Rehabilitation Of Geopolymer Reinforced Concrete I-Section Beams by Fiber Reinforced Polymer Bottom Strips

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ABSTRACT

The key factor contributing to global warming is the huge CO_2 emissions that can be related to the production of cement. Thus, Finding long-term answers to this issue is therefore driven by a variety of motivations for both the writers and research groups. When certain source materials, such as fly ash, metakaoline, rice husk ash, and crushed granulated blast furnace slag are alkali activated, the resulting principal binder is what is known as geopolymer concrete. Commonly, geopolymer concrete has mechanical strength characteristics similar to those of traditional concrete. Repairing RC beams refers to the actions that can be done in order to recover the inherent structural behavior before failure. This study was devoted to examine feasibility of using bottom strips technique that made by fiber reinforced polymers to repair pre-failed I – section reinforced geopolymer beams. Both Glass and Carbon fiber reinforced polymer strips were used and compared. The results showed that the proposed technique was able to recover the service load and the maximum load. The stiffness levels was increased after rehabilitation for both glass and carbon fiber. The initial cracking load occurrence was changed in nature from the tension to compression zone after repairing.

Keywords: *FLEXURAL; Shear; Fly ash; Metakaoline; Slag; and Carbon Dioxide.*

1. Introduction

High energy use and significant waste disposal are characteristics of the building sectors.. Because of the negative consequences on the environment, this is a significant issue in relation to global warming. Within this context, the cement industry has a major share within these problems due to the high Carbon Dioxide (CO_2) emissions [1-5]. In this way, seeking for other alternatives that can compensate cement is a serious task for the authors in the civil engineering scientific field [6-10].

"Geopolymer" are such materials that can be synthesized by the alkali activation of any suitable alumino-silicate materials such as slags, metakaoline, fly ash and red mud [11-14].

The resulted matrix of the "Geopolymerization Process" is a hardened matrix that can play the same role of ordinary Portland cement (as the primary binder). To manufacture adequate and stable geopolymer, the source materials must be highly reactive, easy to release aluminum, and have moderate water consumption [15-22]. Many materials can be used as alkali activators such as Sodium Hydroxide (NaOH), Potassium Silicate (K_2SiO_3), Sodium Silicate (Na_2SiO_3), and Potassium Hydroxide (KOH) [23-30]

Since the geopolymer hardened matrix has good mechanical strength, stiffness, and durability properties [30-34], geopolymer concrete can be reinforced to play the same role of conventional reinforced concrete that wholly used in civil engineering applications.

2. Geopolymerization

In normal cases and circumstances, SiO_4 and AlO_4 tetrahedral units become free after the dissolving of alumino – silicate reaction. Then after that, such units are usually attached to the polymeric precursor and Oxygen atoms are released accordingly. As a result, the bonding structure of Si–O–Al–O are formed. The following chemical formulas describes the chemical reactions of geopolymerization [14].

$$\mathbf{(Si_2O_5.Al_2O_2)_n+H_2O+OH^- \text{-->} Si(OH)^4+Al(OH)^{4-}}$$

$$\mathbf{Si(OH)_4+Al(OH)^{4-} \text{--} (\text{-}Si\text{-}O\text{-}Al\text{-}O\text{-})_2+4H2O} \quad \ldots\ldots\ldots\ldots(1)$$

$$\mathbf{O \quad O}$$

The released water during the intended reaction plays a good role for workability and facilitates handling [36-44]. However, this opposites the role of ordinary Portland cement where high level of water consumption can be noticed during the entire process of hydration [45-49]. Figure 1 illustrates this process schematically.

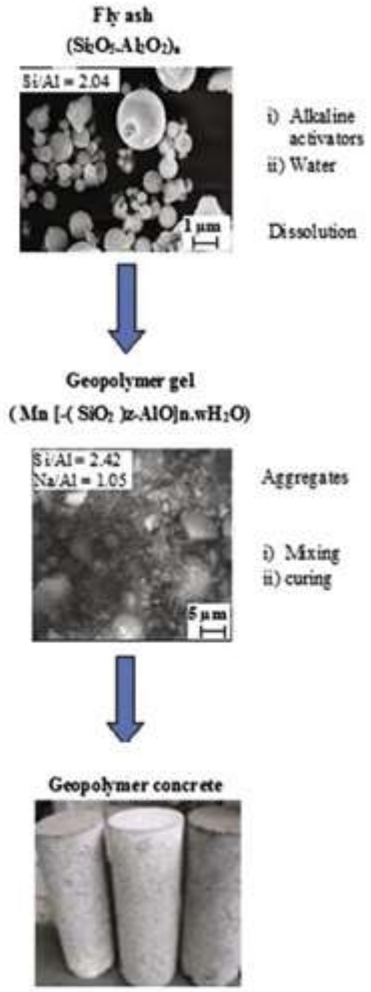


Figure 1. Geopolymerization process, schematic representation [14].

3. Rehabilitation and retrofitting

When a building's structure has fully deteriorated, rehabilitation means enhancing its capabilities by increasing its functions. The term "retrofitting" refers to the strengthening of a building structure after or before it has deteriorated structurally.

Recent important advancements brought by by research programs have offered appropriate effort methods and materials to achieve any improvement. However, major upgrade initiatives in the field of structure repair are included in such development methods.

However, correct technique selection is dependent on the underlying circumstances, and its failures are one of the most critical aspects in the total rehabilitation process. Many practitioners argue that rehabilitation is still a relatively new and demanding field for them. Due to the lack of similarity between any two structures, this process becomes more challenging. Choosing rehabilitation therapies is therefore a challenging endeavor driven by economic, technological, and societal considerations.

4. Importance of the Study

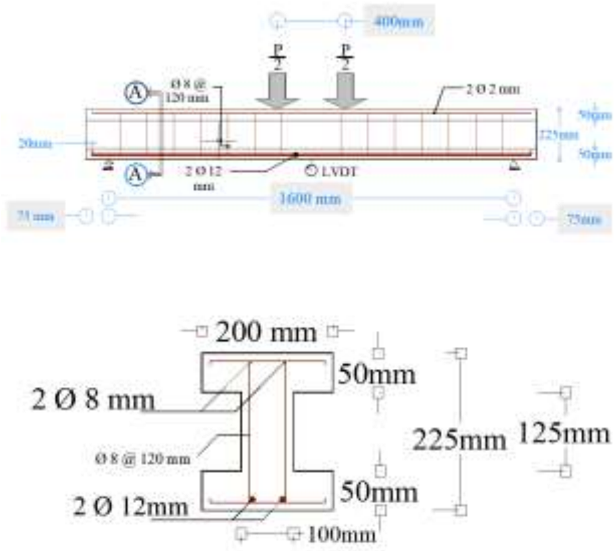
Obtaining trustworthy experimental data is essential for understanding the structural response of any structural part. This is important because the rehabilitation of RC is a very crucial issue within the civil engineering applications.

In this way, building a good background about this topic is justified for interested structural engineers, designers and scientific foundations.

5.Experimental program

5.1 Specimen Description

The span of the tested specimens within this experimental program is 1600mm center to center and 1750mm total length. Dimensions of section are of total height of 225mm and flange width of 200mm while the web width is 100mm and flange depth is 50mm. 2 φ 8mm top reinforcement and 2 φ 12mm bottom bars were used. In addition, φ 8mm stirrups were spaced @ 120mm from each end of beam as illustrated in Figure 2.



