

Shear Strengthening of RC Beams Using NSM Technique and Different Types of Bar Materials and Geopolymer Adhesive

Dhiyaa J. Kadhim¹ *  Ali K. Al-Asadi¹ 

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Abstract

This research investigates the effectiveness of geopolymer adhesive (GPA) as an alternative to epoxy in the near-surface-mounted (NSM) technique for the shear strengthening of reinforced concrete (RC) beams. Five reinforced concrete beam specimens with dimensions of 1200 mm in length, 120 mm in width, and 160 mm in height were tested under three-point loading conditions. The specimens included one reference beam specimen and four strengthened beam specimens. The present paper investigated parameters regarding the types of paste adhesive (epoxy or geopolymer) and the types of strengthening bar materials. Major performance indicators include the load that leads to the first appearance of flexural cracks, ultimate load-carrying capacity, deflection, and crack pattern. According to the results, the epoxy adhesive can increase load capacity to 60.1% compared to the reference beam specimen. While Geopolymer adhesive can be increase load capacity to 47.7% compared to the reference beam. Compared with unstrengthened RC beam specimens, the first crack load on strengthened specimens increased by up to 15.3% and 12.12% when using geopolymer and epoxy adhesive. Using epoxy adhesive shows a greater increase in deflection, reaching up to 96%, while using geopolymer leads to a deflection increase of up to 50%. The steel bar with geopolymer exhibits the lowest increase in deflection at 46.43%, indicating enhanced stiffness and better crack control. The feasibility of geopolymer adhesive in structural strengthening applications can be established due to its adequate bonding strength, excellent thermal resistance, and environmental sustainability.

Keywords— NSM, Geopolymer adhesive, Strengthened, Shear

1 Introduction

Considering that the shear failure of reinforced concrete beams is often sudden and unpredictable, it is preferable to encounter a flexural failure rather than a shear failure. Reinforced concrete beams may experience shear constraints due to many issues, such as insufficient shear reinforcement, bar corrosion that diminishes the steel area, construction errors, and increased service loads. (Askar et al., 2022; Liu et al., 2019; Liu & Jia, 2020; Obaid et al., 2022; Salman et al., 2018). The NSM method is a crucial reinforcement technology that uses epoxy adhesive to enhance and repair reinforced concrete (RC) constructions, and it requires creating grooves in the concrete covers in the required direction (Ke et al., 2024; Rashmi et al., 2021; Thamrin et al., 2019). Strengthening systems employ epoxy; however, it degrades in its mechanical characteristics at high temperatures. (Al-Salloum et al., 2011; Gamage et al., 2005, 2006; Majhi et al., 2019). When the temperature

Dhiyaa J. Kadhim

dhiyaa.kadhim@utq.edu.iq

Ali K. Al-Asadi

alazharco.2005@utq.edu.iq

¹ Department of Civil Engineering, College of Engineering, Thi qar University, Thi qar, Al Nasiriyah, Iraq

surpasses the glass transition temperature (T_g), the covalent bonds disintegrate, leading to the melting of the adhesive and ensuing slippage. (Cabral-Fonseca et al., 2018). Furthermore, it has adverse effects on personnel. The adhesive determines the overall effectiveness of the bonded structure, constituting a significant constraint. (Cabral-Fonseca et al., 2018; Zhou et al., 2023). Therefore, replacing this adhesive with a new material is of utmost importance. Geopolymer is a suitable material for high-temperature applications due to its mechanical properties. (Ding et al., 2017; Hadi et al., 2019; Maras, 2021; Mermerdaş et al., 2017). Geopolymer offer many advantages in building rehapitation, enhancing the structural integrity of components and reducing the occurrence of significant cracks during seismic. (Mao et al., 2023). Geopolymers were designed to demonstrate fire resistance and allow high temperatures. (Deng et al., 2021). It is considered a refined material with exceptional properties in several civil engineering applications. (Hager et al., 2021; Zhang et al., 2018), (Liu et al., 2022), and (Hadi et al., 2020).

In previous studies carried out on the shear strengthening of reinforced concrete (RC) beams by the near-surface mounting (NSM) method, a number of important parameters have been considered, and they include the types of reinforcement, the types of adhesives (epoxy and geopolymer), angle, spacing, and pattern. From the studies, the NSM method is capable of significantly improving the shear strength, and geopolymer adhesive is found to perform equally to epoxy adhesive. Epoxy adhesive performs poorly when exposed to high temperatures and is hazardous to the health of the user.

