

***A Study on Utilization Potential of Microbial Biopolymer
treated Wastes in Civil Engineering***



Thesis submitted in partial fulfilment for the Award of

Doctor of Philosophy

Submitted by

NITEESH SINGH BONAL

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY (BANARAS HINDU

UNIVERSITY)

VARANASI – 221005



भारतीय
प्रौद्योगिकी
संस्थान
वाराणसी हिन्दू विश्वविद्यालय



INDIAN
INSTITUTE OF
TECHNOLOGY
BANARAS HINDU UNIVERSITY

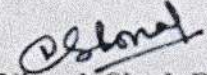
DECLARATION BY THE CANDIDATE

I, **Niteesh Singh Bonal** certify that the work embodied in this thesis entitled -"A Study on utilization potential of microbial biopolymer treated wastes in civil engineering " is my own bonafide work carried out under the supervision of **Prof. Arun Prasad** at Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma.

I declare that I have faithfully acknowledged, given credit to, and referred to the research workers wherever their works have been cited in the text and the body of the thesis. I further certify that I have not wilfully lifted up some other's work, paragraph, text, data, results, etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc., or available at web-sites and included them in this thesis and cited as my own work.

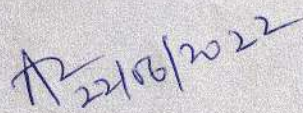
Date:

Place: Varanasi


Niteesh Singh Bonal

Certificate from Head of the Department/ Supervisor

This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.


Prof. Arun Prasad
(Supervisor)
Department of Civil Engineering
Indian Institute of Technology (BHU)
Varanasi, India (221005)


Signature of the Head of Department

विभागाध्यक्ष / HEAD
जानपद अभियांत्रिकी विभाग
Department of Civil Engineering
भारतीय प्रौद्योगिकी संस्थान (बी.एच.यू.)
Indian Institute of Technology (B.H.U.)
वाराणसी-221005/Varanasi-221005

CERTIFICATE

It is certified that the work contained in the thesis titled “**A Study on utilization potential of microbial biopolymer treated wastes in civil engineering**” by Niteesh Singh Bonal has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

22/06/2022

(Prof. Arun Prasad)
(Supervisor)
Department of Civil Engineering
Indian Institute of Technology (BHU)
Varanasi-221005



भारतीय
प्रौद्योगिकी
संस्थान
काशी हिन्दू विश्वविद्यालय



INDIAN
INSTITUTE OF
TECHNOLOGY
BANARAS HINDU UNIVERSITY

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis: "A Study on utilization potential of microbial biopolymer treated wastes in civil engineering"

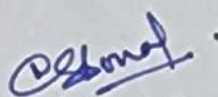
Name of the Student : Niteesh Singh Bonal

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University) Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the degree "Doctor of Philosophy".

Date:

Place: Varanasi


(Niteesh Singh Bonal)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the Institute's copyright notice are indicated.

ACKNOWLEDGEMENTS

The satisfaction and euphoria that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible, whose constant guidance, encouragement and support fructified my effort with success.

I consider it my privilege to express my gratitude and respect to all those who guided me in the completion of my Ph.D. Thesis report.

First, I would like to thank my supervisor and mentor Dr. Arun Prasad, Professor, Civil Engineering Department, Indian Institute of Technology (Banaras Hindu University) for providing me this valuable opportunity for presenting this thesis which has not only enhanced my knowledge about the subject but also increased my confidence level. I take this opportunity to thank him for his constant guidance and invaluable advice which has made this work much easier.

I express my sincere gratitude to the Head of the Department of Civil Engineering, IIT (BHU), for providing me all requisite facilities and encouragement during the course of this work.

I would also like to express my sincere thanks to RPEC members Assoc. Prof. Bala Ramudu Paramkusam, Civil Engineering Department, Indian Institute of Technology (Banaras Hindu University) and Assoc. Prof. Rajesh Rai, Mining Engineering Department, Indian Institute of Technology (Banaras Hindu University) for giving valuable inputs and suggestions to widen my research from various perspectives.

I also want to acknowledge the support of the entire family, colleagues of Civil Engineering Department and the staff member of the Geotechnical Engineering laboratory Mr. Basanta Prasad, Mr. Netra Pal and Mr. Nand Lal Ram for helping me throughout this work which enabled me to complete my dissertation work successfully.

At last but not the least I want to thanks the omnipresent almighty god for support and for answering my prayer in every moment.

