

Experimental Investigation on RC Columns Confined by Jacket with Geopolymer Adhesive

Thakaa A. Hussien, Wissam D. Salman *

Department of Civil Engineering, University of Diyala, 32001 Diyala, Iraq

ARTICLE INFO

Article history:

Received May 6, 2022

Accepted May 27, 2022

Keywords:

RC columns

Confinement

Geopolymer adhesive

Jackets

ABSTRACT

Columns are one of the important structural members of engineering buildings. The impairment of reinforced concrete columns is one of the important problems affecting most structures, therefore the confinement of columns by fiber-reinforced polymers (FRP) is necessary to improve its behavior such as its load capacity, compressive strength, and ductility. The FRP used in the confinement is modern and wide application composite material in the field of civil engineering, which is pasted by epoxy. The fast impairment of epoxy at high temperatures leads to its replacement with an effective adhesive: geopolymers. This study presents the test result of an experimental investigation on confinement of six square RC columns with dimension (100*100*600mm) with geopolymer jacket under axial load conditions. The parameter considered is the jacketing material used (carbon fiber, plastic mesh, steel wire mesh, jute fiber, glass fiber mesh). Results of the test showed that confinement could improve the stiffness of the column by using a different type of material. The confinement with a carbon fiber reinforced geopolymers jackets can enhance the strength of the column after applying axial loading and improvement the performance of columns, but it is expensive. Where the increase in the load improvement and deformation capacity was (1.59 and 1.97), respectively, and the most effective jacket material in terms of economic cost and best performance in confinement operation consisted of (plastic mesh and steel wire mesh) compared to other types of material, with load enhancement by (1.41 and 1.27) and deformation capacity by (1.86 and 1.50), respectively compared with unconfined RC columns. Finally, the confinement by a different type of fiber-reinforced geopolymer adhesive is the most effective and used in the repair and rehabilitation of RC in the area with high-temperature climates.

1. Introduction

Repair and restoration of damaged concrete structures are one of the widespread construction activities globally. Confinement considers one of the rapid techniques in the repair process that have proven its ability to restore the primary capabilities of a damaged building, one of these techniques is the external confinement with fibers reinforced polymer (FRP) techniques. But these techniques have

drawbacks, including the use of epoxy as an adhesive between fibers and columns, where epoxy is a low-efficiency material and loses most of its mechanical properties at high temperatures and is not recommended in areas with hot climates. Choosing the suitable type of confinement is necessary for the field of design because it targets sustainability and thus cost of construction and time. The reinforced concrete (RC) columns are unable to withstand earthquakes due to poor ductility, excessive

* Corresponding author.

E-mail address: dr_wissam80@yahoo.com

DOI: [10.24237/djes.2022.15210](https://doi.org/10.24237/djes.2022.15210)



loads, corrosion of steel reinforcement, or error during design. The basic philosophy of the concept of confinement is to make the column behave in more ductility, that is it will be characterized by its ability to dissipate energy as a result of earthquakes and thus is a way to achieve ductile behavior. The concept of confinement consists of two principles, firstly is that the confining generates axial strength which is restitution for the strength lost as a result of concrete fragmentation. Secondly, that confinement leads to an increase in axial susceptibility without significant loss of strength. The purpose of confinement is to improve the capacity of existing concrete structures. Numerous materials and techniques are used for confining concrete structures. One of the most common confining methods is FRP, which is used to enhance their load capability, ductility, and compressive strength. The advantage of FRP is high strength to weight proportion, lightweight, ease of application, high durability, and good corrosion resistance. Most fibers are used: carbon, glass, and aramid. Generally, carbon fibers are the most widely used because of their high elastic modulus compared to glass fibers obtainable since 1959 [1-5].

