Study on Behaviour of Beam Column Joint using Glass Fibre Reinforced Polymer and Steel as Reinforcing Material

Aswathy A[1] Midhula R Krishna[2]
[1]M.Tech Student [2]Assistant Professor
[1,2]Department of Structural Engineering
[1,2]Rajadhani Institute of Engineering and Technology, Nagaroor, India

Abstract— The beam column joint is an important element to consider while designing structures especially in seismic prone areas. As a result of high wind and earthquake loads, the majority of joints may collapse due to shear failure. Beam column joint is one of the most vulnerable component in a structure. This paper aims at investigating the behaviour of corner beam column joint and interior beam column joint under cyclic loading with steel and Glass Fibre Reinforced Polymer (GFRP) as reinforcing materials. A total of 4 models are used, where the dimensions of beams and columns are taken based on IS 13920:2016 codal provisions. The ductile detailing of steel reinforced models are also designed as per this codal provisions, same ductile detailing is provided for GFRP reinforced specimen also. The ANSYS 2022 R1 is used for modelling and analysis of beam column joints. The results showed that the values of maximum von-mises stress and maximum energy dissipation capacity was high for beam column joint reinforced with GFRP models.

Keywords: Interior Beam Column Joint, Corner Beam Column Joint, Cyclic Loading, ANSYS, Energy Dissipation Capacity, Von-Mises Stress

I. Introduction

The beam column joint is the part of the column that frames the deepest beam or the part of the column that is common to beams. The purpose of a joint is to permit adjoining members to achieve and maintain their maximum capacity. In accordance with the geometrical configuration beam column joint is mainly classified into interior, exterior, and corner beam column joint. An interior joint has beams framing all four sides of the joint, whereas an external joint includes at least two beams framing opposite sides. And a corner joint, on the other hand, has at least one beam framing the joint on one side.

Cyclic loading is the most common type of loading used to analyze structures in earthquake-prone areas. In this paper, cyclic loading analysis on beam column joint were done using steel and GFRP as main bars and stirrups. Whereas, Fibre-Reinforced Polymer (FRP) is a composite material made up of a polymer matrix and fibres. Earlier the use of FRP was limited to aerospace and defence purpose due to its high cost but increase in demand or the demand for the utilization of FRP in other fields around the world has aided the growth in research for better performance of composites at minimized costs. In the last few years, FRP materials have emerged as promising alternative repair materials for reinforced concrete structure.

In addition to its lower cost, GFRP, in particular, is considered the most suitable type of FRP to be used in seismic regions due to its relatively high ultimate strain capacity. These rebars have several important advantages over conventional reinforcing steel, namely, high tensile strength, light weight, non-corrosiveness, anti-fatigue, non-magnetic, small creep deformation etc. All these advantages are the main reasons of their incorporation into the civil engineering structures.

The main objectives of this study are mentioned as follows:

1) To study the behaviour of interior beam column joint and corner beam column joint under cyclic loading using ANSYS software.
2) To predict the stability of beam column joint under the application of cyclic load in beams.
3) To compare the behaviour beam column joint with GFRP and steel reinforcements in both interior and corner beam column joint.

II. Literature Review

Aditya Kumar Tiwary et.al. (2022) analyzed the interior and corner beam column joints. The result shows that the modified reinforcement techniques with diagonal cross bar at joint region increases the shear capacity of beam column joints. The addition of a diagonal cross bar increases the joint's stiffness by adding an extra mechanism for shear transfer and ductility, as well as increased strength with fewer cracks.

Pranali Wasnik et.al. (2021) studied the different types of lateral reinforcement pattern design as per IS 456-2000 and IS13920-2016 using ANSYS software. Specimen with additional lateral reinforcement have more shear strength. Addition of stirrup bar increases the applied load by 65.13%. Beam column joint design as per IS456-2000 undergoes large displacement.

Taha A. El-Sayed et.al. (2021) described the flexural behavior of geopolymer Ultra high-performance concrete (UHPC) beams. Also, the impact of UHPC reinforced with Glass Fiber Reinforced Polymer (GFRP) bars was also studied. The outcomes showed an increase in the ultimate load carrying capacity as well as the first crack load. Using GFRP bars as reinforcement improved concrete deflection, patterns of cracks, cracks number and the failure mode and also exhibits higher ductility regarding the beams.