Date:

Place: IIT (BHU), Varanasi

(Niteesh Singh Bonal)

TABLE OF CONTENTS

Chapter no.	Description	Page no.
	Certificates	
	Declaration by the candidate	
	Copyright transfer certificate	
	Acknowledgements	i-ii
	Table of Contents	iii-vi
	List of Figures	vii-xi
	List of Tables	xii
	List of Abbreviations	xiii
	Preface	xiv-xv
 Chapter 1	 INTRODUCTION AND LITERATURE REVIEW	 01-13
	1.1 General	1
	1.2 Problem statement	2
	1.3 Application of Biopolymer in Geotechnical Engineering	5
	1.4 Literature review	6
	1.4.1 Soil consistency	6
	1.4.2 Soil Strengthening	7
	1.4.2.1 Unconfined compressive strength	7
	1.4.2.2 Shear strength	8
	1.4.3 Soil erosion control	9
	1.4.4 Ground injection	10
	1.4.5 Pavement and earth stabilization	11
	1.4.6 Ground water control	11
	1.4.7 Soil water retention	12
	1.5 Scope and objective	13

Chapter 2	MATERIALS AND METHODOLOGY	14-33
2.1	Materials	14
2.1.1	Bauxite residue	14
2.1.2	Coal mine overburden waste (CMO)	16
2.1.3	Biopolymer	17
2.1.3.1	Xanthan gum	18
2.1.3.2	Guar gum	18
2.2	Testing methodology	20
2.3	Detailed description of Testing Methodologies	21
2.3.1	Specific gravity	21
2.3.2	Grain size distribution	23
2.3.2.1	Sieve analysis	23
2.3.2.2	Hydrometer analysis	24
2.3.3	Consistency limit	24
2.3.3.1	Liquid limit	24
2.3.3.2	Plastic limit	25
2.3.4	Compaction	26
2.3.5	Permeability test	26
2.3.6	Strength study	27
2.3.6.1	Triaxial compressive test	27
2.3.6.2	Unconfined compressive strength	28
2.3.6.3	Sample preparation for the strength test	28
2.3.7	Durability test	29
2.3.7.1	Freezing and thawing (F-T)	29
2.3.8	Mineralogical and morphological analysis	31
2.3.8.1	X-Ray diffraction	31
2.3.8.2	Scanning Electron Microscopy (SEM)	33
 Chapter 3	 RESULTS AND DISCUSSION	 34-97
3.1	Compaction test	34

3.1.1 Effect of Biopolymer Stabilization on the Compaction	35
Parameters of bauxite residue	
3.2 Strength study	42
3.2.1 Effect of the biopolymer stabilization on Bauxite residue	43
3.2.1.1 Triaxial compressive test	43
3.2.1.2 Effect of biopolymer, biopolymer concentration and curing time on the UCS and stress-strain behavior	50
3.2.2 Effect of the biopolymer stabilization on Coal mine overburden waste	56
3.2.2.1 Triaxial compressive test	56
3.2.2.2 Effect of biopolymer on unconfined compressive strength (UCS) of CMO waste	63
3.3 Permeability test analysis	65
3.3.1 Influence of biopolymer on permeability of bauxite residue	66
3.3.2 Influence of biopolymer on permeability of Coal mine overburden waste	68
3.4 Total carbohydrate method (TCM)	70
3.4.1 Standard line for Biopolymer Solution	71
3.4.2 Colorimeter analysis on bauxite residue	73
3.4.3 Colorimeter analysis on Coal mine overburden waste	74
3.5 Durability Study (Freezing and thawing test)	75
3.5.1 Sample preparation using Thermo-gelation	76
3.5.2 Sample preparation without Thermal treatment	77
3.5.3 Effect of Thermo-gelation on Compressive Strength before F-T process	77
3.5.4 Effect of biopolymer on freezing and thawing resistance	80
3.5.5 Behavior of stabilized bauxite residue samples Post F-T cycles	87

3.6 Mineralogical and Morphological Study	92
3.6.1 Mineralogical study (X-Ray diffraction)	92
3.6.2 Morphological study (Scanning Electron Microscopy)	97
Chapter 4 APPLICATIONS OF BIOPOLYMERS IN CIVIL ENGINEERING	98-106
4.1 Application in civil engineering	99
4.1.1 Flexibility of Biopolymer Stabilization for Road Shoulder Construction	99
4.1.2 Increasing soil bearing capacity for shallow foundation	100
4.1.3 Slope surface stabilization	101
4.1.4 Earth stabilization using biopolymer	103
4.2 Economic Feasibility of Biopolymer for Soil/Waste Treatment	104
Chapter 5 CONCLUSIONS AND FUTURE SCOPE	107-109
5.1 Conclusions	107
5.2 Scope of future work	109
REFERENCES	110-122
LIST OF PUBLICATIONS	123