In (2008) Benzaid et al. [6] present a study about the effect of confinement by glass-FRP on the square concrete column. A total of prisms was twenty-one with dimensions $100 \times 100 \times 300$ mm were tested under strain control rate of loading, strengthened with external glass fiber composite. This study was divided into three main groups according to the edge of the square section: The first with sharp-edged, the Second with a radius of the corner was 8 mm, and finally with a radius of corner equal to 16 mm. The main variable was the number of GFRP layers and the radius of the corner for a square section. The adhesive used to bond the fiber over the columns was epoxy. The result showed that confinement effectiveness of square columns

increases with the number of carbon fiber plies and the radius of the corner leads to enhancement of the capability and makes the column more ductility. The failure was near a corner due to high concentrations of stress.

In (2016) [7] Al-Khafaji et al. [7] investigate the behavior of square column confinement by CFRP for non-ductile square reinforced concrete columns. The main parameters were the cross-sectional, the ratio of volumetric to the hoop reinforcement, the number of layers by CFRP, and the loading condition (cyclic and monotonic). Thirty-four columns were divided into groups according to the mentioned parameters. The average compressive strength was 25.5Mpa of concrete used in these specimens. The thickness of FRP used in this study was 0.167 mm and the ultimate tensile strength was 4340 MPa. The test results showed the failure mode was ruptured for all the CFRP-wrapped specimens in the midheight region near the corners with a sudden loss in the axial strength. The CFRP application significantly improved the axial strain capacity and low enhanced the capability of axial compressive stress.

In (2016) Ozbakkaloglu et al. [8] gave an investigation study on the behavior of concrete-filled fiber-reinforced polymer (FRP) tubes (CFRTs) under axial load conditions. Thirty-six CFRTs were tested under axial compression. The main parameters were the concrete type using (geopolymer concrete (GPC) ordinary Portland cement (OPC) concrete (OPCC)) material of FRP tube, number of FRP layers, and shape of cross-sectional. The test results showed that the axial strain enhancement ratio in OPCCFRTs is higher than GPCFRTs but the same in strength enhancement. OPCCFRTs exhibit a plateau at the transition region of their stress-strain curves which is not seen in GPCFRTs due to the higher shrinkage of the OPCC. At the same confinement ratio, slight differences in the improvement ratio of strength

and strain are seen among GPCFFTs manufactured with different fibers but converts in OPCCFFTs. The decrease in FRP thickness tube leads to an increase in strength and strain enhancement coefficients of both OPCC- and GPC-FFTs.

In (2018) Razvia et al. [9] presented a study on the effect of confinement on the behavior of short concrete columns. The main parameters were nine square reinforcement concrete columns with dimensions 150*150 mm with a height of 960 mm with stirrups of Ferro-mesh jacket as confinement reinforcement and confinement column with Ferro-mesh jackets only. The test results showed that the increase in axial strength with additional Ferro-mesh as confinement was 20% compared to the regular control column. It also showed that ductility of columns with Ferro-mesh jacket was better than ductile manner columns without strips.

From the previous study, we noted that the confinement of RC column by FRP, the jacket was using epoxy adhesive. So, this study considered the first study using geopolymer as adhesive in the confinement of RC columns, the experimental program includes testing 6 columns to get the ratio of load enhancement and deformation capacity.

2. The experimental scheme

2.1 Materials

2.1.1 Concrete

The concrete compressive strength was 35 MPa for each column, where all RC columns were poured at once and vertically. Six cylinders of 300mm heights and 150mm diameters which cast to investigate the compressive strength of concrete at (7 and 28) days. After the mold was taken out, the specimens were treated with tap water for 28 days.

2.1.2 Geopolymer adhesive

Geopolymer paste as an adhesive in concrete confinement technology is a good alternative to epoxy and sustainable material that has good mechanical properties that can be used at ambient and high temperatures. Recently, research tends to use inexpensive and environmentally friendly materials in the manufacture of jackets. The production of geopolymer paste adhesive is completed by dissolving the flakes of hydroxide AL sodium (NaOH) with a concentration of 10 molar for pure water, to get the alkaline solution. Then mixed with a solution of sodium silicate (Na₂SiO₃) in an (SH/SS) ratio equal to 1:2, respectively, 24 hr before use. A ratio of 0.55 was used for the fluid to binder utilized. Table 1 showed the design of the mix.

