

**HYDRAULIC PROPERTIES AND WATER-REPELLENCY OF
ORGANOSILANE-TREATED SOIL AS AN ALTERNATIVE
MATERIAL UTILISED IN A LANDFILL LINER SYSTEM**

**EPELLE, PROMISE SOKARI
(14CI016680)**

SEPTEMBER, 2022

**HYDRAULIC PROPERTIES AND WATER-REPELLENCY OF
ORGANOSILANE-TREATED SOIL AS AN ALTERNATIVE
MATERIAL UTILISED IN A LANDFILL LINER SYSTEM**

BY

**EPELLE, PROMISE SOKARI
(14CI016680)**

B.Eng. Civil Engineering, Covenant University, Ota

**A DISSERTATION SUBMITTED TO THE SCHOOL OF
POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE AWARD OF MASTER OF
ENGINEERING (M.Eng.) DEGREE IN CIVIL ENGINEERING IN THE
DEPARTMENT OF CIVIL ENGINEERING, COLLEGE OF
ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE,
NIGERIA**

SEPTEMBER, 2022

ACCEPTANCE

This is to attest that this dissertation was accepted in partial fulfilment of the requirements for the award of Master of Engineering (M.Eng.) degree in Civil Engineering, Department of Civil Engineering, College of Engineering, Covenant University, Ota.

Mr. Taiwo B. Erewunmi
(Secretary, School of Postgraduate Studies)

Signature and Date

Prof. Akan B. Williams
(Dean, School of Postgraduate Studies)

Signature and Date

DECLARATION

I, **EPELLE, PROMISE SOKARI (14CI016680)** declares that this research work was carried out by me under the supervision of Dr. Isaac I. Akinwumi of the Department of Civil Engineering, Covenant University. I also solemnly declare that to the best of my knowledge, no part of this report wholly or partially has been submitted here in Covenant University or elsewhere in a previous application for award of a degree. All sources of data and scholarly publications have been duly acknowledged.

EPELLE, PROMISE SOKARI

Signature and Date

CERTIFICATION

We certify that this dissertation titled “**HYDRAULIC PROPERTIES AND WATER-REPELLENCY OF ORGANOSILANE-TREATED SOIL AS AN ALTERNATIVE MATERIAL UTILISED IN A LANDFILL LINER SYSTEM**” is an original research work carried out by **EPELLE, PROMISE SOKARI (14CI016680)** in the Department of Civil Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria under the supervision of Dr. Isaac I. Akinwumi. We have examined and found this work acceptable as part of the requirements for the award of Master of Engineering (M.Eng.) in Civil Engineering.

Dr. Isaac I. Akinwumi
(Supervisor)

Signature and Date

Prof. Anthony N. Ede
(Head of Department)

Signature and Date

Prof. Gbenga M. Ayininuola
(External Examiner)

Signature and Date

Prof. Akan B. Williams
(Dean, School of Postgraduate Studies)

Signature and Date

DEDICATION

This research is dedicated to God Almighty for His grace upon my life throughout the course of this project.

ACKNOWLEDGEMENTS

I want to thank God firstly, because all that I have or is connected to me comes from Him. I am deeply grateful to Him for His constant love, mercy, and grace. I thank Him for the beautiful opportunities and for being more than a friend.

To the Chancellor, Covenant University, Dr. David O. Oyedepo and Vice Chancellor, Prof. Abiodun H. Adebayo. God bless you for your impactful leadership over the years. I also wish to appreciate the Dean School of Postgraduate Studies, Prof. Akan B. Williams.

I want to appreciate the management of civil engineering department, under the leadership of Prof. Anthony N. Ede also the PG coordinator, Dr. Gideon O. Bamigboye. You have been a blessing to the civil engineering department of Covenant University.

To my gracious supervisor, Dr. Isaac I. Akinwumi, the degree of impact you have had in my life cannot be over-emphasized. May God continue to bless you and may you attain greater heights.

I also acknowledge Prof. Vincent O. Ogunro and the Fulbright Scholarship programme for all the support in making sure this research work ran without a hitch.

Also, to my parents, the foundation of my discipline and source of my joy, Arc. and Mrs. Epelle. I cannot thank you enough for your love, care and support. May you live long and eat the fruit of your labour, Amen. My beloved sister, Rhoda Epelle who has been a steppingstone for me to make progress in life and has been an arm of support for me in times of need. I am forever grateful, and I love you.

To my friends turned brothers; Victor Ajayi, Moses Ichado, David Ijie and Wisdom Folorunsho for your support and the experiences we have had along the way, I love you brothers.