The purpose of this research is to enhance the shear strength of RC beams through the use of the NSM technique, with a geopolymer adhesive paste substituting the epoxy adhesive paste.

2 Experimental Work

This work involves designing and testing five beams with a width of 120 mm, height of 160 mm, and length of 1200 mm, with a clear span of 1100 mm, and are made of reinforced concrete. The beams are subjected to three-point loading, where one beam served as a control (unstrengthened), and the others were RC beams strengthened in shear using the NSM technique and the types of adhesive paste (epoxy or geopolymer) and the NSM bar materials. The main test results focus on the parameters ultimate load capacity, failure characteristics, fracture patterns, deflection, and crack load.

2.1 Materials

2.1.1 Preparation of contents of a typical reference concrete mixes specimens

The specimens of RC beams were designed and cast using traditional methods. The concrete mixture in this study consisted of crushed gravel (maximum particle size of 19 mm) and conventional Portland cement (type I) mixed with natural sand. The concrete was mixed and cured with tap water. Table 1 illustrates the contents of reference concrete mixes. Three cubes (150 x 150 x 150)mm were used for compressive strength test, while three specimens of concrete cylinders (150 mm diameter and 300 mm height) were used for tensile strength test. After 28 days of making and curing concrete test specimens, the finding indicated that, the compressive strength was 25 MPa and tensile strength test was 3.54 MPa.

Table 1 :The contents of reference concrete mixes.

Cement (kg/m ³)	Coarse aggregate (kg/m ³)	Fine aggregate (kg/m ³)	Water (kg/m ³)	w/c
374	736	996	228	0.61

2.1.2 The Adhesive

The NSM method utilized geopolymer adhesive (GA) as a binding agent to improve the shear strength of RC beams. The geopolymer is environmentally sustainable, economically viable, and operates at high temperatures. According to (Sachet & Salman, 2020) Geopolymer adhesive production Requires an binder and alkaline solution, namely Ground Granulated Blast Furnace Slag (GGBFS). An alkaline solution is created by dissolving sodium hydroxide (NaOH) in pure water to achieve a 10 molar concentration at least 24 hours before casting, employing

a NaOH/water ratio of 1:2. Thereafter, sodium silicate (Na_2SiO_3) is amalgamated with the sodium hydroxide solution at an SH/SS ratio of 1:2. The fluid-binder ratio (F/B) was 0.55. Table 2 delineates the composition of the employed geopolymer. The geopolymer exhibits a compressive strength of 62 MPa.

Table 2: The Geopolymer mix contents

Slag binder (mg)	F/B	Na_2SiO_3 (mg)	NaOH (mg)
2100	0.55	770	385

The epoxy glue employed is Sikadur-30, utilized for comparison with geopolymer adhesive with the Compressive Strength was 85 N/mm², Tensile Strength 29 N/mm², Shear Strength 18 N/mm², Tensile adhesion strength >21 N/mm².

2.1.3 Steel Bars

A deformed steel bar with a diameter of 16 mm, an ultimate stress of 700.94 MPa, a modulus of elasticity of 200 GPa, and a yield stress of 612.64 MPa was utilized as the main steel bar. NSM-Steel bars with an 8mm diameter were employed to reinforce the beams, possessing an ultimate stress of 686.1 MPa, a modulus of elasticity of 200 GPa, and a yield stress of 656.67 MPa.

2.1.4 GFRP Bars

GFRP was used with a (8 mm-diameter) Ultimate tensile strength of 910 MPa, and a tensile modulus of elasticity of 47 GPa.

2.2 Preparation of reference and targeted improved concrete specimens

Five RC beams with simple supports were cast and tested. As shown in Table 3, one RC beam served as a reference specimen (unstrengthened), while four RC beams were strengthened in shear using the NSM technique and bars. The grooves of the NSM technique were made before casting the beams by putting the wood pieces into the molds with the dimensions needed. The groove dimension of the present investigation is equal to (20mm wide and 20mm depth), which was 2.5 times the NSM-bar diameter taken from the previous research (Hadi et al., 2020). The first group strengthened the RC beams in shear by utilizing epoxy with various strengthening bar materials (steel and GFRP). The second group had two specimens with different strengthening bar materials (steel and GFRP), and geopolymer was the adhesive material. The specimen's name depended on the type of adhesive, and type of NSM bars, such as BE-D8st, which means BE: beam specimen and epoxy adhesive, D8st: 8mm diameter NSM steel bars. 16mm steel bars were used to resist flexure in beams. As shown in Figure 1, all specimens were designed to fail in shear. The height of the RC beams was 160mm, the width was 120mm, and the length was 1200mm, with a clear span of 1100mm. After the RC beams had cured, the NSM technique was applied. Clean the grooves using pressurized water and let them dry. Adhesive (epoxy or geopolymer) was used to fill the grooves partially, and then the bars were pressed into the grooves, and the adhesive was used to fill the remainder of the grooves, following which the surface was leveled. The specimen was strengthened and rested for 7 days before the test. White paint was used to coat the specimens to detect cracks during testing. Figure 2 shows the stages in which NSM has strengthened.

