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

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ABSTRACT

The research teams have a variety of reasons for wanting to find suitable solutions to the problem of global warming. When certain alumino-silicates materials, such as metakaoline, fly ash, slag and rice husk ash are alkali activated, the resulting principal binder is what is known as geopolymer concrete. Commonly, geopolymer concrete has mechanical strength characteristics like conventional 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 possibility of using side flange 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 outcomes illustrated 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]. So, trying to get other alternatives is a difficult task for the authors in the subject of civil engineering science. [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].

Results of the "Geopolymerization Process" is a stiff structure like the hydration. To produce adequate and stable geopolymer, the source materials should be able to react easily and consume reasonable quantities of water [15-22]. Numerous substances, including sodium hydroxide (NaOH), potassium silicate (K_2SiO_3), sodium silicate (Na_2SiO_3), and potassium hydroxide, can be employed as alkali activators (KOH) [23-30]

Due to the geopolymer hardened matrix's excellent mechanical strength, stiffness, and durability characteristics [30–34], reinforced geopolymer concrete can perform the same functions as conventional reinforced concrete and be employed exclusively in civil engineering applications.". Implementing low water / cement ratio: in order to ensure that all the water within mix will be combined with Calcium Silicate Hydrate (CSH) and getting consequent high strength, water cement ration should be between 0.15 to 0.23.

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].

$(Si_2O5.Al^2O^2)n+H_2O+OH\text{--->}Si(OH)4+Al(OH)^{4-}$

$Si(OH)^4+Al(OH)^4\text{---}(\text{-}Si\text{-}O\text{-}Al\text{-}O\text{-})^2+4H2O$ | | …………(1)

| |

O O

The water that is released during the planned reaction contributes to workability and makes handling easier [36-44]. However, this contrasts with the function of regular Portland cement, which exhibits substantial levels of water consumption throughout the whole hydration process [45-49]. Figure 1 provides a graphic representation of this process.

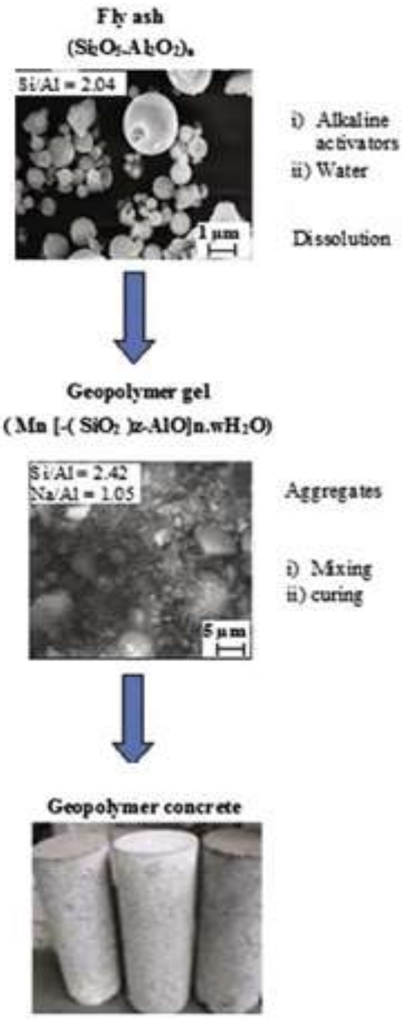


Figure (1) Geopolymerization process, schematic representation [14].

3. Rehabilitation and retrofitting

When a building's structure has fully deteriorated, rehabilitation means enhancing its capabilities by increasing its functions. Strengthening a building's structure either before or after it has structurally deteriorated is referred to as "retrofitting".

Recent important advancements brought by by research programs have offered appropriate effort methods and materials to achieve any improvement. However, Such development strategies incorporate significant upgrades in the field of structural rehabilitation.

One of the most important factors in the entire rehabilitation process is how to choose the right technique, which depends on the underlying circumstances. Many professionals contend that the field of rehabilitation is still new to them and challenging. This technique becomes more difficult because no two structures are similar to one another. Therefore, selecting rehabilitation therapy is a difficult process influenced by economic, technological, and societal factors.

4. Importance of the Study

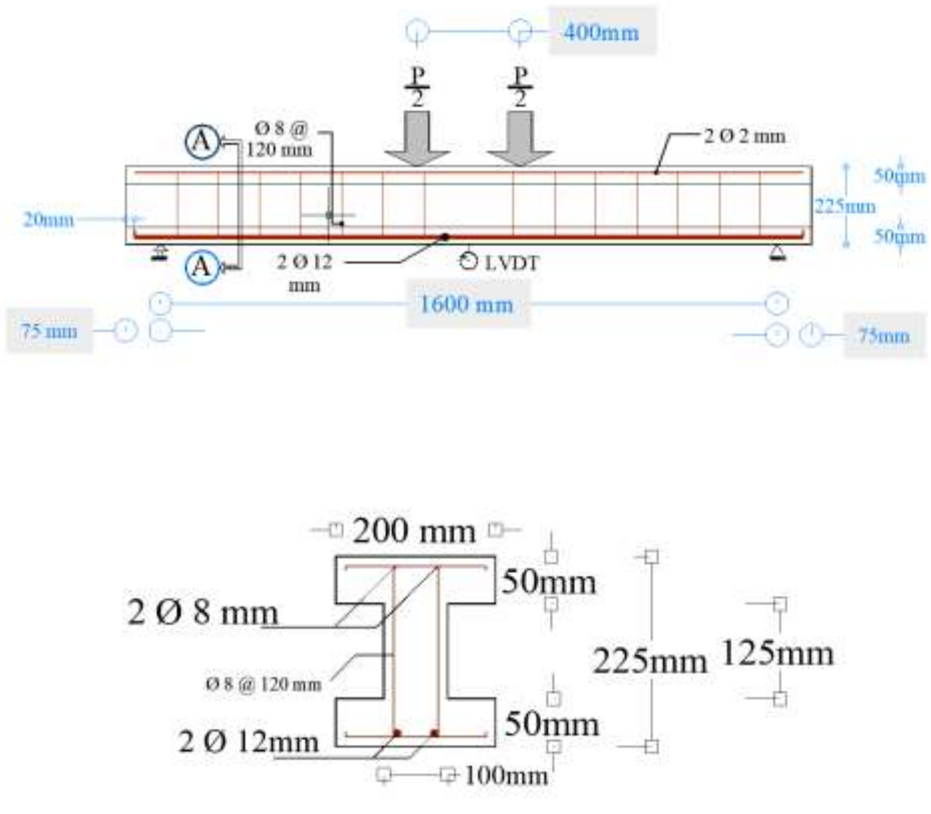
Obtaining trustworthy experimental data is essential for understanding the structural response of any structural part. This is important because the rehabilitation of RC is a very crucial issue within the civil engineering applications.