Afnan Nafees et.al. (2021) studied the displacement controlled analysis rather than load control analysis to obtain the actual response of a beam-column joint using Reactive Powder Concrete (RPC). The results showed that using RPC in the joint region increased the overall strength of the structure by more than 10%. Moreover, it also helped in controlling the crack width. Furthermore, using RPC in the joint region increased the ductility of the structures.

Mohamed Mady et.al. (2011) studied the behaviour of exterior T-shaped beam column joint under seismic load conditions. Experimental results showed that GFRP reinforced joints can successfully sustain 4% drift ratio without any significant residual deformation. For GFRP reinforced joints, as long as the joint was safe under applied shear stresses, increasing beam reinforcement ratio enhance the ability of joint to dissipate seismic vibrations.

III. MODELING

For the study a total of 4 models have to be prepared that are two interior and two corner beam column joint. They are listed as follows:

1) Interior Beam Column Joint with Steel main bars and Steel stirrups (IBCJ-SS)
2) Interior Beam Column Joint with GFRP main bars and GFRP Stirrups (IBCJ-GG)
3) Corner Beam Column Joint with Steel main bars and Steel stirrups (CBCJ-SS)
4) Corner Beam Column Joint with GFRP main bars and GFRP Stirrups (CBCJ-GG)

After the analysis of all the above models, the results were compared in terms of von mises stress, load and energy dissipation capacity.

A. Dimensions of Beam Column Joint

For the purpose of modeling of Interior Beam Column Joint (IBCJ) and Corner Beam Column Joint (CBCJ), following dimensions have been used and are same for all the 4 cases of joint. And all the details for modeling the interior and corner joints are taken as per IS13920:2016.

Width of beam : 230mm
Depth of beam : 400mm
Length of beam : 2100mm
Depth of column : 300mm
Width of column : 450mm
Height of column : 3500mm

The material properties of concrete, GFRP and steel are demonstrated in TABLE I and TABLE II. And the reinforcement detailing of interior and corner beam column joint was shown in “Fig.1” and “Fig.2.”

Properties	Diameter of bar		
	8mm	12mm	16mm
Young's Modulus (N/mm^2)	42000	45400	46400
Poisson's Ratio	0.26	0.26	0.26
Density (kg/m^3)	2500	2500	2500
Bulk Modulus (N/mm^2)	29167	31528	32222
Shear Modulus (N/mm^2)	16667	18016	18413

Table I: PROPERTIES OF CONCRETE AND STEEL

Properties	Concrete	Steel
Mix/Grade	M20	FE 415
Density (kg/m^3)	2500	7850
Young's Modulus (N/mm^2)	22360.679	2x10^5
Poisson's Ratio	0.2	0.3
Bulk Modulus (N/mm^2)	12422.59	1.6667x10^5
Shear Modulus (N/mm^2)	9316.95	7.692310^5

