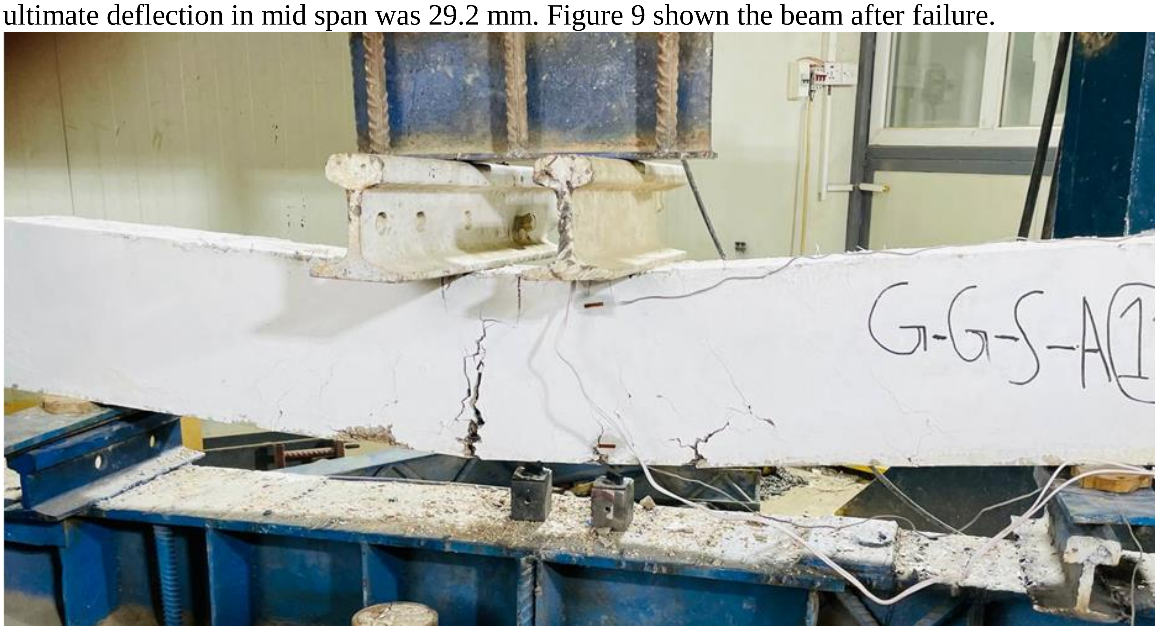


Figure 9. Beam GGSA11 after failure.

- Beam (GGSB12)

Beam GGSB was made from geopolymer concrete with percentage of PVA 0.75% designed with longitudinal GFRP reinforcement 2ϕ10mm at top and 2ϕ14mm at bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 50 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 250 KN. The ultimate deflection in mid span was 25.31 mm. Figure 10 shown the beam after failure.

Figure 10. Beam GGSB12 after failure.

3.2.3 Third group:

Including Beam (RCS 17) was made from concrete designed with longitudinal steel reinforcement 2ϕ12mm at top and bottom. When testing the specimen and applying the static load, the first crack appeared at tension zone when the load was about of 45 KN. With increasing of load the flexural cracks appeared and the beam was failure in flexural at ultimate load was 151 KN. The ultimate deflection in mid span was 9.65 mm. Figure 11 shown the beam after failure.

Figure 11. Beam RCS 17 after failure.

Ultimate loads, cracking loads and modes of failure for all beams provided in Table (8).

Table 8. ultimate loads, cracking loads and modes of failure for all beams.

