



# **AN INVESTIGATION INTO GEOPOLYMER ADHESIVE AS A VIABLE SUSTAINABLE MATERIAL FOR NSM STRENGTHENING OF RC BEAMS IN SHEAR**

**Dhiyaa J. Kadhim<sup>1</sup> and Ali K. Al-Asadi<sup>2</sup>**

<sup>1</sup> MSc. Student, Civil Eng. Dept., University of Thi-qar, Thi-qar, Iraq,  
Email:dhiyaa.kadhim@utq.edu.iq

<sup>2</sup> Professor, Ph.D., Civil Eng. Dept., University of Thi-qar, Thi-qar, Iraq,  
Email:alazharco.2005@utq.edu.iq

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## **ABSTRACT**

This paper aims to investigate the performance of geopolymer adhesive (GPA) as a substitute for epoxy in the near-surface-mounted (NSM) technique to enhance the shear strength of reinforced concrete (RC) beams. Seven RC beams of 1200 mm in length, 120 mm in width, and 160 mm in height were tested under three-point loading. The specimens involved one control beam and six strengthened beams. This paper investigates several parameters, namely the types of paste adhesive (epoxy or geopolymer), spacing of NSM bars (80 and 65 mm), and inclined NSM bars (90° and 45°). The initial crack opening load, ultimate load-carrying capacity, deflection, and crack pattern. According to the results, the epoxy adhesive can increase load capacity by up to 96.36%. Geopolymer adhesive yielded a maximum of 68.62% compared to un-strengthened RC beams. The first crack load on strengthened specimens was increased by up to 18% compared to un-strengthened RC beams.

## **KEYWORDS**

NSM, geopolymer adhesive, strengthened, RC beams, shear.



## 1. INTRODUCTION

Shear failure of RC beams is usually sudden and without any warning, so it's better to have a flexural failure than a shear failure. Shear deficiencies can arise in RC beams for various reasons, such as insufficient shear reinforcement or bar corrosion, which decreases the steel area, creates a construction deficiency, and raises the service load (Alasadi and El-Zanaty, 2015; Salman, Mansor and Mahmood, 2018; Liu, Jia and Wang, 2019; Liu and Jia, 2020; Sahib and Al-Asadi, 2022). The NSM technique, which uses epoxy adhesive to strengthen and restore reinforced concrete (RC) structures, is one of the crucial strengthening methods (Thamrin, Haris and Haris, 2019; Ketab and Attiya, 2024) (Rashmi, Anand and Balaji, 2021). High temperatures cause epoxy, an adhesive used in strengthening techniques, to lose its mechanical properties (Gamage, Wong and Al-Mahaidi, 2005; Gamage, Al-Mahaidi and Wong, 2006; Al-Salloum, Elsanadedy and Abadel, 2011; Majhi, Mukherjee and Spadaccini, 2019). The covalent bond begins to weaken and the adhesive melts when it is subjected to temperatures higher than the glass transition temperature ( $T_g$ ), which causes slippage (Cabral-Fonseca et al., 2018) and it poses certain risks to the workers as well. It is important to remember that the adhesive is the crucial factor governing the bonded structure's overall efficacy (Cabral-Fonseca et al., 2018; Zhou et al., 2023). As a result, the necessity to switch out this glue for a fresh one is growing. Because of its natural composition, geopolymers are a sustainable material with excellent mechanical qualities that may be used in high-temperature settings (Ding, Cheng and Dai, 2017; Mermerdaş et al., 2017; Hadi, Salman and Oleiwi, 2019; Maras, 2021). Geopolymer mortars provide numerous benefits in building restoration, improve the structural integrity of building components, and diminish the likelihood of extensive cracking during seismic events (Mao et al., 2023). Geopolymers were engineered as fire-resistant substances with excellent resilience to high temperatures (Deng et al., 2021). It is considered another advanced material showing tremendous properties in several civil engineering applications (Zhang et al., 2018; Hager, Sitarz and Mróz, 2021; Mohammed and Ikram A. Saeed, 2021; Shamsa, Al-Shathr and Al-Attar, 2021), (Liu, Su and Yan, 2022), and (Hadi, Salman and Oleiwi, 2020). In a prior study utilizing Geopolymer Paste glue (GPA) inside the NSM approach, the pull-out test outcomes for strengthening prism GPA indicated a bond strength equivalent to 70% of that of epoxy adhesive (Hadi, Salman and Oleiwi, 2020).