Section A – A

Figure 2: Specimen details of the present study

5.2. Materials

5.2.1 Fly Ash

The Class F fly ash that provided from "EUROBUILD" construction chemicals company was used within the present study as a source material for manufacturing GC. In addition, the X-Ray Fuorescence (XRF) testing was done in the National Center of Construction Laboratories and Researches (NCCLR) according to BS EN 196-2-2013 and the results shown in Table 1.

Table 1 XRF Analyses results of fly ash*

Composition Name	Composition Chemical	Weight %

	symbol	
Silica	SiO_2	47.67
Alumina	Al_2O_3	27.73
Alumina	Al_2O_3	27.73
Lime	CaO	5.11
Magnesia	MgO	2.65
Sulfur salts in term of SO3	When C3A < 3.5%	/
	When C3A > 3.5%	0.34
Insoluble residue	IR	/
Loss on ignition	LOI	2.39
Tri-calcium Aluminate	C3A	42.38
Chloride	Cl	/

*The National Center of Construction Laboratories and Researches (NCCLR) conducted this examination.

5.2.2 Sand

The sand used within the current study is Al-Ekhaider natural sand which is of 4.75mm maximum size for being the fine aggregate within mixes. The grading of such aggregate was illustrated within Figure 3. The required test of this sand was done in the according to Iraqi specification No.45/1984 within the laboratories of the Engineering Consulting Office / University of Al - Mustansiriyah.

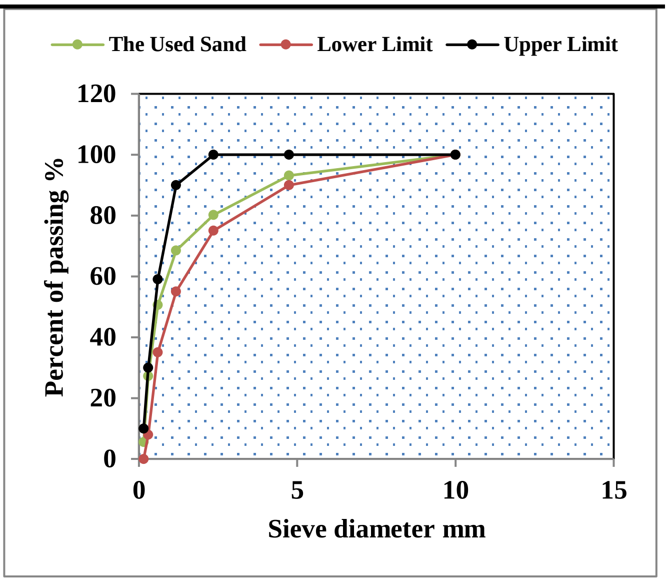


Figure 3. Sieve analyses of the used sand

5.2.3 Gravel

The 10mm maximum sized gravel that used within the present experimental program was brought from "AL-Nibaey" to be used as coarse aggregate within the mix. Such gravel was washed and air dried then stored by suitable containers till the date of testing, at that date, the gravel would be saturated "surface dried" before using. Figure 4 shows the grain size distribution of that gravel. The required test of this sand was done in the according to (B.S 882/1992) within the laboratories of the Engineering Consulting Office / University of Al - Mustansiriyah.

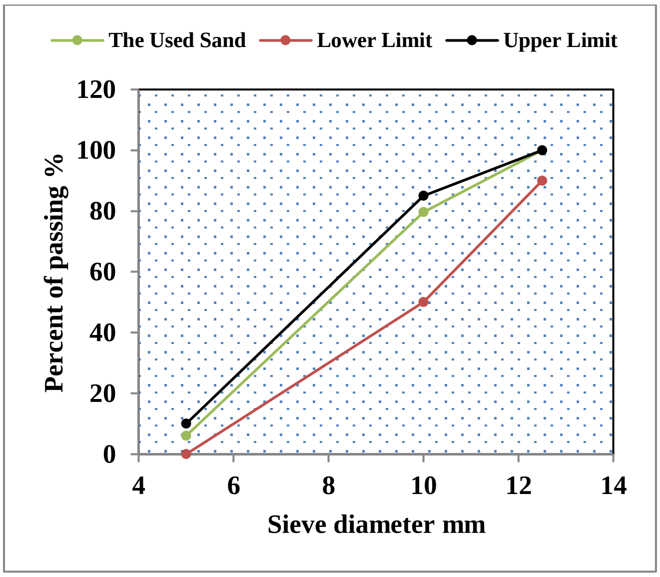


Figure 4. Sieve analyses of the used gravel

2.1.4 Sodium Hydroxide NaOH

The commercial NaOH solid slakes "Provided from Al Kout projects company" that were 98% pure and packed in 25 kg sealed containers was used within this study. The solvent of "sodium hydroxide" liquid is initially set by melting flakes to prepare the alkaline solution; the volume of "NaOH flakes" in the solution varies depending on the concentration that works needed. For this work, three solutions prepared with molar 10 M. This arbitrarily done by using NaOH flakes "314 g", respectively to make "(1kg) of the solution".

Table 2 Properties Sodium Hydroxide*

Components	Specification ASTM E291-09	Results
Sodium hydroxide (NaOH)%	>97.5	98.14
Sodium chloride (NaCl)ppm**	<200	70
Sodium carbonate (Na2C03)%	<0.40	0.36
Sulphate as Na2S04(ppm)	<200	70
Iron as Fe+3 (ppm)	< 10	4.5
Copper as Cu+2 (ppm)		0.1
Nickel as Ni+2 (ppm)	<5	2.42
Manganese as Mn+2 (ppm)		0.02
Silicate as SiO2 (ppm)	<20	14
Water Insoluble (ppm)	<200	60

* According to Manufacturer.

*Ppm: part per million according to manufacturer.

5.2.5 Sodium Silicate Na_2SO_3

Hal chemicals company sodium silicate or (glass water) is commercially available for industrial use. Na_2SiO_3 is a dense, sticky liquid that is clear to off white in color and has a faint odor. The water content of the sodium silicate was 55% by mass and their properties scheduled in Table 3 According to manufacturer.

Table 3 Sodium Silicate's Properties*

Value	Description
Appearance	hazy
Specific Gravity	1.534 - 1.551
Density - 20° Baume	51 ±0.5
The SiO_2-Na_2O ratio	2.4 ±0.05
Viscosity 20 ° C (CPS)	600-1200
SiO_2 % by weight	32-33
H_2O % by weight	55.1
Na_2O_3 % by weight	13.1 - 13.7

*According to Manufacturer.

5.2.6 Reinforcing Bars

The deformed bars that used throughout the present study are of 6mm and 8mm in diameter. The reinforcing steel testing results of such bars are listed in Table 4. Such tests are done according to American Testing Standard Measurements (ASTM) A615 within the laboratories of the Engineering Consulting Office / University of Al - Mustansiriyah.