Table II: PROPERTIES OF GFRP

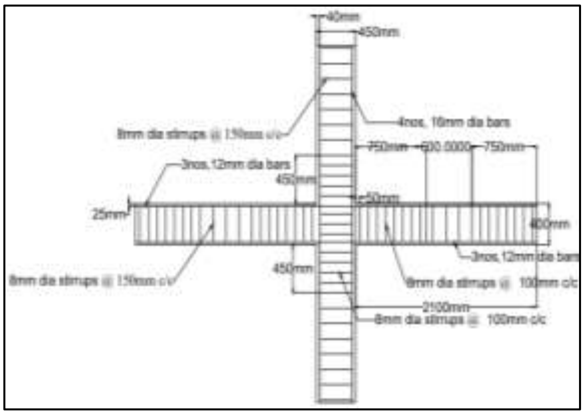


Fig. 1: Reinforcement details of interior beam column joint

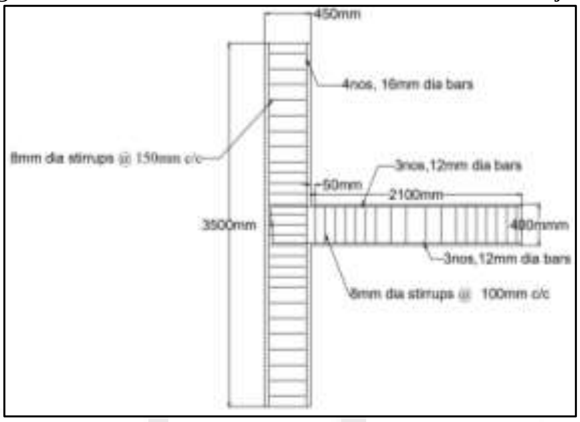


Fig. 2: Reinforcement details of corner beam column joint

The modeling of interior and corner beam column joint was done using ANSYS 2022 R1 and was shown in “Fig.3” and “Fig.4”. And the meshed model was shown in “Fig.5” and “Fig.6”. In meshing, number of nodes and number of elements used in case of interior joint was 56604 and 12348 and in case of corner joint it was 38596 and 8599.

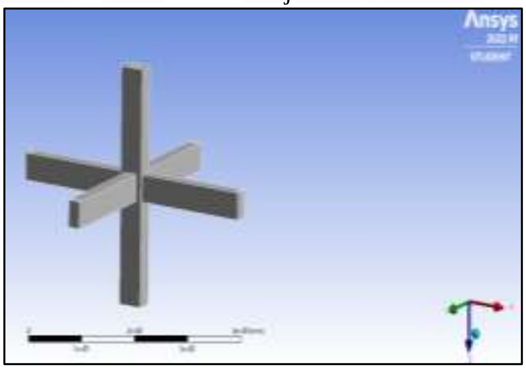


Fig. 3: Modelled IBCJ

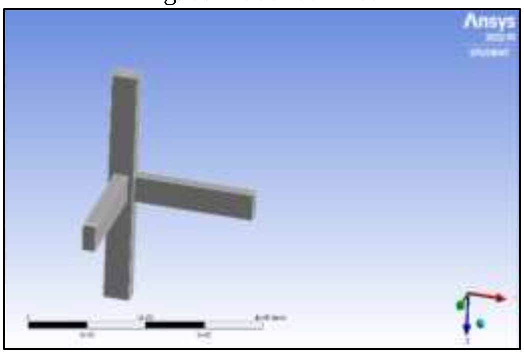


Fig. 4: Modelled CBCJ

The boundary conditions were, the bottom end of the column was supported by fixed support while at the top of the column an axial load 800kN was applied. Whereas, on beams all the ends were supported by roller support conditions. And in all beams cyclic load was applied at a distance of 50mm from the roller support. These were shown in “Fig.7” and “Fig.8”. The cyclic load was applied in the form of displacement that is based on the displacement protocol. The cyclic load was given were 0,15,-15.30.-30,50,-50 respectively. The “Fig.9” Shows the loading cycle that is the time dispalcement graph.

