

**Ministry of Higher Education
and Scientific Research
University of Diyala
College of Engineering**



**IMPROVEMENT OF SOME SOFT CLAY SOIL
PROPERTIES USING GEOPOLYMER
MATERIALS**

**A THESIS SUBMITTED TO THE COUNCIL OF COLLEGE
OF ENGINEERING,
UNIVERSITY OF DIYALA IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
SCIENCE IN CIVIL ENGINEERING**

**By
Abdalla Mohamed Shihab**

Supervised by
Assist. Prof. Dr. Jasim Mohammed Abbas

September, 2018

IRAQ

Muharram, 1440

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا

إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العظيم

سورة البقرة

(الاية 32)

SUPERVISORS' CERTIFICATE

I certify that this thesis entitled "**Improvement of Some Soft Clay Soil Properties Using Geopolymer Materials**" was prepared by "**Abdalla Mohammed Shihab**" under my supervision in the University of Diyala in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Signature:.....

Name: Assist. Prof. Dr. Jasim M. Abbas,

(Supervisor)

Date: / /2018

COMMITTEE DECISION

We certify that we have read the thesis entitled (**Improvement of Some Soft Clay Soil Properties Using Geopolymer Materials**) and we have examined the student (**Abdalla Mohammed Shihab**) 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**.

Examination Committee

Signature

1- Assist. Prof. Dr. Jasim M. Abbas, (Supervisor)
2- (Member)
3- (Member)
4- (Chairman)
Assit. Prof .Dr.Hafeth Ibrahim Naji (Head of Department)

The thesis / dissertation was ratified at the Council of College of Engineering / University of Diyala.

Signature.....

Name: Prof.Dr. Abdul Monem Abbas Karim
Dean of College Engineering / University of Diyala

SCIENTIFIC AMENDMENT

I certify that the thesis entitled **“Improvement of Some Soft Clay Soil Properties Using Geopolymer Materials”** presented by **(Abdalla Mohammed Shihab)** has been evaluated scientifically, therefore, it is suitable for debate by examining committee.

Signature:

Name: Assist. Prof. Dr.

Address: University of
Engineering Department

Date: / / 2018

LINGUISTIC AMENDMENT

I certify that the thesis entitled “**Improvement of Some Soft Clay Soil Properties Using Geopolymer Materials**” presented by (**Abdalla Mohammed Shihab**) has been corrected linguistically, therefore, it is suitable for debate by examining committee.

Signature:

Name: Assist. Prof. Dr.

Address: University of Diyala / College of Education for Human Sciences

Date: / / 2018

Dedication

To ...

God, The greatest truth in my life.

My father spirit, the nice memory of my life

My mother, the sight of my eyes.

My wife, who supported me.

*Our honorable teachers who taught and rewarded us their
knowledge.*

Everyone, who wishes me success in my life,

I dedicate this humble work.

Abdalla

Acknowledgments

"In the Name of Allah, the most beneficent, the most merciful"

First praise be to "Allah" who gave me the strength and health to work and enable me to finish this work.

I would like to express my sincere thanks to my supervisor Assist. Prof. Dr. Jasim Mohammed Abbas for his valuable advice, guidance, constructive criticism, cooperation and giving generously of his expansive time when help was needed through out the preparation of this study. I am greatly indebted to him.

I would also like to express my deep appreciation and sincere gratitude to Prof. Dr. Amer Mohammed Ibrahim the vice presedent of Diyala university who did not hesitate anytime to support me in my way to get the of master degree.

Appreciation and thanks are also extended to the all staff of Civil engineering department, and the staff of Soil mechanics Laboratory.

Thanks are also due to all my friends for their kindest help.

Finally, I would like to express my love and respect to my mother, my family, My brother, no word can express my gratitude to them.

Abdalla Mohamed Shihab

IMPROVEMENT OF SOME SOFT CLAY SOIL PROPERTIES BY GEOPLYMER MATERIALS

By

Abdalla Mohamed Shihab

Supervisor

Assist. Prof. Dr. Jasim M. Abbas

ABSTRACT

In general, soil improvement by admixtures or simply (soil stabilization) is a common cost effective way to treat soft clay soils and overcome its undesirable behavior. In this way, this field have seen increasingly many attempts for finding the suitable soil admixtures.