Table 1: The mix of geopolymer adhesive

Binder slag (mg)	F/B	Na ₂ SiO ₃ (mg)	NaOH (mg)
2100	0.55	770	385

2.1.3 Fabric jacketing

Various types of fabric were used in the confinement of RC columns, and this fabric has proven its effectiveness as a good confining material with geopolymer adhesive in the strengthening of columns, thus improving the behavior of RC columns. Five different types of

fabric were used in this study, and the properties of the fabric were laboratory verified.

2.1.3.1 Carbon fiber fabric

The carbon fibers used in this study were unidirectional in the form of a roll as shown in Figure (1-a). The properties of Sika Wrap-300C carbon fiber are prepared according to ASTM

D3039 standard [10], which is introduced in Table 2. The effective adhesive used to bond the

carbon fabric for all columns was geopolymer adhesive.

Table 2: CFRP Properties supplied by manufacturer

Carbon fiber width(mm)	Ultimate tensile strength (MPa)	Fiber thickness (mm)	Elastic modulus (GPa)	Average rupture strain
300	2200	0.169	230	0.0175

2.1.3.2 Polyethylene fabric

Polyethylene (PE) means the (4x4) mm mesh reinforced woven fabric polyethylene or polythene is the most standard widely used type of plastic with tensile strength 257 MPa. The mesh reinforced woven fabric polyethylene is in the form of rolls with a width of 1000 mm as shown in Figure (1-b). The properties of plastic mesh are; mean fiber diameter 0.4mm, size opening (4 x 4) mm. Elongation at failure is 3.3%.

2.1.3.3 Steel Wire Mesh

Steel wire mesh materials are in the form of rolls, it is low cost and widespread in its use with a width of 1200mm. Figure (1 –c) shows the steel wire mesh. The properties of steel wire mesh, mean fiber diameter 0.2mm, size opening (2x 1.5) mm. Elongation at failure 4.5%, tensile strength 384.6MPa.

2.1.3.4 Jute Fiber Fabric

It is one of the materials used in the manufacture of sewing, knitting, and weaving thread, as it is spun and prepared for this purpose and is in multi-layer or single-layer. It can be used in the operations of confining the columns because it is sustainable, environmentally friendly and natural as well and has high tensile strength equal to 350MPa. Figure (1-d) shows the jute fiber material that is prepared in rolls with a width of 400mm. The properties of jute fiber are; mean fiber diameter 0.27mm, size opening (1.5 x 1.5) mm, elongation at failure 5.6%.

2.1.3.5 Glass fiber material

The glass fiber material has a random alignment, made with pioneering technology and sophisticated raw completed with white color. The glass fiber mesh is equipped in rolls as shown in Figure (1-e). The advantages of glass fiber mesh are easy to install, high quality and the best technical specifications. The properties of glass fiber mesh are; mean fiber diameter (0.1), width of 1250mm, the thickness of 3mm, elongation at failure 2.8%, and tensile strength 210Mpa.



Figure 1. Fabric mesh used

2.2 Experimental work

An experimental study consisted of six RC columns, one of them was reference (unconfined) and is indicated by the symbol (RCC), and the remaining five were confined with two layers of the sheet, (Carbon Fiber, Plastic Fiber Mesh, Steel Wire Mesh, Jute Fiber Mesh, Glass Fiber Mesh), reinforced geopolymer adhesive jacket symbolized by (CCF2L, CPM2L, CSM2L, CJM2L, and CGM2L), respectively, as shown in Figure 2. All tested columns have a square section, were 600mm in height and 100mm in width, and with a radius of corner 25 mm (the mold are made

with diameter 25 mm). The main longitudinal reinforcement of four-bar Ø8 mm with 450 MPa yield strength, and the transverse reinforcement Ø4 mm bars with yield strength 465 MPa at 95 mm distance between them, as present in Figure 3. Cured at the water for 28 days after finishing

the casting of columns. Then confinement of fiber-reinforced by geopolymer adhesive (FRGA) and cured at factory temperature and became ready for the test. The Details of RC columns are shown in Table 3.