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 building chemicals business "EUROBUILD" provided Class F fly ash, which was used in the current investigation as a raw material for making GC.

5.2.2 Sand

Al-Ekhaider natural sand, which has a maximum size of 4.75 mm for usage as the fine aggregate in mixes, was used in the current study

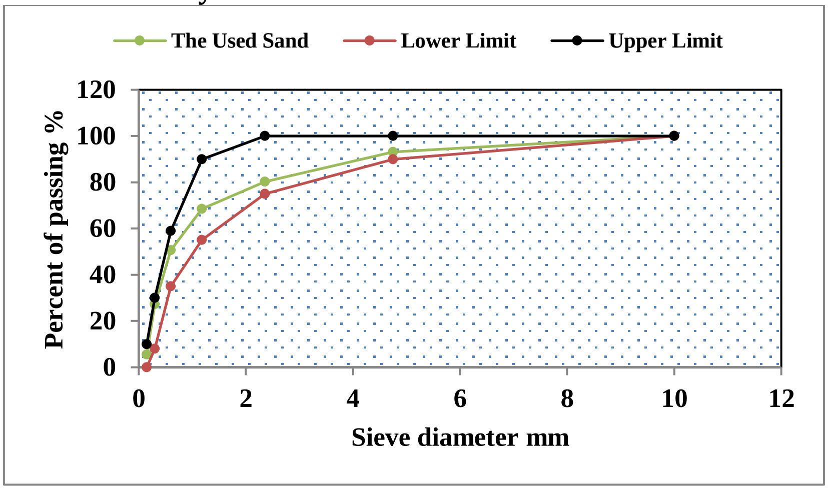


Figure (3(Sand grading curve

5.2.3 Gravel

Gravel with a maximum size of 10 mm was brought from "AL-Nibaey" to be employed as coarse aggregate in the mix during the current trial program.

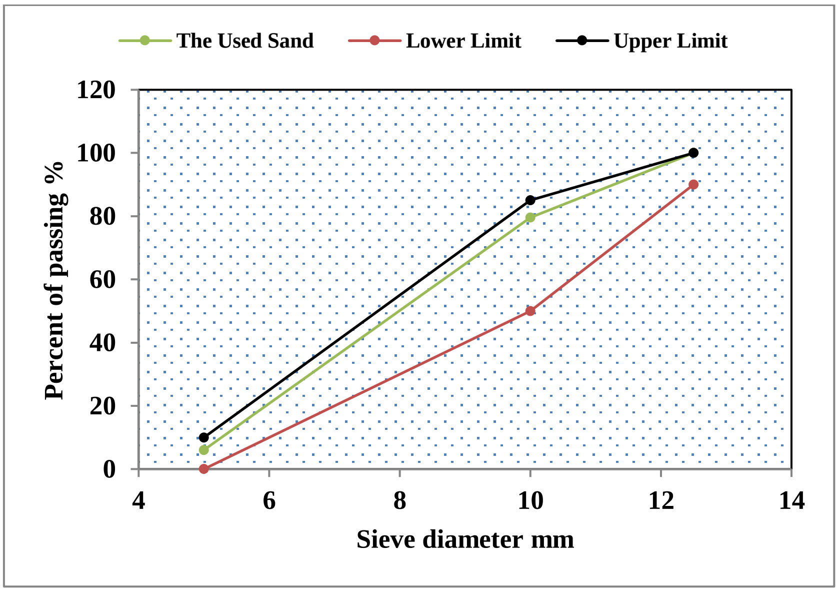


Figure (4) Sieve analyses of the used gravel

2.1.4 Sodium Hydroxide NaOH

This investigation made use of commercial NaOH solid slakes that were 98% pure, packaged in 25 kg sealed containers, and provided by Al Kout projects firm.

5.2.5 Sodium Silicate Na_2SO_3

Sodium silicate, also known as "glass water," is a commercially accessible product for industrial application from Hal Chemicals. This substance is a clear to off-white, viscous, sticky liquid with a light odor.

5.2.6 Reinforcing Bars

The deformed bars that used throughout the present study are of 6mm and 8mm in diameter.

5.2.7 The FRP Properties

FRP were used in this study to rehabilitate geopolymer beams in four arrangements as presented within the next sections.

