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Confinement of Reinforced Concrete Columns with Fiber Reinforced Geopolymer Adhesive Jackets

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-Structure

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2021 **IRAQ** **1443**

CERTIFICATION

I certify that the thesis entitled “Confinement of Reinforced Concrete Columns with Fiber Reinforced Geopolymer Adhesive Jackets” is prepared by “Saif Mohammed Salman” under my supervision at the Department of Civil Engineering-College of Engineering-Diyala University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering-Structure.

Signature :

Supervisor: Prof. Dr. Wissam D. Salman

Date: / / 2021

بسم الله الرحمن الرحيم

الله الذي رفع السموات بغير عمد ترونها ثم استوى على العرش وسخر
الشمس والقمر كل يجري لأجل مسمى يدبر الأمر يفصل الآيات لعلكم
بلقاء ربكم توقنون

صدق الله العلي العظيم

سورة الرعد الآية ﴿ ٢ ﴾

Dedication

To the one who left our world, but their wisdom still

with me, to the soul of my father.

To the one who supports me with her best, mother.

To the one who teach me the life has meaningless

without them, my family.

To all whom trust me teachers and friends my thesis

won't be completed without your support.

With my thanks and Respect.

Saif Mohammed Salman

2021

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Saif Mohammed Salman

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Abstract

The strengthening and rehabilitation of reinforced concrete structures is an important issue all over the world. Fiber reinforced composites are mainly used for the strengthening and rehabilitation of concrete members. However, its use is limited due to its high price and environmental effects and its adoption of epoxy as an adhesive, where epoxy is considered inefficient at high temperatures and loses most of its properties. This study presents the experimental work on the use of geopolymer compounds as a sustainable adhesive in confinement of RC columns. Where, examined the axial compressive behavior of the circular RC columns confined by fiber reinforced geopolymer adhesive (FRGA) jacket. Totally 15 confined RC columns and one unconfined RC columns with dimensions of 100mm diameter x 600mm height were tested. The parameters of the study were: layers of confining jacket, (1, 2, 3) layer of carbon fiber. To improving the bonding strength of the geopolymer adhesive using discrete fibers, (Carbon fiber, micro steel fiber, Polypropylene fiber) with volumetric ratios of (0.2%, 2%, and 0.4%). Jackets material used (carbon fiber, jute fiber, Steel Wire Mesh, Window Mesh Fabric, (3x3) mm polyethylene mesh and (4x4) mm polyethylene mesh), confinement rate of RC columns (25%, 50%, 75% and 100%). Based on the test results, in the first group found that the confinement by three layer of carbon fiber reinforced geopolymer

adhesive jacket improved the (load enhancement ratio and deformation capacity) by (4.33 and 5.11) respectively, compared with the unconfined RC column. Also in group two noted that adding (micro steel fibers, carbon fibers and polypropylene fibers) to the adhesive led to an improvement in the compressive strength about (16.1%, 8.4%, 7.96%) respectively, Also that the geopolymer paste is an efficient adhesive with the various types of materials used in the formation of the confinement jackets, the confinement jackets consisting of (jute fiber, steel wire mesh) are considered the most efficient in terms of cost and performance compared to other specimens. The use of (jute fiber and steel wire mesh) jackets leads to a significant development in load enhancement by (1.79 and 1.7) and deformation capacity by (2.43 and 1.62) respectively compared to the unconfined RC columns. Also that an increase in the confinement ratio from 25% to 100% led to a significant development in (load enhancement and deformation capacity) by (3.146 and 3.68), respectively. Finally, it is worth noting that it could be considered the geopolymer adhesive as a sustainable and effective alternative to epoxy adhesive in RC columns confinement technology. Whereas, provided a good confinement of RC columns, it has proven its effectiveness as a good adhesive with various jacket materials, allowing the possibility of confined of columns by a low cost with good performance.

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List of Symbols and Terminology

P_u : ultimate axial load

ε_u : ultimate axial strain

ε_{lu} : ultimate longitudinal strain

ε_{tu} : ultimate transverse strain

V : Poisson's ratio

ε_{lcu} : ultimate longitudinal strain of concrete

ε_{tcu} : ultimate transverse strain of concrete

ε_{lsu} : ultimate strain of longitudinal steel reinforcement

ε_{tsu} : ultimate strain of transverse steel reinforcement

List of Abbreviations

RC	Reinforced Concrete
FRP:	Fiber Reinforced Polymer.
FRC	Fiber Reinforced compsite.
OPC:	Ordinary Portland Cement.
GPC	Geopolymer Concrete.
EA:	Epoxy Adhesive.
GA:	Geopolymer Adhesive.
CFREA:	Carbon Fiber Reinforced Epoxy Adhesive.
CFRGA:	Carbon Fiber Reinforced Geopolymer Adhesive.
F.A:	Fly Ash.