Table 4 Tension tests results for steel bars within this study*

Nominal diameter mm	8	12
Normal diameter mm	7.89	11.983
Yield stress MPa	517	705
Yield strain mm/mm	0.00201	0.00211
Ultimate strength	654	557

MPa		
Ultimate strain mm/mm	0.167	0.171
Elongation %	10	9

*Engineering Consulting Office / University of Al - Mustansiriyah

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5.2.7 The FRP Properties

The mechanical characteristics of the FRP materials have used for this study presented in Table 5. Such FRP types were used in this study to rehabilitate geopolymer beams in four arrangements as presented within the next sections.

Table 5. Mechanical properties of the FRP materials

FRP materials	Young's Modulus (GPa)	Ultimate tensile strength (MPa)	Thickness of sheet in microns
Carbon	260	3330	670
Glass	70	3150	650

5.2.8 Epoxy Resin

For doing the required rehabilitation, KUT BOND epoxy resin is used within the current study, such material is a specially formulated non - shrink, non-sag, solvent free based system. It is supplied as a two component material in pre weighed quantities ready for on - site mixing . It is normally used as a bonder for old concrete to new freshly laid as well as old concrete and cementitious repair products.

5.3 Mix Proportions

Within the proposed experimental program, the mix design was taken from **Abdul Aleem and Arumairaj, (2012)**. Table 5 lists the final mix proportioned that used in casting the specimens.

Tables 6 The mix proportions quantities per one cubic meter.

Material	Fly Ash	Sand	Gravel	Na_2SO_3	10 Molar NaOH
Quantity (kg/m3)	408	571.2	1305.6	103	41

5.4 The Bottom Strips Technique

The rehabilitated specimens were fixed by conducting this technique by one layer of 800mm of CFRP and GFRP sheets taking the entire width of bottom flange as shown in Figure 5.

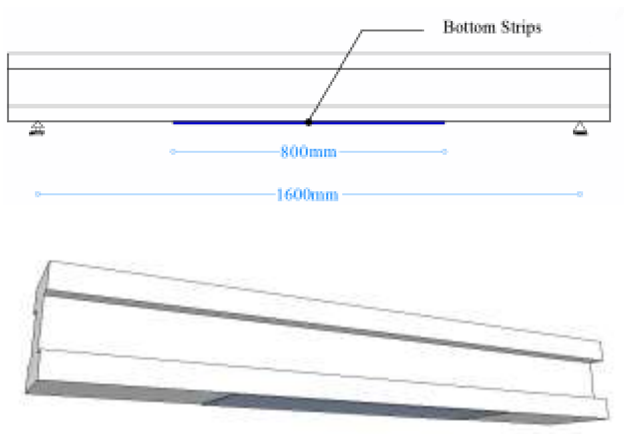


Figure 5 Bottom strips technique

6. Results and Discussion

This paper discusses the performance of the bottom strips technique in repairing the pre failed I – section reinforced GC beams. the intended repairing technique was examined by comparing the performance of the constructed specimen before and after repairing. The performance of the specimens is examined using the Initial Cracking Load (ICL), Service Load (SL), Maximum Load (ML), Deflection at service load (DS), Deflection at maximum load (DM), Stiffness Index (SI), Ductility Index (DI), Toughness Index (TI), Maximum Tension

Strain (MTS), Maximum Compressive Strain (MCS), Cracking and failure pattern.

The first specimen is BC which is I – section reinforced GC beam repaired by CFRP bottom strips. The second specimen is BG which is I – section reinforced GC beam repaired by GFRP bottom strips.

6.1 ICL, SL and ML

Table 7 and Figure 6 show the ICL, SL and ML of the BC and BG specimen before and after repairing. When CFRP used in bottom strips repairing technique, ICL, SL and ML increased by 144.31%, 10.84% and 10.94% respectively.

On the other hand, When GFRP used in bottom strips repairing technique, ICL, SL and ML increased by 102.02%, 6.99% and 7.01% respectively.

The presented outcomes refer clearly to the successful of the proposed technique (both with CFRP and GFRP) in the recovery of the original ICL, SL and ML. This successful can be interpreted by the fact that CFRP, GFRP as well as the used epoxy have good levels of mechanical strength .

In addition to that, the degrees of recovery of GFRP are less than the corresponding of CFRP as an expected result to the inherent preeminence of CFRP mechanical strength.

Table 6 ICL, SL and ML of BC and BG specimen before and after repairing.

Specimen	ICL (kN)	Change in ICL %	SL (kN)	Change in SL %	ML (kN)	Change in ML %
BC Before repairing	11.42	/	54.13	/	62.93	/
BC After repairing	27.90	144.31	60	10.84	69.82	10.94
BG Before repairing	12.83	/	50.34	/	60.51	/
BG After repairing	25.92	102.02	53.86	6.99	64.75	7.01

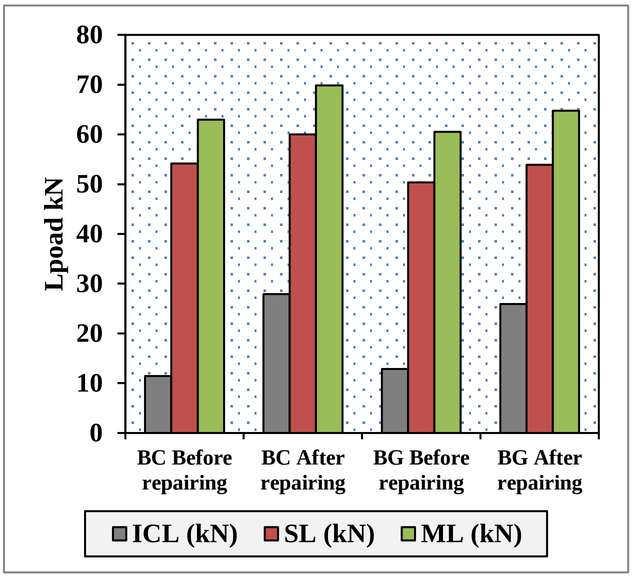


Figure 6. ICL, SL and ML of BC and BG specimen before and after repairing.

6.2 DS, DM and The Load Deflection Curve

Table 8 and Figure 7 show the DS and DM of the BC and BG specimen before and after repairing. When CFRP used in bottom strips repairing technique, decreased by 2.88% and 1.77% respectively .

When GFRP used in bottom strips repairing technique, DS and DM decreased by 14.99% and 20.03% respectively .

DS levels were decreased for both CFRP and GFRP. This may be due to the high level of stiffness of FRP – epoxy composite. DM level decreasing rate of BG is more than BF due to the ductility of CFRP is more than GFRP .

Figure 8 shows the load deflection response of the BC and BG before and after repairing. The response of the specimens before repairing is divided into three distinct states, the first state is located between the beginning of the response and the ICL limit. The second state begins after the ICL till the SL limit which corresponds the steel reinforcement yielding. The last state begins after SL till ML which corresponds the fracture limit (load carrying capacity. For the repaired specimens, the ICL occurred at the extreme fiber of compression since the sectional tensile face is pre-cracked then repaired by CFRP and GFRP which have high level of mechanical strength. So, the stresses were re distributed and a special kind of compressive failure was occurred. As a result of that, the ICL is higher than the un repaired specimen as illustrated previously .

The second state within the repaired completed the intended path to SL. The last state is also developed but in lower levels of ductility .

However, the next sections discusses the stiffness, ductility and toughness before and after repairing.

Table 8. DS and DM of BC and BG specimen before and after repairing.