5.2.8 Epoxy Resin

For doing the required rehabilitation, KUT BOND epoxy resin is used within the current study,

5.3 Mix Proportions

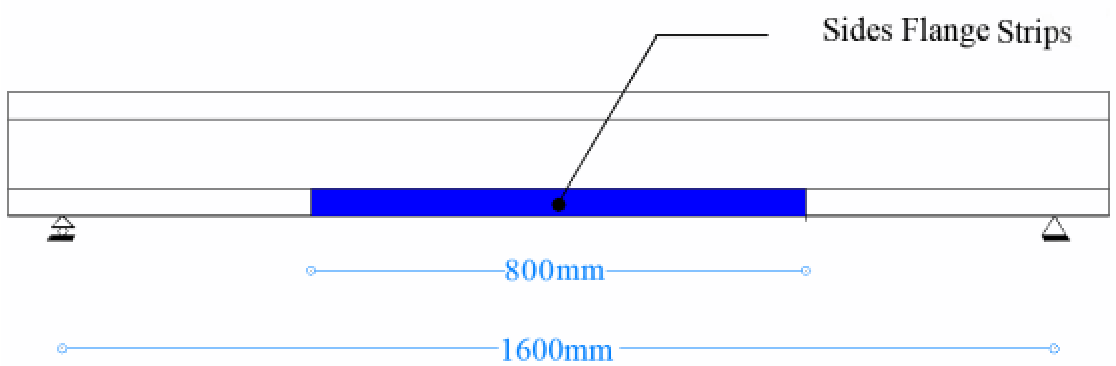
Within the proposed experimental program, the mix design was taken from **Abdul Aleem and Arumairaj, (2012).** Table 5 lists the final mix proportioned that used in casting the specimens.

Tables (6) The mix design of the current study.

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

5.4 The Side Flange 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.



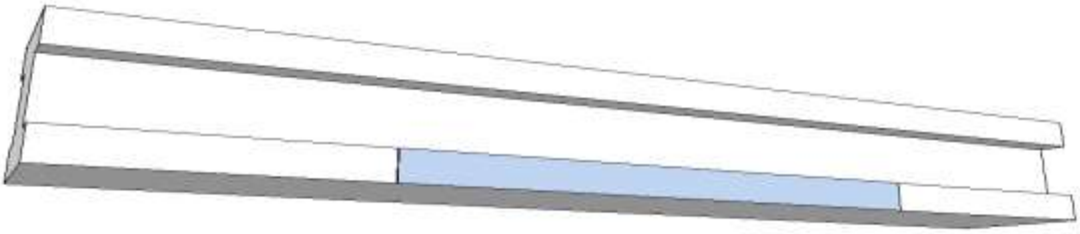


Figure (5) Side flange strips technique

6. Results and Discussion

This paper discusses the performance of the side flange 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 SC which is I – section reinforced GC beam repaired by CFRP side flange strips. The second specimen is SG which is I – section reinforced GC beam repaired by GFRP side flange strips.

6.1 ICL, SL and ML

Table 1 and Figure 8 show the ICL, SL and ML of the SC and SG specimen before and after repairing. When CFRP used in side flange strips repairing technique, ICL, SL and ML increased by 149.06%, 7.50% and 7.48% respectively. In addition, When GFRP used in side flange strips repairing technique, ICL, SL and ML increased by 126.60%, 3.50% and 3.51% respectively.

The results outcomes revealed that the side flange strips is a succeeded technique with respect to ICL, SL and ML. This can be attributed again to the good mechanical properties of FRP-Epoxy composite.

The superiority of CFRP mechanical properties over GFRP is reflected again on the results of this group. If these results compared with the results of bottom strips, the SL and ML degree of recovery of this group is less than bottom strips results. This can be attributed to the difference in repairing boundary condition in addition to possibility of inherent denting of side flange strips.

Table (1) ICL, SL and ML of SC and SG specimen before and after repairing.

Specimen	ICL (kN)	Change in ICL %	SL (kN)	Change in SL %	ML (kN)	Change in ML %
SC Before repairing	10.60	/	52.03	/	61.48	/
SC After repairing	26.40	149.06	55.93	7.50	66.08	7.48
SG Before repairing	12.40	/	55.17	/	67.86	/

SG	After repairing	28.10	126.60	57.1	3.50	70.24	3.51

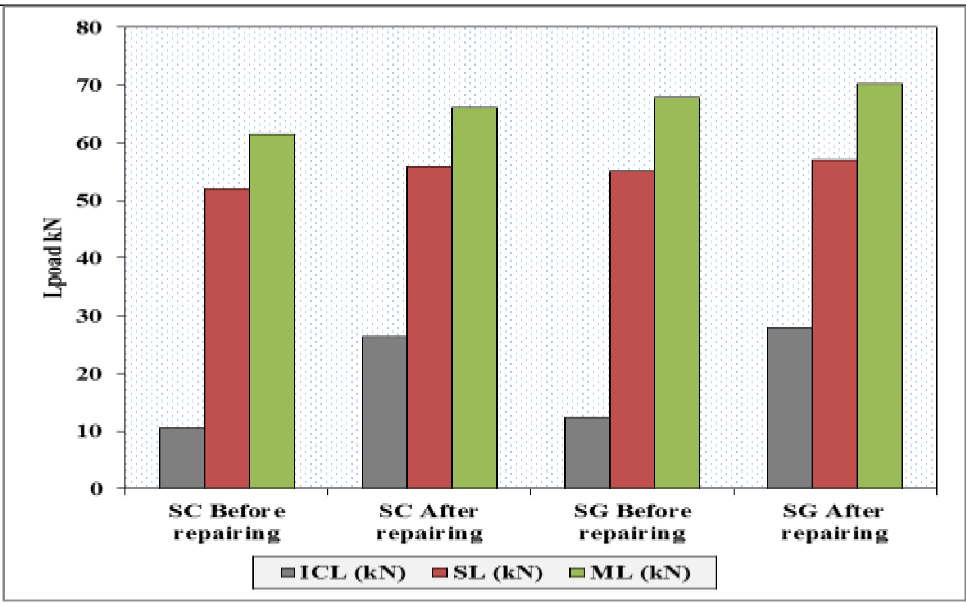


Figure (8) ICL, SL and ML of SC and SG specimen before and after repairing.