The Geopolymers are innovative materials that illustrate good properties which were argued to overcome the other usual soil admixtures shortcomings. In order to develop the knowledge about the Geopolymer – soft clay strength and the consequent geotechnical performance, an experimental program was introduced, moreover, a considerable concern was conducted throughout this program to the temperature effects which can vary the properties of the resulting Geopolymers to a great extent.

The experimental program consists of main two parts to make a preliminary assessment of soft soil with this new admixture. The first part included the temperature effects on the mechanical strength of Geopolymer – soft clay mix that characterized by the unconfined compressive strength as well as the ductility and the stiffness that represented by failure strain and Young's modulus, respectively. While in the second part, some heated conditions was devoted to investigate some geotechnical properties like specific gravity, liquid and plastic limit, compaction characteristics and California bearing ratio. The microstructure of the treated soil was observed by the scanning electron microscope and the mineralogical changes

were detected by the X-ray powder diffraction using specific heating conditions. The percentage of source material used are 8, 10, 12, and 14 % by dry weight and the total liquid is 38 % which corresponds 4.75, 3.8, 3.167 and 2.714 liquid over fly ash used.

The experimental results showed that the optimum liquid over fly ash ratio with respect to peak unconfined compressive strength is 3.8 when the reported degree of improvement factor about 20.1. Ductility and stiffness were also enhanced considerably with degree of improvement of 3.5 and 8.7 respectively. It can be concluded also that the optimum temperature can vary according to the source material percent and nature.

The specific gravity and the maximum dry density decreased as the fly ash content increased whereas the optimum moisture content increased. The scanning electron microscope test illustrated the formation of the Geopolymer gel and the X-ray powder diffraction analyses confirms the chemical composition of this gel represented by the potassium aluminosilicat hydrate and sodium aluminosilicat hydrate.

TABLE OF CONTENTS

Article	Detail	Page
ABSTRACT		I
CONTENTS		III
LIST OF FIGURES		VI II
LIST OF PLATES		XI
LIST OF TABLES		XI I
LIST OF Abbreviations		XI V
CHAPTER ONE	INTRODUCTION	
1.1	General	1
1.2	Soft Clay Soil	2
1.3	Geopolymers	4
1.4	Problem Statement	4
1.5	Importance of the Study	5
1.6	Objectives of This Study	5
1.7	Thesis Layout	6

CHAPTER	LITERATURE REVIEW	
TWO		
2.1	Introduction	7
2.2	Methods of Improving Soft Clay Properties	7
2.3	Admixtures Soil Improvement	9
2.4	Admixtures Soil Improvement Agents	10
2.4.1	Cement	10
2.4.2	Lime	12
2.4.3	Fly Ash	14
2.4.4	Silica Fume	15
2.4.5	Rice Husk Ash	16
2.4.6	Sugarcane Straw Ash	17
2.4.7	Tire Ash	19
2.5	Geopolymers Definition, Features and Motivation	19
2.5.1	Geopolymerization Process	20
2.5.2	Materials of Geopolymers	21
2.5.2.1	Fly Ash	21
2.5.2.2	Sodium Hydroxide NaOH	22
2.5.2.3	Sodium Silicate Na ₂ SiO ₃	22
2.6	Applying Heat in Geopolymers	22

2.7	Soil – Geopolymer mixes	24
2.8	Literature Summary	27
CHAPTER	EXPERIMENTAL WORK	
THREE		
3.1	Introduction	31
3.2	Materials Used	31
3.2.1	Soil	31
3.2.2	Fly ash	33
3.2.3	Sodium Silicate Na_2SiO_3	34
3.2.4	Sodium Hydroxide	35
3.2.5	Distilled Water	37
3.3	Preparation of Alkaline Solution for Geopolymers	37
3.3.1	Preparing NaOH Solution	38
3.3.2	Adding Na_2SiO_3 to NaOH Solution	38
3.4	Source Materials and Total Liquid Percent	38
3.5	Sample Preparation	39
3.6	Mechanical Strength and Temperature Effects	42
3.6.1	Failure Strain and Young's Modulus Assessment	44
3.6.2	Soil pH	45
3.6.3	Shrinkage Observation	45
3.6.4	Remaining Moisture	47
3.7	Geotechnical Tests	47
3.7.1	Specific Gravity	47
3.7.2	Liquid and Plastic Limit	47

