
Investigation of Flexural Strengthening for RC Beams by NSM with Geopolymer

Hajer Khaleel Gatia ¹  Ali Kareem Al-Asadi*¹ 

Received: 22th December 2025/Accepted: 25th March 2026/ Published Online: 1st June 2026

© The Author(s), under exclusive license to the University of Thi-Qar

Abstract

This research examines the performance of geopolymer paste compared with epoxy adhesive for flexural strengthening of RC beams. Five beam specimens were cast with dimensions of 130 x 160 x 1300 mm. One specimen was non-strengthened and served as a reference beam, while four beams were strengthened using the near-surface-mounted (NSM) method. The strengthened samples included either a single groove or a double groove. Geopolymer paste and epoxy paste were employed as adhesive materials in this paper. Additionally, the NSM -bar reinforcement consisted of a steel bar with a diameter of 8 mm. The study parameters were the number of grooves and the adhesive material type. All RC beam specimens were tested under a four-point loading. The ultimate load capacity, load-deflection behavior, initial crack load, and mode of failure of the RC beam were analyzed. This study aims to investigate the influence of geopolymer adhesive on the flexural strengthening of RC beams using the NSM technique. In general, the findings demonstrate that the ultimate load of strengthened specimens with two grooves increased in initial crack load and load bearing capacity by 64.29% and 71.87 %, respectively, in contrast to an un-strengthened beam (control beam).

Keywords – Flexure, NSM, Strengthening, Geopolymer

1 Introduction

Strengthening concrete construction is an essential challenge in civil engineering. Concrete construction is subjected to various factors, including design errors, increased service loads, workmanship issues during construction, code updates, and the need to extend the service life period, which leads to the need to strengthen the construction. (Salman & Mansor, 2021). Because of these causes, the sudden failure of concrete structures may occur; therefore, the researchers in the structural field have identified many techniques of strengthening (Salman et al., 2018).

One of the strengthening technologies is the externally bonded reinforced (EBR) method. This method uses carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) sheets. These materials (CFRP, GFRP) are

Hajer Khaleel Gatia

Hajar.k@utq.edu.iq

Ali Kareem Razaq Al-Asadi

alazharco.2005@utq.edu.iq

1 Department of Civil Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, Iraq

popularly used because they have some characteristics such as resistance to corrosion, weight efficiency, and feasibility, in addition to being applied in different layers. Many previous studies gave a good indication of the performance of these materials in improving and strengthening structures, and they found that the (EBR) technique increases ultimate load capacity by 48.2% (Abed et al., 2022). The effectiveness of this technique depends on the bond between the sheet fiber and the concrete. However, the main issue in applying this method is debonding. The debonding causes loss of effectiveness of strengthening and leads to premature failure in the structural member (De Lorenzis L & Teng JG, 2007) (Ahmed M. Khalifa, 2016). As a result, the alternative technique is essential.

The researchers in the engineering community have developed a technology that uses embedded bars or strips and is more effective with less debonding. It is a near-surface-mounted (NSM) technique (Alnemrawi & Al-Rousan, 2025). The NSM technique exhibits excellent bond performance, protection of the NSM-bar, and surface preparation compared to the EBR-FRP technique (Mohamed et al., 2024). The epoxy paste was employed as an adhesive material in the NSM method, where the epoxy bonds the bars to the concrete. Epoxy exhibits good performance but has some drawbacks associated with its use, such as loss of mechanical properties at high temperature (Al-Abdwais A and Al-Mahaidi R, 2016) (Hadi et al., 2020) In addition, it poses health risks to workers due to toxic gases released during its production (Salman & Mansor, 2021) (Al-Abdwais & Al-Mahaidi, 2020) Consequently, given these factors and the potential unavailability of epoxy, there is an increasing need for a replacement for epoxy.