6.2 DS, DM and The Load Deflection Curve

Table 8 and Figure 2 show the DS and DM of the SC and SG specimen before and after repairing. When CFRP used in side flange strips repairing technique, DS decreased by 2.70% and 17.99% respectively.

When GFRP used in side flange strips repairing technique, DS and DM decreased by 0.37% and 22.01% respectively. As in the previous technique, DS decreased for both SC and SG due to the good obtained stiffness. SG decreasing level was also still less than SC due to the same reason discussed earlier. If the decreasing rate of DS of SC and SG compared with the corresponding values of BC and BG, the change levels are more in bottom strips technique. This can be attributed to the good confinement level of bottom strips technique.

Regarding DM, the changing rate is more in BC and BG. This can be ascribed again to such confinement where GC fragments can be comprised by such confinement (within the second and third states of response).

Figure 10 shows the load deflection response of the SC and SG before and after repairing. The same three states that reported within the previous technique was observed in the specimens before and after repairing.

Table 2 DS and DM of SC and SG specimen before and after repairing.

Specimen		DS (mm)	Change in DS %	DM (mm)	Change in DM %
SC	Before repairing	2.59	/	14.17	/
SC	After repairing	2.52	-2.70	11.62	-17.99
SG	Before repairing	2.68	/	14.13	/

SG	**After repairing**	2.67	-0.37	11.02	-22.01

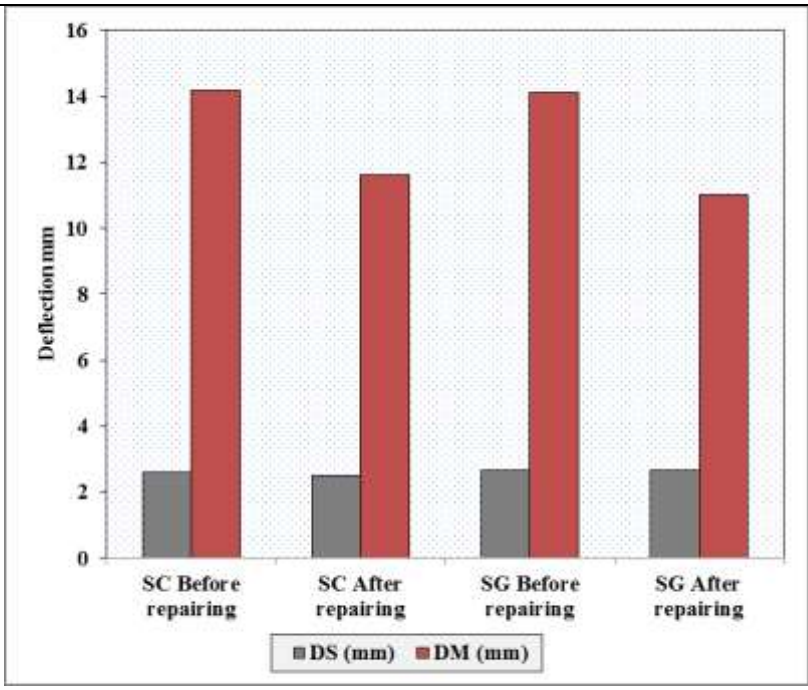
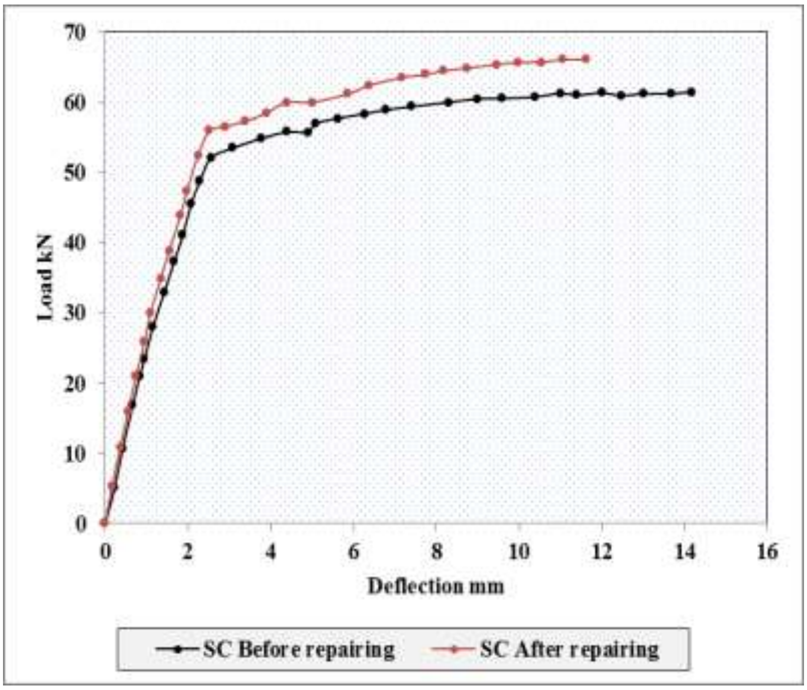
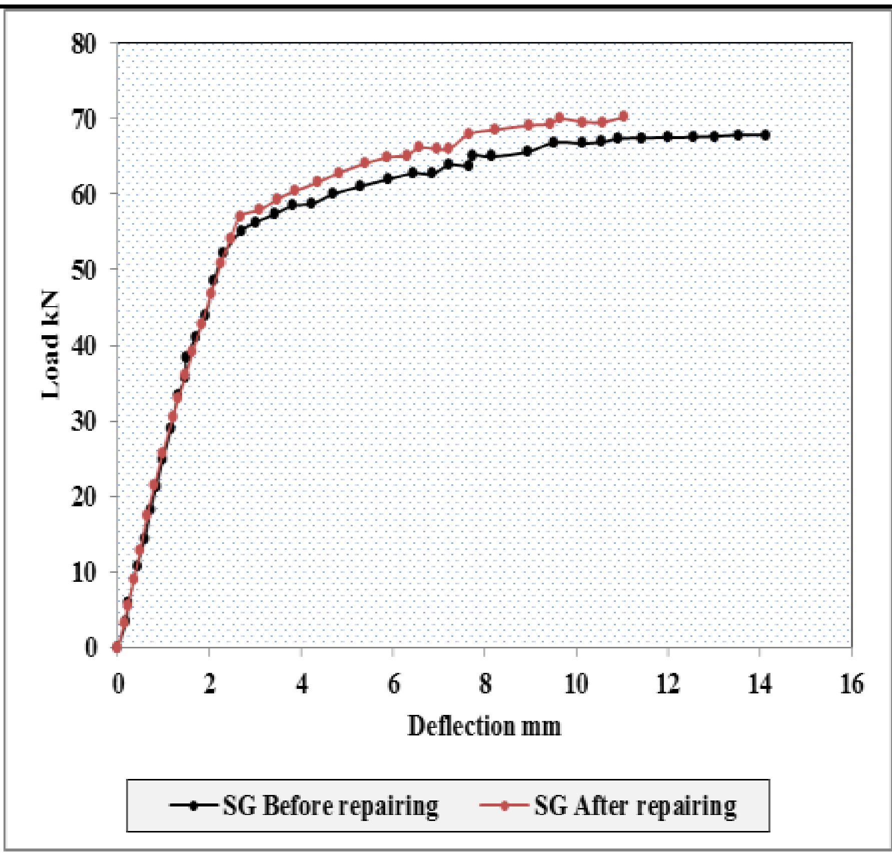


