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College of Engineering

Confinement of Square Reinforced Concrete Columns by 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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Abstract

Strengthening process for old and damaged reinforced concrete structure have become sources of interest to researchers in recent times. Therefor, there are many techniques used for this purpose including the use of fiber reinforced polymers, but the undesirable properties of polymers such as high cost, emission of gases, toxic fumes and global warming, made it necessary to find an alternative materials with high efficiency and ability to withstand high temperature (Salman et al, 2021). The geopolymer adhesive is a sustainable and environment friendly material.

This work considered experimental study to confinement square reinforced concrete columns using geopolymer as a sustainable adhesive material. The experimental program includes testing of fourteen square reinforced concrete columns with dimensions of 10cm width x 60cm height. The axial compressive behavior of all columns was tested. The variables of the study were: the effect of the number of jacket layers by carbon fiber reinforced with geopolymers adhesive (1, 2, and 3) layers, effect of jackets material which are (carbon fiber, steel mesh, plastic mesh, and glass mesh), the confinement ratio (25%, 50%, 75% and 100%) of the length of RC columns and distribution of strips confinement (1.5, 2.5 and 3.5)cm with 50% confinement ratio.

Through the test result, it was found in the confinement by three layer of carbon fiber reinforced geopolymer adhesive jacket development the (load enhancement ratio and deformation capacity) by (1.86 and 2.52) respectively, compared with the reference RC column (unconfined). Also, it was noted that, the use of (plastic mesh and steel wire mesh) jackets led to significant development in load enhancement ratio by (1.41 and 1.27) and deformation capacity by (1.86 and

1.50) respectively. Also, the increase in confinement ratio from 25% to 100% show significant development in (load enhancement ratio and deformation capacity) by (1.59 and 1.86), respectively. Finally, it was found the use of carbon fiber with distribution 1.5cm led to improvement in (load enhancement ratio and deformation capacity) by (1.40 and 1.43), respectively.

The test result showed that the geopolymer used in the confinement square reinforced concrete columns is an effective material with high efficient and has good adhesion strength with different types of material, therefor it considered sustainable material and its use led to reduce the cost and improvement columns behavior.

In conclusion, comparing test result to analytical calculations, the ratio of experimental to theoretical calculation for concrete columns confined with two layers of carbon fiber in the first and second suggested equations was (1.00 and 0.99), respectively, while the ratio of experimental to theoretical calculation in the concrete columns confined by two layers of jute fiber in the first and second suggested equations, was (1.09 and 1.19), respectively. Finally, it was found the ratio of experimental to theoretical calculation in the concrete columns confined with 50% by carbon fiber in the first and second equations was (1.03 and 1.12), respectively.

Certification

I certify that the thesis entitled "Confinement of Reinforced Concrete Columns with Fiber Reinforced Geopolymer Adhesive Jackets" is prepared by "Thakaa Amer Hussein" 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: / / 2022

بسم الله الرحمن الرحيم

«وقل اعملوا فسيرى الله عملكم ورسوله والمؤمنون وستردون إلى عالم الغيب والشهادة فينبئكم بما كنتم تعملون»

صدق الله العلي العظيم

(التوبة) ﴿105﴾

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 "Haider", who supported me through my journey,

I won't be able to accomplish this without you.

To my uncle" Ali Khalifa", who encourages me, thank you very much

To my brother and sisters the key of my success

To my lovely sons "Karar, Yousif and Shahim"

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

With my Love and Respect

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List of Symbols and Terminology

f_{cc}: Compressive strengths of confined concrete

f_{co}: Compressive strengths of unconfined concrete

k: Confinement effectiveness coefficient

v: Poisson's ratio

f_l: Pressure of lateral confining

K_s: Shape factor

ε_{lcu}: Ultimate longitudinal strain of concrete

ε_{lsu}: Ultimate strain of longitudinal steel reinforcement

ε_{lu}: Ultimate longitudinal strain

ε_{tcu}: Ultimate transverse strain of concrete

ε_{tsu}: Ultimate strain of transverse steel reinforcement

ε_{tu}: Ultimate transverse strain

ε_{u}: Ultimate axial strain

P_u: Ultimate axial load

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:	Tetra calcium alumino Ferrite.
C-S-H:	Calcium-Silicate Hydrate gel.
N-A-S-H:	Sodium-Aluminum-Silicate Hydrate gel.
$CaSO\text{-}2H_2O$:	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.
Ae/Ac:	Effective Confinement Area 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.
NSM:	Near Surface Mounted.
BFS:	Blast Furnace Slag.
DSTCs:	Double Skin Tubular Columns.
CFFTs:	Concrete Filled FRP Tubes.