Specimen	DS (mm)	Change in DS %	DM (mm)	Change in DM %
BC Before repairing	2.69	/	14.57	/
BC After repairing	2.59	-2.88	12.39	-14.99
BG Before repairing	2.82	/	14.07	/
BG After repairing	2.77	-1.77	11.25	-20.03

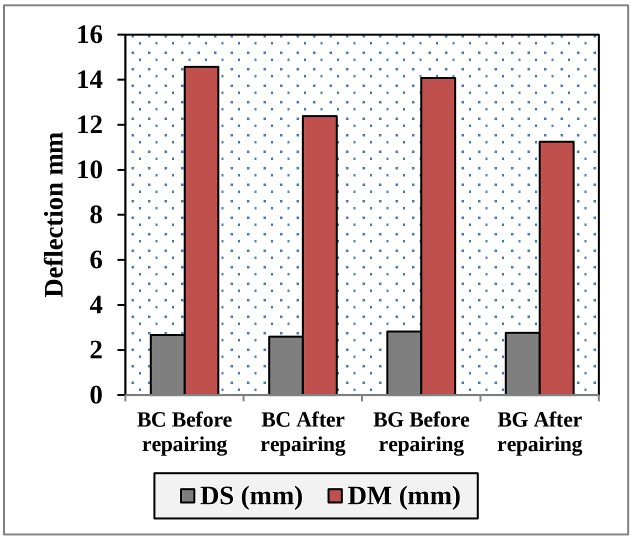
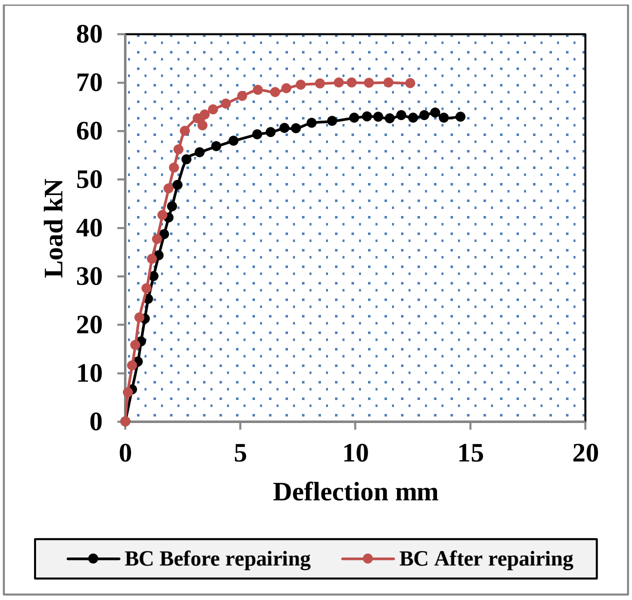


Figure 7. DS and DM of BC and BG specimen before and after repairing.



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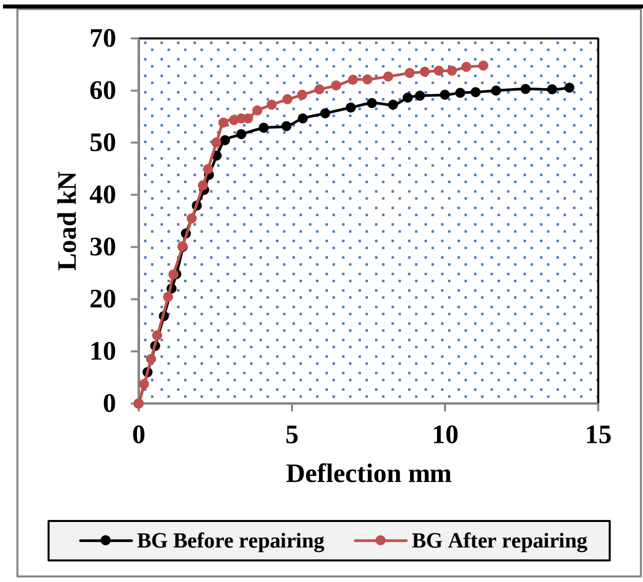


(b)

Figure 8. Load deflection response of Group one: (a) BC. (b) BG.

6.3 SI

The stiffness behavior of the I – section reinforced GC beams is represented by SI :

SI= SL/DS ………..……………..(4-1)

Where:

SI= Stiffness Index (kN/m)

SL= Service load (kN)

DS= Service deflection (mm).

Table 9 and Figure 9 show the SI of the BC and BG specimen before and after repairing. When CFRP used in bottom strips repairing technique, SI increased by14.14% while when CFRP used in bottom strips repairing technique, SI increased by 8.92% .

The increase in SI is an expected result to the decrease in DS and the resulted increase in SL. This can be attributed to the inherent good stiffness of FRP – epoxy composite. The difference in stiffness between CFRP and GFRP (as a material) is reflected on SI between BC and BG.

Further work is required to know the relation between the stiffness of FRP (as a material) and the resulted SI for every specified repairing technique .

Table 9 SI of BC and BG specimen before and after repairing.

Specimen	**DS (mm)**	**SL (kN)**	**SI=SL/DS (kN/mm)**	**Change in SI %**
BC Before repairing	2.69	54.13	20.30	/
BC After repairing	2.59	60.00	23.17	14.14
BG Before repairing	2.82	50.34	17.85	/
BG After repairing	2.77	53.86	19.44	8.92

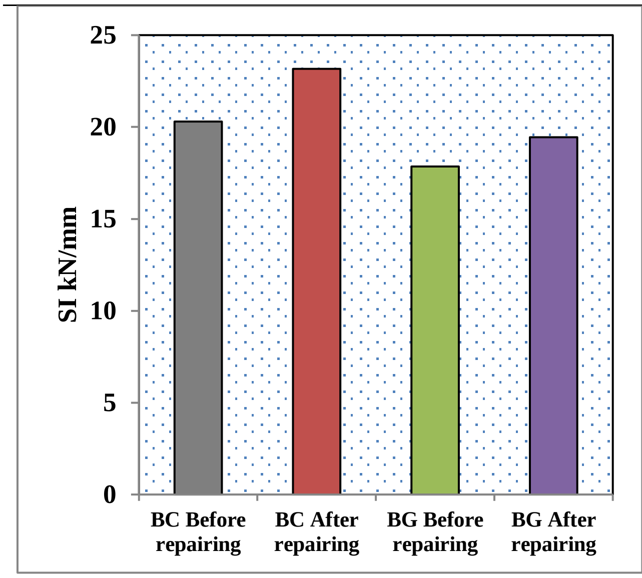


Figure 9. SI of BC and BG specimen before and after repairing.

6.4 DI

Turning again to Figure 8, there are obvious plastic deformation for repaired and unrepaired specimens. In this way the DI can be used to represent ductility behavior which represents the range of deformation within the third state of load deflection path. Such index can be calculated as follows:

DI=DM/DS ………..…….……………..(2)

Where:

DI= Ductility index.

DS= Service load (kN)

DM= Service deflection (mm).

Table 10 and Figure 10 show the DI of the BC and BG specimen before and after repairing. When CFRP used in bottom strips repairing technique, DI decreased by 12.45% while when CFRP used in bottom strips repairing technique, DI decreased by 18.64% .