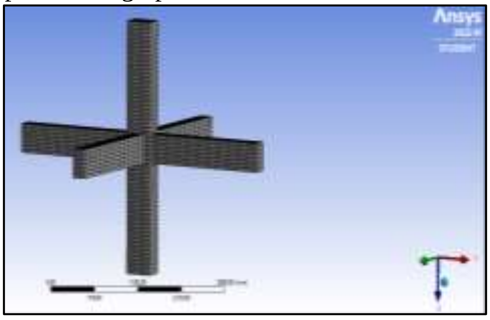


Fig. 5: Meshed Model of IBCJ

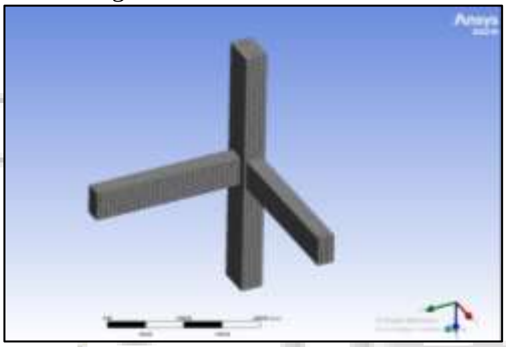


Fig. 6: Meshed Model of CBCJ

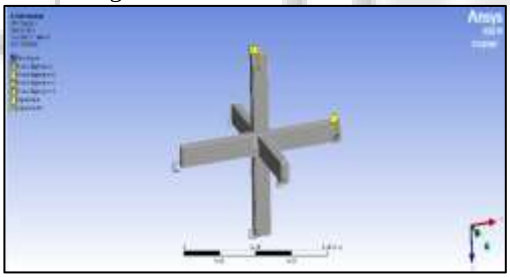


Fig. 7: Application of Load and Boundary Conditions in IBCJ

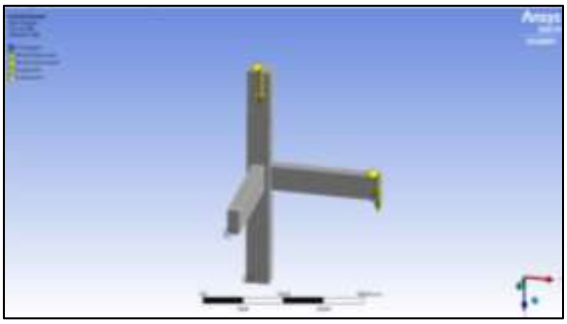


Fig. 8: Application of Load and Boundary Conditions in CBCJ

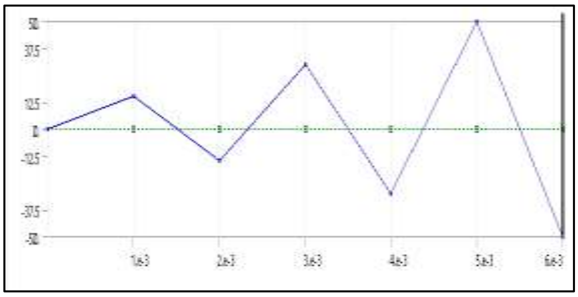


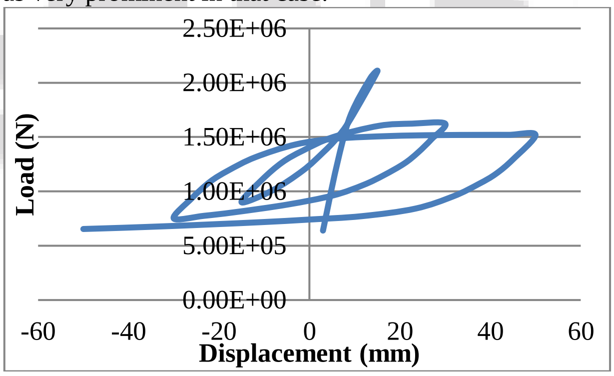
Fig. 9: Loading Cycle

IV. Results and Discussions

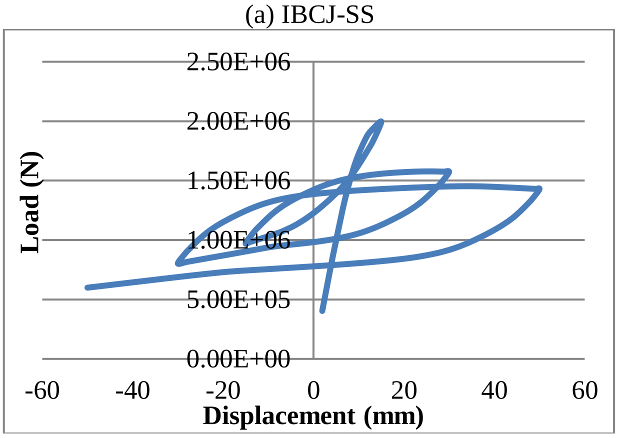
A. *Hysteretic Behavior of Joint*

The “Fig.10” shows the hysteretic load-displacement relation of an interior beam column joint during cyclic loading. The load carrying capacity were increased in all the four models during the first cycle, and then the capacity started to decrease. In case of interior beam column joint, the peak loads in positive and negative cycles for IBCJ-SS were obtained to be 2.1x10^6 N and 1.37x10^6 N, and for IBCJ-GG was 1.99 x10^6 N and 1.38x10^6 N. While on the other hand, the peak loads in positive and negative cycles for CBCJ-SS was obtained to be 1.719x10^6 N and 1.33x10^6 N, and for CBCJ-GG it was 1.68 x10^6 N and 1.383x10^6 N respectively.

From the load-displacement hysteretic graph of IBCJ-SS, yielding was clearly visible. Therefore, even the steel is having maximum load carrying capacity but yielding was very prominent in that case.



