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STRUCTURAL APPLICATION OF GEOPOLYMER ADHESIVE BONDING MATERIAL BETWEEN NSM-BARS AND REINFORCED CONCRETE BEAMS

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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بسم الله الرحمن الرحيم

"وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ
رَبِّي وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلاً "

صدق الله العظيم

مـــن ســورة الاســراء – آيـــة ٨٥

CERTIFICATION

I certify that the thesis entitled **"Structural Application of Geopolymer Adhesive Bonding Material between NSM-Bars and Reinforced Concrete Beams"** was prepared by **"Noor Salim Hadi"** under my supervision at the Department of Civil Engineering-College of Engineering-Diyala University in a partial fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

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In view of the available recommendation, I forward this thesis for debate by the examining committee.

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COMMITTEE DECISION

We certify that we have read the thesis titled **(Structural Application of Geopolymer Adhesive Bonding Material between NSM-Bars and Reinforced Concrete Beams)** and we have examined the student **(Noor Salim Hadi)** in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

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Dedication

To my mother and father, their affection, love, encouragement and prays of day and night made me able to get a great success.

To my husband, who supported me through my journey, I won't be able to accomplish this without you.

To my brothers and sisters the key of my success

To my lovely son "Rayan"

To all whose teach, support and trust me, I dedicate this work

With my Love and Respect

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Abstract

External strengthening techniques for buildings are considered promising techniques in civil engineering because buildings may be exposed to different reasons making it in need to external strengthening. One of the most important strengthening techniques is Near Surface Mounted (NSM) with using epoxy as adhesive material. Epoxy is good adhesive material, but its mechanical properties deteriorate quickly when exposed to temperature more than 55°C; so it is necessary to find a new adhesive material that replaces the epoxy.

Geopolymers are a sustainable material and have desired properties as adhesive materials, especially at high temperature; so they were used in this study to produce an adhesive paste instead of epoxy. This study is divided into three parts: the first part was the preparation of a geopolymer paste at ambient temperature by adding different proportions of nano-silica. The optimum mix was to replace (0.8)% of fly ash with nano-silica which gave the highest compressive strength of 72.8 MPa (more than the reference mix by 108%) after (28 days) of treatment at (35 ± 2)°C with acceptable hardening time.

The second part was to examine the bond property of the Geopolymer Paste Adhesive (GPA) by applying it in the NSM technique to strengthen concrete prism and conduct single lap shear test, then compare the results with another concrete prism strengthened with NSM technique but using epoxy adhesive. The bond efficiency of the GPA was equal to (70)% of epoxy. After that, GPA was improved by adding different dosages and types of fibers (micro steel fibers, carbon fibers and polypropylene fibers) to exceed bonding force of the epoxy adhesive.

The third part of this study was the application of MGPAs in the NSM

technique for strengthening Reinforced Concrete (RC) beams and studies its behavior under flexural load. This part includes casting and testing of fourteen RC beams specimens (200 * 125 * 1050) mm. Two specimens were controlled (without strengthening) and the remained divided into two groups. The first group consists of: six RC beams strengthened by NSM-steel bars (8 mm-diameter) and the second group consists of six RC beams strengthened by NSM-GFRP bars (6 mm-diameter). Each group consist of three specimen had single NSM groove, and other three had double NSM grooves. The adhesives were ($MGPA_{SF,}$ $MGPA_{CF}$ and $MGPA_{PF}$).

The results showed a clear improvement in the characteristics of RC beams when strengthened compared to the control RC beam. $MGPA_{CF}$ gave the best results, where the increase of the first crack load was equal to (70%) more than the control RC beam, while the increase in the ultimate load reached to (61.7%) higher than the control RC beam.