LIST OF FIGURES

Figure No.	Description	Page No.
1.1	(a) Ajka, alumina waste pond, Hungary (b) The Pond of NALCO factory in Damandjodi (India) (c) Coal mine Overburden waste dumping near Kusunda Opencast mines (India)	4
1.2	Biopolymer applications in geotechnical engineering practices	6
2.1	Structure of Xanthan gum ($C_{35}H_{49}O_{29}$)	18
2.2	Structure of Guar gum ($C_{10}H_{14}N_5Na_2O_{12}P_3$)	19
2.3	Deep freezer for durability study (F-T cycles)	30
2.4	Biopolymer stabilized bauxite residue samples after curing for 28 days: (a) Without F-T cycles, and (b) after F-T cycles for thawing	31
2.5	A photograph of high resolution X-Ray diffractometer (Rigaku Miniflex 600, Germany)	32
2.6	A photograph of high-resolution scanning electron microscope (SUPRA 40, Zeiss 4.0)	33
3.1	Compaction characteristics of bauxite residue stabilized with Guar gum (Method: solution mixing) (a) Effect of guar gum on dry density and moisture content (b) Variation of MDD and OMC with guar gum	36
3.2	Compaction characteristics of bauxite residue stabilized with Xanthan gum (Method: solution	37

	mixing) (a) Effect of Xanthan gum on dry density and moisture content (b) Variation of MDD and OMC with Xanthan gum	
3.3	Compaction characteristics of bauxite residue stabilized with Composite gum (Method: solution mixing) (a) Effect of Composite gum on dry density and moisture content (b) Variation of MDD and OMC with Composite gum	38
3.4	Compaction characteristics of bauxite residue stabilized with Guar gum (Method: dry mixing) (a) Effect of guar gum on dry density and moisture content (b) Variation of MDD and OMC with guar gum	39
3.5	Compaction characteristics of bauxite residue stabilized with xanthan gum (Method: dry mixing) (a) Effect of xanthan gum on dry density and moisture content (b) Variation of MDD and OMC with xanthan gum.	40
3.6	Compaction characteristics of bauxite residue stabilized with Composite gum (Method: solution mixing) (a) Effect of Composite gum on dry density and moisture content (b) Variation of MDD and OMC with Composite gum	41
3.7	Shear strength parameters of Bauxite residue treated with different concentration (m_b/m_w) [%] of biopolymer solution (GG, XG and composite) at different curing time (28d; 14d; 7d): (a) Cohesion (c), (b) Peak Friction angle (ϕ°)	44-45
3.8	Failure Envelope of Stabilized Bauxite Residue Sample for Varying Biopolymer Concentration	46-50

	(mb/mw) at Different Curing Time: (a) GG (7d), (b) GG (14d), (c) GG (28d), (d) XG (7d), (e) XG (14d), (f) XG (28d), (g) XG+GG (7d), (h) XG+GG (14d), (i) XG+GG (28d)	
3.9	Variation in UCS (q_u) with Biopolymer, Biopolymer Content (P %) and Curing Time (d): (a) Guar Gum, (b) Xanthan Gum, (c) Composite (XG+GG)	51-52
3.10	Effect of xanthan Gum (XG), guar gum (GG) and composite (XG+GG) on the stiffness of bauxite residue at 28 days curing	53-54
3.11	Effect of curing period on the stiffness of GG, XG and composite stabilized bauxite residue	55-56
3.12	Sample before triaxial test	57
3.13	Sample after triaxial test (a) 0.5% XG (b) 1% XG	57
3.14	A plot of deviator stress and axial strain of GG-treated CMO sample after 1 day curing at different cell pressure (a) 50 kPa, (b) 100 kPa, (c) 150 kPa	58
3.15	A plot of deviator stress and axial strain of XG-treated CMO sample after 1 day curing at different cell pressure (a) 50 kPa, (b) 100 kPa, (c) 150 kPa	59
3.16	A plot of deviator stress and axial strain of GG-treated CMO sample after 7 days curing at different cell pressure (a) 50 kPa, (b) 100 kPa, (c) 150 kPa	60
3.17	A plot of deviator stress and axial strain of XG-treated CMO sample after 7 days curing at different cell pressure (a) 50 kPa, (b) 100 kPa, (c) 150 kPa	61