The geopolymer paste adhesive (GPA) material was an alternative material. GPA is a new sustainable bonding material and improves the crack width of concrete construction in events such as seismic, leading to more safety for the structure (Yuguang Mao et al., 2023). Also, the GPA showed excellent influence in high temperatures (Kadhim & Al-Asadi, 2025). Five beam specimens with dimensions 130x160 mm and 1300 mm in length were cast and cured. One of them was un-strengthened as a control beam, and the other four beams were strengthened using the NSM method with two adhesive materials, geopolymer (GPA) and epoxy. Ultimate load capacity, modes of failure, crack load, and behavior of load-deflection were analyzed. Under a four-point load, the RC beams were tested to study their flexural behavior.

2 Methodology and materials

This work involves design and testing five beams with a width of 130 mm, height of 160 mm, and length of 1300 mm, with a clear span of 1100 mm, and made of reinforced concrete. The beams are subjected to four-point loading, where one beam served as a control (un-strengthened), and the other four beams were strengthened in flexure using the NSM technique. Two types of adhesives, epoxy and geopolymer, were used, and the NSM steel bars of 8mm diameter. The strengthened beams consist of one or two grooves applied to the bottom face of the beam. The main test results focus on the ultimate load capacity, failure characteristics, load-deflection curve behavior, and crack load.

2.1 Normal concrete

Normal concrete consists of sulfate-resisting Portland cement (Type V), sand, crushed gravel, and water. It was used in this study. The details of the mix design used are summarized in Table 1. To prepare the mix, the sand and crushed gravel were mixed using a rotary mixer machine with a (0.1 m³) capacity for (2-3 minutes). Then the cement was added to the mixer, and the mixture was remixed until a uniform color was obtained. The concrete mix was mixed with one quarter of the water in the first minute and the remaining water for the next two minutes to get homogeneous fresh concrete. Afterward, the molds were filled with the concrete mix. After 24 hours, the specimens were demolded and cured for 28 days. The obtained compressive strength was 30 MPa.

Investigation of Flexural Strengthening for RC Beams by NSM with Geopolymer

Table 1: Mix design of concrete

Compressive Strength (MPa)	Cement (Kg/m ³)	Coarse aggregate (Kg/m ³)	Fine aggregate (Kg/m ³)	Water (Kg/m ³)
30	410	1050	765	210

The physical and chemical properties of Sulfate-resisting Portland cement (Type V) used in this study are listed in Tables 2 and 3 in order. The properties of the cement were selected according to (Iraqi Stand.Specif.N.5 IQS, 1984)

Table 1: Physical properties of Portland cement

	Test results		Limit of IQ. S No. 5/1984
Physical Property	initial	118	≥ 45
Setting Time (min)	final	145	≤ 600
Compressive Strength	3 days	15	≥ 15
	7 days	23.0	≥ 23

Table 2: Chemical properties of Portland cement

Chemical property	Test results	Limit of IQ. S No. 5/1984
CAO %	60.91	-----
SIO ₂ %	21.34	-----
Al ₂ O ₃ %	3.8	-----
Fe ₂ O ₃ %	3.5	-----
Mgo %	4.0	≤ 6
SO ₃ %	2.21	≤ 2.3
C ₃ A %	4.16	≤ 5
Insoluble residue (%)	1.22	≤ 1.5
Loss on ignition	2.49	≤ 3
C ₄ AF	10.6	-----
C ₃ S	49.3	-----
C ₂ S	24.2	-----

The natural sand that is locally available was used in the current study. Sieve analysis was employed to test the sand according to (Iraqi Stand.Specif.N.5 IQS, 1984). Results of sieve analysis are listed in Table 4.