This study includes castings and testing. seven reinforced concrete (RC) beams with dimensions of 120mm width, 160mm height, and 1200mm length and a clear span of 1100mm. They were subjected to three-point loading to study the behavior of beams in shear, one of which was considered a control beam (unstrengthened), while other RC beams were strengthened in shear by

NSM. The parameters include types of paste adhesive (epoxy or geopolymer), spacing of NSM bars (80 and 65mm), and Inclined NSM bars (90° and 45°). This study employed geopolymer paste adhesive as an alternative to epoxy for the NSM strengthening method since it is a more economical, environmentally friendly, and sustainable substance. More significantly, it performs better at higher temperatures. The principal test outcomes encompass the ultimate load capacity, failure characteristics, crack patterns, deflection, and crack load.

## 2. MATERIALS

### 2.1. Normal concrete

Normal concrete was utilized to fabricate the reinforced concrete beam specimens. This study utilized Ordinary Portland cement (Type I) in conjunction with natural sand and crushed gravel, with a maximum particle size of 19 mm, as the aggregate. Tap water was utilized to mix and cure the concrete. The specifics of the mixed design employed are presented in Table 1. After 28 days of curing, the compressive strength of concrete reached 30 MPa. Three cubes (150 mm x 150 mm x 150 mm) were evaluated for compressive strength, while three cylinders (150 mm in diameter and 300 mm in height) were assessed to determine their tensile strength, which was measured at 3.54 MPa.

**Table 1. Concrete mix used**

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

### 2.2. Adhesive

#### 2.2.1. Geopolymer Paste Adhesive

For strengthening RC beams in shear with the NSM technique, Geopolymer Adhesive (GA) was used as binding material. GA is environmentally friendly, sustainable, low cost, and at high temperatures it operates. For the preparation of geopolymer adhesive, the alkaline solution and binder (Ground Granulated Blast Furnace Slag (GGBFS)) are required. The alkaline solution is prepared by using pure water to dissolve flakes at a 10-molar concentration to prepare a solution of sodium hydroxide (NaOH) before 24 hours of casting in a (NaOH/water) ratio of 1:2, then mixing sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) with sodium hydroxide solution in an (SH/SS) ratio of 1:2. The ratio of fluid to binder (F/B) is 0.55 was used. Table 2 shows the geopolymer mix used. The geopolymer compressive strength was equal to 62MPa.

**Table 2. Geopolymer mix used**

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

#### 2.2.2. Epoxy Adhesive

Epoxy Sikadur-30 was used as an adhesive compared with geopolymer adhesive. The

Compressive Strength was 90 N/mm<sup>2</sup>, Tensile Strength 29 N/mm<sup>2</sup>, Shear Strength 18 N/mm<sup>2</sup>, Tensile adhesion strength >21 N/mm<sup>2</sup>.