Figure (9) DS and DM of SC and SG specimen before and after repairing.



(a)



(b)

Figure (10) Load deflection response: (a) SC. (b) SG.

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 3 and Figure 9 show the SI of the SC and SG specimen before and after repairing.

When CFRP used in side flange strips repairing technique, SI increased by10.48% while when GFRP used in bottom strips repairing technique, SI increased by 3.89%.

It is believed that the high stiffness levels of FRP-composite revealed good levels of SI for the repaired specimens. This behavior is dictated by high levels of SL and ML and corresponding decrease in DS (as in the previous technique). If SC and SG compared with BC and BG, the rate change of SI levels within this technique are less than bottom strips. This supremacy can be again related to the orientation of the bottom strips which revealed good levels of SL and low DS.

Table (3) SI of SC and SG 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

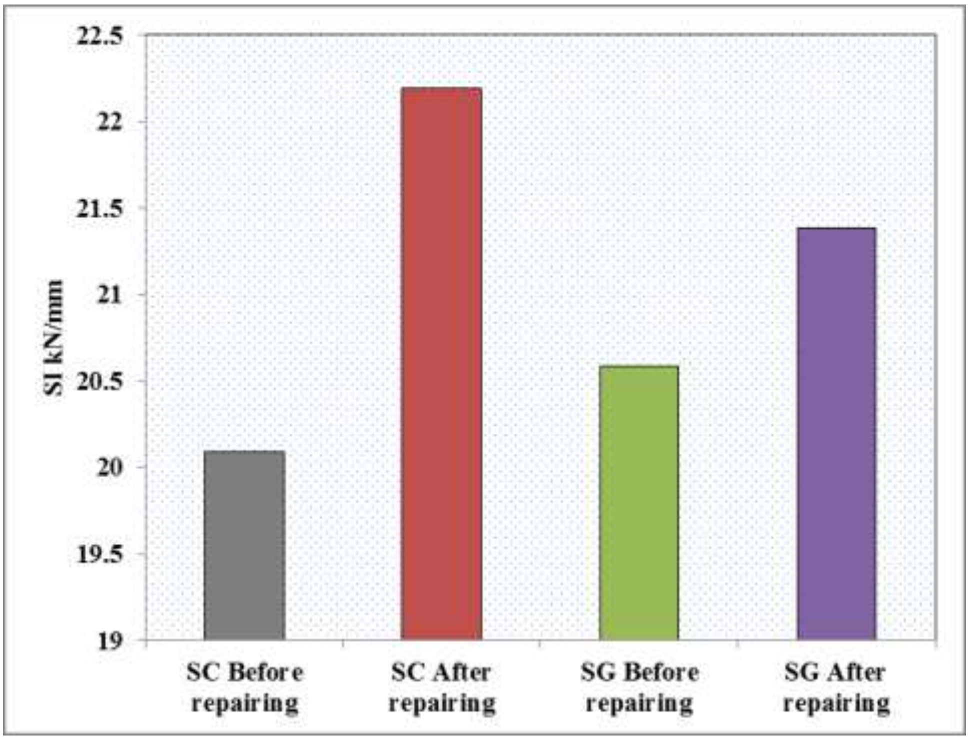


Figure (9) SI of SC and SG specimen before and after repairing.