Table 3: Details of RC columns

No	Specimens	Jackets Material	Price (\$) for 1m ²	Thickness (mm)	Opening size mm ²	Fy (MPa) of fiber	Elongation at failure%
1	RCC	-	-	-	-	-	-
2	CCF2L	carbon fiber	34	0.017	-	2200	4.9
3	CPM2L	Polyethylene plastic mesh (4*4)	0.3	0.4	4x4	257	3.3
4	CSM2L	Steel Wire Mesh	0.33	0.2	2x15	384.6	4.5
5	CJM2L	Jute fiber	0.25	0.27	1.5x1.5	350	5.6
6	CGM2L	Glass fiber	3	0.3	-	210	2.8



Figure 2. Custom of reinforced concrete columns

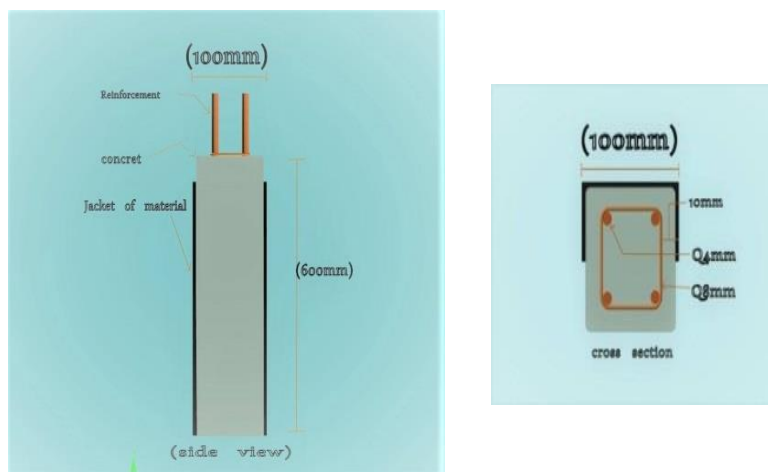


Figure 3. Dimensions of RC columns

3. Results and discussion

3.1 Column failure pattern

Figure 4 shows the RC columns after testing and failure. The failure mode of RC columns (CCF2L, CPM2L, CSM2L, CJM2L, CGM2L) was ruptured at the confinement jackets in the upper part of the column except the column confinement by plastic mesh the failure was in the middle of column. Gravity and weight effect on casting mechanism, where the casting was vertical and the vibrators were used, this led to

going down of coarse aggregate, while the fine aggregates remain at the upper of the column, which made the top part of RC column weak and failure. The reason for this due to generate tension pressures because stretch and crushing of the core of concrete after applying the axial load then transmitted to the jacket, which withstands these stresses. The mode of failure was observed and found to be typical and identical to the mode of failure columns [11,12].



Figure 4. Failure pattern of RC columns

3.2 Enhancement of load and deformation capacity

Table 4 pointed to the test results of columns. Figure 5 showed the load-strain curves

of the column. Figure 6 showed the axial load capacity.

Table 4: The results of tested columns.

Specimens	Pu (KN)	ϵ_u (mm/mm)	Pu/Pu, RCC	ϵ_u/ϵ_u , RCC	Failure mode
RCC	395	0.00313	-	-	-
CCF2L	630	0.00616	1.59	1.97	Rupture
CPM2L	556	0.00552	1.41	1.86	Rupture
CSM2L	500	0.00471	1.27	1.50	Rupture
CJM2L	480	0.00427	1.22	1.36	Rupture
CGM2L	473	0.00388	1.19	1.24	Rupture

Where: Pu: ultimate axial load, ϵ_u : ultimate axial strain, Pu/Pu, RCC: load enhancement ratio of confined RC columns, ϵ_u/ϵ_u , RCC: deformation capacity of confined RC columns.