### 2.3. Reinforcement Bars

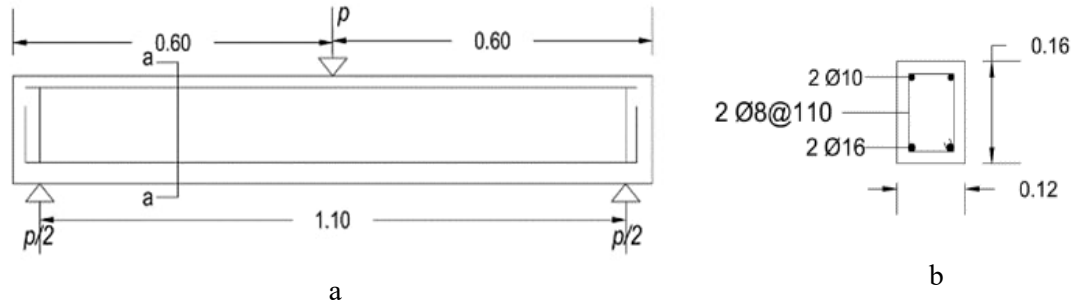
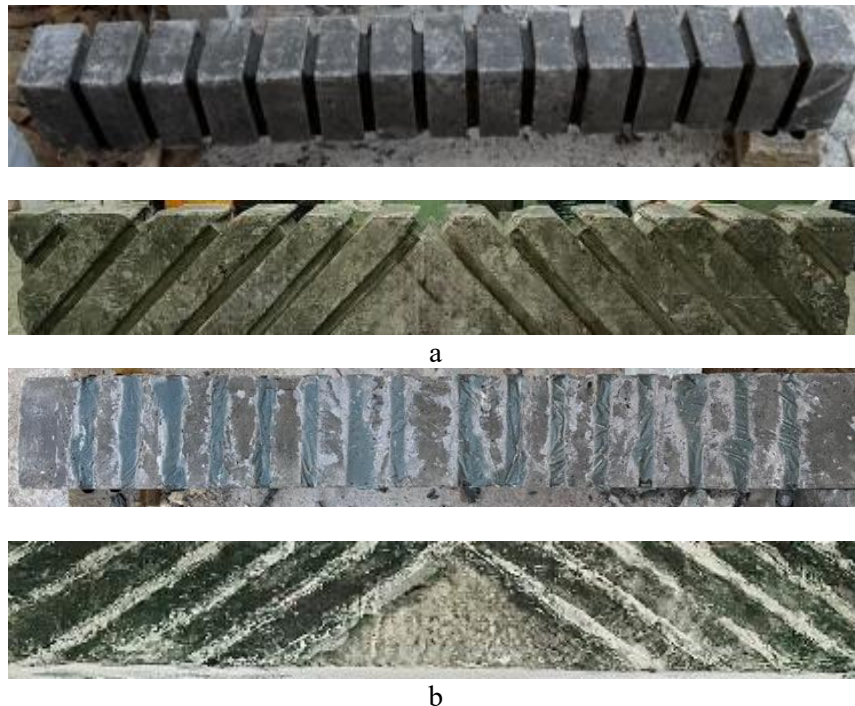
A deformed steel bar of 16mm diameter with 700.94 MPa ultimate stress, modulus of elasticity 200 GPa, and 612.64 MPa yield stress was used as the main flexural reinforcement. The strengthened beams used NSM–steel bars with a diameter of 8mm (U-shape) which have the following properties: 686.1 MPa ultimate stress, modulus of elasticity 200 GPa, and 656.67 MPa yield stress.

## 3. EXPERIMENTAL PROCEDURE

As simply supported, seven RC beams were cast and tested. As depicted in [Table 3](#), one RC beam was used as a control beam (un-strengthened), and six additional RC beams were strengthened in shear using the NSM technique and steel bars. The grooves of the NSM – technique was constructed before casting the beams by putting the wood strips into the molds with the dimensions required, the groove dimension of this search is (20mm ×20mm) equal to 2.5 times the NSM-bar diameter that was taken from the previous study ([Hadi, Salman and Oleiwi, 2020](#)). Epoxy and NSM bars with different spacing (80, 65mm) and inclined NSM bars (90°, 45°) were used by the first group to strengthen the RC beams in shear. Geopolymer was the adhesive material in the second group which comprised of three specimens with varying spacings of NSM steel bars (80 and 65 mm) and inclined NSM bars (90° and 45°). The name of the specimen depended on the type of adhesive, spacing of NSM–bars, and Inclined of NSM bar, such as BE – S65 – D8st – 90° means B: beam specimen, S65: the spacing of NSM–bars (65 mm), D8st: 8mm NSM- steel bars, and 90°: The inclination angle of NSM–bar (90°). In flexural applications, the beams were strengthened with 16mm steel bars. To ensure shear failure, all specimens were designed without shear reinforcement, as demonstrated in [Fig. 1](#). The RC beams were 16mm in height, 120mm wide, and 1200mm long with a clear span of 1100mm. The applied NSM technique occurred after the curing time of the RC beams. Use the pressured water to clean the grooves 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 leveled the surface. Before the test, the specimen strengthened and rested for 7 days. To detect the cracks during testing, the specimens were covered in white paint. The stages that have been strengthened by NSM are shown in [Fig. 2](#).