H-CFFTs:	Inner Void Concrete Filled FRP Tubes.
GPCFFTs:	Geopolymer Concrete Filled Fiber Tubes.
OPCCFFTs:	Ordinary Portland Cement Concrete Filled Fiber Tubes.
PET:	Polyethylene Terephthalate FRP.
FCHCS:	FRP-Confined Hollow Stub Columns.
FRGA:	Fiber Reinforced Geopolymer Adhesive.
GGBFS:	Ground Granulated Blast Furnace Slag.

CHAPTER ONE

INTRODUCTION

1.1 General

Columns are one of the major and important structural members in the building. The columns carry vertical load and transport to the foundations then into ground and unable to with stand earthquakes due to poor ductility, excessive loads, corrosion of steel reinforcement, or error during design. Therefor it considered a critical member.

Repair and rehabilitation of damaged reinforced concrete columns is one of the widespread construction activities globally. Confinement consider one of the rapid techniques in the repair process that have proven their ability to restore the primary capabilities of damage building. Choosing suitable type of confinement is necessary in the field of design because it targets sustainability, cost of construction and time. Various materials and techniques are used for confining structures such as jacketing of concrete, steel, external steel wiring, and fiber-reinforced polymer (FRP). The confinement by fiber reinforced polymer FRP composites is one of the most common confining method used to repair damage reinforced concrete columns, which is very effective and necessary to improve the behavior of columns such as their load capacity, compressive strength, and ductility for short columns, the designer still face difficulties of using FRP in slender or long columns due to inadequate research, guidelines and provision of design.

The advantage of FRP high strength to weight proportion, lightweight, ease of application, high durability, and good resistance of corrosion. There are various type of FRP such as carbon fiber reinforced polymer (CFRP), glass, and aramid. The CFRP is a modern and wide application composite materials in the civil engineering field because of their high elastic modulus, which is pasted by epoxy (Jijin and Prabhakaran, 2015) as shown in Figure (1-1). The rapid deterioration of polymers such as epoxy at high temperatures lead to its replacement an effective adhesive geopolymers because the success of strengthening process depends on the bond characteristic between FRP-adhesive-concrete interfaces. The bonding layer of adhesive is consider a medium to transfer and distribute the stresses from concrete to FRP. The basic philosophy of the concept of confinement is to make the column behave in more ductility, thats will be characterized by its ability to delays and minimized the collapse of structure elements and dissipate energy due to multiple reason.

Figure (1-1): Jacketing of Columns by CFRP (Jijin and Prabhakaran, 2015)

1.2 Techniques of External Confinement of RC Columns by FRP

The external confinement technique applied to concrete members such as columns, beams or panels are used eliminate some undesirable properties of concrete, like the brittle behavior or because the deterioration due to lack of maintenance and other reasons. The concept of confinement consists of two principle, firstly is that the confining generates axial strength which is restoring for the strength lost as a result of concrete fragmentation. Secondly, is that confinement led to increase in axial capacity without significant loss of strength, (Mohammed and Karim, 2020).

In order to strengthen the damage concrete structure, the technique of fiber reinforced polymer (FRP) were used to increase the strength of column depending on the properties of FRP (material type, tensile strength, thickness etc), but this technique depends in its efficiency on epoxy as adhesive material. The rapid deterioration of epoxy at high temperature, causes a loss of most mechanical properties, (Sachet et al, 2020). Bonding hoop FRP to the column surface resists lateral deformations and delaying collapse of the concrete by enhancing both the ultimate compressive strength and strain of the concrete as shown in Figure (1-2), (Russell and Modi, 2001).