Beam	Beams	First crack	Ultimate	Increasing of	Failure mode

No.	Symbol	loading (KN)	load (KN)	ultimate load %	
9	RCS17	45	151	------	Flexure failure
1	GSSA1	57	221	46	Flexure failure
2	GSSB2	80	300	99	Flexure failure
3	GGSA3	50	170	13	Flexure failure
4	GGSB4	61	241	60	Flexure failure
5	GSSA9	53	238	58	Flexure failure
6	GSSB10	92	350	132	Flexure failure
7	GGSA11	61	200	32	Flexure failure
8	GGSB12	50	250	66	Flexure failure

Comparison the Load-deflection curve for beams in 1st group (beams No. 1, 2, 3, 4) and 3rd group (beam No. 9) also for beams in 2nd group (beams No. 5, 6, 7, 8) and 3rd group (beam No. 9) as shown in Figure 12. And Comparison the Load-deflection curve for each two beams which have the same properties and steel bars with normal concrete beam (No. 9) shown in Figure 13.

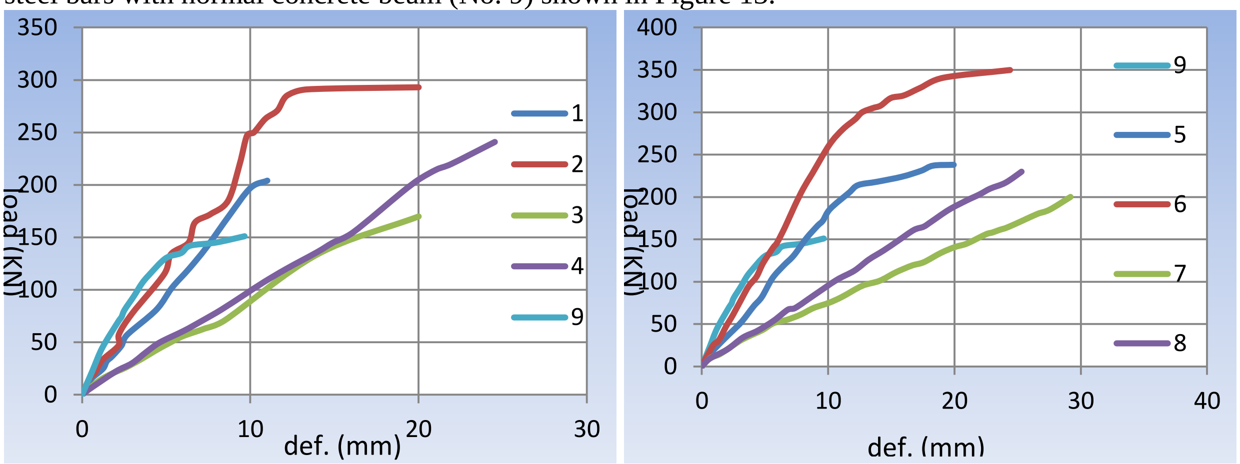
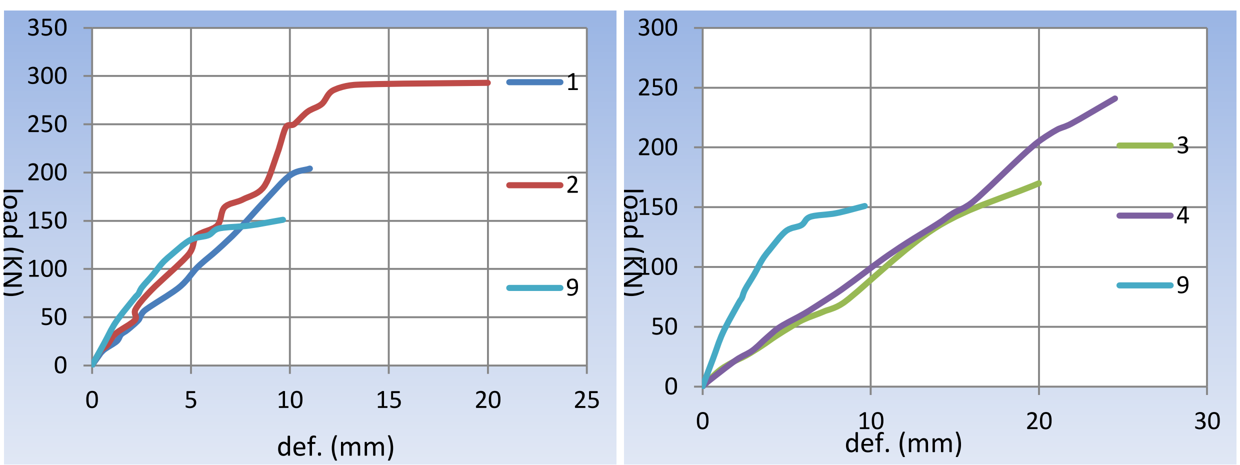