6.4 DI

Table 4 and Figure 10 show the DI of the SC and SG specimen before and after repairing. When CFRP used in side flange strips repairing technique, DI decreased by 15.72% while when GFRP used in bottom strips repairing technique, DI decreased by 21.63%. The DI levels decreased for the repaired specimens as in the previous technique due to the same purpose mentioned above. On the other hand, the decreasing levels for SC and SG are more than BC and BG. This can be related to the low levels of DM in side flange strips. The decrease in DI is more in GFRP as in the previous technique.

Table (4) DI of SC and SG specimen before and after repairing.

Specimen		DS (mm)	DM (mm)	DI = DM/DS	Change in DI %
SC	Before repairing	2.59	14.17	5.47	/
SC	After repairing	2.52	11.62	4.61	-15.72
SG	Before repairing	2.68	14.13	5.27	/
SG	After repairing	2.67	11.02	4.13	-21.63

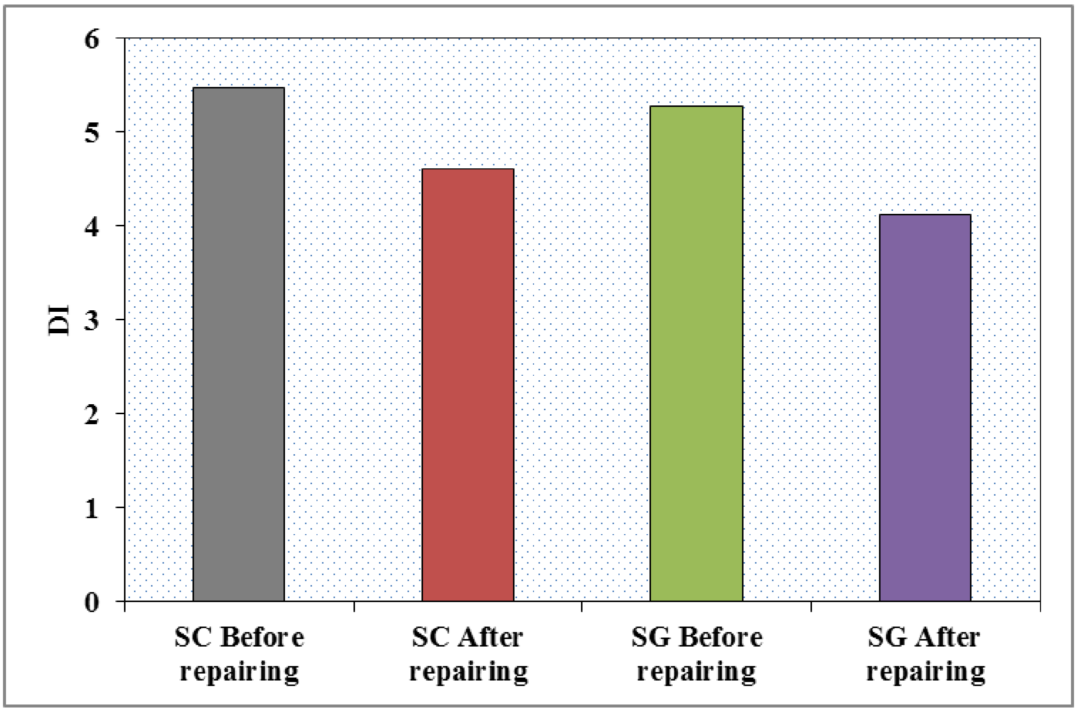


Figure (10) DI of SC and SG specimen before and after repairing.

6.5 TI

Table 5 and Figure 11 show the TI of the SC and SG specimen before and after repairing. When CFRP used in side flange strips repairing technique, TI decreased by 14.63% while when GFRP used in bottom strips repairing technique, TI decreased by 23.04%.

The toughness levels of the repaired specimens are lower than before repairing as noticed and discussed in the bottom strips results. As in the bottom strips, the loss in TI is more in SG than in SC due to the same context noticed in bottom strips. If the TI changing rates of SC and SG compared with BC and BG, the loss in TI is more due to the dictated differences in of SL, ML, DS and DM levels.

Table (5) TI of BC and BG specimen before and after repairing.

	Specimen	TI	Change in TI%
SC	**Before repairing**	758.45	/
SC	**After repairing**	647.51	-14.63
SG	**Before repairing**	819.96	/
SG	**After repairing**	631.06	-23.04