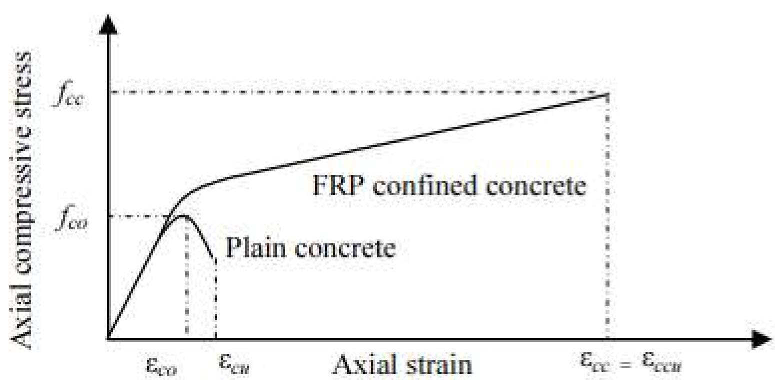
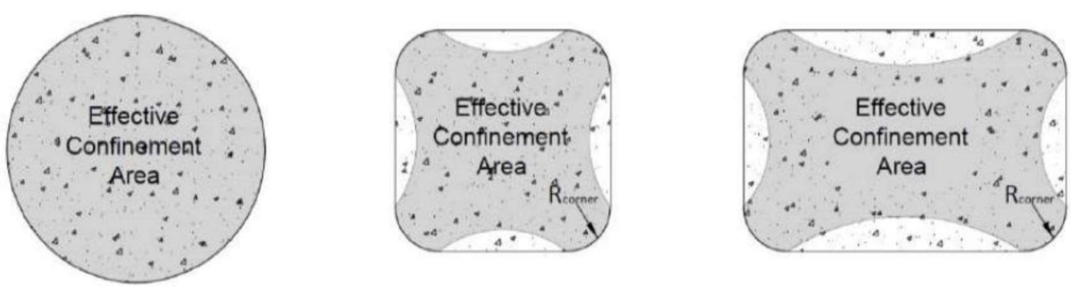


Figure (1-2): Axial compression stress-strain curve of confined concrete by FRP (Russell and Modi, 2001).

1.3 Behavior of Square RC Columns Confinement by FRP Jacket

The Square RC columns are special case of rectangular columns with (width = depth) and the most common in concrete structures. These columns should have edge that are not sharp (rounded) to avoid the failure due to stress concentration and to improve the effectiveness of FRP confinement. The value of angle should be small due to the presence of internal steel reinforcement. The researcher (Mander et al, 1988) present a study on steel confined concrete on deferent sections (square or rectangular). They were able to reach the best site for concrete that is confined to transvers, and the effective concrete shall include by the four parabolas of second-degree because it is completely confined and neglected the concrete at rest.

The confining pressure in square columns was lower effectiveness than circular columns for two reasons, the first the FRP jacket applies non-uniform lateral pressure of concrete due to the non-uniform dilation of concrete and this pressure concentrated in the corners due to stress concentrated at corners. Thus, the stress of confinement transmitted to the concrete at the cross section four corner is a percentage of the effective cross-sectional area due to the geometry of the section and the non-uniform distribution of confinement pressure. The second cause of fewer effectiveness is that, in circular columns the confinement action depend on the tensile stiffness of the FRP jacket, while in rectangular or square columns, it relys on the flexural stiffness of the jacket, which is much less than the tensile stiffness (Doan, 2013). The effective area of confinement the rectangular, square, and circular cross section shown in Figure (1-3).



(a) **(b)** **(c)**

Figure (1-3): Confinement effectiveness areas in columns(a)circular, (b)square, (c)rectangular columns (Parvin and Brighton, 2014)

1.4 Geopolymer Paste Adhesive

Geopolymer is a pozzolanic and ‘‘green” material because it utilizes as a binder rather than cement binder, that it is profuse in silicates and aluminates, like fly ash (FA), blast-furnace slag (BFS), rice husk ash and metakoline. The first name of geopolymer was used by Davidovits (1978) and produced inorganic polymeric materials (1990). Geopolymer is a real replacement to conventional Portland cement. It relies on minimally processed natural materials or industry produced materials to significantly reduce its carbon footprint, also being high resistant to many of the durability issues that can get to conventional concretes (Davidovits, 2013).

The geopolymer is manufactured by mixing an aluminum silicate waste industrial material (i.e. fly ash and blast furnace slag) with an alkaline activator, i.e. sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solution via a process called polymerization (Shihab et al, 2018), as shown in Figure (1-4).