3.7.3	Compaction Test	48
3.7.4	California Bearing Ratio	48
3.7.5	SEM-Analysis (Scanning Electron Microscope)	50
3.7.6	Mineralogical Analysis: X-Ray Powder Diffraction (XRD)	50
3.8	Testing Program	51
CHAPTER	RESULTS AND DISCUSSION	
FOUR		
4.1	General	53
4.2	Temperature Effects to Mechanical Strength.	53
4.2.1	Assessment of Peak Unconfined Compressive Strength	54
4.2.1.1	Effect of Liquid over Fly Ash Ratio	54
4.2.1.2	Effect of Initial Duration Time on the UCS	55
4.2.1.3	Effect of Duration temperature to UCS	57
4.2.2	Development of Failure Strain	59
4.2.3	Young's Modulus	63
4.2.4	Soil pH	67
4.2.5	Shrinkage Behavior	70
4.2.6	Remaining Moisture Observation	73
4.3	Investigation of Some Soft Clay - Geotechnical Properties	76
4.3.1	Specific Gravity	76

4.3.2	Liquid and Plastic Limit	77
4.3.3	Compaction Test	78
4.3.4	California Bearing Ratio	79
4.3.5	Microstructure and Mineralogical Analysis	81
4.3.5.1	Scanning Electron Microscope (SEM) – Energy Dispersive Spectroscopy (EDS).	81
4.3.5.2	X – Ray Powder Diffraction (XRD)	83

**CHAPTER
FIVE**

**CONCLUSIONS AND
RECOMMENDATIONS**

5.1	Conclusions	84
5.2	Recommendations for Future Work	85

TABLE OF FIGURES

No.	Title	Pa ge
2.1	Soil improvement techniques according to grain size ranges (after Mitchell, 1981)	8
2.2	Stress-strain graphs from unconfined compressive strength tests(after Sarkar et al., 2012)	11
2.3	Relationships of plastic limit of lime-treated soil with curing time (after Sakr et al., 2009)	13
2.4	Compressive stress-strain curve for soil with different silica fume content(after Al - Azzawi et al., 2012)	16
2.5	Variation of UCS with rice husk ash content content (after Alhassan, 2008)	17
2.6	Variation of CBR due to sugar crane addition (after Amu et al., 2011)	18
2.7	Strength comparison of OPC, air cured and heat cured Geopolymer mortar (after Adam and Horento, 2014).	24
2.8	UCS results of alkaline activation mixtures with NaCl, CaO and concrete superplasticiser additives (after Cristelo et al., 2012)	25
2.9	The influence of meta kaolin gel concentration to compressive strength (after	29

Zhang et al., 2013)

2.10	UCS and Young modulus results at 28 days for the 16 mixtures (after Rios et al., 2016)	27
2.11	Soil improvement techniques according to grain size ranges (after Fang and Daniels, 2006)	28
3.1	Failure strain and Young's modulus evaluation (D24C90 for Group 2)	44
3.2	Flow chart of laboratory program	52
4.1	Variation of peak UCS due to different Liquid over fly ash ratio for different durations	54
4.2	Variation of peak UCS due to different initial duration time for different liquid over fly ash ratios	56
4.3	Variation of of peak UCS due to increasing duration temperature for different liquid over fly ash ratios	57
4.4	Variation of failure strain due to different temperatures for initial duration time	59
4.5	Variation of of failure strain due to liquid over fly ash ratio for different durations	61
4.6	Variation of of failure strain due to different initial duration time for different liquid of fly ash ratios	62
4.7	Variation of Young's modulus due to	63

	initial duration time for different liquid over fly ash ratios	
4.8	Variation of of Young's modulus due to different temperatures of initial durations	65
4.9	Variation of of Young's modulus due to liquid over fly ash for different values of initial durations	66
4.10	Variation of soil pH due to duration temperatures for different liquid over fly ash ratio	67
14.1	Variation of pH level due to liquid over fly ash for different values of initial durations	68
24.1	Variation of pH due to different initial duration time at different liquid of fly ash ratios	69
34.1	Variation of soil volumetric strain due to duration temperatures for different liquid over fly ash ratio	70
4.14	Variation of volumetric strain due to different liquid over fly ash ratios for different values of initial durations	71
4.15	Variation of volumetric strain due to different initial time for different liquid of fly ash ratios	72
4.16	Variation of remaining moisture due to duration temperatures for different liquid over fly ash ratio	73
4.17	Variation of remaining moisture due to	74

	initial duration time at different liquid of fly ash ratios	
4.18	Variation of remaining moisture due to different temperatures of initial durations	75
4.19	Specific gravity of treated and treated soil for the proposed conditions	69
4.20	Compaction diagram for natural and treated soil under the proposed conditions	78
4.21	Variation of maximum dry density due to the proposed conditions	78
4.22	Variation of optimum moisture content due to the proposed conditions	79
4.23	Load penetration curve for natural soil	80
4.24	Load penetration curve for treated soil under the proposed conditions	80
4.25	XRD pattern of Untreated soil and Group 2 D6C70.	85