TABLE OF CONTENTS

	PAGES
ACCEPTANCE	iii
DECLARATION	iv
CERTIFICATION	v
DEDICATION	vi
ACKNOWLEDGEMENTS	vii
LIST OF FIGURES	xi
LIST OF TABLES	xii
LIST OF ABBREVIATIONS AND SYMBOLS	xiii
ABSTRACT	xv
CHAPTER ONE: INTRODUCTION	1
1.1 Background to the study	1
1.2 Statement of problem	4
1.3 Aim	5
1.4 Objectives of study	5
1.5 Justification for the study	5
1.6 Scope of study	6
CHAPTER TWO: LITERATURE REVIEW	8
2.1 Waste management	8
2.2 Landfills	9
2.2.1 Municipal solid waste landfills	11
2.2.2 Industrial waste landfills	11
2.2.3 Hazardous waste landfills	12
2.2.4 Green waste landfills	12
2.3 Landfill leachate	13
2.4 Landfill liner	15
2.4.1 Liner failure	16
2.4.2 Compacted clay liner (CCL)	17
2.5 Organosilane	18
2.5.1 Utilisation in soil stabilisation	19
2.5.2 Modification with organosilane	20
2.5.3 Application in corrosion	21
2.6 Geomembranes	22
2.7 The role of municipal solid waste segregation on its performance	22

2.8 Gap in Knowledge	23
CHAPTER THREE: MATERIALS AND METHODS	24
3.1 Materials	24
3.1.1 Soil	24
3.1.2 Organosilane	25
3.1.3 Micropipette	26
3.1.4 Digital stopwatch	26
3.2 Methods	27
3.2.1 Soil characterisation	28
3.2.2 Chemical composition, mineralogical properties and microstructural properties	29
3.3 Experimental methods for observation of water-repellency effect	30
3.4 Cost analysis	31
3.5 Method of analysis	31
CHAPTER FOUR: RESULTS AND DISCUSSION	32
4.1 Introduction	32
4.2 Geotechnical properties of natural soil	32
4.2.1 Natural moisture content	32
4.2.2 Specific gravity	32
4.2.3 Particle size distribution (Sieve and hydrometer analysis)	32
4.2.4 Atterberg limits	34
4.2.5 Hydraulic conductivity	36
4.2.6 Compaction Characteristics	37
4.2.7 Unconfined compressive strength (UCS)	38
4.3 Hydraulic properties of organosilane-treated soil	38
4.4 Water-repellency of Soil	39
4.5 Microstructural Characteristics of Soil	41
4.5.1 Scanning electron microscope (SEM)	41
4.5.2 X-ray diffraction (XRD)	42
4.5.3 X-ray fluorescence (XRF)	44
4.6 Cost analysis	45
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	49
5.1 Conclusions	49

5.2 Contributions to Knowledge	50
5.3 Recommendations	50
REFERENCES	51
APPENDIX A	56
APPENDIX B	57
APPENDIX C	60
APPENDIX D	65
APPENDIX E	67
APPENDIX F	69

LIST OF FIGURES

FIGURES	TITLE OF FIGURES	PAGES
1.1	Transport through composite versus sole soil liner	5
2.1	A sanitary landfill featuring an engineered liner and leachate collection system	10
2.2	Illustration of landfill leachate (with improper lining/no lining) mobilization ingroundwater and surface water	14
2.3	The reaction mechanism during the formation of SP-H-MOC	18
2.4	Simulation of the waterproofing process that happens after the addition of organosilane	19
2.5	Kinetics of organosilanes adsorption on the surface of freshly sprayed aluminium from aqueous solution: (1) DAS; (2) VS ↓ addition of organosilanes to aqueous solution to concentration equal 1×10^{-5} M	21
3.1	A map showing the location where the soil was gotten	25
3.2	Organosilane used for this research	25
3.3	A micropipette used for this research	26
3.4	Digital stopwatch used to estimate penetration time	27
3.5	Method of analysis for this research	32
4.1	Particle size distribution of natural soil	34
4.2	Graphical representation of compaction and zero air-void line	39
4.3	Hydraulic conductivity test results for different variations of organosilane to soil	41
4.4	WDPT results for different variations of organosilane to soil	43
4.5a	SEM micrograph for the natural soil at 9,000x magnification	44
4.5b	SEM micrograph for the natural soil treated with organosilane	45
4.6a	XRD for the natural soil sample	46
4.6b	XRD for the soil treated with organosilane	46
4.7a	Schematics of a landfill with geomembrane	49
4.7b	Schematics of a landfill with organosilane-treated layer	50