It is obvious from that table that the ductility levels of the repaired specimens are less than these before repairing. This behavior can be attributed to the stiffness gain and the related loss in ductility.

Research questions that could asked include how much the ductility of the repaired specimen (for a specified repairing technique) is correlated to the inherent ductility of FRP (as a material).

Table 10. DI of BC and BG specimen before and after repairing.

Specimen	DS (mm)	DM (mm)	DI = DM/DS	Change in DI %
BC Before repairing	2.69	14.57	5.46	/
BC After repairing	2.59	12.39	4.78	-12.45
BG Before repairing	2.82	14.07	4.99	/
BG After repairing	2.77	11.25	4.06	-18.64

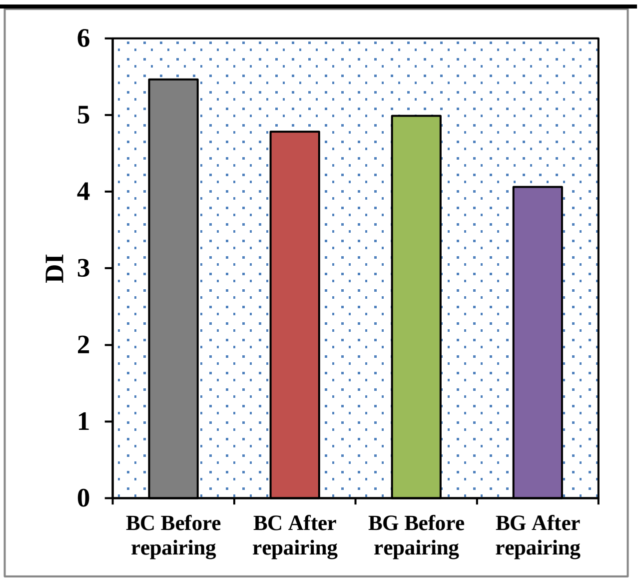


Figure 10. DI of BC and BG specimen before and after repairing.

6.5 TI

The toughness can be represented by the area under the load deflection curves (energy absorption). This represents the TI during this study which devoted to further understanding to the role of repairing after the plastic deformation phase (the third state within the path of load deflection curves).

Table 11 and Figure 11 show the TI of the BC and BG specimen before and after repairing. When CFRP used in bottom strips repairing technique, TI decreased by 5.71% while when CFRP used in bottom strips repairing technique, TI decreased by 17.72% .

The toughness of the repaired specimens are less than before repairing for both BC and BC. This results confirmed the outcomes of DI in the previous section.

The TI loss is more in GFRP than in CFRP due to the intended levels of SL and ML.

However, further research on this topic should be undertaken to examine more repairing technique that can compensate the resulted loss in toughness.

Table 11. DI of BC and BG specimen before and after repairing.

Specimen	TI	Change in TI%
BC Before repairing	801.68	/
BC After repairing	755.89	-5.71
BG Before repairing	720.92	/
BG After repairing	593.14	-17.72

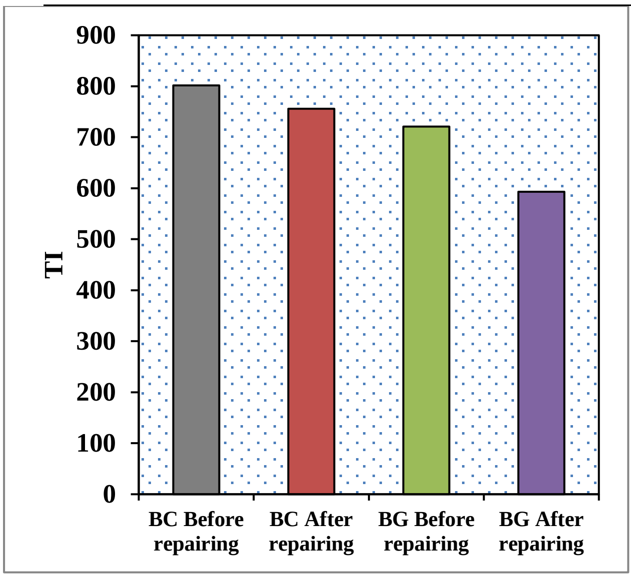


Figure 11. TI of BC and BG specimen before and after repairing.

6.6 Load Strain Behavior

The load strain behavior of the specimens before and after repairing is represented by load tension and load compressive strain diagrams.

6.6.1 The Load Tension Strain

Table 12 and Figure 12 show the load tension strain behavior of the BC and BG specimen before and after repairing .

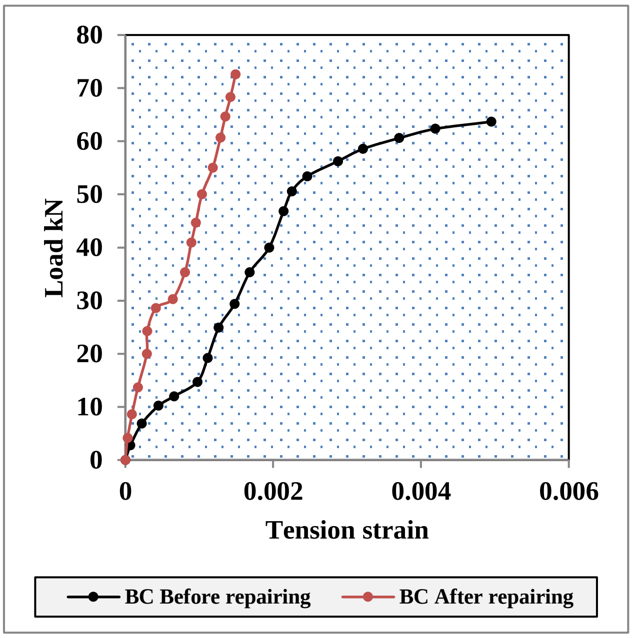
For the specimens before repairing, the load strain path showed a clear abrupt deviation at ICL as shown, in addition, the strain levels approach the yielding of steel reinforcement at the service load (0.002 to 0.0025) as shown.

For the repaired specimens, the new ICL is also obvious for both BC and BG, these load limits occurs at the compressive face as discussed earlier. The difference in load tension paths showed the difference in stiffness between GFRP and CFRP .

However, when CFRP used in bottom strips repairing technique, MTS decreased by 232.21% while when GFRP used in bottom strips repairing technique, MTS increased by 4.56%. These results confirmed the difference in load strain path mentioned above and the final MTS levels were still slightly lower than the known ultimate levels.

Table 12. MTS of BC and BG specimen before and after repairing.