Table 4: Sieve analysis results

Sieve No.	Sieve size(mm)	Passing sand %	Iraqi Standard limits
1	9.5	100	100
2	4.75	99	95-100
3	2.36	88	75-100
4	1.18	70	55-90
5	0.6	49	35-59
6	0.3	19	8-30

7	0.15	3	0-10
8	pan	-----	
	SO ₃	0.491 %	≤ 0.5

The locally sourced crushed coarse aggregate was also used with a maximum size of 19 mm. The test was carried out by sieve analysis according to ("Iraqi Specification No.45 M. B. Structures, 1984). The result is presented in Table 5

Table 5: Sieve analysis results

Sieve No.	Sieve size (mm)	Passing gravel %	Iraqi Standard limits
1	25	100	100
2	19	98	95-100
3	9.5	36	30-60
4	4.75	0	0-10
5	pan	-----	-----
SO ₃		0.09	≤ 0.1

2.2 Geopolymer Paste Adhesive

The NSM method utilized geopolymer paste adhesive (GPA) as a binding agent to enhance the flexural strengthening of RC beams. The geopolymer is environmentally sustainable and economically viable. The geopolymer paste was prepared according to (alman & Mansor, 2021). To this end, the geopolymer adhesive material is prepared by first obtaining a 10-molar sodium hydroxide solution (NaOH) and mixing it with sodium hydroxide flakes with the calculated quantity of water. After adding the water, the sodium hydroxide flakes were mixed thoroughly until completely dissolved. Before using, the solution must be prepared at least 24 hours in advance to reduce the high temperature produced by a chemical reaction, so care must be taken during the preparation of the solution geopolymer adhesive material employed in this study was formulated based on the mix design presented in Table 6. To assess the compressive strength of geopolymer, three cube specimens measuring 50 x 50 x 50 mm were cast and cured for 3 days, then tested using a testing machine with a capacity of 2000 kN, as shown in Fig. 1, because this material had no manufacturer's data sheet, including the compressive strength. The average compressive strength obtained was 72 MPa.

Table 6: Mix used of geopolymer adhesive paste.

Slag binder(mg)	F/B	Na ₂ SiO ₃ (mg)	NaOH(mg)
2100	0.55	770	385

Investigation of Flexural Strengthening for RC Beams by NSM with Geopolymer



Figure 1: Geopolymer mix and testing machine

2.3 Epoxy paste adhesive.

The type of epoxy used in this study was "Sika dur@ -30 L P". As shown in Fig.2, the epoxy was prepared by mixing two parts, A and B, in a 1:3 ratio according to [product data sheet]. An electric drill was used to mix the two components and produce the epoxy adhesive paste.



Figure 2: Epoxy paste

2.4 Geometry and Details of RC Beams

Five beams with a cross-section of (130x160 mm) and 1300 mm in length. All beam designs are intended to fail in flexure. Steel bars with 8 mm diameter are used in the main reinforcement and shear reinforcement. The main reinforcement consists of two bars with 8 mm diameter at the tension zone of the beam and one bar at the compression zone of the beam. While the shear reinforcements were \varnothing 8 mm with a spacing of 50 mm for the region between loads and supports, and 100 mm for the middle third of the span. All of the reinforcement details are illustrated in Fig.3