(a) IBCJ-SS

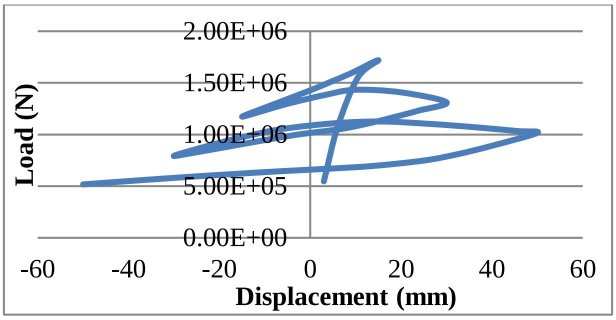


(b) IBCJ-GG

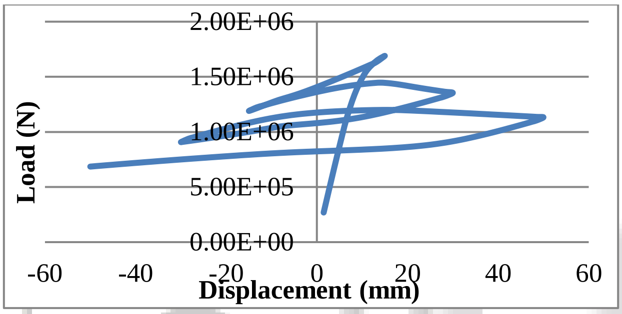
Fig. 10: Hysteretic load-displacement relation of IBCJ

From the load-displacement hysteretic graph of CBCJ-SS, and CBCJ-GG, it was noticed that the even though during the first cycle the steel reinforced joint showed a greater load carrying capacity. But, at the last cycle the CBCJ-GG model showed a greater load carrying capacity while compared to CBCJ-SS.

Therefore, beam column joint with GFRP as main bars and GFRP as Stirrups be a better choice for structures which were subjected to vulnerable loading conditions. The "Fig.11" shows the hysteretic load-displacement relation of and corner beam column joint subjected to cyclic loading conditions.



(a) CBCJ-SS

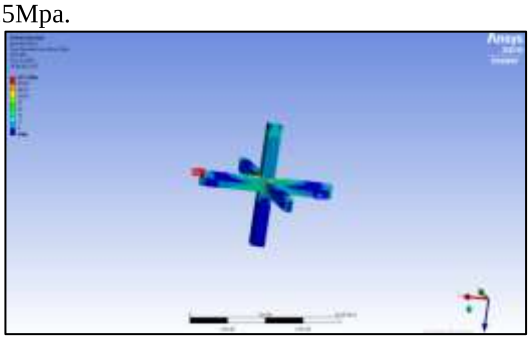


(b) CBCJ-GG

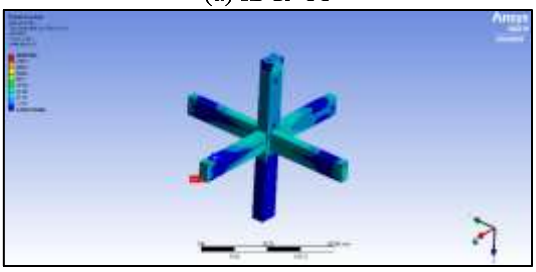
Fig. 11: Hysteretic load-displacement relation of CBCJ

B. Von-Miss Stress or Equivalent Stress

The von-miss stress or equivalent stress of two interior beam column joints was shown in "Fig.12". The maximum von-mises stress of IBCJ-SS and IBCJ-GG were 501.52Mpa and 4044.5Mpa.



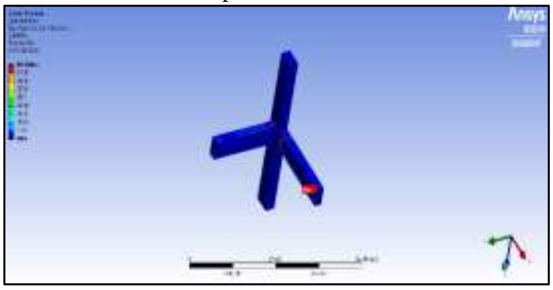
(a) IBCJ-SS



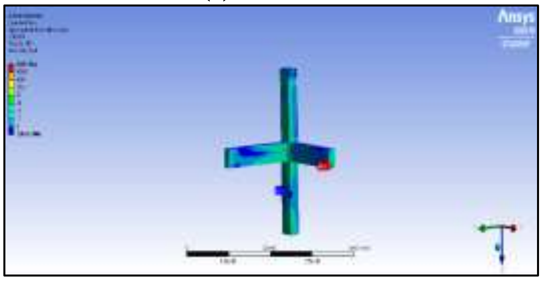
(b) IBCJ-GG

Fig. 12: Von-miss stress of IBCJ

The von-miss stress or equivalent stress of corner beam column joints was shown in "Fig.13". The maximum von-mises stress for CBCJ-SS was 461.34Mpa, and for CBCJ-GG was 4118.1 Mpa.