Specimen	MTS	Change in MTS %
BC Before repairing	0.00495	/
BC After repairing	0.00149	-232.21
BG Before repairing	0.00482	/
BG After repairing	0.00504	+4.56



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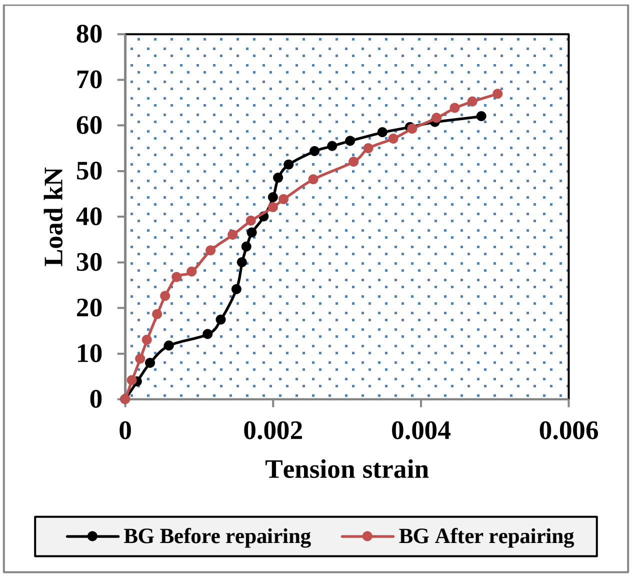


(b)

Figure 12. Load tension strain response before and after repairing: (a) BC. (b) BG.

6.6.2 The Load Compressive Strain

Table 13 and Figure 13 show the load compressive strain behavior of the BC and BG specimen before and after repairing .

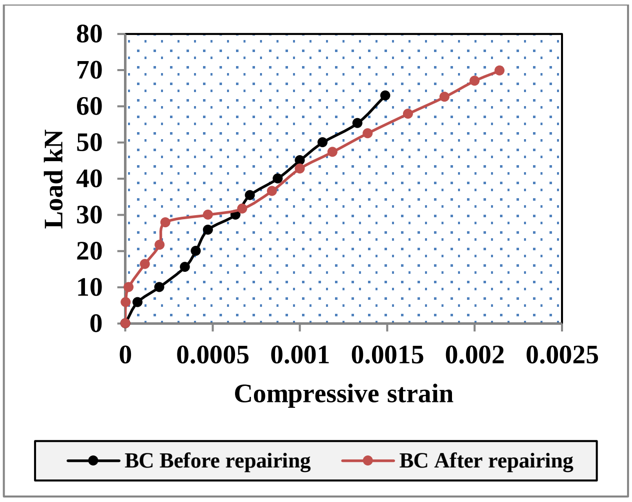
It can be seen from Figure 13 that the abrupt change in load compressive strain response (in the repaired specimens) is sharper than load tension strain. This behavior can be attributed to the fact that the first cracking occurrence in the repaired specimens is near the compressive strain gauge location within the specimen domain .

When CFRP used in bottom strips repairing technique, MCS increased by 43.62% while when GFRP used in bottom strips repairing technique, MCS increased by 34.19% .

The MCS levels didn't reach the crushing limits of the GC before repairing. On the other hand, the Crushing levels didn't exceeded extremely after the repairing due to the dictated confinement by CFRP and GFRP.

Table 13. MTS of BC and BG specimen before and after repairing.

Specimen	MCS	Change in MCS %
BC Before repairing	0.00149	/
BC After repairing	0.00214	43.62
BG Before repairing	0.00155	/
BG After repairing	0.00208	34.19



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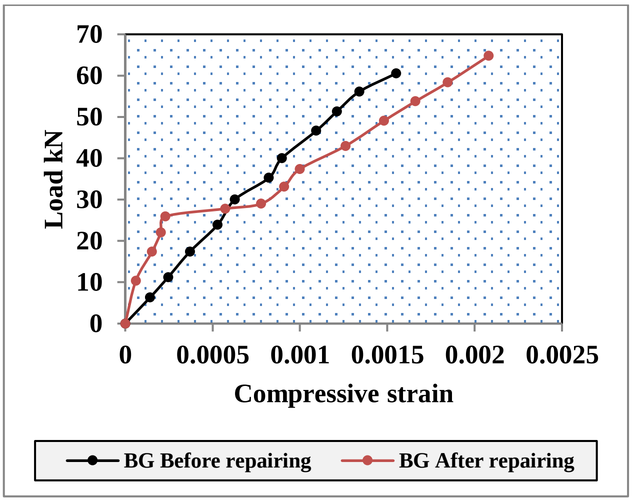

(b)

Figure 13. Load tension strain response before and after repairing: (a) BC. (b) BG.

6.6.3 Cracking and Failure Pattern

Figure 14. shows the cracking and failure patterns of BC and BG after repairing. As much

as possible, all the reference specimens are intended to be failed in the same manner in order to build a base point for comparison .

Generally, the compressive cracks are clear in both BC and BG after repairing, the central pre crack was continued toward top flange for BG but did not reach it in BC as shown. The final cracks width is generally more in BG.

Figure 14. Cracking and failure pattern for BC and BC

7. Conclusions

The following conclusions can be drawn from this experimental program:

- The bottom strips of CFRP can recover the original behavior of the inherent failed geopolymer I section beams.
- The stiffness of the rehabilitated Geopolymer beams can be more than the inherent beam.
- The ductility levels of the rehabilitated specimens by bottom strips are less than the original beams.
- The toughness levels of the rehabilitated specimens by bottom strips are less than the inherent beams.
- Rehabilitation the failed beams changes the location of the initial cracking load from tension to compressive zone within beam domain.

8.Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

9.Abbreviations

ASTM	American Standard Testing Measurements
ACI	American Concrete Institute
Ansys	Analysis System
C_3A	Tri-calcium Aluminate
CaO	Calcium Oxide
CSH	Calcium silicate hydrate
DS	Deflection at service load
DM	Deflection at maximum load
DI	Ductility Index
FE	Finite Element
ICL	Initial Cracking Load
GC	Geopolymer Concrete
IR	Insoluble residue
K_2CO_3	potassium carbonate
LOI	Loss on ignition
LRFD	Load Resistance Factor Design
MCS	Maximum Compressive Strain
MTS	Maximum Tension Strain
MK	Meta kaoline
ML	Maximum Load
Na_2CO_3	Sodium carbonate
Na_2SO_3	Sodium Silicate
NaOH	Sodium Hydroxide
RC	Reinforced Concert
SL	Service Load
SiO_2	Silicon Oxide
SI	Stiffness Index
TI	Toughness Index

References

1. Dattatreya J. K. and Rajamane N. P. (2011) "*Flexural Behavior of Reinforced Geopolymer Concrete Beams*," International journal of civil and structural engineering, Vol. 2, No. 1, pp. 138-159.
2. Sarathi, D.P, Nath, P. and Sarker, P.K. (2014). "*The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature*". Materials Design. Vol. 62, pp. 32-39. DOI : 10.1016/j.matdes.2014.05.001.