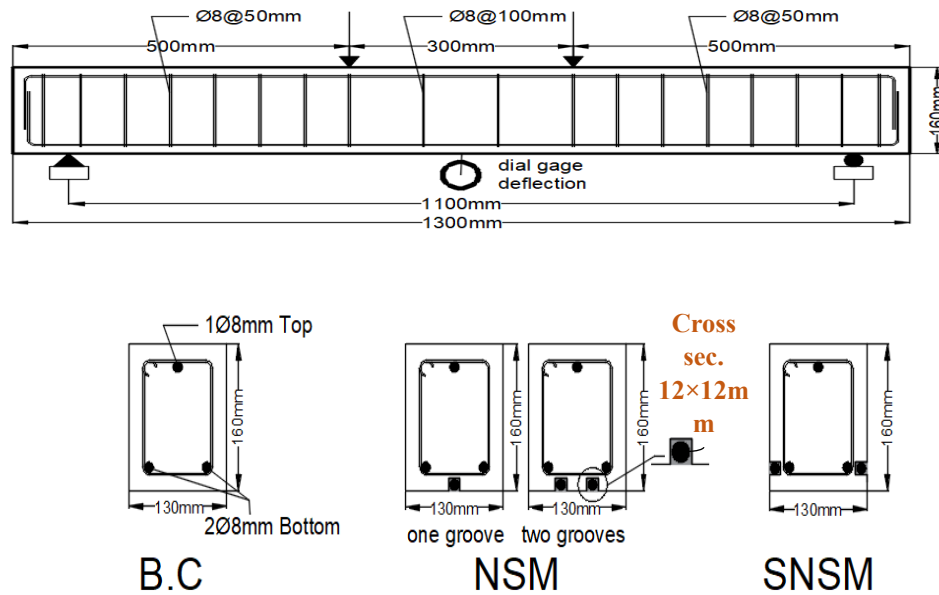


Figure 3: Details of reinforcement beams and grooves

Table 7: Details of the reinforced beam

Beam Name	Reinforcement of NSM, SNSM	Number of Grooves	Adhesive material
B.C	-	-	-
BE-D8st-1	Steel 8mm	1	Epoxy
BE-D8st-2	Steel 8mm	2	Epoxy
BG-D8st-1	Steel8mm	1	Geopolymer
BG-D8st-2	Steel8mm	2	Geopolymer

B: beam E: Epoxy G: Geopolymer D8 st : (Diameter of steel bar 8mm),

2.5 Grooves configuration

The groove dimensions are $(1.5 d \times 1.5 d)$, where d is the diameter of the steel bars. In the current study, the dimensions of the groove were a $(12 \times 12 \text{mm})$ cross-section and 1000 mm in length. The size of the grooves and the spacing between them are specified in [(ACI 440.2R, 2017)]. The grooves were formed using wooden strips, which were fixed in the mold as shown in Fig.4. After that, the concrete mix was placed in the molds and left for 24 hours. Afterward, the mold and the wood strips were removed, and the grooves appeared.



Figure 4: Formation groove in the wooden mold

2.6 Strengthening Technology

After curing the beams for the specified duration, the specimens became ready for strengthening using the near-surface mounted (NSM) technique. In this method, the grooves are applied to the bottom surface of the beam. First, prepare grooves by following the process as shown in Figure 5. Roughen the inner surface of the grooves by hand chisel. The purpose of roughening is to ensure perfect adhesion between the adhesive and concrete. Afterward, clean them with water and pressurized air to dry them. Next, the NSM technology is applied using epoxy as follows: fill half-depth groove with epoxy, insert the steel bar, press bar into groove, and finally add extra epoxy and level the surface as shown in Figure 6. Then leave the beams to cure and allow the epoxy to achieve full strength for 7 days at 25 °C according to the manufacturer's data sheet. Regarding strengthening specimens using NSM with geopolymer, follow the same steps as with epoxy: prepare grooves, then apply NSM with geopolymer, fill half-depth groove with geopolymer adhesive, insert the steel bar, press the bar, and finally add extra geopolymer, level the surface, and cover as shown in Figure 7. Now leave the beams to cure and allow the geopolymer to achieve full strength in ambient temperature, 25 °C, for 28 days. Then all specimens were painted white. The specimens were painted to see cracks



Figure 5: Preparation grooves stages



Figure 6: Strengthened beams using NSM with epoxy



Figure 7: Strengthened beams using NSM with geopolymer

2.7 Testing Procedure for RC Beams

In the College of Engineering laboratory, simply supported beams under two concentrated loads (four-point loading) were tested, as shown in Figure 8. The testing machine had a maximum capacity of 180 kN, which was used to apply the load. A digital dial gauge (0.01 mm accuracy) was fixed at midspan of the RC beam to record the deflections. The load was applied at a rate of 5 kN per minute. The test was considered complete when the applied load started to decrease.