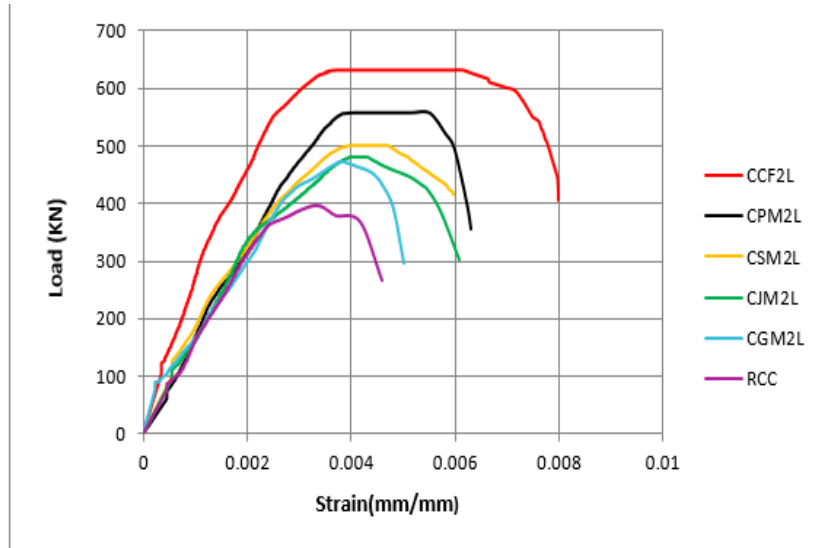


Figure 5. Load-strain curves of RC columns

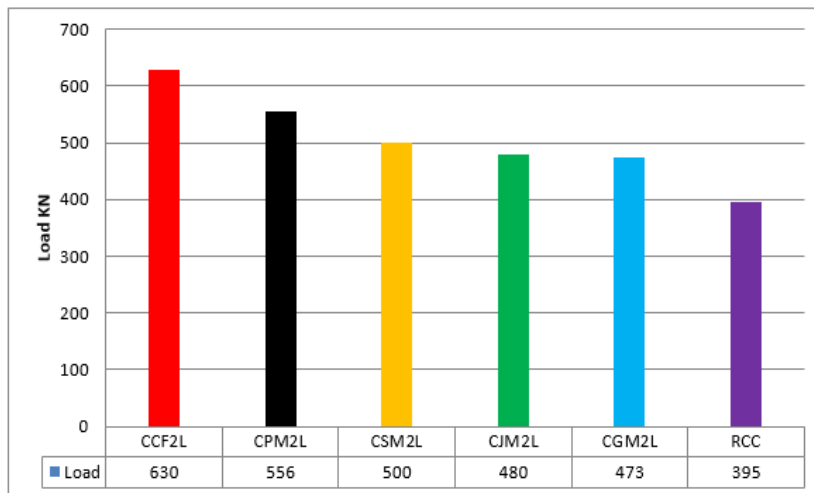


Figure 6. The axial load capacity of RC columns

Through the failure (rupture) of all confined RC columns, the geopolymer adhesive formed a strong matrix with fibers to resist the stresses transmitted to it from the concrete core after applying the load, and thus proved its effectiveness as an adhesive. The experiment results showed that all confined RC columns led to the development of axial load. Where, the (CCF2L, CPM2L, CSM2L, CJM2L, and CGM2L) are giving enhancement in load by (1.59, 1.41, 1.27, 1.22, and 1.19), and deformation capacity of (1.97, 1.86, 1.50, 1.36,

and 1.24), respectively. The properties of jackets material such as (thickness of the fabric, opening size, elongation at failure, tensile strength) effect on the increase in load capacity and increase in strain of confined RC columns. The percentage increase in ultimate load capacity of RC columns compared to the unconfined specimen was shown in Figure 7. Thus, the best types of jacket material were plastic fabric mesh and steel wire mesh from the economic cost and efficient performance.