3. Sofi., A. and Phanikumar., B.R. (2015). "*An experimental investigation on flexural behaviour of fibre-reinforced pond ash-modified concrete*". Ain Shams Engineering Journal. Vol. 6, pp. 1133-1142. DOI :10.1016/j.asej.2015.03.008.
4. Ambily, G., Umarani, R., Kapali, D and Iyer, N. (2014). "*Development of ultra-high-performance geopolymer concrete*." Magazine of Concrete Research. Vol 66. pp. 82-89. DOI:10.1680/macr.13.00057.
5. Kumar, B.S.C., Ramesh, K. and Poluraju., P. (2017). "*An Experimental Investigation on Flexural Behavior of GGBS and Metakaolin Based Geopolymer Concrete*". ARPN journal of engineering and applied sciences. Vol. 12, No. 7, pp. 2052-2062.
6. Bakharev T.(2005). "*Geopolymeric materials prepared using Class Fly ash and elevated temperature curing*". Cement and Concrete Research. Vol. 35, pp. 1224-1232. DOI:10.1016/j.cemconres.2004.06.031.
7. Kaur, K., and Chand, J., (2019). "*Replacement of concrete by geopolymer concrete by using fly ash and GGBS*". International Journal of Innovative Technology and Exploring Engineering (IJITEE). Vol. 8, No. 6. DOI:10.35940/ijitee.l3676.1081219
8. Jeyasehar, C.A., Saravanan, G., Salahuddin, M. and Thirugnanasambandam., S. (2013). "*Development of fly ash based geopolymer precast concrete elements*". Asian journal of civil engineering. Vol. 14, No. 4, pp. 605-615.
9. Chau-Khun, A and Abdullah, O.W. (2018). "*Structural and material performance of geopolymer concrete: A review* ". Construction and Building Materials. Vol 186.pp. 90-102. DOI:10.1016/j.conbuildmat.2018.07.111.
10. Hardjito, D. and Rangan, B. V. (2005) "*Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete*," Research Report, Faculty of Engineering, Curtin University of Technology.
11. Kumar B.S.H and K. Ramesh. (2018). "*Analytical Study on Flexural Behaviour of Reinforced Geopolymer Concrete Beams by ANSYS*." IOP Conf. Series: Materials Science and Engineering. Vol. 455, No. 1.
12. Rangan B. V. (2010) "*Fly Ash-Based Geopolymer Concrete*," Proceedings of the International Workshop on Geopolymer Cement and Concrete, Allied Publishers Private Limited, 2010.
13. Provis, J.L., Deventer, V.J.S.J. (2009). "*Geopolymers, structure, processing, properties and application*', Woodhead Publishing Limited. DOI:10.1533/9781845696382
14. Singh B., Ishwarya G., Gupta M., and Bhattacharyya S.K., (2015) "*Geopolymer concrete: A review of some recent developments*" Construction and Building Materials Vol. 85, pp. 78–90. DOI:10.1016/j.conbuildmat.2015.03.036.
15. Bakharev T. (2005). "*Resistance of geopolymer materials to acid attack*". Cement and Concrete Research. Vol. 35, No. 4, pp. 658-670. DOI:10.1016/j.cemconres.2004.06.005.
16. Duxson, G. and Lukey, C. (2006). "*Geopolymer technology the Current State of The Art*," Journal of Material Science, Vol. 42, No. 9, pp. 2917-2933. DOI:10.1007/s10853-006-0637-z
17. Varga G. (2007). "*The Structure of Kaolinite and Metakaolinite,*" Epitoanyag, Vol. 59, No. 1, pp. 6-9. DOI:10.14382/epitoanyag-jsbcm.2007.2.
18. Habert, G., De LacaillerieJ.B.D.E and Roussel, N. (2011). "*An environmental evaluation of geopolymer based concrete production reviewing current research trends*". Journal of clean production. Vol.

11, pp. 1229-1238. DOI:10.1016/j.jclepro.2011.03.012

19. Islam A., Johnson U.A., Jumaat M.Z. and Bashar, I.I. (2014). "*The development of compressive strength of ground granulated blast furnace slag-palm oil fuel ash-fly ash based geopolymer mortar*". Materials & Design, Vol. 56 pp. 833-841. DOI:10.1016/j.matdes.2013.11.080.
20. Davidovits, J. (1991). "*Geopolymers: inorganic polymeric new materials*," Journal of Thermal Analysis, Vol. 37, , pp. 1633-1656. DOI:10.1007/bf01912193.
21. Yost, J.R., Radlinska, A., Ernst, S., Salera, M. and Martignetti, N.J. (2013). "*Structural behavior of alkali activated fly ash concrete-Structural Testing and Experimental Findings*". Materials structures. Vol. 46, pp. 449-462. DOI:10.1617/s11527-012-9985-0
22. Li C, Sun H, and Li L.(2010) "*A review the comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements*" Cement and Concrete Research. Vol. No. 9., pp. 1341–1349. DOI:10.1016/j.cemconres.2010.03.020.
23. Ishwarya, B.S.G., Gupta, M. and Bhattacharyya, S.K. (2015). "*Geopolymer concrete: A review of some recent developments*". Construction and building materials. Vol. 85, pp. 78-90. DOI:10.1016/j.conbuildmat.2015.03.036
24. Vaitkevicius V., Stuopys, A. and Ivanauskas, E., (2010) " *Preconditions for the application of petrasiunai "quarry dolomite screenings and dolomite powder in conventional and self-compacting concrete mixes*". Engineering structers technology. Vol. 4, pp. 138-138. DOI:10.3846/skt.2010.18.
25. Pires, E. F.C., Limab, T.V., Marinhoa, F.J.V., De Vargas, A.S., Mounzer, E.C., Darwish, F.A.I. and Silva, F.J. (2019). "*Physical nonlinearity of precast reinforced geopolymer concrete beams*".Journal of Materials Research and Technology .Vol. 8 No. 2, pp. 2083–2091. https://doi.org/10.1016/j.jmrt.2019.01.016.
26. Huseien, G.F., Sam, A.M. and Shah, K.W. (2019). "*Utilizing spend garnets as sand replacement in alkali-activated mortars containing fly ash and GBFS*". Construction and Building Materials Vol. 225, pp. 132–145. DOI:10.1016/j.conbuildmat.2019.07.149.
27. Vijai, K., Kumutha, R., and Vishnuram, B.G. (2012). "*Experimental Investigations on Mechanical Properties of Geopolymer Concrete Composites*". Asian Journal of Civil Engineering (Building and Housing). Vol. 13, No.1 pp.89-96. DOI:10.9790/1684-140305105109.
28. Komnitsas, K.A. (2011) "*Potential of geopolymer technology towards green buildings and sustainable cities*. International conf. on green buildings". and cities", Procedia Engineering, vol. 21, pp. 1023–1032. DOI:10.1016/j.proeng.2011.11.2108.
29. Pradip, N. and Sarker, P.K. (2014). "*Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition*". Construction building materials. Vol. 66. Pp. 163-171. DOI:10.1016/j.conbuildmat.2014.05.080.
30. Kumar, Y.H., and Chandra, B.S. (2017). "Effect of Molarity on Compressive Strength of Geopolymer Mortar with GGBS and Metakaoline". International Journal of Civil Engineering and Technology, Vol. 8, No. 4, pp. 935-944.
31. Kumar, Y.H, and Chandra, B.S. (2017). "Effect of Sodium Hydroxide and Sodium Silicate Solution on Compressive Strength of Metakaolin and GGBS Geopolymer". International Journal of Civil Engineering

and Technology, Vol. 8, No. 4, pp. 1905-1917.