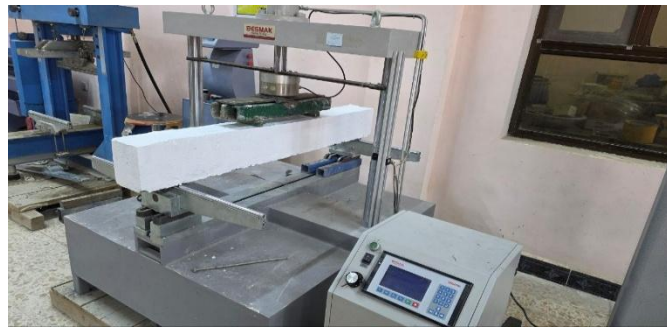


Figure 8: The testing machine

3 Results and Discussion

3.1 Ultimate Load-bearing capacity of RC Beams

The major objective of this paper is to increase the ultimate load-carrying capacity of the tested beam specimens. The experimental findings demonstrate that the strengthened beam specimens using the NSM method that had a single groove with epoxy and geopolymer (BE-D8st-1) and (BG-D8st-1) showed an increase in the load-bearing capacity by 14.9% and 36.2%, respectively, more than the un-strengthened beam. The RC beam specimens, which had two grooves with epoxy and geopolymer (BE-D8st-2) and (BG-D8st-2), exhibited an enhancement in ultimate load equal to 52.8% and 71.9%, respectively, higher than the reference beam. The results showed that the specimens that used Geopolymer paste as an adhesive material recorded values more than those that used Epoxy as an adhesive material. Also, the change in the number of grooves from single to double grooves leads to an increase in maximum load. Specimens with two grooves (BE-D8st-2, BG-D8st-2) displayed improved strengthening equal to 26.27% and 32.93%. more than specimens with one groove (BE-D8st-1, BG-D8st-1). This increase is attributed to a rise in the area of embedded bars, which led to improved resistance of the strengthened beam to applied load and provided better stress distribution. The test results of the RC beams are shown in Table 8.

3.2 Cracks Characteristics

From the results of the first crack load, as shown in Table 8, it can be seen that all the retrofitted RC beam specimens' appearance improved with initial crack load, with a range of 14.3% to 64.3%, respectively, compared with the control beam. This improvement, due to the geopolymer and epoxy, made the concrete cover of the strengthened beams stronger than the reference beam. Additionally, the strengthened beams that had two embedded bars show an improvement in initial crack load compared to those that had one embedded. When comparing the adhesive materials, the beams reinforced with geopolymer recorded an increase in the first crack load with arrange 28.6% to 64.3% over the control beam, while specimens reinforced with epoxy showed an increase of 14.3% to 50% more than the reference beam. This indicates that the geopolymer materials produce good performance compared to epoxy.

Table 8: Test results of RC beams

Beam	Ultimate load (kN)	Increase in ultimate load %	P cr(KN)	P cr %	Deflection(mm)	Mode failure
B.C	22.04	-----	14	-----	5.67	Flexural failure
BE-D8st-1	25.33	14.9	16	14.3	6.8	Flexural failure
BE-D8st-2	33.67	52.8	21	50	7.23	Concrete cover separation
BG-D8st-1	30	36.2	18	28.6	6	Debonding adhesive material
BG-D8st-2	37.88	71.9	23	64.3	7.9	Debonding adhesive material

Pcr: First crack load

3.3 The Modes of Failure of the Tested Beam

Three modes of failure were observed in the tested beam specimens and classified as follows: pure flexure failure, cover concrete separation, and debonding adhesive failure. The control beam and the beam (BE-D8st-1) failed by flexural failure. This type of failure occurred when the vertical cracks began to spread at the midspan of the RC beam gradually with the increase in applied load, completely crushing the concrete at the top of the beam as shown in Figure 9 (a, b). However, the strengthened beam specimen (BE-D8st-2) failed by concrete cover separation. This failure occurred at the end of the beam owing to shear stress, which led to the separation of the concrete cover from the beam and failure at an early stage, as shown in Figure 9 (c). Regarding the (BG-D8st-1, BG-D8st-2), the failure was the debonding. It was partial on one side of the beam. The primary mechanism of this failure was the concentrated stress at the end of the beam, causing loss of bond between the material and the NSM-bar, and debonding of the adhesive material, as shown in Figure 9 (d, e).