Figure 12. comparison the Load-deflection curve between beams in the same group.



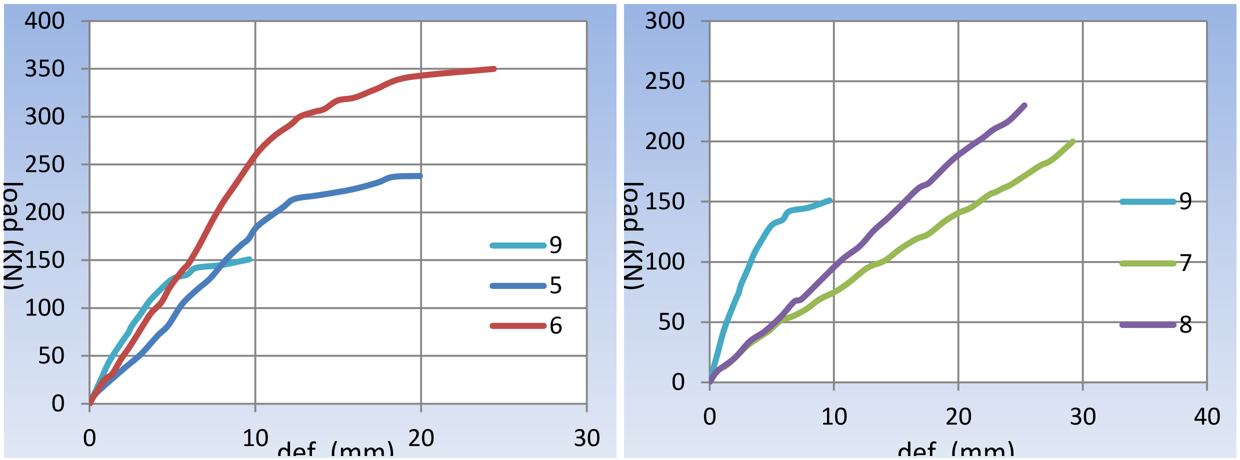


Figure 13. comparison the Load-deflection curve between beams which have the same properties.

4. CONCLUSIONS

- When comparing the geopolymer concrete beam with the normal concrete beam, noticed that the ultimate strength is equivalent to many times the normal concrete.
- The best percentage for improving the ultimate load for beam NO.6 (GSSB10) where the percentage of increase was 132 % this beam is reinforced by steel bars 2ϕ12mm at top and 2ϕ16mm at bottom.
- As for the other beams, the percentage increase in ultimate load was for beam NO.1 (46%), beam NO.2 (99%), beam NO.3 (13%), beam NO.4 (60%), beam NO.5 (58%), beam NO.7 (32%) and beam NO.8 (66%).
- The geopolymer mixture significantly strengthens the tensile strength of concrete because it contains PVA and steel fiber ... in addition to its resistance to compressive strength.
- The maximum deflection in all samples was high compared with the normal concrete, where the ultimate deflection reached 30 mm, while in the normal concrete it was 9.65 mm.
- When observing the lode-deflection curve, we notice the best behavior of beam NO.6 (GSSB10).
- Noticed the curve of the load -deflection, as in beam No.8 (GGSB12), that tends to be more brittle , and that is because geopolymer concrete is considered a ductility material and the iron used in it is was GFRP considered a brittle material.
- 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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