GGBFS: Ground Granulated Blast Furnace Slag.
XRF: X-Ray Fluorescence.
NaOH: Sodium Hydroxide.
Na_2SiO_3: Sodium Silicate.
SF: Micro Steel Fiber.
CF: Carbon Fiber.
PPF: Polypropylene Fiber.
F/b: Fluid to Binder Ratio.
$M_1 \times V_1$: Initial Mass× Initial Volume, before dilution.
$M_2 \times V_2$: Final mass× Final Volume, after dilution.
LVDTs: Linear Variable Displacement Transformers.
i.e. Such as.
SiO_2: Silica.
Al_2O_3: Alumina Oxide.

List of Abbreviations

HCL: Hydrochloric acid.
HNO_3: Nitric acid.
As: Arsenic.
Fe: Iron.
Pb: Lead.
C_3S: Tricalcium Silicate.
C_2S: Dicalcium Silicate.
C_3A: Tricalcium Aluminate.
C_4AF: Tetracalciumalumino Ferrite.
C-S-H: Calcium-Silicate Hydrate gel.
N-A-S-H: Sodium-Aluminum-Silicate Hydrate gel.
CaSO-2H2O: Gypsum.
L/D: Slenderness Ratio (Length to Diameter Ratio).
Lf/Df: Length to Diameter Ratio of Fiber.
As: Aspect Ratio.
Aw/Bi: Extra Water to Binder Ratio.

AL/Bi:	Activator Solution to Binder Ratio.
Si/AL:	Aluminosilicate to Alkaline Activator Ratio.
CFRP:	Carbon Fiber Reinforced Polymer.
BFRP:	Basalt Fiber Reinforced Polymer.
AFRP:	Aramid Fiber Reinforced Polymer.
GFRP:	Glass Fiber Reinforced Polymer.
SCC:	Self-Compact Concrete.
NSC:	Normal Strength Concrete.
HSC:	High Strength Concrete.
RCA:	Recycle Aggregate.
SEM:	Scanning Electron Microscopy.

CHAPTER ONE

INTRODUCTION

1.1 general

Columns are structural compression members subjected to combinations of axial compression and bending moment. They are considered to be a critical member in the performance and safety of structures. However, the reinforced concrete columns considered brittle member that shows the impact of bending and high loads due to significantly different factors on them, such as unbalanced moments when connecting beams, or lateral forces resulting from wind or seismic activity or unexpected overloads.

There is need to strengthening or modification of RCC columns. This may be due to various reasons, which are: change in structure usage, increased load capacity requirements due to design / construction errors, review of code requirements, change in structure usage, or rehabilitation of structure, improvement in ductility and compressive strength for reinforced concrete columns to match the environmental and service variables required. Therefore, researchers have resorted to a number of methods to improve and usually rehabilitate columns, among which is the external confinement technique, which is an important application in civil engineering. For various reasons such as increasing the capacity, making the structures more flexible, reducing the section dimensions. For this reason, civil engineering researchers have found many external confinement techniques as shown in Figure1-1. One of the confinement techniques is to fibers reinforced polymer FRP confinement. The efficiency of these techniques depends on the type of material used for confinement and the bonding material between the confinement material and the concrete member.

Figure (1-1) Concrete confinement technique

(https://images.app.googl/Hq6ttnXU6nv5jHN38)

Confinement of RC columns is a useful approach for increasing their load capacity and ductility. Steel jackets stuffed into the concrete core were used to strength RC columns at initially, but in the 1990s, they were replaced by Fiber Reinforced Polymer (FRP) jackets. In recent years, the FRP technology for column strengthening has gained popularity, not only because of its simplicity of installation, flexibility, and attractiveness, but also because of its properties, such as: high strength to weight ratio, and good behavior for corrosion. On other hand, there are several disadvantages of FRP technique which are namely: Low quality control and environmental stability (long-term performance of some components of the FRP jacket may not be optimal under various impacts such as ultraviolet (UV) radiation, heat cycles, and humidity) are some of the negatives of the FRP technology of the FRP jacket might not be optimum under different effects like ultraviolet radiation, thermal cycles, and humidity. **Rocca (2007).**

1.2 External confinement of concrete by FRP Technique

The technique of external insulation of concrete is a technique applied to concrete members such as columns, beams or panels, to achieve advanced mechanical properties, and with high efficiency in strengthening and rehabilitating structural members