a) B.C



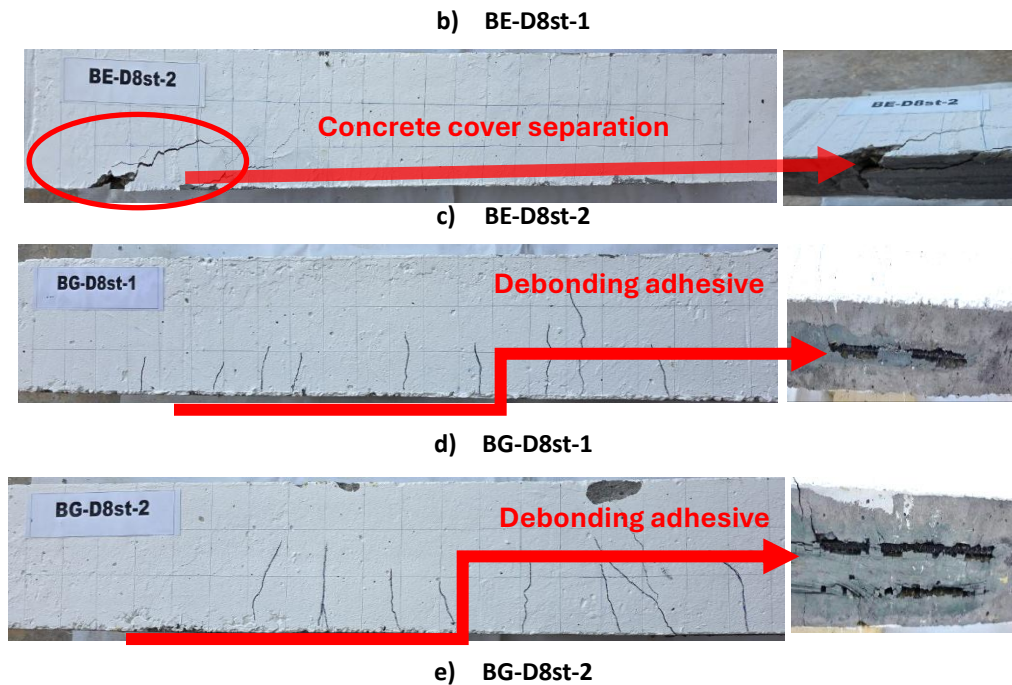
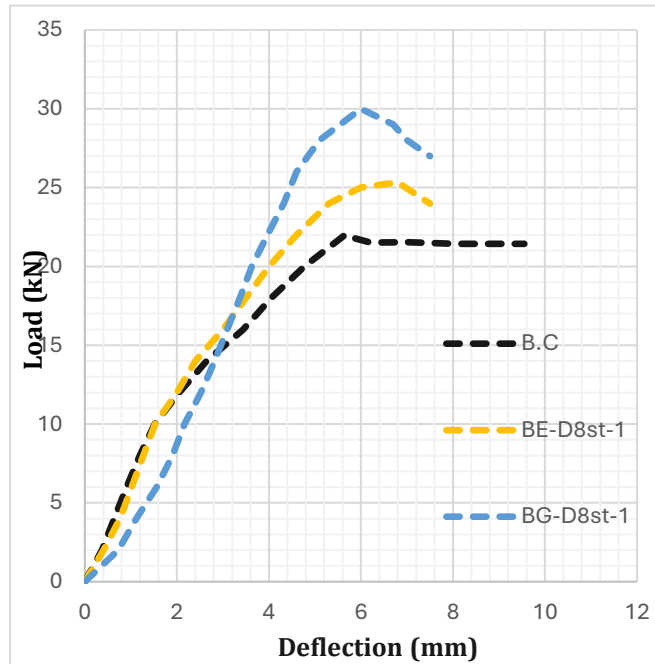