Table 3: reference and targeted improved R.C. beams specimens details

Group name	Beam name	Adhesive paste	Angle	NSM Rod	Spacing (mm)
reference specimen	B.R.	-	-	-	-
Group 1	BE-D8gl	Epoxy	90	GFRB 8mm	80
	BE-D8st	Epoxy	90	Steel 8mm	80
Group 2	BG-D8gl	Geopolymer	90	GFRB 8mm	80
	BG-D8st	Geopolymer	90	Steel 8mm	80

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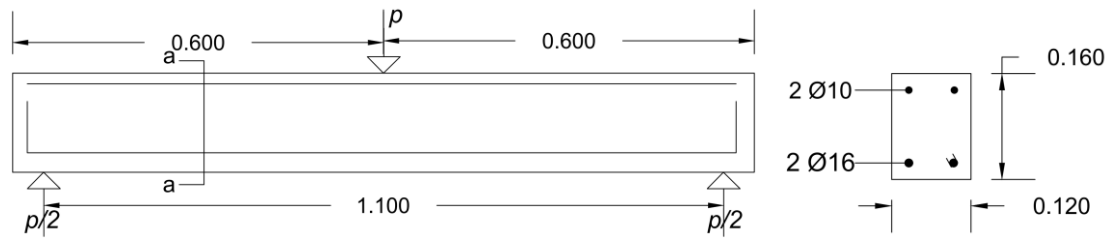


Figure 1: designed R.C. concrete specimen details



(a)



(b)

Figure 2: NSM – strengthened stages: (a) Groove cleaned; (b) NSM applied.

2.3 Test of Specimens

The specimens were tested using the hydraulic universal machine, shown in Figure 3, which had a capacity of 180 KN. After the load and supports were installed, the specimen was tested at a load rate of 0.25 kN/sec. The LVDT was mounted on the center bottom surface of the RC beams. The specimen was subjected to static loads in stages until it failed. The test is finished when the static load decreases. The main test results focus on the parameters ultimate load capacity, failure characteristics, fracture patterns, deflection, and crack load.