Over the last decades, the issue of upgrading existing structures has been of great importance because of their deterioration, ageing, environmental induced degradation, a lack of maintenance, or the need to meet current design requirements. Fiber reinforced polymers (FRP) have been widely used as an externally applied reinforcement of existing structurally deficient structure. This technique is accomplished by rolling fibers mainly transverse to longitudinal axis of RC column providing passive confinement, which is activated once the concrete core starts dilating as a result of Poisson’s effect and internal cracking, but this technique is based on epoxy resin as adhesive between fibers and concrete. Epoxy resin have excellent binding properties at ambient temperatures, but deterioration of its mechanical properties occurs quickly at high temperature (Sachet et al. 2020),

1.3 General behavior of axial compression FRP confined concrete

Typical conduct Fundamentals must be given a lot of attention while trying to understand the behavior of a new type of structural element. As a result, a lot of research has been done on the behavior of small axially loaded plain concrete specimens confined by FRP. Such research can serve as the foundation for more complicated applications. However, because many investigators have undertaken very similar research, some findings are repeatedly repeated. With this in mind, before presenting the unique results of separate studies, a brief explanation of the generally reported properties of FRP-confined concrete and the definition of some terminologies will be given before the unique results of individual researchers are presented.

As shown in Figure (1-2) by the upper two curves, the axial stress-axial strain curves of concrete passively restricted by FRP are effectively divided into two portions by the upper two curves, with a minor transition zone at the point of slope change. The initial component of the curve will be referred to as the elastic zone, while the portion to the right of the transition zone will be referred to as the plastic zone.

The elastic section of the curve has a slope that is nearly identical to that of unconfined concrete. Except for a stiffer jacket, which tends to marginally raise the stress and strain at which the transition zone occurs, the type of jacket with which the concrete is contained has minimal effect on this region of the curve. The stress-strain curve of unconfined concrete is plotted with the confined concrete curves for comparison (see Figure 1-2). The confined and unconfined curves in the elastic zone are remarkably similar because concrete has limited lateral expansion under tiny loads and hence does not react against the jacket constraint to produce confinement pressure.The plastic zone develops shortly after the unconfined concrete reaches its peak strength. The concrete is currently expanding rapidly because of its plastic behavior and has fully activated the jacket.

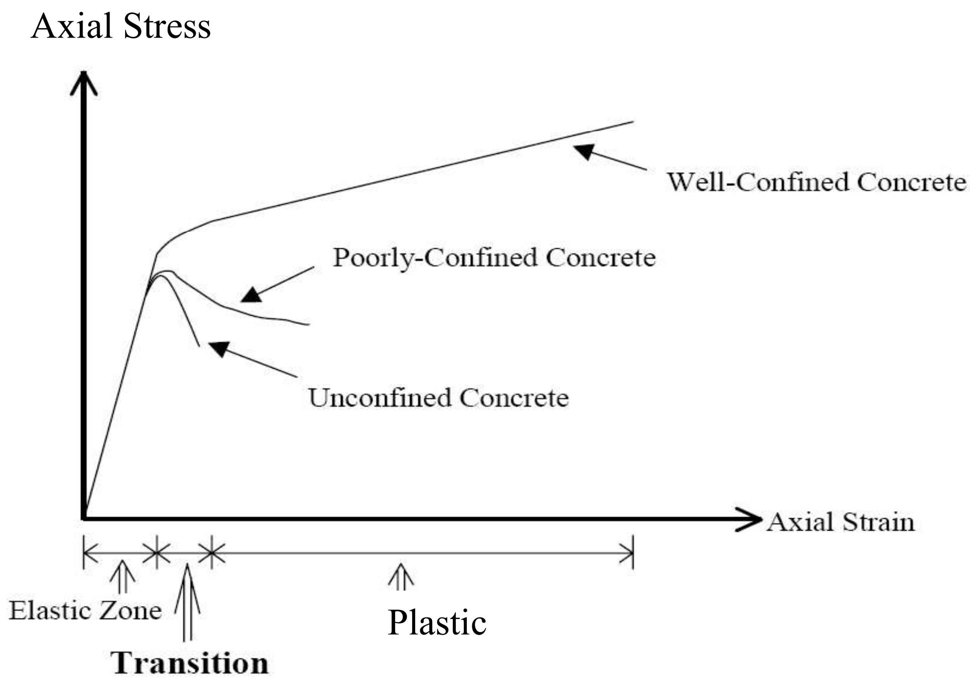

Figure (1-2) Typical Shape of an Axial Stress-Axial Strain Curve for Concrete Confined by FRP (2001 Belarbi)