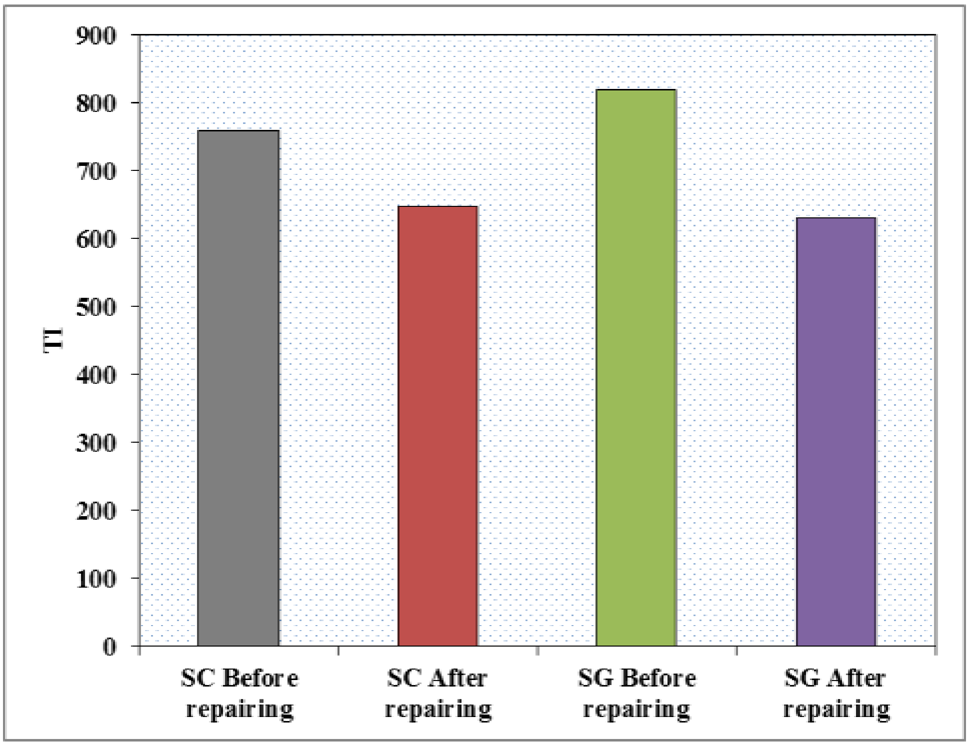


Figure (11) TI of SC and SG specimen before and after repairing.

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

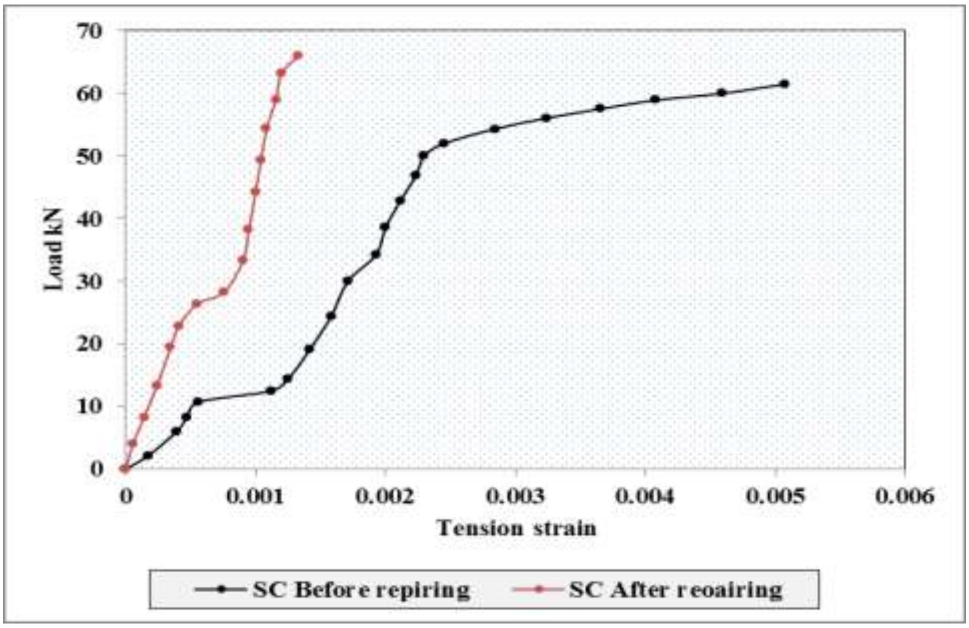
Table 6 and Figure 12 show the load tension strain behavior of the SC and SG specimen before and after repairing. The same usual load strain path was reported before the repairing since the tension strain location in this technique is not far away from the extreme fiber of tension.

Turning to the repaired specimen, the load strain paths are somewhat similar to the corresponding paths in bottom strips where the new ICL limit is also obvious. The difference in stiffness between CFRP and GFRP is clear (as in the preceding technique).

When CFRP used in side flange strips repairing technique, MTS decreased by 73.77% while when GFRP used in bottom strips repairing technique, MTS decreased by 8.12%. The MTS levels are still lower than the known levels as discussed earlier.

Table (6) MTS of SC and SG specimen before and after repairing.

	Specimen	MTS	Change in MTS %
SC	Before repairing	0.00507	/
SC	After repairing	0.00133	-73.77
SG	Before repairing	0.00505	/
SG	After repairing	0.00464	-8.12



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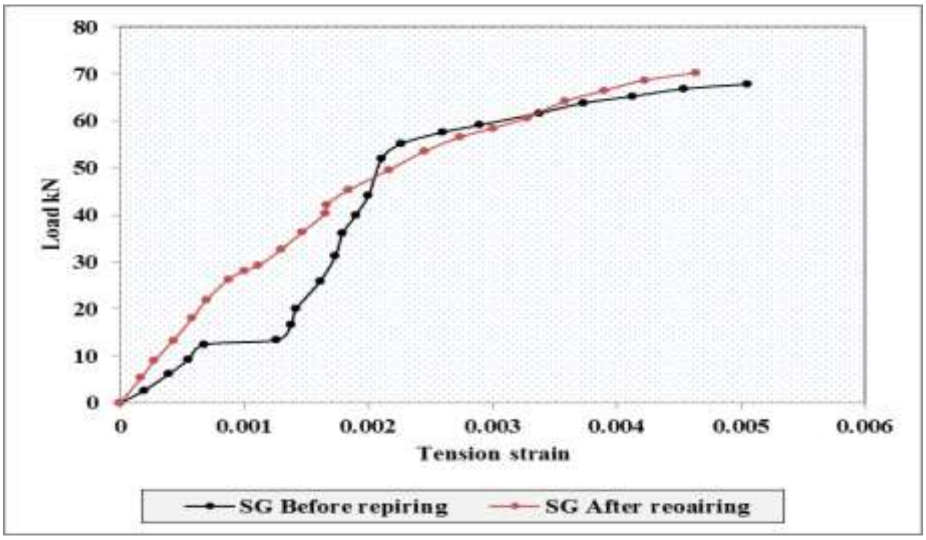