TABLE OF PLATES

No.	Title	Pa ge
1.1	Failure of flexible pavement due to weak underlying soils	2
2.1	Conceptual model for Geopolymerization (after Duxson et al. 2007).	21
3.1	Natural soil location	32
3.2	Fly ash used in this study	34
3.3	Sodium silicate used in this study	35
3.4	Sodium hydroxide flakes used	37
3.5	The drying oven used	40
3.6	(a) UCS specimens. (b) Universal matest frame	43
3.7	pH equipment used in the present study	45
3.8	Digital caliper used in the present study	46
3.9	Typical Liquid and plastic limit equipments	47
3.10	Typical Compaction equipments	48
3.11	Typical CBR testing equipments	49
3.12	Typical SEM equipment	50
3.13	Typical XRD equipment	51
4.1	SEM images for Untreated soil, 5 μm	74
4.2	SEM images (a) Group 2, D6C70, 10 μm . (d) Group 2, D6C70, 20 μm .	75

TABLE OF ABBREVIATIONS

Abbreviation	Total name
ASTM	American Standard of Testing Measurements
CaO	Calcium Oxide
CBR	California Bearing Ratio
CSH	Calcium Silicate Hydrate
C_u	Undrained Shear Strength
EDS	Energy Dispersive Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
KASH	Potassium Aluminosilicate Hydrate
NASH	Sodium Aluminosilicate Hydrate
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscope
UCS	Unconfined Compressive Strength
XRD	X – Ray Powder Diffraction

CHAPTER ONE

INTRODUCTION**1.1 General**

In fact, soil improvement refers to any general action that can be done to the soil in order to enhance / control the general behaviour and / or some desired soil properties. Usually, this goal can be achieved by following common trends, for the first glance, the soil can be modified without any addition of any other materials, or some certain materials can be used to treat the problematic soils or inclusions can be provided to play the role of reinforcement agent. On the other hand, soil stabilization can be defined as a frequent and economic method to improve the properties of soil by using admixtures which is involving blending soil with suitable type of materials to render some of the target soil properties less sensitive to fluctuation or simply “stable”. There are no clear differentiations between soil stabilization and improvement because of the overlap between the applications which dictates to use these two terms interchangeably (Murthy, 2007 and Nickolson, 2015).

Furthermore, this method can be considered as an effective technique as it results in a non-water soluble soil matrix. However, admixtures like ordinary Portland cement (OPC), lime and high calcium fly ash and bitumen are widely used and examined to do this function (Swain 2015).

Geopolymers are binding gels that result from the alkali activated aluminosilicate sources which is expected to be a suitable alternative to Portland cement as a primary binder, in this study, it tries to investigate the effectiveness of using fly ash based geopolymers to treat soft clay soils.

1.2 Soft Clay Soil

Usually, soft clay soils are very sensitive to the presence of water and illustrate a dramatic changes in its performance if water content varies. In general, soft clay soils are stiff when dry and loss this property when become more wet. Leakage of sewer lines, floods, rains and lack of evaporation due to buildings or pavements are the popular reasons of increasing moisture content in clayey soils (Firoozi et al., 2017). The consequent undesirable behavior of such soils causes considerable problems like fracture and cracking in pavements as shown in Plate 1.1



Plate 1.1 Failure of flexible pavement due to weak underlying soils (www.dailycivil.com)

In fact, the construction of buildings, highways and other structures may be dictated to be done over such type of soils, at the first sight, these soils have to be avoided as much as possible due to its inadequacy to be foundation ground because of its low bearing capacity. However, It is believed that there are some factors which must be taken into account when the decision of soft soil

improvement are subjected to discussion like the degree of stabilization required, site conditions and cost effectiveness (Ibrahim et al., 2014).