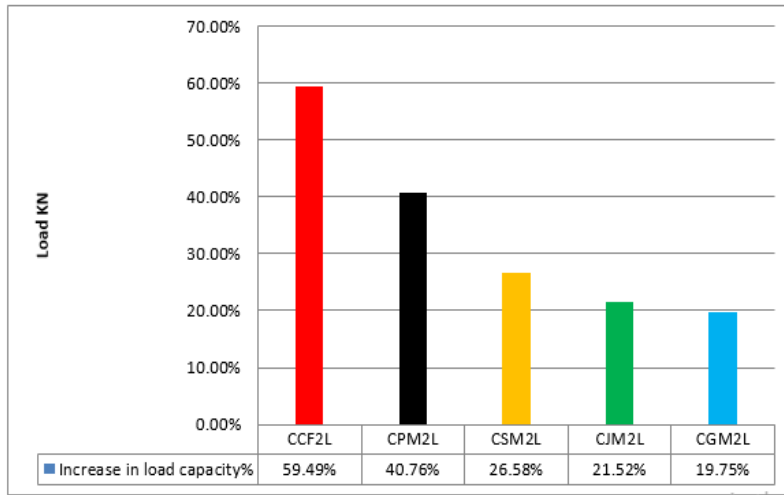


Figure 7. Increase in load capacity at ultimate

3.3 Strain jackets

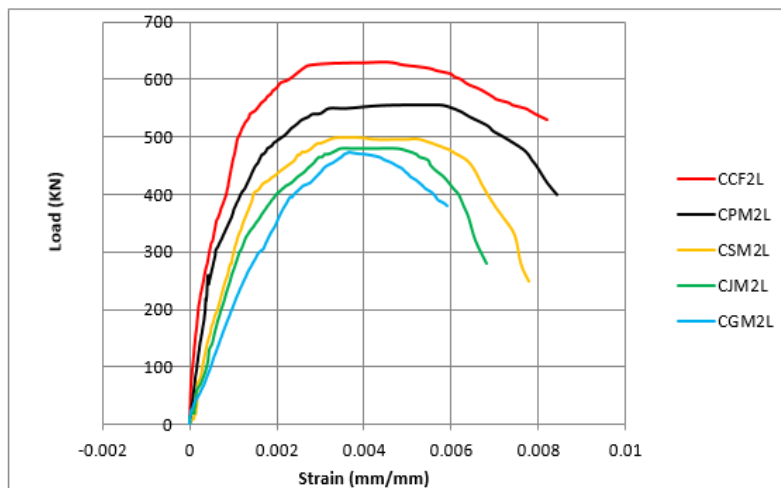
Table 5 present the test results of jacket strain and Figure 8 showed the longitudinal

axial load-and transverse strain in confinement jackets of RC column.

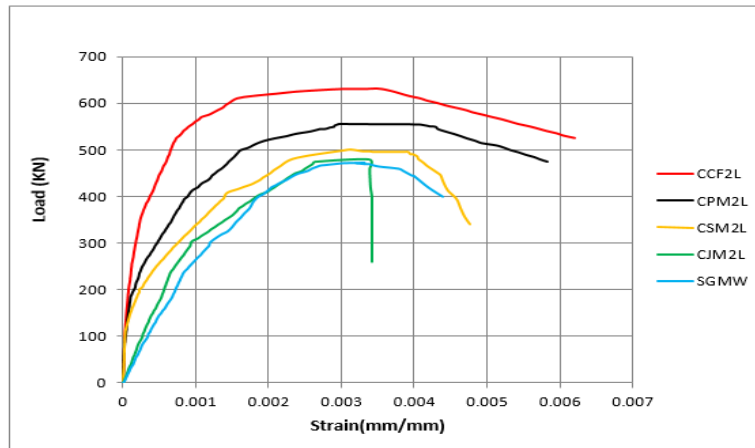
Table 5: Jacket strain of RC confined columns

Specimens	ϵ_{lu}	ϵ_{tu}	V
CCF2L	0.00456	0.00300	0.66
CPM2L	0.00400	0.00296	0.74
CSM2L	0.00392	0.00338	0.86
CJM2L	0.00375	0.00274	0.73
CGM2L	0.00365	0.00332	0.91

Where: ϵ_{lu} : ultimate longitudinal jacket strain, ϵ_{tu} : ultimate transverse jacket strain, V: Poisson's ratio



a)



b)

Figure 8. Load- jackets strain a) Load-longitudinal strain b) Load-transverse strain

From Table 5 it was noted that the different types of jackets material gave the different values of poisson ratio due to the properties of jacket materials. Thus, there is significant improvement in the resistance to lateral strain of the longitudinal strain of jackets. Specimens (CCF2L, CJM2L, CPM2L, CSM2L, and CGM2L) give a decrease of Poisson's ratio by

(0.66, 0.73, 0.74, 0.86, and 0.91), respectively. The properties of the jacket materials which caused the difference in value of Poisson ratio.