**Table 3. RC beams details**

Group name	Beam name	Adhesive paste	Angle	NSM Rod	Spacing (mm)
Control	B.C.	/	/	/	/
Group 1	BE – S65 – D8st – 90°	Epoxy	90	Steel 8mm	65
	BE – S80 – D8st – 90°	Epoxy	90	Steel 8mm	80
	BE – S65 – D8st – 45°	Epoxy	45	Steel 8mm	65
Group 2	BG – S65 – D8st – 90°	Geopolymer	90	Steel 8mm	65
	BG – S80 – D8st – 90°	Geopolymer	90	Steel 8mm	80
	BG – S65 – D8st – 45°	Geopolymer	45	Steel 8mm	65

**Fig. 1. Details of RC beams: (a) longitudinal section; (b) section a-a****Fig. 2. NSM – strengthened stages: (a) Groove cleaned; (b) NSM applied.**

#### 4. RC BEAMS TESTING PROCEDURE

RC beams with three-point loading were tested as simply supported in the structural lab at Thi-Qar University/Engineering College. The 180 KN capacity of the hydraulic universal machine was used for testing the specimens. The specimen was tested at a load rate of 0.25 KN/Sec after the load and supports were set up. The LVDT was secured on the center bottom surface of the RC beams. The specimen was subjected to static load in increments until it failed. The test is complete when the static load decreases. The capacity of ultimate load, deflection, and crack load were the results of this test.

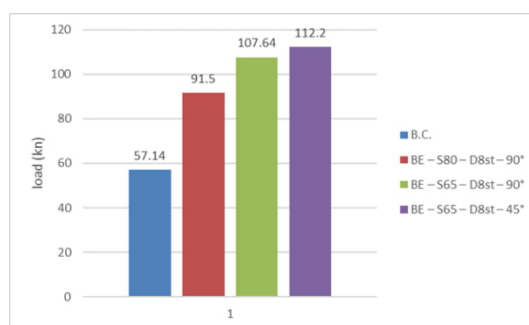
## 5. RESULTS AND DISCUSSIONS

### 5.1. Ultimate Load Capacity

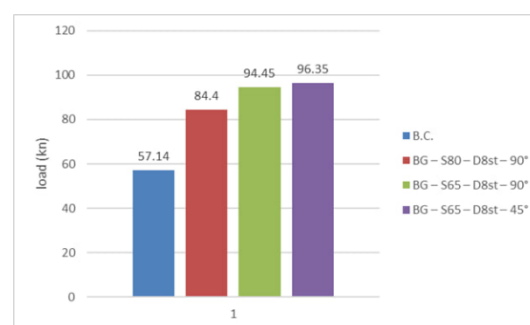
This study aims to evaluate the increase in ultimate load capacity of RC beam specimens strengthened using the NSM technique with GPA compared to the reference beam without strengthening. An increase in ultimate load capacity can be seen in Table 4 and Fig. 3. The results obtained from using epoxy adhesive showed that the specimens (BE – S80 – D8st – 90°, BE – S65 – D8st – 90°, and BE – S65 – D8st – 45°) showed an increase of (60.1%, 88.38%, and 96.36%), respectively. These results came from the effectiveness of using the NSM technique in strengthening RC beams. The results obtained from using geopolymer adhesive showed that the specimens (BG – S80 – D8st – 90°, BG – S65 – D8st – 90°, and BG – S65 – D8st – 45°) showed an increase of (47.7%, 65.3%, and 68.62%), respectively. This increment came from the fact that the geopolymer adhesive has excellent bond strength and can be used as adhesive material with NSM technique in shear strengthened, the reason for this difference was that the compressive strength of geopolymer (62MPa) is less than that of epoxy (90 MPa). Fig. 4 shows the failure modes of the RC beams.

**Table 4. The increased ultimate load of RC beam specimens.**

Specimen name	Pcr (KN)	Pu (KN)	Increased in Pu (%)
B.C.	28.12	57.14	/
BE – S80 – D8st – 90°	31.53	91.5	60.1
BE – S65 – D8st – 90°	32	107.64	88.38
BE – S65 – D8st – 45°	32.5	112.2	96.36
BG – S80 – D8st – 90°	32.42	84.4	47.7
BG – S65 – D8st – 90°	33	94.45	65.3
BG – S65 – D8st – 45°	33.2	96.35	68.62