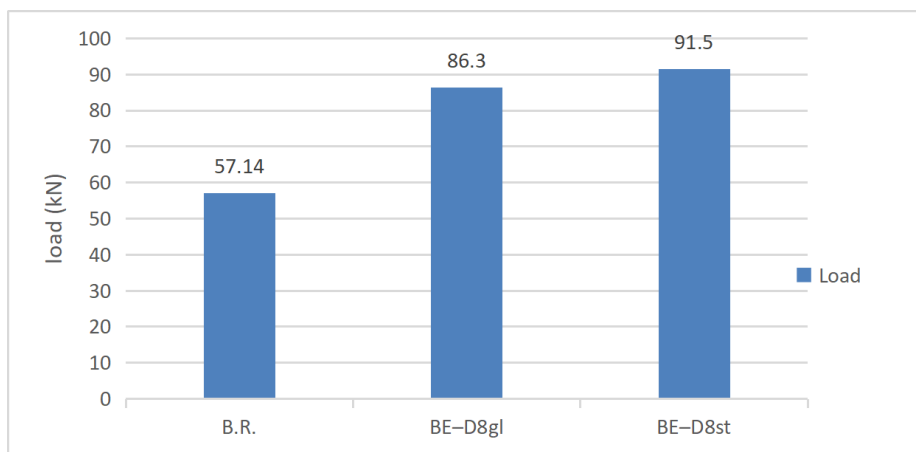


Figure 3: Testing machine of RC beams

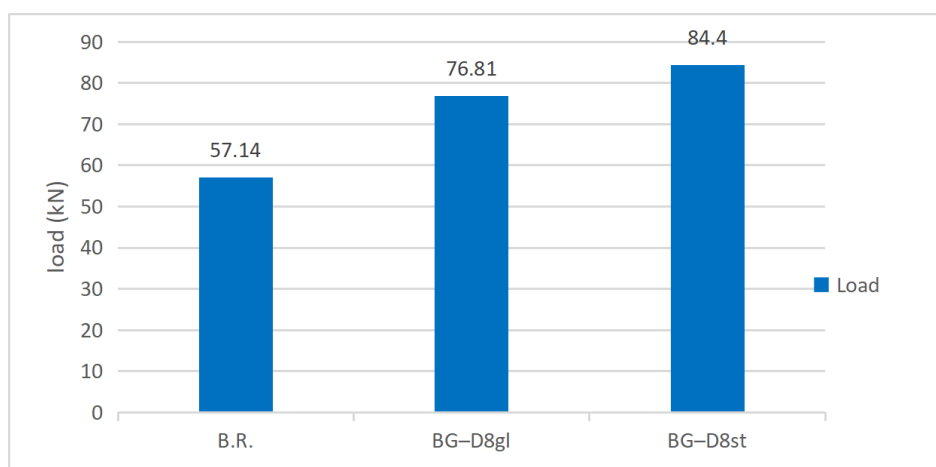
3 Results and Discussions

3.1 Ultimate Load Capacity

Table 4 and Figure 4 display an increase in ultimate load capacity compared to the control beam. The outcomes based on the utilization of epoxy adhesive indicated that the specimens (BE-D8gl and BE-D8st) showed an increase of 51.03% and 60.1% compared to the control beam specimen. Using the NSM technique to strengthen RC beams led to these results. Compared with a previous study (Wiwatrojanagul, Ayudhya, & Sahamitmongkol, 2012), the RC beams were strengthened using the NSM technique with fibre-reinforced polymer rods. The study considered various variables such as types of FRP (aramid and carbon), spacing between the FRP (75, 150, 300 mm), and the inclination of FRP rods (90° and 45°). The result showed that the improvement in the shear capacity of RC beams by 23%-41%, but in the current study, it reached up to 60.1% compared to the reference beam specimen, which is higher than the previous study. The outcomes obtained from utilizing geopolymer adhesive demonstrated that the specimens (BG-D8gl, BG-D8st) showed an increase of 34.4% and 47.7% compared to the control beam specimen. Compared with a previous study (Kuntal et al., 2020), the prestressed concrete beams were strengthened in shear using NSM-CFRP strips and geopolymer mortar as bonding material. The result showed that the shear capacity of beams without stirrups increased to 44.4%, but in the current study, it reached up to 47.7% compared to the control beam specimen, which is higher than the previous study. The increase results from the geopolymer adhesive's excellent bond strength and ability to act as an adhesive material with the NSM technique in shear-strengthened applications.



(a)



(b)

Figure 4: Comparison between the ultimate load capacity of the RC beam specimens: (a) Strengthened specimens by NSM with epoxy adhesive; (b) Strengthened specimens by NSM with geopolymer adhesive.

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Figure 5 shows a comparison between the failure modes of the RC beam. The cases illustrated in Figure 5 showed that the unstrengthened beam failed in a clear shear mode, characterized by deep diagonal cracks due to the absence of shear reinforcement. Beams strengthened with epoxy or geopolymer showed a more cohesive failure pattern, where failure occurred due to concrete crushing in the compression zone or bar rupture, indicating improved bonding and enhanced structural performance. When comparing shear strengthening using NSM-steel Bars versus NSM-GFRP bars, steel bars are generally stronger than GFRP bars regarding shear resistance. The main reason is that steel bars have higher yield strength and a significantly higher modulus of elasticity than GFRP bars. This means steel bars can withstand higher stresses before failure. Although Steel Bars outperform in strength, GFRP may be preferred in environments where corrosion is a major concern, such as marine or chemically aggressive environments. In general, each type has its advantages. Where GFRP bars are lightweight, have a high tensile strength, are not conducive to heat, and, more importantly, are not threatened by the risk of rust, especially since the strengthening technique used is a near-surface technique, while steel bars are inexpensive, available locally, and have high ductility (Dhamyaa, 2018).