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List of Symbols and Terminology

ae:	Minimum distance between the center of groove and the concrete edge (mm).
ag:	Minimum distance (center-to-center) between two grooves (mm).
A_{NSM}:	The area of NSM bars (mm^2).
A_s:	The area of main reinforcement (mm^2).
b:	The beam width (mm).
bp :	CFRP strip thickness (mm).
d:	Depth of main reinforcement (mm).
d_{NSM}:	Depth of NSM bars (mm).
F_r :	Residual pull-out force at end of test (kN).
f_{at}:	Tensile strength of epoxy (MPa).
f_c :	Concrete compressive strength at 28 day (MPa).
f_{ct}:	Tensile strength of concrete (MPa).
f_{NSM}:	The tensile strength of NSM bars (MPa).
F_{NSM}:	The tensile force of NSM bars (kN).
f_{NSMu}:	Maximum tensile strength of NSM bars (MPa).
f_{rupt} :	Laminate tensile strength as laboratory tested (MPa).
F_s:	The tensile force of the main reinforcement (kN).
Fs` max :	Maximum pull-out force during the test (kN).
f_y:	The tensile strength of main reinforcement (MPa).
G1 and G2:	Coefficients which were evaluated by finite element analysis.
P_u :	Predicted pull-out force (kN).
T max :	Maximum bond strength (MPa).
T r :	Residual bond strength (MPa).
y:	The depth of neutral axis (mm).
ε_c:	The strain of concrete.
ε_{NSM}:	The strain of NSM bars.
σ max :	Maximum bond strength (MPa).

List of Abbreviations

CFRP:	Carbon Fiber Reinforce Polymer.
FRP:	Fiber Reinforced Polymer.
GFRP:	Glass Fiber Reinforce Polymer.
GPA:	Geopolymer Paste Adhesive.
MGPA:	Modified Geopolymer Paste Adhesive.
$MGPA_{CF}$:	Modified Geopolymer Paste Adhesive with addition carbon fibers.
$MGPA_{PF}$:	Modified Geopolymer Paste Adhesive with addition polypropylene fibers.
$MGPA_{SF}$:	Modified Geopolymer Paste Adhesive with addition micro steel fibers.
Na_2SiO_3	Sodium silicate.
NaOH:	Sodium hydroxide.
NSM:	Near Surface Mounted.
RC:	Reinforced Concrete.
Si/Al:	Alumina silicate.

CHAPTER ONE
INTRODUCTION

1.1 General

The external strengthening of the Reinforced Concrete (RC) structures is one of the important challenges in civil engineering. The need to strengthening RC structures go back to different causes such as increased serving loads, errors in design or during implementation, codes updating, the service period may be need to extend, and exposure to different environmental conditions. Sudden failure of structures may be happen because of these factors; so researchers in civil engineering found many techniques of external strengthening. The most common strengthening techniques are near surface mounted technique (NSM) and external strengthening (ES) technique by carbon fiber reinforced polymer (Wissam and et al., 2015). The efficiency of these techniques depended on the type of material used for strengthening and the bond between the added material and concrete substrate.

1.2 Near Surface Mounted Technique

Near Surface Mounted may be defined as one of the most promising strengthening techniques to RC structures that have attracted the attention of researchers. It`s include cutting a grooves in the concrete cover of members in required direction; therefore the groove`s depth must be less than the cover of concrete for not damaging the existing reinforcement. The grooves are partially filled with bond material, and then the bars or strips are pressed in groove, and the remainder of the groove is filled with bond material, after that the surface is leveled (Asplund 1949). This technique can be used to strengthening the member in flexural, shear and torsion. In this technique, epoxy was using as bond material, epoxy is a good adhesive material but the rapid failure of the mechanical properties of the matrix of

epoxy at high temperature (Gamage and et al., 2005), and the dangerous effects of toxic gases during the application (Bourne and et al., 1959), leads to reduce the use of this technique in high temperature areas. Plate (1-1) shows the steps of NSM technique.

Plate (1-1): NSM technique: (a) cutting of the groove, (b) filling of the groove by epoxy adhesive and (c) positioning of the bar (Turco and et al., 2003)

1.3 Geopolymer Paste

Geopolymer is an innovative material and a real alternative to conventional Portland cement for use in transportation infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial byproducts to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concretes (Davidovits, 2013). It is a three-dimensional structure material consists of an aluminosilicate. These aluminosilicate reactive materials are rapidly dissolved in alkaline solution resulting in formation of free SiO_4 and AlO_4 tetrahedral units (Davidovits and 2017). This is Polymerization process which depends on the reaction of silica and alumina with alkali solution (Abdullah and et al., 2018), as shown in Figure (1-1). In case of using geopolymer, high temperature in early curing stage is essential to provide enough strength increases to access high mechanical properties (Mermerdaş and et al., 2017). However, there are several practical issues with the application of heat curing in

structures; so we go towards several ways to accelerate polymerization process for cured in ambient temperature. Nano Silica (NS) is one of the common mineral admixtures for gaining wider attention due to its significant effect on the microstructural and mechanical properties of Portland cement based binders (Hadi and et al. ., 2019 and Aggarwal and et al., 2015). Now, NS may be added to geopolymer mixture to accelerate polymerization process under ambient temperature and improve the properties of paste.