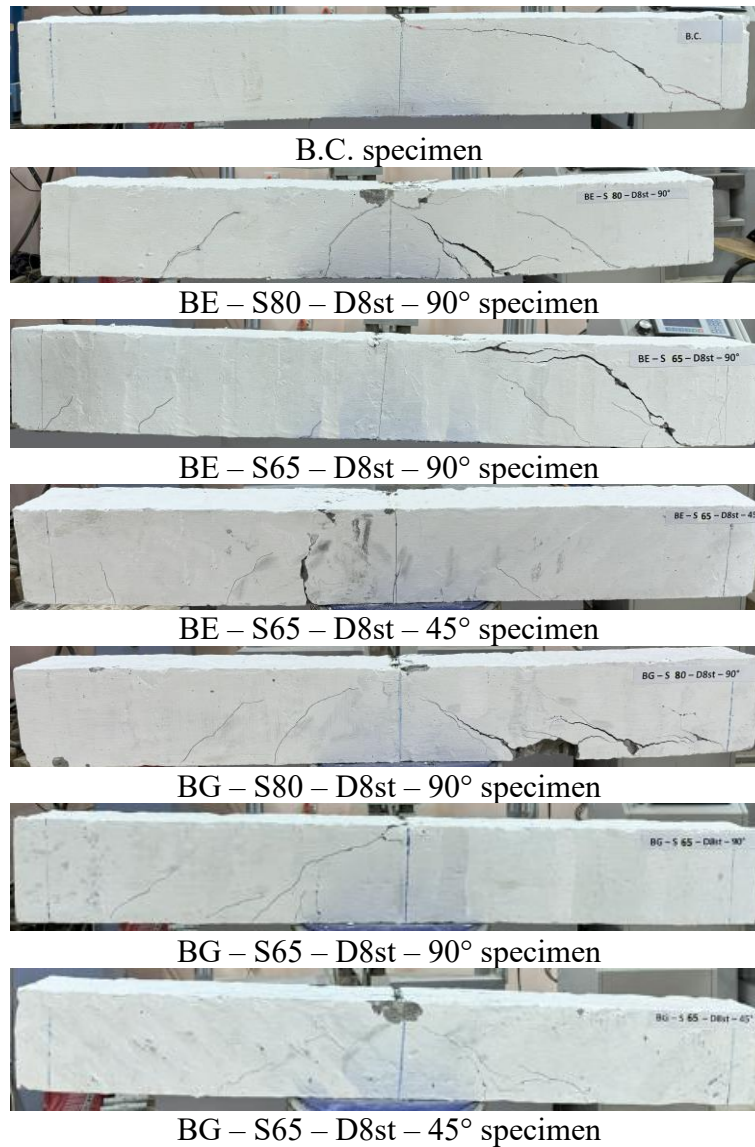


**a) Strengthened by NSM with epoxy adhesive**



**b) Strengthened by NSM with geopolymer adhesive**

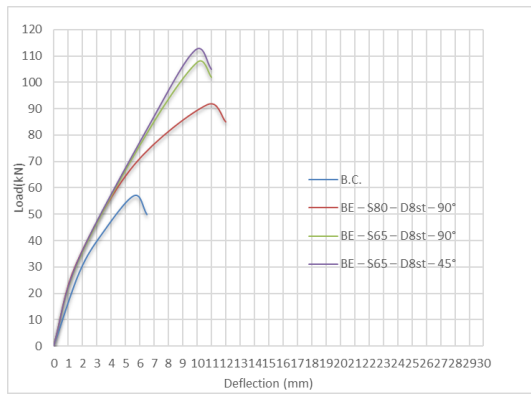
**Fig. 3. The RC beams ultimate load capacity**



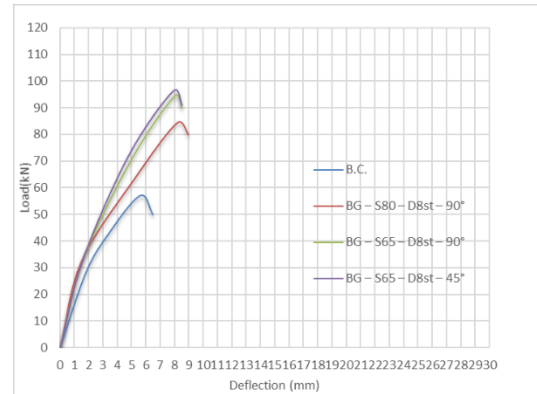
**Fig. 4. The failure modes of the RC beams.**

## 5.2. Load-Deflection Characteristics

Fig. 5. displays load-deflection curves. These curves consist of three stages: pre-cracking, cracking, and failure stages. From the start of the load, until the first crack appears, this is the zone of pre-cracking. In this stage, the RC beams proportionally increase deflection with the load. 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 decreasing the beam stiffness. The failure stage occurs when reaching the load to 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 results of deflection for RC beams can be found in Table 4.