Figure 9: Mode failure of all specimens

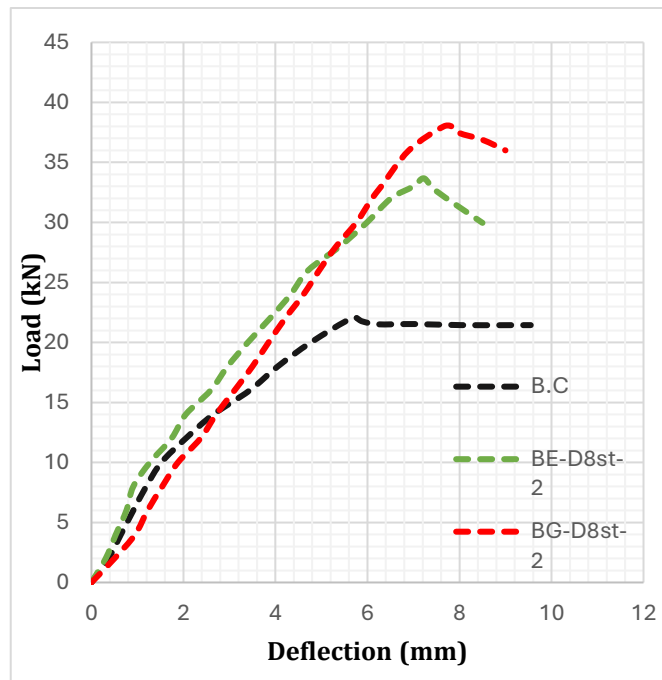
3.4 Behavior of Load-Deflection Curves of RC Beam

The load deflection curves are presented in Figure 10. In general, these curves include three phases: the pre-cracking phase, the cracking phase, and the failure phase. The pre-cracking phase begins with applied loading and ends with the appearance of the initial crack. At this stage, the control beam and the strengthened beam exhibit the same linear elastic behavior. The cracking phase extends from the initiation of the first crack to the yielding of the steel reinforcement. In this stage, the load increases. The yield load of the strengthened specimens is higher than that of the beam without strengthening. Finally, the failure phase extends from yield to ultimate load. When the load reaches its maximum value and then quickly decreases, it is due to exceeding the beam's load-carrying capacity. The retrofitted beams had lower deflections compared to the reference beam at the same load. This decrease is owing to the contribution of the NSM-steel bar, which carries some load. The curves illustrate that all strengthened specimens and the control beam shared the same behavior at the elastic stage. Moreover, the beams with single and double grooves increase the flexural load over the control beam. It can be observed from Figure 10 (a) that the strengthened beams that had a single groove exhibit an increase in ultimate load compared to the control beam. Also, the beam reinforced by geopolymer yielded a value higher than the beam with epoxy. Figure 10 (b) illustrates that all strengthened specimens recorded enhanced maximum load compared with the control beam; however, the beam with geopolymer was the highest. Moreover, the curves show that all samples had ductility less than the control beam due to an increased steel ratio.

Investigation of Flexural Strengthening for RC Beams by NSM with Geopolymer



a. load deflection curves of beams with a single groove



b. load-deflection curves of beams with double grooves

Figure 10: Load-Deflection Curves

4 Conclusion

This paper explored the application of geopolymer paste material in the NSM technique as an alternative to epoxy and investigated its behavior under the load of flexure. The type of adhesive material and the number of grooves were the variables in this study. From the discussion of the results of the test, reach a conclusion

- 1- The specimens with double grooves were more effective than those with a single groove with GPA and epoxy. The beams with one and two grooves recorded an increase in the ultimate load by 52.8 % and 72.18%, respectively, compared to the control beam.
- 2-The specimens that were reinforced with geopolymer as the adhesive material showed an increased ultimate load-bearing capacity, exceeding beams reinforced with epoxy. The RC beams with geopolymer exhibit an enhancement by 36.2% to 71.9% over the control beam; on the other hand, beams with epoxy recorded 14.9% to 52.8% more than the non-strengthened beam.
- 3-Using epoxy and geopolymer made the concrete cover of the strengthened beam stronger than the reference beam. Therefore, the RC beams exhibit an increase in the first crack load by a range 14.3% to 64.3% higher than the control, but samples with geopolymer were the best.
- 4- There was no debonding observed in the specimens reinforced with epoxy.
- 5- Recommended study on strengthening RC beams using the NSM technique with additional anchorage and geopolymer.