In the plastic zone, a little increase in stress induces a substantial (compared to the elastic zone) increase in radial expansion in the plastic zone. This expansion has two effects: first, it deteriorates the state of the concrete's interior structure. Second, it increases the amount of confining pressure. The jacket's fibers have a linear elastic tendency until they fail. These two operations aid in the definition of the slope of the plastic portion of the curve. If the concrete is well confined, then the slope will be positive and usually relatively linear if the concrete is well contained, indicating that the confining pressure is sufficient to curb the effect of the deteriorating condition of the concrete and allow additional stress to be applied. The peak axial stress will be equivalent to that of unconfined concrete if the concrete is not well-confined, indicating that the confining pressure is not sufficient to overcome the effect of the degradation of the concrete under the large strains it is experiencing. A stiffer jacket tends to make the slope of the plastic zone more positive. **(2000 Xiao, Y)**

Finally, while their specimens are loaded, several investigators monitor the strain in the fibers in the FRP jackets. The ultimate tensile strain achieved by the fibers in the jackets before rupture is frequently reported to be much less than the ultimate fiber strain achieved during coupon tests. This outcome is expected for three main reasons. Firstly, Flat coupons are less hard to make than jackets and, as a result, may be of greater quality. Second, in a coupon test, the fibers are solely subjected to axial loads. Expanding concrete, on the other hand, creates both axial and transverse loading in a jacket's fibers. **(2000 Xiao, Y)**

1.4 Geopolymer Paste Adhesive

Geopolymer is a pozzolanic material filled with aluminates and silicates which are good and sustainable alternatives for producing materials with better or similar properties to those of Ordinary Portland Cement (OPC). Davidovits 1978, the first to name the geopolymer to pozzolanic materials such as fly ash, slag, rice husk ash and metakoline, which is considered a rich source of silicate and aluminate that are activated by mixing them with alkaline solutions via a process called polymerization **(Hadi, et al.2019)**, as shown in Figure (1-3).

The geopolymer materials depend on the acquisition of their strength on the formation of sodium-aluminum-silicate hydrate (N-A-S-H) gel, in addition to calcium-silicate hydrate (C-S-H) gel **(Davidovits, 2008)**. In the case of using geopolymer, high temperature in early curing stage is essential to provide enough strength increases to access high mechanical properties (El-Hassan, and Ismail, 2018, Hadi, et al.2019).

However, there are a number of practical challenges with using heat to cure structures; as a result, researchers are looking at a number of techniques to speed up the polymerization process so that it can be cured at room temperature. Ground granulated blast furnace slag (GGRFS) is one of the common pozzolanic materials for gaining wider attention due to its significant effect on the microstructural and mechanical properties of geopolymer based binders. Due to slag significant effect on the microstructural and mechanical properties of geopolymer based binders, (GGRFS) is one of the most frequent pozzolanic materials that is getting more attentionto speed up the polymerization process. **(Saha, et al. 2017, El-Hassan, Ismail, 2018 and Wrood et al.2020)**. So, slag may be used to geopolymer mixture to accelerate polymerization process under ambient temperature and improve the properties of paste.

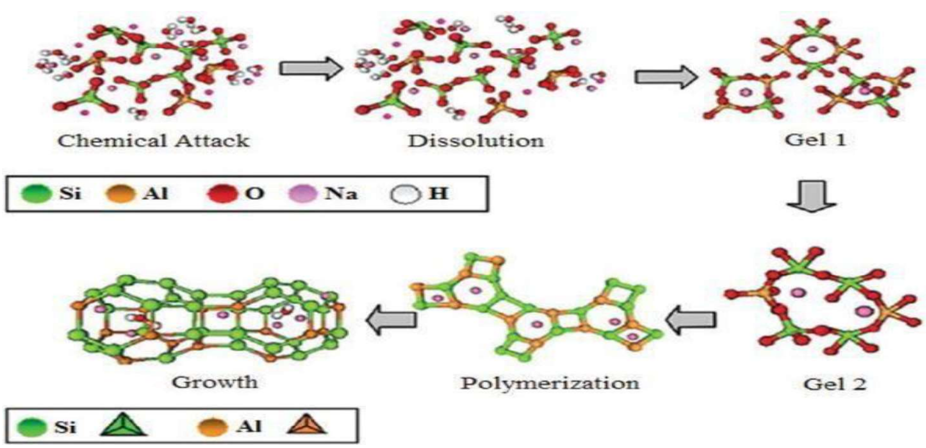

Figure (1-3) Graphic model of alkali activation of geopolymer (2019. Hadi, et al)