(b)

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

6.6.2 The Load Compressive Strain

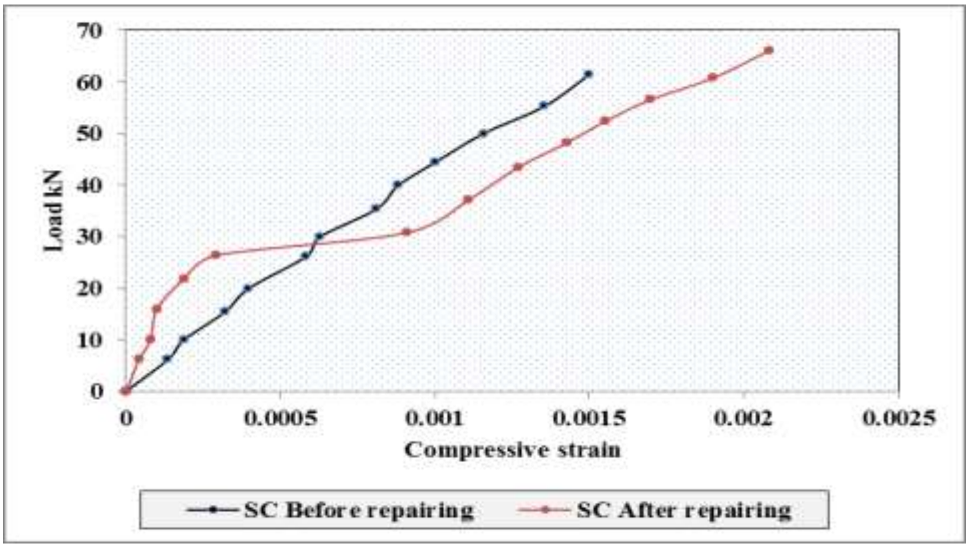
Table 7 and Figure 13 show the load compressive strain behavior of the SC and SG specimen before and after repairing.

Since the compressive strain location is at the extreme fiber of compression, the radical change is so clear in load compressive strain diagram as reported in the prior technique. The load compressive strength paths of SC and SG did not break the classical form (before repairing) while the gap between the paths (before and after repairing) is more distinctive her than in BC and BG, this may be related to the difference in stiffness if compared to previous technique.

When CFRP used in bottom strips repairing technique, MCS increased by 40% while when GFRP used in side flange strips repairing technique, MCS increased by 32.34%. Generally, these levels are more than BC and BG but still not radically more than the known levels of GC crushing limits.

Table (7) MTS of SC and SG specimen before and after repairing.

	Specimen	MCS	Change in MCS %
SC	**Before repairing**	0.0015	/
SC	**After repairing**	0.0021	40.00
SG	**Before repairing**	0.0016 7	/
SG	**After repairing**	0.0022 1	32.34



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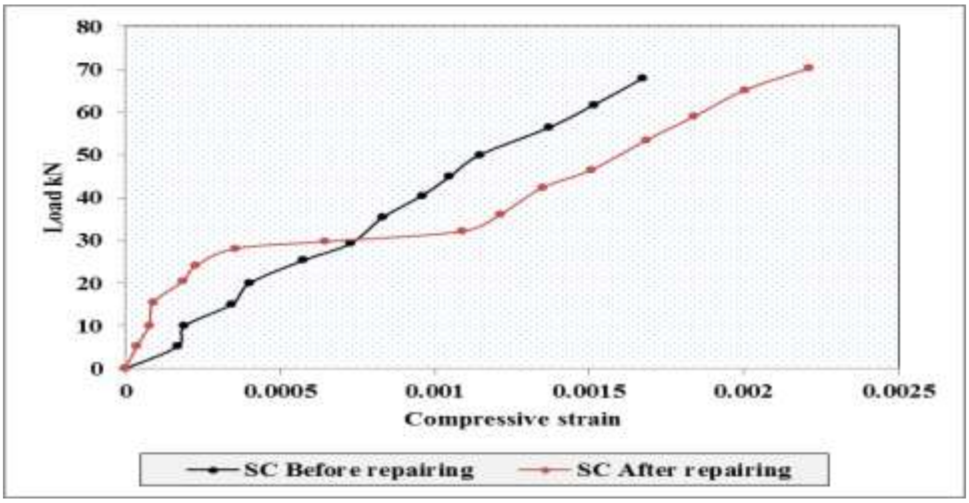

(b)

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

6.6.3 Cracking and Failure Pattern

Figure (14) shows the cracking and failure patterns of SC and SG after repairing. as in the previous technique, the compressive cracks are so clear after repairing and the pre cracking was continued to reach the top flange for both SC and SG.

In addition, there are additional developed central cracks (after repairing) in SG and some of them have reached the top flange. Both SC and SG showed some additional cracks in the top surface of the bottom flange (after repairing) but they are higher in SG.

Figure (13) Cracking and failure pattern for SC and SC

7.Conclusions

The Following conclusions can be drawn from this study:

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

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