When comparing strengthening using NSM-bars with epoxy versus NSM-bars using geopolymer, epoxy adhesives are generally stronger than geopolymer adhesives regarding ultimate load capacity. The main reason for the difference in values is the lower compressive strength of geopolymer adhesive (62 MPa) compared to epoxy adhesive (85 MPa). The increase in the ultimate load (Pu) is calculated according to the following equation:

Increase in ultimate load (Pu) =
$$\frac{\text{ultimate load (Pu) for beam specimens} - \text{ultimate load (Pu)for reference specimen}}{\text{ultimate load (Pu)for reference specimen}} \times 100\%$$

Table 4: An increased ultimate load of RC beam specimens compared to the reference beam specimen

Specimen name	ultimate load (Pu) (KN)	Increase in ultimate load (Pu) (%)
B.R.	57.14	-
BE-D8gl	86.30	51.03
BE-D8st	91.50	60.13
BG-D8gl	76.81	34.42
BG-D8st	84.40	47.70



(a)



(b)



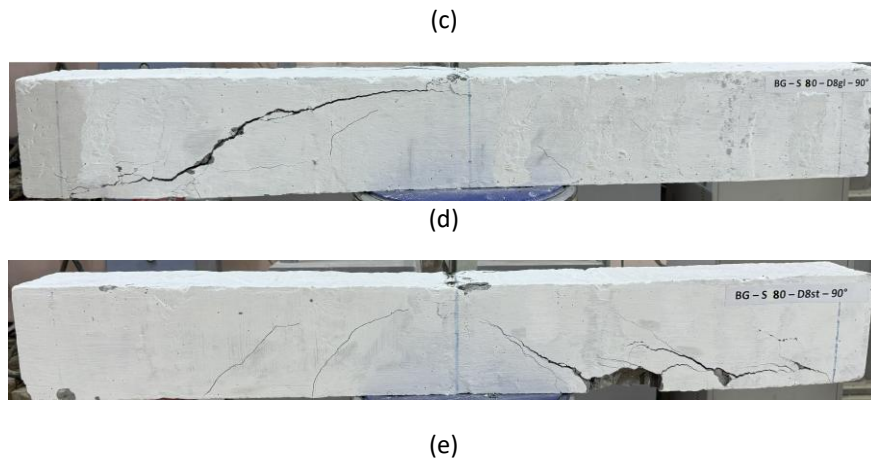


Figure 5: Comparison between the failure modes of the RC beam specimens: (a) B.R. specimen; (b) BE– D8gl specimen; (c) BE– D8st specimen; (d) BG– D8gl specimen; (e) BG– D8st specimen

3.2 Load–Deflection Behavior

Load-deflection curves illustrated in Figure 6 are defined into three stages: pre-cracking, cracking, and failure stages. The zone of pre-cracking begins from the start of the load until the first crack appears. The RC beam's deflection increases proportionally with the load in this stage. While the cracking stage began after the appearance of the crack, in this stage, the slower rate of increasing load occurs in comparison with the pre-cracking stage, the faster rate of increasing deflection with increasing load, and increased crack width and appearance of shear crack due to a decrease in the beam stiffness. The failure stage occurs when the load reaches the peak value and rapidly drops; in this stage, the deflection is uncontrolled, and the cracks in the shear become dominant due to the load-carrying capacity of the beam being lost. The deflection increment for epoxy adhesive has a higher increment of deflection of up to 96% compared to the control beam specimen, while for geopolymers, the deflection increment has a higher increment of up to 50%. The steel bar with geopolymers has the lowest deflection increment of 46.43% compared to the control beam specimen. The results of deflection for RC beams can be found in Table 5. The increase in the deflection is calculated according to the following equation:

$$\text{Increase deflection} = \frac{\text{deflection of beam specimens} - \text{deflection of reference specimen}}{\text{deflection of reference beam specimen}} \times 100\%$$