LIST OF TABLES

TABLES	TITLE OF TABLES	PAGES
2.1	Summary of experimental results	20
4.1	Soil types and average grain sizes according to BS 1377:1990	35
4.2	Percentage composition of particles in the sample	35
4.3	Results from Atterberg limits tests	35
4.4	Typical Atterberg Limits for soils	36
4.5	Activity of clay-rich soils	37
4.6	Coefficients of hydraulic conductivity	38
4.7	Relationship between Consistency and UCS	40
4.8	Hydraulic conductivity values for organosilane-treated soil	40
4.9	Classification of water-repellency based on WDPT	42
4.10	WDPT results for different ratios	42
4.11a	XRF results for the natural soil sample	47
4.11b	XRF results for organosilane-treated soil	47
4.12	Chemical composition of Terrasil	48

LIST OF ABBREVIATIONS AND SYMBOLS

Σ	-	Summation
BOD	-	Biological Oxygen Demand
C&D	-	Construction and Demolition
CBR	-	California Bearing Ratio
CCL	-	Compacted Clay Liner
COD	-	Chemical Oxygen Demand
DAS	-	Diaminesilane
EPA	-	Environmental Protection Agency
GCL	-	Geosynthetic Clay Liner
GM	-	Geomembrane
HDPE	-	High Density Polyethylene
HDTMS	-	Hexadecyltrimethoxysilane
HM	-	Heavy Metal
ICP	-	Inductively Coupled Plasma
ISWA	-	International Solid Waste
LGA	-	Local Government Area
MDD	-	Maximum Dry Density
MOC	-	Magnesium Oxychloride Cement
MRF	-	Material Recovery Facilities
MSW	-	Municipal Solid Waste
OES	-	Optical Emission Spectroscopy
OM	-	Organic Matter
OMC	-	Optimum Moisture Content
P123	-	Polyethylene oxide-polypropylene oxide-polyethylene oxide triblock copolymer
PERI	-	Potential Ecological Risk Index
PVC	-	Polyvinyl Chloride
SDM	-	Sessile Drop Method
SI-C	-	Silicon-Carbon Link
SSC	-	Sewage Sludge Compost

TKN	-	Total Kjeldahl Nitrogen
TSF	-	Tailings Storage Facilities
UCS	-	Unconfined Compressive Strength
VOC	-	Volatile Organic Compound
VS	-	Vinyltrimethoxysilane
WDPT	-	Water Drop Penetration Time
XRD	-	X-ray Diffraction
XRF	-	X-ray Fluorescence

ABSTRACT

In developing countries, where cost and availability of geomaterials utilised in the design and construction of landfills is an issue, cost-effective options are urgently needed. This work focuses on the issue of waste management, landfills, and a more economical alternative for a landfill liner system. It assesses the hydraulic properties and water-repellency of organosilane-treated soil as an alternative material utilised in a landfill liner system. Hydraulic conductivity test and water droplet penetration tests were carried out on the untreated and treated soil at variations; 1:1000, 1:500, 1:100, 1:80 and 1:50. These variations were done by mass with respect to an organosilane to soil correlation. The hydraulic conductivity of the natural soil at 1.74×10^{-5} cm/s reduced to 5.03×10^{-6} cm/s, 4.54×10^{-6} cm/s, 1.77×10^{-6} cm/s, 7.78×10^{-7} cm/s and 6.36×10^{-8} cm/s at 1:1000, 1:500, 1:100, 1:80 and 1:50 respectively. This reduction indicated that higher organosilane content in the soil causes lower hydraulic conductivity. From the tests on hydraulic characteristics, it was concluded that only 1:50 met the requirement for a liner material with the value being less than 1×10^{-7} cm/s. Also, the water droplet penetration time using precision pipette and a stopwatch was carried out to determine its degree of water-repellency. It was observed from the tests that the water droplet penetration time for the untreated soil at zero seconds increased to 300, 1140, 6210, 7800 and 9450 seconds at 1:1000, 1:500, 1:100, 1:80 and 1:50 respectively. This increment in time indicated that an increase in organosilane content increases the time it takes for water to penetrate into the soil fabric. Mix ratio 1:1000 came out as strongly repellent, 1:500 was severely repellent while 1:100, 1:80 and 1:50 were extremely water repellent samples. From these analyses, it was concluded that organosilane-treatment causes the soil structure to become compact causing higher packing density, and low porosity in the microstructure. Hence, an organosilane-treated layer in a composite liner system is a promising replacement for geomembrane in a landfill.

Keywords: Geomembrane, Hydraulic Conductivity, Landfill, Organosilane, Waste Management.