Declaration

The author reports no declaration of interest

Acknowledgments

The laboratories of the Engineering College in the University include a structural and construction laboratory that sponsors this work—acknowledgments to all team members who work there.

References

- Abed, R. J., Mashrei, M. A., & Sultan, A. A. (2022). Flexural behavior of reinforced concrete beams strengthened by carbon fiber reinforced polymer using different strengthening techniques. *Advances in Structural Engineering*, 25(2), 355–373. <https://doi.org/10.1177/13694332211049992>
- ACI 440.2R. (2017). *Guide for the Design and Construction of Externally Bonded FRP Systems for Retrofitting Concrete Structures*. ACI Report, American Concrete Institute
- Ahmed M. Khalifa. (2016). Flexural performance of RC beam strengthened with near surface mounted CFRP strips . *Alexandria Engineering Journal*, 55,1497-1505.
- Al-Abdwais A and Al-Mahaidi R. (2016). Modified cement -based adhesive for near surface mounted CFRP strengthening system. *Construction and Building Materials*, 124: 794-800.
- Al-Abdwais, A. H., & Al-Mahaidi, R. S. (2020). Performance of reinforced concrete beams strengthened with NSM CFRP composites for flexure using cement-based adhesives. *Structures*, 27, 1446–1457. <https://doi.org/10.1016/j.istruc.2020.07.047>

Investigation of Flexural Strengthening for RC Beams by NSM with Geopolymer

- Alnemrawi, B. R., & Al-Rousan, R. Z. (2025). Flexural performance of NSM and PNSM beams maintaining the ACI440 bar diameter to groove size limitation. *Results in Engineering*, 25. <https://doi.org/10.1016/j.rineng.2025.104570>
- De Lorenzis L, & Teng JG. (2007). Near-surface mounted FRP reinforcement: An emerging technique for strengthening structures. *Composite Part B: Engineering*, 38(2): 119-143.
- Hadi, N. S., Oleiwi, S. M., Salman, W. D., Ibrahim, A. M., & Mansor, A. A. (2020). Modified geopolymer paste adhesive bond material for near surface mounted strengthening technique. *IOP Conference Series: Materials Science and Engineering*, 888(1). <https://doi.org/10.1088/1757-899X/888/1/012053>
- "Iraqi Specification No.45 M. B. Structures. (1984). "Natural Sources for Gravel that is Used in Concrete and Construction," Baghdad Iraq, 1984."
- Iraqi Stand. Specif. N.5 IQS. (1984). "N.5 IQS," Portland Cement, "Iraqi Stand. Specif., 1984,".
- Kadhim, D. J., & Al-Asadi, A. K. (2025). AN INVESTIGATION INTO GEOPOLYMER ADHESIVE AS A VIABLE SUSTAINABLE MATERIAL FOR NSM STRENGTHENING OF RC BEAMS IN SHEAR. *Kufa Journal of Engineering*, 16(4), 573–584. <https://doi.org/10.30572/2018/KJE/160433>
- Mohamed, S. S., Hamdy, O., Seleem, M. H., & Sharaky, I. A. (2024). The flexural behavior and efficiency of RC beams strengthened with SNSM bars under the effect of several end conditions and material properties. *Engineering Structures*, 308. <https://doi.org/10.1016/j.engstruct.2024.117990>
- Salman, W. D., & 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. <https://doi.org/10.1016/j.cscm.2021.e00529>
- Salman, W.D., Mansor, A. A., & Mahmood, M. (2018). Behavior of reinforced concrete one way slabs strengthened by CFRP sheets in flexural zone. *Int. J. Civ. Eng. Technol*, 9(10), PP.1872-1881.
- Yuguang Mao, Yunxing Du, Hyeon-jong Hwang, Jie Su, Xiang Hu, Yuzhong Liu, & Caijun Shi. (2023). Seismic performance of interior beam -column joints using reinforced slag-based geopolymer concrete. *International Association for Earthquake Engineering*, 52(2), PP.285-307.