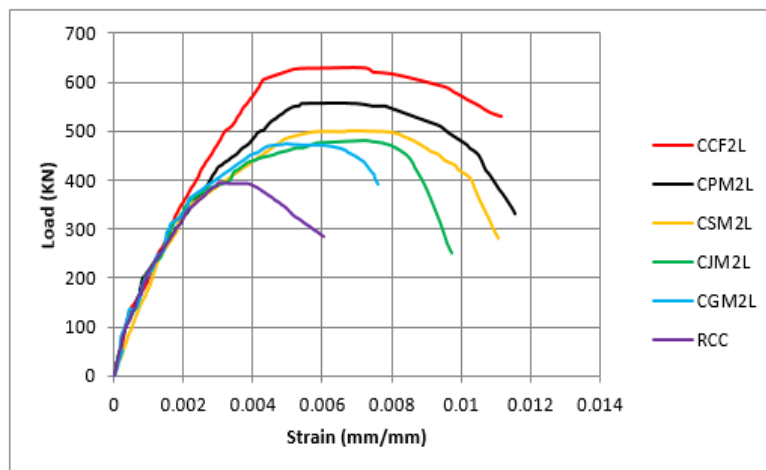
3.4 Concrete strain

Table 6 reported the test results of concrete strain and Figure 9 showed the load-concrete strain of RC columns.

Table 6: strain at concrete

Specimens	ϵ_{lcu}	ϵ_{tcu}	$\epsilon_{lcu}/\epsilon_{lcu, RCC}$	$\epsilon_{tcu}/\epsilon_{tcu, RCC}$	V
RCC	0.00300	0.00327	-	-	1.09
CCF2L	0.00685	0.00522	2.28	1.59	0.69
CPM2L	0.00664	0.00592	2.21	1.81	0.82
CSM2L	0.00678	0.00610	2.26	1.87	0.83
CJM2L	0.00724	0.00577	2.41	1.76	0.73
CGM2L	0.00498	0.00349	1.66	1.07	0.64

Where: ϵ_{lcu} : ultimate longitudinal strain of concrete, ϵ_{tcu} : ultimate transverse strain of concrete, $\epsilon_{lcu}/\epsilon_{lcu, RCC}$: longitudinal deformation capacity of concrete, $\epsilon_{tcu}/\epsilon_{tcu, RCC}$: transverse deformation capacity of concrete, V: Poisson's ratio



a)

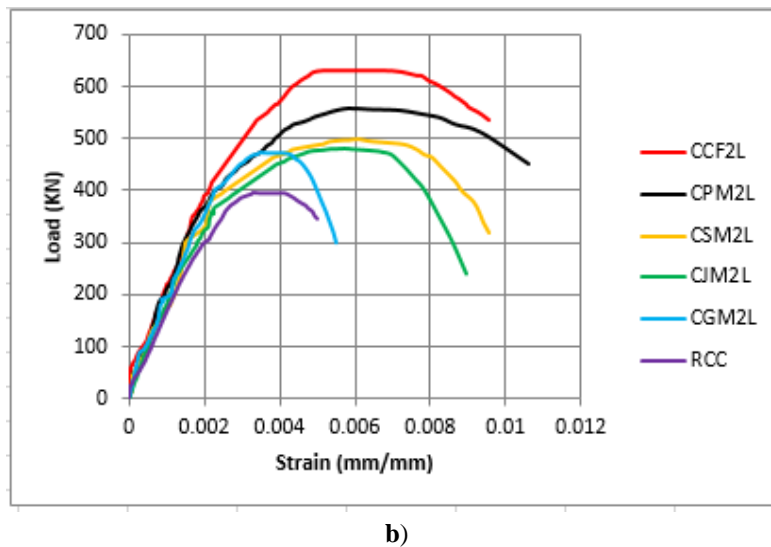


Figure 9. Load-strain in the concrete of RC columns a) Load-longitudinal strain b) Load-transverse strain

Table 6 explain the various type of jackets material gave different values to the Poisson ratio causes a significant improvement in resistance on lateral strain of the longitudinal strain of concrete. The specimens (CGF2L, CCM2L, CJM2L, CPM2L, and CSM2L) give a decrease of Poisson's ratio by (0.64, 0.69, 0.73, 0.82, and 0.83) respectively. The reason for the difference in the Poisson ratio due to the properties of the jacket materials.

