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Shear Behaviour of Reinforced Concrete Beams Strengthened by NSM-bar with Geopolymer Adhesive Material

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Abstract

This work considered the first experimental and theoretical study on strengthened of reinforced concrete (RC) beams in shear by near surface mounted (NSM) – steel bar with geopolymer adhesive. Totally thirteen of RC beams with dimensions of 150mm width, 250mm height, and 1200mm length with clear span 1100mm, one of which considered control beam (unstrengthened), while other RC beams were strengthened in shear by NSM – steel bars with geopolymer adhesive and epoxy. The parameter include: the spacing between NSM – steel bars (50, 100, and 160mm), the diameter of NSM – steel bar (6, 8, and 10mm), and the inclination angle of NSM – steel bars (90°and 45°). The theoretical study includes suggested equation used for predicted shear strength of RC beams strengthened in shear by NSM – steel bars with (epoxy and geopolymer) adhesive.

Based on experimental results, it was found that the ultimate load capacity of the RC beams strengthened in shear by different spacing of NSM – steel bars (50, 100, and 160mm) with (geopolymer and epoxy) adhesive increased up to (89 and 117%), respectively, while the first crack load increased up to (37 and 22%), respectively, and the modes failure were shear failure for all specimens expect the specimen that strengthened with epoxy adhesive by 100 mm NSM – spacing which convert the failure from shear to flexural failure. The ultimate load capacity when using different diameter of NSM – steel bars (6, 8, and 10mm) with (geopolymer and epoxy) increased up to (79 and 117%), respectively, while the first crack load increased up to (27 and 17%), respectively. The ultimate load capacity when using different inclination of NSM – steel bars (90°and 45°) with (geopolymer and epoxy) increased up to (118 and 117%), respectively, while the first crack load increased up to (47 and 44%), respectively, all specimens strengthened by NSM – steel bar with 45° inclination angle failed as flexural failure. Furthermore, the results showed that the cost of geopolymer adhesive equal to 47% of the cost of epoxy adhesive.

The results showed that the geopolymer adhesive is cheaper cost than epoxy adhesive, environmentally friendly, safe, sustainable material, and produced results are close compared with epoxy, as such, it can be used as replacement of epoxy adhesive in strengthened the RC beams in shear by NSM – steel bars.

Based on theoretical results, it was found that the ratio of experimental ultimate shear load to theoretical calculation of RC beams strengthened with different spacing of NSM – steel bars (50, 100, and 160mm) range from (0.8 to 1.2), while it was found in range (0.9 to 1.2) of RC beams strengthened with different diameter of NSM – steel bars (6, 8, and 10mm)

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Shear strength is a critical property of reinforced concrete (RC) beams, determining their capacity to resist forces acting perpendicular to their longitudinal axis. A thorough understanding of its components, potential failure modes, and influencing factors is essential for engineers to design safe and durable structures. The shear resistance of an RC beam is a composite action involving both the concrete and steel reinforcement.

1. Concrete Contribution (Vc): before diagonal tension cracks form, the concrete itself provides shear resistance. This capacity is influenced by the concrete's compressive strength, the beam's effective depth, and its width.
2. Steel Reinforcement Contribution (Vs): Once inclined cracks develop, steel stirrups (or bent-up bars) become crucial. They transfer shear stresses across the crack, preventing its propagation and enhancing the beam's load-carrying capacity. The effectiveness of steel reinforcement depends on its spacing, diameter, and inclination.

The primary failure modes due to shear include:

1. Diagonal Tension Failure: This is the most common mode, characterized by inclined cracks originating near the supports and progressing towards the maximum shear zone. The beam may experience a sudden and brittle collapse if not adequately reinforced.
2. Flexural-Shear Failure: A combination of flexural and shear stresses can lead to this failure mode. It occurs when the beam's flexural and shear strengths are closely matched, resulting in a brittle failure.

3. Shear-Compression Failure: Typically found in deep beams with short shear spans, this failure mode involves crushing of the concrete in the compression zone due to excessive shear stresses.