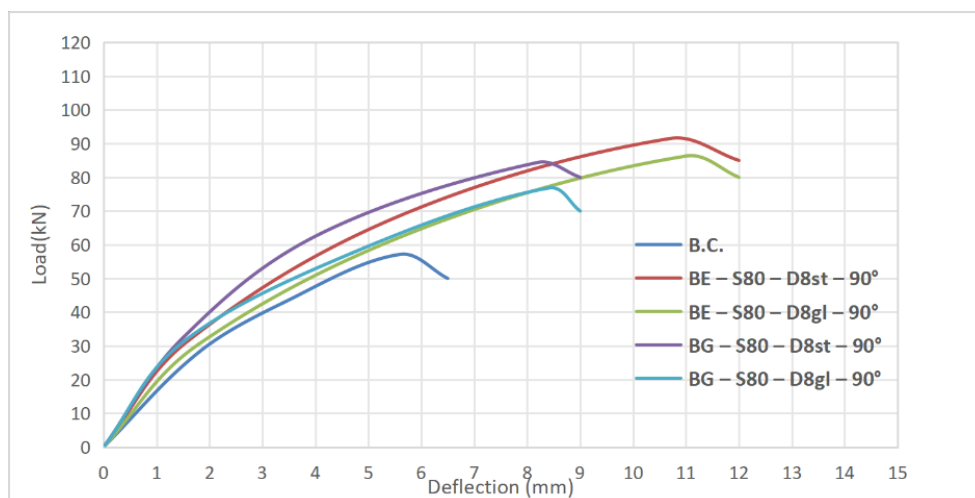


Figure 6: The RC beams load-deflection curve of strengthened specimens

Table 5: Deflection results of RC beam specimens

Name of specimens	Pcr (KN)	Deflection at Pcr (mm)	Pu (KN)	Deflection at Pu (mm)	increase deflection (%)
B.R.	28.12	1.8	57.14	5.6	/
BE-D8gl	30.54	1.8	86.30	11	96.43
BE-D8st	31.53	1.6	91.50	10.7	91.07
BG-D8gl	31.11	1.5	76.81	8.4	50.00
BG-D8st	32.42	1.5	84.40	8.2	46.43

3.3 Cracks Characteristics

The load of the first crack was 28.12,30.54,31.53,31.11, and 32.42 KN for the specimens of RC beams (BC, BE-D8gl, BE-D8st, BG-D8gl, and BG-D8st), respectively. The results of the tested specimens indicate that the largest increase in the first crack load compared to the control specimen was for the strengthened specimen with NSM steel bar and geopolymer adhesive, with percentage of increase in Pcr (15.3%) . When using epoxy, there is a 12.12% increase in the percentage of their first crack load . The first crack loads for all strengthened RC beams were larger compared to the control beam specimen. This can be explained by the fact that the NSM bar provided additional tensile capacity and a stronger concrete cover compared to the reference beam specimen. Table 6 shows the tested RC beams' crack characteristics. The increase in the first crack loads (Pcr) is calculated according to the following equation:

$$\text{Increase in the first crack loads (Pcr)} = \frac{\text{Pcr of beam specimens} - \text{Pcr of reference specimen}}{\text{Pcr of reference beam specimen}} \times 100\%$$

Table 6: The tested RC beams' crack characteristics

Name of specimens	Pcr (KN)	Percentage of increase in Pcr (%)
B.R.	28.12	-
BE-D8gl	30.54	8.60
BE-D8st	31.53	12.12
BG-D8gl	31.11	10.63
BG-D8st	32.42	15.29

This research presents an environmentally friendly approach for the external bonded NSM, which is reinforced using an epoxy adhesive, and proposes an advanced, eco-friendly, and innovative approach for reinforcing existing structures. Conventional epoxy resin displays high strength, but it has some limitations, such as brittleness and poor performance under elevated temperature levels. Geopolymer, being an innovative and advanced material, shows enhancement in ductility, absorption capacity, and bond strength of reinforced concrete beams, besides having environmentally friendly characteristics.

4 Conclusion

This paper proposed an experimental study for shear strengthened reinforced concrete beams through the Near-Surface Mount (NSM) technique, with the use of the geopolymer paste as the adhesive. This study considers the use of different paste adhesives such as the epoxy paste and the geopolymer paste, as well as the use of different bars such as steel or GFRB. The test and discussion results indicate to the following conclusions:

- Strengthening with geopolymer adhesive could delay the first appearance of flexural cracks, by a huge margin. The first crack load of strengthened RC beam specimens increased up to 15.3% and 12.12% when using geopolymer and epoxy adhesive, respectively, compared with unstrengthened RC beams.

- With geopolymer and epoxy adhesives, the ultimate load on the RC beam samples was 47.7% and 60.1% higher compared to the reference beam. The geopolymer paste has a good bonding ability; therefore, it can be used effectively as an adhesive in strengthening.
- Strengthened RC beam specimens in shear that were strengthened with NSM and geopolymer adhesive experienced an increase in deflection of up to 50.00% when subjected to an ultimate load, compared to an unstrengthened RC beam specimen.
- Geopolymer adhesive can be used to strengthen NSM in RC beams in a feasible manner. While epoxy achieved better results in increasing ultimate load, geopolymer adhesive showed suitable efficiency and added thermal stability and sustainability.
- Shear was the failure mode for all the specimens, and the geopolymer adhesive improves crack control and distribution.
- GFRP bars offer a viable alternative in conditions where durability and resistance to environmental factors such as corrosion are critical.

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