4. Conclusions

The main endeavor of the experimental work which consists of six RC columns, one unconfined and five confined by different type of jacket, was to evaluate the effectiveness of these jacket on the behavior of RC columns. According to the test result of the experimental study, it can be concluded that:

1. The geopolymers are an effective adhesive material and high temperature tolerance with the different types of jackets materials which used in the confinement process of RC columns jackets,
2. The confinement by jackets of (plastic fiber and steel wire mesh) are the best

effectiveness in the cost and performance compared to other types of jackets.

3. The confinement by jackets of (Plastic and steel wire mesh) led to a remarkable development in the enhancement of load by (1.41 and 1.27) and deformation capacity by (1.86 and 1.50) at a price of (0.3 and 0.33) \$, respectively
4. The carbon fiber which is used in confinement RC columns led to remarkable development load enhancement ratio and deformation capacity by (1.59 and 1.97), respectively.
5. The effectiveness of the adhesive material and the tensile strength of jackets material leads to development in the performance of RC columns.

References

- [1] Shin, H.O., Min, K.H. and Mitchell, D., 2017. Confinement of ultra-high-performance fiber reinforced concrete columns. *Composite Structures*, 176, pp.124-142.
- [2] Salman, W.D. and Mansor, A.A., 2021. Confinement of concrete in double skin tubular members under axial compression loads. *Asian Journal of Civil Engineering*, 22(3), pp.431-442.

- [3] Salman, W.D. and Mansor, A.A., 2021. Fibrous geopolymer paste composites for near-surface-mounted strengthening of reinforced concrete beams in flexure. *Case Studies in Construction Materials*, 14, p.e00529.
- [4] Hussain, Q., Ruangrassamee, A., Tangtermsirikul, S. and Joyklad, P., 2020. Behavior of concrete confined with epoxy bonded fiber ropes under axial load. *Construction and Building Materials*, 263, p.120093.
- [5] Wu, H.C. and Eamon, C.D., 2017. Strengthening of concrete structures using fiber reinforced polymers (FRP): design, construction and practical applications.
- [6] Benzaid, R., Chikh, N.E. and Mesbah, H., 2008. Behaviour of square concrete column confined with GFRP composite wrap. *Journal of civil engineering and management*, 14(2), pp.115-120.
- [7] Al-Khafaji, H.L., 2016. *Experimental Investigation of CFRP Wrapped Square Non-Ductile Reinforced Concrete Columns* (Doctoral dissertation, Portland State University).
- [8] Ozbakkaloglu, T. and Xie, T., 2016. Geopolymer concrete-filled FRP tubes: Behavior of circular and square columns under axial compression. *Composites Part B: Engineering*, 96, pp.215-230.
- [9] Razvi, S.W.N. and Shaikh, M.G., 2018. Effect of confinement on behavior of short concrete column. *Procedia Manufacturing*, 20, pp.563-570.
- [10] ASTM D3039. 2015. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, *American Society for Testing and Materials, West Conshohocken, USA*,
- [11] Ali, H.A. and Salman, W.D., 2019, August. Effect of void ratio of inner steel tube on compression behavior of double skin tubular column. In *IOP Conference Series: Materials Science and Engineering* (Vol. 584, No. 1, p. 012027). IOP Publishing.
- [12] Salman, S.M. and Salman, W.D., 2021, October. Confinement of RC Columns by Carbon Fiber Reinforced Geopolymer Adhesive Jackets. In *2021 International Conference on Advance of Sustainable Engineering and its Application (ICASEA)* (pp. 107-112). IEEE.