1.5 Fibers

Fibers are small and separate materials that are natural, industrial, or animal. They are added to concrete, mortar or paste in order to improve their mechanical properties, especially tensile strength, then compressive and flexural strength, control cracking due to drying and plastic shrinkage and reduce the permeability of concrete **(Salman, et al. 2019)**, by bridging cracks and reorganizing their distribution and thus increasing capacity loaded. Each type of fiber is added according to its availability, characteristics, price, and purpose of the concrete member. 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).**

figure (1-4) Different types of fibers (2017, Buttignol, et al.)

1.6 Problem Statement

In recent years, Iraq has become within the vicinity of seismic activity, and due to environmental changes and high temperatures, there is a need to find technique of maintenance and strengthening that are commensurate with the current conditions.

In strengthening techniques, epoxy is usually used as an adhesive. However, it has disadvantages, as at a high temperature (55-60) C° rapid deterioration of the mechanical properties of the epoxy occurs as it loses most of adhesive properties, high cost, inability to apply on wet surfaces, incompatibility with substrate materials (concrete). To reduce the problems arising when using epoxy, we need to replace the epoxy with a material that is efficient at high temperatures. The use of geopolymer paste as an adhesive in concrete confinement technology is a good alternative to epoxy and a sustainable material that has good mechanical properties that can be used at ambient and high temperatures. Therefore, in this study, geopolymer paste was used as an alternative to epoxy to confine the reinforced concrete columns.

1.7 The Objectives of the Work

The aim of the present study is to investigate experimentally the effect of confinement on compressive behavior of RC columns when using fiber reinforced Geopolymer jacket, and an investigation into the production of confinement vests at the lowest cost and best performance by using different types of jacket fabric with lower cost, improve capacity load and ductility of reinforced concrete columns under axial loads.

1.8 Methodology and Parameters of Study

In order to verify the behavior of RC columns confined by fiber reinforced geopolymer adhesive, the work was carried out by casting and testing 15 confined specimens and 3 unconfined specimens with dimensions of 100 mm diameter x 600 mm height. Parameters of study were:

1) Increase layers of confining jacket, (1, 2, 3) layer of carbon fiber reinforced geopolymer adhesive jacket, to verify the effect of the increased confinement on the behavior of the columns.
2) Improving the bond strength between the jacket and concrete by adding fibers to the geopolymer adhesive, which included; carbon fiber with 0.2% volumetric ratio, micro steel fiber of 2% volumetric ratio, and Polypropylene fiber with 0.4% volumetric ratio.
3) Effect of jackets material which is (carbon fiber, jute fiber, steel wire mesh, window mesh fabric, (3x3) mm polyethylene mesh and (4x4) mm polyethylene mesh).
4) The confinement rate (25%, 50%, 75% and 100%) of the specimen length.

1.9 Research Layout:

The thesis divides into five chapters:

I. Chapter one attend an introduction to the external strengthening, concrete confinement technique, geopolymer paste adhesive, problem statement, objective of the study, methodology and parameters.
II. Chapter two deals with the literature review about the concrete confinement technique 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.

CHAPTER TWO
LITRATURE REVIEW

2.1 Introduction

This chapter covers three orients major of previous studies. Firstly, confinement of concrete by fiber reinforced polymer, which is a common method used to rehabilitate and strengthening of structural building. Secondly, designing geopolymer paste mixtures, which cure at ambient condition, and improve its mechanical properties via usage of fibers, where recently studies tend to be used geopolymer paste as the adhesive material instead of epoxy due to the problems of epoxy at high temperatures as it loses its efficiency. Third, the use of different textile materials in the manufacture of confinement jackets, recently, research tends to used inexpensive and environmentally friendly materials in the manufacture of jackets.

2.2 Confinement of Concrete by Fiber Reinforced Polymer

In (2004) Berthet, et al. provided an experimental study of compressive behavior of concrete columns confined by FRP jackets made of carbon and glass. Variables included (type of jacket material, confinement level represented by number of layers and thickness of fabric, compressive strength of concrete core from 25 to 170 MPa). specimen has a diameter of 160 mm and a height of 320 mm, after casting and cured of specimen for 28 days, they were confined with jackets consisting of carbon fiber glass and epoxy as adhesive. The results showed that external confinement significantly improves the ultimate strength and ductility of columns, while specimens confined by carbon fiber gave the highest values of compressive strength