(a) CBCJ-SS



(b) CBCJ-GG

Fig. 13: Von-miss stress of CBCJ

Here, the stresses were high for GFRP reinforced models.

C. Energy Dissipation Capacity

The energy dissipation capacity of beam column joint subjected to cyclic loading in all the cases were found by taking the area under the curve of a load displacement graph. The values of maximum energy dissipation capacity of IBCJ-SS and IBCJ-GG were 61kNm and 194.64kNm. The values of energy dissipation capacity of CBCJ-SS and CBCJ-GG were 45.48kNm and 182.167kNm respectively. In both interior and corner beam column joint the joint with GFRP main bar and GFRP as stirrups showed a maximum energy dissipation capacity.

V. CONCLUSION

On the basis of the analysis results, following conclusions can be made:

– The load carrying capacity was increased in the first cycle, and after that there was a gradual decrement in load carrying capacity of all the models of interior and corner beam column joint.
– From load-displacement hysteric graph of IBCJ-SS, the yielding was very evident. The graph of CBCJ-GG showed a greater load carrying capacity during the increase of loading cycle compared to CBCJ-SS.
– The maximum von-mises stresses were developed at the ends of the beam in all the four beam column joints. The maximum stress was found to be less for IBCJ-SS and CBCJ-SS models. And also noted that the beam column joint with main bars and stirrups as GFRP showed a better stress values.
– When the stress was high, the strength can also be high. Therefore, GFRP might be a promising reinforcing material for several constructions.

- Both interior and corner beam column joint with GFRP showed a greater value of maximum energy dissipation capacity. And the minimum energy dissipation capacity was shown by steel reinforced joints.
- Therefore, GFRP be a better choice for constructions in seismic regions and for vulnerable loading conditions also.

REFERENCES

[1] Aditya Kumar Tiwary, Sandeep Singh, Jasgurpreet Singh Chohan, Raman Kumar, Shubham Sharma, Somnath Chattopadhyaya, Farid Abed and Mislav Stepinac, "Behavior of RC Beam Column Joints Strengthened with Modified Reinforcement Techniques," *Sustainability*, vol. 14, February 2022.
[2] Afnan Nafees, Muhammad Faisal Javed, Muhammad Ali Musarat, Mujahid Ali, Fahid Aslam and Nikolai Ivanovich Vatin, "FE Modelling and Analysis of Beam Column Joint Using Reactive Powder Concrete," *Crystals*, vol. 11, 2021.
[3] Balamuralikrishnan R and Saravanan J, "Finite Element Analysis of Beam-Column Joints Reinforced with GFRP Reinforcements," *Civil engineering journal*, vol. 5, 2019.
[4] IS 13920:2016, Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice.
[5] Mohamed Mady, Amr El-Ragaby and Ehab El-Salakawy, "Seismic behavior of beam column joints reinforced with GFRP bars and stirrups," *Journal of composites for construction*, vol.15, 2011.
[6] Palak S. Agrawal, Varsha R. Harne, Vinay G. Popli, "Study of RC Beam Column Joint under Seismic Loading," *RESEARCH PAPER Si-manager's Journal on Structural Engineering*, vol. 8, 2019.
[7] Pranali Wasnik, Sanket Sanghai and Dr. P.Y. Pawade, "Cyclic load analysis of beam column joint using ANSYS," *International Conference on Advances in Civil Engineering (ICACE 2021)*, 2021.
[8] Shervin K. Ghomi1 and Ehab El-Salakawy, "Seismic Behavior of GFRP-Reinforced Concrete Interior Beam–Column–Slab Subassemblies," *Journal of Composites for Construction*, vol. 23, 2019.
[9] Taha A. El-Sayed, Yasser A. Algash, "Flexural behavior of ultra-high performance geopolymer RC beams reinforced with GFRP bars," *Case Studies in Construction Materials*, vol.15, 2021.