Several factors influence the shear behavior of RC beams:

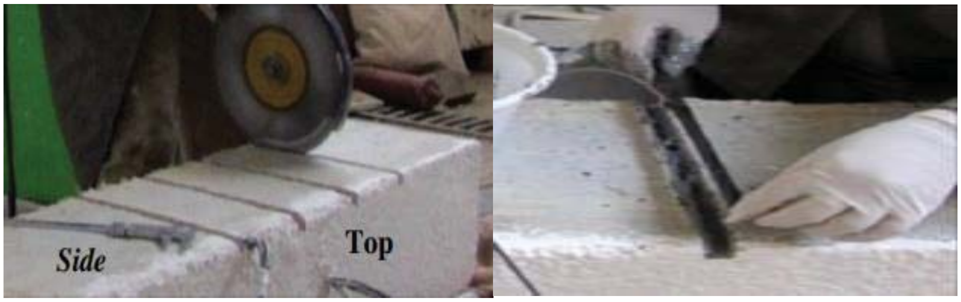
1. Shear span-to-depth ratio (a/d): This ratio significantly affects the shear strength and failure mode. Short shear spans (small a/d) are prone to shear-compression failures, while long shear spans (large a/d) are more susceptible to diagonal tension failures.
2. Concrete Strength: higher concrete compressive strength generally improves shear resistance, but it can also increase the brittleness of failure.
3. Steel reinforcement: adequate stirrup spacing, diameter, and anchorage are essential. Bent-up bars can also contribute significantly to shear strength.
4. Loading conditions: concentrated loads, impact loads, and cyclic loading can increase shear stresses and demand careful design consideration.
5. Material properties: factors like concrete mix proportions, aggregate type, and steel yield strength influence the beam's shear behavior.
6. Size and shape of the beam: the dimensions and cross-sectional shape of the beam affect its shear capacity.

Thus, the strength of RC beams in shear is provided by the combination of strength of concrete and strength of steel stirrups. This system normally existent in the normal RC beams, but when the structural deficient found in the RC beams it should overcome by strengthened the beams. It is preferred to make the failure of the RC beams as flexural failure rather than shear failure because of the shear failure occurs quickly without warning (Tureyen and Frosch. 2003, and Russo and Pauletta. 2013).

External strengthening of the RC beams is one of the important challenges in civil engineering. The RC beams required strengthened when the structural deficient is found in the RC beams which caused due to various reasons such as increasing servicing loads, updating codes, mistakes during design or implementation, subjecting to different environmental conditions, and when need to extend the serving time of the structure. Due to these reasons the structure may subjected to sudden failure, Thus, many external techniques have been found by the civil engineering researchers. Near Surface Mounted (NSM) and external strengthening techniques are the most common techniques for strengthening (Salman et al. 2018, Hadi et al. 2020, and Mahmood et al. 2023).

Since when comparison between the cost of rebuilding and strengthened of the RC beams, the cost of strengthened is always less than the cost of rebuilding, therefore the engineers tend to strengthened the RC beams with structures of poor features.

Among the most effective techniques for strengthened of RC structure is Near-Surface Mounted technique which have drawn the researcher's attention. The member can be strengthened in flexural, shear, and torsion by using this technique. It involves making groove in the members concrete covers in the needed direction, Therefore, in order to protect the existing reinforcement, the groove depth must be less than the concrete cover. Bond material is partially placed into the grooves, and after that the strips or bars are driven into the groove, after which bond material fills the remaining groove, the surface is then leveled (Asplund 1949). This technique used epoxy as the bonding material, epoxy considered as a good bonding material, but at high temperature, it rapidly loss its mechanical properties (Gamage et al., 2005), and during the application the toxic gases emission dangerous is possible (Bourne et al.1959), which leads to decrease the application of this technique in areas with high temperature. Figure (1 – 1) show the NSM technique.



(a) The grooves cutting. (b) The rods positioning.

(c) Applying the epoxy adhesive for filling the grooves.

Figure (1 – 1): NSM strengthening: (a) The grooves cutting, (b) The rods positioning and (c) Applying the epoxy adhesive for filling the grooves (Jalali et al. 2012).

1.2 Geopolymer Adhesive

Geopolymer is a pozzolanic and green substance that rich in aluminates and silicates which are regarded as sustainable and suitable replacement to make materials with characteristics similar to or superior than the strength of Ordinary Portland Cement (O.P.C). Davidovits 2008, first presented the name of geopolymer to the pozzolanic materials like slag, rice husk, metakoline and fly ash, which is regarded as rich source of aluminates and silicates that are activated by combining them with alkaline solutions via a technique called polymerization, as shown in Figure (1 – 2), (Abdullah et al, 2018).