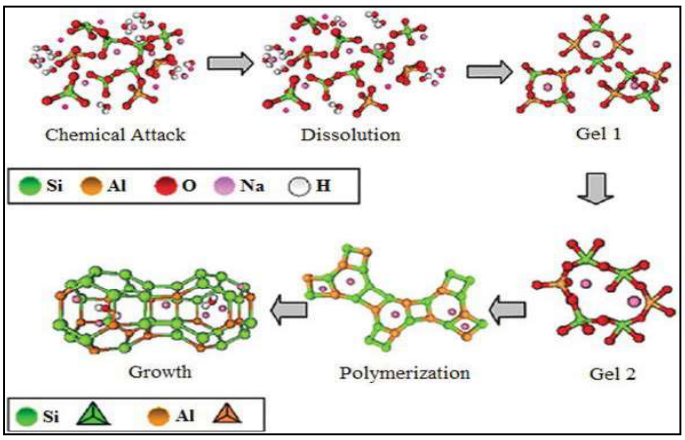

Figure (1-1): Graphic model of alkali activation of geopolymers (Abdullah and et al., 2018)

1.4 Fibers

Fibers are a short separated materials addition to (paste, mortar or concrete) to improve mechanical properties. There are several types of fibers such as steel fibers, carbon fibers, polypropylene fibers and natural fibers, as shown in plate (1-2). Each type added under special case, like price, availability material and its function. Fibers are used to improve bond strength, developed compressive, tensile and rupture strength, control cracking due to drying and plastic shrinkage and reduce the permeability of concrete (Wissam and et al., 2018). The amount of fibers is added to a mixture as a percentage of the total volume with ranges from 0.1 to 3% (ACI 544.4R 2018).

Plate (1-2): Different types of fibers (Buttignol and et al., 2017)

1.5 Problem Statement

Epoxy is usually used in the strengthening techniques as adhesive material. The quickly deteriorates of its mechanical properties when exposed to high temperature leads to reduce the use of this technique in high temperature areas. In addition, epoxy is unsustainable material; therefore now we need to replace the epoxy by new material. The use of geopolymer paste as adhesive bond material in near surface mounted technique is the first study in Iraq in which epoxy is replaced with a sustainable material, having good mechanical properties and it can be used in ambient and high temperature.

1.6 The Aim and the Objectives of the Work

The purpose of this work is to produce bond material that can be used in near surface mounted technique instead of the epoxy depending on geopolymer paste (fly ash with sodium hydroxide and sodium silicate solution) in addition to materials (nano silica) to accelerate polymerization process and (different types of fibers) to improve mechanical properties of paste.

This was done by studying the effects of:

a) Production of geopolymer paste cured under ambient temperature by adding different proportions of nano silica.
b) Check the bonding force of geopolymer paste applied it in NSM technique for concrete prisms and compared the results with epoxy adhesive by execution of the single lap shear test.
c) Improved geopolymer paste by adding different types of fibers and then apply it in NSM technique for prisms, and by the single lap shear test on specimens can obtain three optimum geopolymer pastes
d) Casting 14 RC beams with dimensions (200 * 125 * 1050 mm) (2 specimens were controls, 6 specimens had a single NSM groove and other 6 specimens had double NSM grooves).
g) Applying the three geopolymer pastes developed in NSM technique in RC beams with two groups (firstly use steel bars in technique and secondly use glass fiber reinforced polymer (GFRP) bars in technique).
h) Testing the specimens at flexural.

1.7 Research Layout:

The thesis divides into five chapters:

i. Chapter One attend an introduction to the external strengthening, NSM and geopolymer paste with the significance, objectives and scope of the research.
ii. Chapter Two deals with the literature review about the NSM and geopolymer paste.
iii. Chapter Three includes materials, the tests and details of experimental program.
iv. Chapter Four shows the results, discussion and interpretation.
v. Chapter Five presents the conclusions from this study and recommendations for further work.