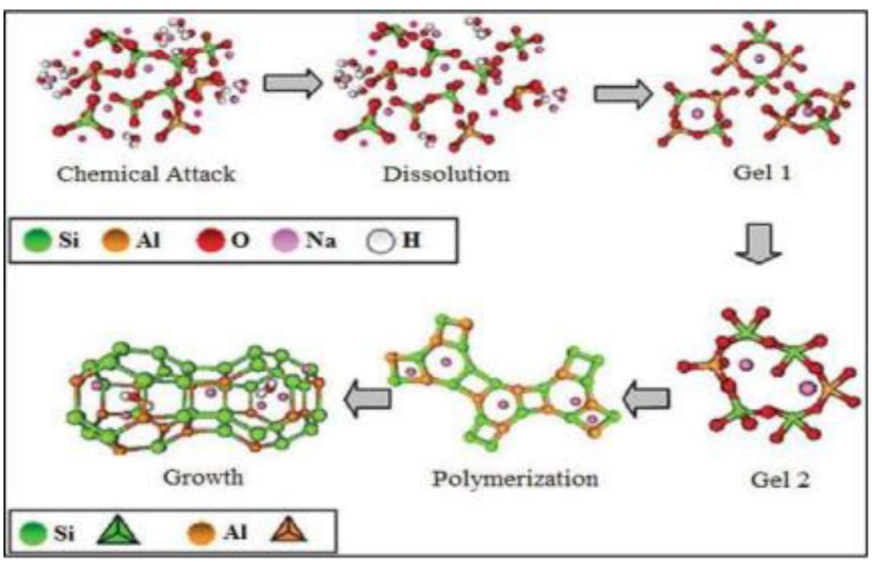


Figure (1-4): Graphic model of alkali activation of geopolymer (Shihab et al. 2018)

The acquired strength of geopolymer depend 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). The high temperature is needful in the early curing stage for geopolymer to provide enough increases in strength to access high mechanical properties (El-Hassan et al, 2018). The 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 is a pozzolanic materials has a great effect on the microstructural and mechanical properties, also accelerate polymerization process under ambient temperature and improve the properties of geopolymer paste based binders (Saha et al, 2017, El-Hassan et al, 2018, Sachet et al, 2020 and Salman et al, 2021).

1.5 Problem Statement

The quickly deteriorates of polymers when exposed to high temperatures (55 to 60^{o}C) and lost of its mechanical properties, also the emission of toxic gases and fumes during the implementation. It causes hazard problems for manual workers life. Contributes to the development of global warming, made it was necessary to find for a new adhesive material and operating at high temperature.

1.6 The aim of Study

The main goal of this research is to use a geopolymers adhesive as sustainable environmentally friendly material in the confinement process of short square reinforced concrete columns, and to improving load carrying capacity, compressive strength and ductility of reinforced concrete columns under axial load.

1.7 Study Methodology and Variables

To achieve the above-mentioned objectives and to investigate the performance of RC columns confined by fiber reinforced geopolymer adhesive, the study was done by casting and testing fourteen confined RC columns, one unconfined RC and the remaining thirteen are confined by geopolymer adhesive jackets with cross-section 10cm and 60cm height. Variable of study were:

1) Number of carbon fiber reinforced geopolymer adhesive jackets (1, 2, and 3) layers.
2) Jackets material which is (carbon fiber, steel mesh, plastic mesh, and glass mesh).
3) The confinement rate (25%, 50%, 75%, and 100%) of the column length.
4) Distribution of strips confinement (1.5, 2.5, and 3.5)cm with 50% confinement ratio.

1.8 Thesis Layout :

The thesis has been divided into five chapters:

Chapter one showed the introduction, technique of external confinement of concrete by FRP on RC columns, behavior of square RC columns confinement by FRP jacket, geopolymer paste adhesive, problem statement, the significance of study, Study Methodology and variables.

Chapter two showed the literature review about the technique of confinement columns and geopolymer adhesive.

Chapter three is showed the experimental program and the procedure followed to develop the research specimens which includes s a full explanation of the mechanical testing conducted on the material used in this research.

Chapter four showed the experimental results, discussion and explication.

Chapter fives showed the summarizing of the test results, high lighting the conclusions and the important recommendations for future studies.