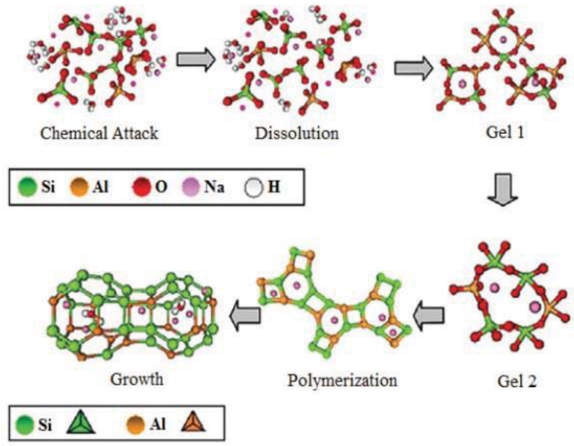


Figure (1 – 2): Alkali-activation of geopolymer (Abdullah et al, 2018).

The geopolymer strength is dependent upon the production of sodium-aluminum-silicate-hydrate gel (N-A-S-H), moreover to calcium-silicate-hydrate gel (C-S-H) (Davidovits, 2008). To acquire higher mechanical properties of geopolymer, high temperature during early curing stages should be provided (El-Hassan and Ismail. 2018). The researchers are examining a number of techniques to accelerate the polymerization process to enable it to be cured at room temperature. Ground Granulated Blast Furnace Slag (GGBFS) is a pozzolanic materials has a significant impact on the microstructure and mechanical characteristics, also quicken polymerization process at the surrounding temperature and enhance the characteristics of geopolymer paste (El-Hassan and Ismail. 2018, Sachet and Salman. 2020, Saha and Rajasekaran. 2017, and Salman, S and Salman, W. 2021).

1.3 Problem of the Study

Usually, epoxy is used as binding materials in strengthening technique. when subjected to high temperatures, its mechanical properties quickly deteriorate which causes reduce using strengthening techniques when the temperatures are high. Furthermore, epoxy is also unsustainable material. Thus, this search tends to replace the epoxy with a new material. Using geopolymer adhesive as an adhesive bonding material in shear strengthened of RC beams with NSM technique consider the effective research which the replacement of epoxy with a sustainable material, having excellent mechanical properties and it is appropriate for both ambient and hot temperatures (up to 1000℃).

1.4 Objectives of the Study

The objective of this research is to strengthened the RC beams in shear by using Near- Surface Mounted Technique with geopolymer adhesive paste as replacement of epoxy adhesive paste. The geopolymer adhesive paste is sustainable and environmentally friendly. The theoretical study also included in this search by derivation equation that predict the shear strength of the strengthened RC beams.

1.5 Methodology and Variables of the Study

To look into shear behavior of RC beams strengthened by NSM bar with geopolymer adhesive paste or epoxy paste, the research was carried out by casting and testing of thirteen of RC beams, one unstrengthened beam BC and the remaining twelve beams are strengthened by geopolymer adhesive paste and epoxy adhesive paste to conduct a comparative study between the geopolymer adhesive paste and epoxy adhesive paste, The beams dimensions are (150 mm width, 250 mm height, and 1200 length). The experimental program involves the variables that could significantly effect on the strengthening technique.

These variables were:

1) NSM bars diameter (6 mm, 8 mm, and 10 mm).
2) Spacing between NSM bars (50 mm, 100 mm, and 160 mm).
3) Inclined of NSM bars (90 ° , 45 °) .

The theoretical program involves derivation equation used in prediction the shear strength of RC beams that strengthened in shear by NSM – steel bar.

1.6 Layout of the Study

<u>Chapter One</u>:

Contains a summary of external strengthening, Near-Surface Mounted technique (NSM), geopolymer paste with the importance, goals, and the problem statement of the research.

<u>Chapter Two</u>:

Contains a literature review on the shear strengthened of RC beams, epoxy binding material, and geopolymer binding material.

<u>Chapter Three</u>

Contains the characteristics of the materials as well as the information of the experimental work. It also focusses the specific of the test specimen and the RC beams testing procedure.

<u>Chapter Four</u>

Contains experimental results and discussions.

<u>Chapter Five</u>

Contains theoretical analysis and discussions.

<u>Chapter Six</u>

Contains conclusions derived from current investigation, proposals and recommendation for the future research.