As a matter of fact, There is no clear definition for the term "soft soil", usually, it can be can be identified by high water content (40-60) % (Broms, 1990) which may equal or higher than its liquid limit or it can be defined as the normally or lightly over consolidated which have liquidity index greater than 0.5 and possess un drained shear strength c_u usually less than 10 kPa according to Terzaghi, 1936 (as cited by Brand Brenner, 1981). In addition, as suggested by Brand and Brenner, 1981, such type of soil can be identified by c_u less than 40 kPa.

British Standard (B.S: C.P 8004: 1986), defined a soil as soft if its C_u ranged between 20 to 40 kPa while the term very soft referred to soil with $c_u < 20$ kPa.

Kamon and Bergado, 1991 (as cited by Bergado et al., 1996) stated that for clayey soils, the softness of the ground can be assessed by its c_u , or by its unconfined compression strength (UCS), soft soils are considered very soft when UCS is less than 25 kPa and soft if between 25 and 50 kPa (Terzaghi and Peck, 1967).

In fact, the presence of soft clays in Iraq are concentrated in central and southern parts (Al Jubouri, 2013), C_u to about 30 kPa was reported in Basrah and 40 kPa or less in Maysan and Dhi Qar governorates. Random surveys show that compression indeces are of approximately 0.3 and clay fraction between 50 % and 70 % (Buringh, 1960). Therefore, high water table level in the Iraqi southern basins revealed poor soft deposits (Abbawi,2010). Textures of those soils consist of fine silty clay loams.

1.3 Geopolymers

The reaction of the materials which have aluminosilicate such as red mud, fly ash, meta kaolin and rice husk ash by alkaline solutions produces binding gels called Geopolymers (Davidovits, 1988). These innovative materials appears to be promising alternatives to the OPC and other common soil stabilizers due to its good mechanical properties and sustainable nature.

Additionally, Geopolymers can be used in numbers of field applications likes precast units, pavement, bricksetc (Aldred and Day, 2012). Generally Geopolymer gel has a technical advantageous over the traditional cement common binding gels like high mechanical strength development, ability to gain strength rapidly, high chemical resistance, sulfate attack and cost effectiveness.

Many source material can be used as aluminosilicate source such as fly ash, meta kaolin, rise husk ash, slagetc.

1.4 Problem Statement

Actually, the industry of OPC emits 10% of carbon dioxide around the world (Khedary et al. 2005), furthermore, when lime and high calcium fly ash and/or calcium based additives are used, the formation of ettringate and thaumasite is possible due to the sulfate attack (Firoozi et al., 2017) which dictates strength loss with respect to its long term performance. Bitumen has many problems including deterioration with age, drying and failure due to repeated load.

It is evident that there is a considerable lack of information about soil – Geopolymer applications (Singhi et al., 2016) which motivates to develop this field by scientific research programs.

1.5 Importance of the Study

In many flexible and rigid pavements surface layers failure records, it can be recognized that the subgrade and or other bottom layers failure is the main source of such hazard.

In this way, using admixtures in road ways layers design is very usefull for many purposes like cost savings in materials used through reduction in the thickness required for each layer, reducing mainainance and enhancing the deterioration rate of the upper pavement layer. For that reason, it is needed to seek for new admixtures that can play the desired role and overcome the shortcomings of the common stabilizers.

Therefore, this study tries to improve the knowledge about the soil Geopolymers application through an experimental program.

1.6 Objectives of This Study

The basic aim of this study is to investigate the effect of using fly ash based Geopolymer as an admixture on soft clay mechanical strength and some relevant geotechnical properties taking into account some of the most important key elements that govern the production of Geopolymers gels.

In order to achieve the basic aim of this study, the experimental program is divided into two general main parts:

- **Part one:** comprises a parametric study to understand the effect of temperature on soil - Geopolymer mix in term of mechanical strength.
- **Part two:** comprises an investigation to the effect of Geopolymer on some geotechnical properties using certain soil

-Geopolymer conditions concluded in part one.

1.7 Thesis Layout

The general layout of this study consists of five chapters as explained below:

Chapter one: Presents a brief introduction of the problem and geopolymers demonstrating the importance, aim and objectives of the study.

Chapter Two: Presents a background depending on the literature re view of the recent studies.

Chapter Three: Presents the experimental works describing the laboratory testing and chemical analysis covered in this study.

Chapter Four: Shows the presentation of results recorded in this study and a brief discussion.

Chapter Five: Contains the conclusions and recommendations based on testing results.