Strengthened with NSM and Epoxy adhesive



Strengthened with NSM and geopolymer adhesive

Fig.5. The RC beams load–deflection curve

Table 4. Deflection results of RC beams

Name of specimens	Pcr (KN)	Deflection at Pcr (mm)	Pu (KN)	Deflection at Pu (mm)	increase deflection (%)
B.C.	28.12	1.8	57.14	5.6	/
BE – S80 – D8st – 90°	31.53	1.6	91.5	10.7	91.07
BE – S65 – D8st – 90°	32	1.7	107.64	10	78.57
BE – S65 – D8st – 45°	32.5	1.7	112.2	9.85	75.89
BG – S80 – D8st – 90°	32.42	1.5	84.4	8.2	46.43
BG – S65 – D8st – 90°	33	1.6	94.45	8	42.86
BG – S65 – D8st – 45°	33.2	1.6	96.35	7.9	41.07

### 5.3. Cracks Characteristics

Table 5 shows the results of the tested RC beam cracks. The load of the first crack was (28.12, 31.53, 32, 32.5, 32.42, 33, and 33.2) of the specimen of RC beams (BC, BE – S80 – D8st – 90°, BE – S65 – D8st – 90°, BE – S65 – D8st – 45°, BG – S80 – D8st – 90°, BG – S65 – D8st – 90°, and BG – S65 – D8st – 45°) respectively. The increased percentage of the first crack load of specimens strengthened with NSM –steel bar and geopolymer adhesive reached 18%. All first crack loads of strengthened RC beams were greater than the control beam, this can be explained by the fact that the NSM - bar provided the additional tensile capacity and more strongly of concrete cover in comparison with the control beam.

Table 5. The tested RC beams crack characteristics

Name of specimens	Pcr (KN)	Percentage of increase in Pcr (%)
B.C.	28.12	/
BE – S80 – D8st – 90°	31.53	12.12
BE – S65 – D8st – 90°	32	13.8
BE – S65 – D8st – 45°	32.5	15.57
BG – S80 – D8st – 90°	32.42	15.3
BG – S65 – D8st – 90°	33	17.35
BG – S65 – D8st – 45°	33.2	18

could investigate the behavior of geopolymer adhesives in different environmental parameters, such as humidity, chemical exposure, and freeze-thaw cycles. Moreover, this study is limited to the certain materials and arrangements tested and suggested and could study the efficiency of geopolymer adhesives with different types of NSM bars, strengths of concrete, and sizes of beams.

## **6. CONCLUSION**

The purpose of this search was to conduct an experimental study on strengthened RC beams in shear using the NSM technique, which utilizes geopolymer as an adhesive material. The parameters of this study involve a type of paste adhesive (epoxy or geopolymer), spacing of NSM bars (80 and 65mm), and inclined of NSM bars (90° and 45°). The test and discussion results led to the following conclusion:

1. Strengthening with geopolymer adhesive delayed the appearance of cracks by a huge margin. The first crack load of strengthened RC beams increased up to 18% and 15.57% when using geopolymer and epoxy adhesive, respectively, compared with un-strengthened RC beams.
2. Using geopolymer and epoxy adhesive, the ultimate load of strengthened RC beams increased to 68.62% and 96.36%, respectively, as compared to un-strengthened RC beams.
3. Strengthened RC beams in shear that were strengthened with NSM and geopolymer adhesive experienced an increase in deflection of up to 46.43% when subjected to an ultimate load, compared to un-strengthened RC beams.
4. Geopolymer adhesive can be used to strengthen RC beams in shear by using the NSM technique in a feasible manner. While epoxy had better ultimate load gains, geopolymer adhesive displayed adequate performance and added thermal stability and sustainability.
5. The failure mode of the specimen BE – S65 – D8st – 45° converts from shear to flexural failure. While other strengthened beams failed in shear, the Geopolymer adhesive provides better crack control and distribution.

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