32. Sofi D., Van Deventer J.S.J., Mendis P.A., Lukey G.C. (2006). "Engineering properties of inorganic polymer concretes (IPCs)". Cement and Concrete Research. Vol. 37, pp. 251-257. DOI:10.1016/j.cemconres.2006.10.008.
33. Patil, S.G. and Manojkumar, (2013) "*Factors Influencing Compressive Strength of Geopolymer Concrete*". International Journal of Research in Engineering and Technology. pp. 372-385. DOI:10.15623/ijret.2013.0213070.
34. Van Jaarsveld J.G.S., van Deventer J.S.J., Lukey G.C. (2002). "*The effect of composition and temperature on the properties of fly ash and kaolinite based geopolymers*". Chemical Engineering Journal. Vol. 89 No. 13, pp. 63-73. DOI:10.1016/s1385-8947(02)00025-6.
35. Prachasaree, W., Limkatanyu, S., Hawa, A., and Samakrattakit, A. (2014). "*Development of equivalent stress block parameters for fly-ash-based geopolymer concrete*". Arabic journal of scientific engineering. Vol. 39, No. 12, pp. 8549–8558. DOI:10.1007/s13369-014-1447-2.
36. Li C., Sun H. and Li, L. (2010). "*A review the comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements*" Cement concrete research. Vol. 40, pp. 1341–1349. DOI:10.1016/j.cemconres.2010.03.020.
37. Bakharev T. (2005). "Durability of geopolymer materials in sodium and magnesium sulfate solutions". Cement and Concrete Research. Vol. 35 No. 6, pp. 1233-1246. DOI:10.1016/j.cemconres.2004.09.002.
38. Salim, B. (2011). "*Effects of fly ash and dolomite powder on the properties of self-compacting concrete*". Construction building materials. Vol. 8, pp. 3301-3305. DOI:10.1016/j.conbuildmat.2011.03.018.
39. Chun LB, Sung KJ, Sang KT, Chae ST. (2008). "*A study on the fundamental properties of concrete incorporating pond-ash in Korea*". 3rd International conf. on the sustainable concrete technology and structures sustainable concrete technology and structures in local climate and environmental conditions, Vietnam. pp. 401-408.
40. Gali S., Ayora, C.P., Alfonso, E.T, and Labrador, M. (2001). "*Kinetics of dolomite–portlandite reaction Application to Portland cement concrete*". Cement Concrete Research. Vol. 6, pp :933-939. DOI:10.1016/s0008-8846(01)00499-9.
41. Dattatreya, J., Umarani. G., Kapali., R., and Nagesh, I., (2004). "*Development of ultra-high-performance geopolymer concrete*". Magazine of Concrete Research..volume 66. No. 6 pp. 82-89. DOI:10.1680/macr.13.00057.
42. VenkataKiran, P. and Jawahar, G.J. (2017). "*Flexural Studies on Fly Ash and GGBS Blended Reinforced Geopolymer Concrete Beams*," International Journal of Research and Scientific Innovation, Vol. 4, No. 8, pp. 91-95.
43. Palomo A., Grutzeck M.W., Blanco M.T. (1999). "*Alkali activated Fly Ashes Cement for the Future*", Cement and Concrete Research. Vol. 29, pp. 1323-1329. DOI:10.1016/s0008-8846(98)00243-9.
44. Kumaravel, S. and Thirugnanasambandam, S. (2013) "*Flexural behaviour of reinforced lowcalcium fly ash based geopolymer concrete beam*". Global journal of research engineering. Vol. 13, No. 8.
45. Kumaravel, S., Thirugnanasambandam, S. and Jeyasehar, C.A. (2014). "*Flexural behavior of geopolymer concrete beams with GGBS*". IUP journal of structural engineering. Vol. 7, No. 1. pp. 45-54.

46. Saranya, P., Praveen, P. and Shashikala, A.P. (2020). "*Behaviour of GGBS-dolomite geopolymer concrete beamcolumn joints under monotonic loading*". Structures.Vol. 25. DOI:10.1016/j.istruc.2020.02.021.
47. Shi C., and Jiminez F.A, (2002)."*A. New cements for the 21st century the pursuits of an alternative to Portland cement*". Cement concrete research.Vol.32 pp. 865–879. DOI:10.1016/j.cemconres.2011.03.016.
48. Kumar, Y.H. and Kumar, S.C. (2017). "*Study on Strength and Durability Parameters of Geopolymer Concrete With GGBS for 12M and 14M Alkali Activators*," ARPN Journal of Engineering and Applied Sciences, Vol. 12, No. 4, pp. 1202-1212.
49. Kumar, Y.H. and Keerty, V. (2017)."*Experimental Studies on Properties of Geopolymer Concrete With GGBS and Fly Ash*". International Journal of Civil Engineering and Technology, Vol. 8, No. 1, pp. 602-609.
50. Chang, E. H., (2009). "*Shear and Bond Behaviour of Reinforced Fly Ash-Based Geopolymer Concrete Beams*". Department of Civil Engineering. PHD Thesis. Curtin University of Technology.
51. Vecchio, F.J. (2000). "*Disturbed Stress Field Model for Reinforced Concrete Formulation*" Journal of Structural Engineering, Vol. 126 No. 9. pp. 1070–1077. DOI:10.1061/(asce)0733-9445(2000)126:9(1070).
52. Canbay, E. and Frosch, R.J. (2005). "*Bond Strength of Lap-Spliced Bars*", ACI Structural Journal, Vol. 102 No.4, pp. 605–614. DOI:10.14359/14565.
53. Ambily.P.S, Madheswaran. C.K , Sharmila.S and Muthiah.S, (2011). "*Experimental and analytical investigations on shear behavior of reinforced geopolymer concrete beams*" Volume 2. No. 2.
54. Jeyasehar, C.A., Saravanan, G., Salahuddin and Thirugnanasambandam S. (2013). "*Development Of Fly Ash Based Geopolymer Precast Concrete Elements*" Asian Journal Of Civil Engineering (BHRC), Vol., 14 No., 4. Pp.607 – 615.
55. Park R, Pauley T. (1975) "*Reinforced Concrete Structures*". John Wiley & Sons, New York. DOI:10.1002/9780470172834.
56. Hutagi, A and Khadiranaikar, R.B. (2016). "*Flexural Behavior of Reinforced Geopolymer Concrete Beams*". International Conf. on Electrical, Electronics, and Optimization Techniques (ICEEOT). DOI:10.1109/iceeot.2016.7755347.
57. Yacob, N.S. (2016)"*Shear Behavior Of Reinforced Fly Ash-Based Geopolymer Concrete*". Masters Theses. Presented to the Graduate Faculty of the Missouri University Of Science And Technology.
58. Kumar, B.S., Ramesh, K. and Poluraju, P., (2017). "*An experimental investigation on flexural behavior of GGBS and Metakaolin based Geopolymer concrete*". ARPN Journal of Engineering and Applied Sciences. Vol. 12. pp. 2052-2062.
59. Maranan, G.B. , Manalo, A.C., Benmokrane, B., Karunasena, K and Mendis, P., (2017). "*Shear Behavior of Geopolymer Concrete Beams Reinforced with GFRP Bars*". ACI Structural Journal, Vol. 114 No. 2. DOI:10.14359/51689150.
60. Srinivas, M.R, Kumar, Y.H., and Kumar, B.S.C., (2019). "*Studies on Flexural Behavior of Geopolymer Concrete Beams with GGBS*". International Journal of Recent Technology and Engineering (IJRTE). Vol. 7.
61. Bhavana, P., and Srinivas, T. (2021). "*Manufactured sand effect on flexural behavior of geopolymer RCC structural elements*". Seventh International Symposium On Negative Ions, Beams And Sources (NIBS 2020). DOI:10.1063/5.0058556.