3.18	Shear strength parameters of XG and GG-treated CMO sample at different curing periods. (a) Cohesion (kPa), (b) friction angle (deg)	62
3.19	Shear strength of CMO treated with different concentrations of XG and GG solution at different curing time	63
3.20	Variation in UCS (q_u) of CMO with Biopolymer and Curing Time (d): (a) Guar Gum, (b) Xanthan Gum, (c) Composite (XG+GG)	64-65
3.21	Long term falling head permeability tests on bauxite residue with different concentration of biopolymer solution (0.25, 0.5, and 1%) and 90 days ageing:(a) Guar Gum, (b) Xanthan Gum, and (c) Composite (XG+GG)	67-68
3.22	Long term constant head permeability tests on CMO with different concentration of biopolymer solution (0.25, 0.5, and 1%) and 90 days ageing: (a) Xanthan Gum, (b) Guar gum	69-70
3.23	Standard line for different biopolymer total carbohydrate test: (a) Guar gum (b) Xanthan gum (c) Composite gum solution	71-72
3.24	Variation in UCS (q_u) with varying biopolymer concentration and curing time: 7 days (7D), 14 days (14D) and 28 days (28D): (a) GG(WTT), (b) XG(WTT), (c) GG(TT), and (d) XG(TT)	78-79
3.25	Effect of F-T cycles on the UCS (q_u) of the untreated bauxite residue	80
3.26	Effect of F-T cycles on stabilized bauxite residue without thermal treatment at varying biopolymer concentration and curing time: (a) GG(7D), (b)	81-84

	GG(14D), (c) GG(28D), (d) XG(7D), (e) XG(14D), and (f) XG(28D)	
3.27	Effect of F-T cycles on stabilized bauxite residue with thermal treatment at varying biopolymer concentration and curing time: (a) GG(7D), (b) GG(14D), (c) GG(28D), (d) XG(7D), (e) XG(14D), and (f) XG(28D)	84-87
3.28	UCS (q_u) versus time during F-T process and post F-T conditioning: (a) GG(WTT), (b) GG(TT), (c) XG(WTT), and (d) XG(TT)	89-90
3.29	Loss of strength (after 10 F-T cycles) and Recovery of strength (post F-T cycles conditioning)	91
3.30	XRD analysis of untreated and biopolymer stabilized bauxite residue sample at 1.5% concentration: (a) Untreated bauxite residue, (b) guar gum, and (c) xanthan gum.	92-93
3.31	SEM micrographs of bauxite residue samples: (a) untreated, (b) 1.5% GG, (c) 1.5% XG, (d) 1.5% (XG+GG), and (e) 1.5% XG, 28 days curing time and 10 F-T cycles	95-97

LIST OF TABLES

Table No.	Description	Page No.
2.1	Engineering properties of Bauxite residue	15
2.2	Chemical composition of Bauxite residue	15
2.3	Physical and Chemical properties of Coal mine overburden waste	17
2.4	Physical properties of biopolymer	20
2.5	Relevant Standard for Laboratory Testing	21
2.6	Sieves utilized in the Grain Size Analysis test	23
3.1	Compaction test results of untreated and stabilized bauxite residue samples	42
3.2	Results of bauxite residue effluent water colorimeter analysis	74
3.3	Results of Coal mine overburden waste effluent water colorimeter analysis	75
4.1	Economic feasibility comparison of biopolymer stabilization with cement treatment	106

LIST OF ABBREVIATIONS

w	Water content
m_b	Mass of biopolymer
m_b / m_w	Biopolymer-to-water ratio
m_b / m_{br}	Biopolymer-to-bauxite residue in mass
q_u	Unconfined compressive strength (kPa)
CMO	Coal mine overburden waste
XG	Xanthan gum
GG	Guar gum
XG+GG	Composite gum
OMC	Optimum moisture content
MDD	Maximum dry density
P	Biopolymer content (%)
c	Cohesion
ϕ°	Peak Friction angle
TT	Thermal treatment
WTT	Without thermal treatment
GG(WTT)	Guar gum without thermal treatment
GG(TT)	Guar gum with thermal treatment
XG(WTT)	Xanthan gum without thermal treatment
XG(TT)	Guar gum with thermal treatment
F-T	Freezing and thawing cycles
XRD	X-ray diffraction
SEM	Scanning Electron Microscopy

PREFACE

Rapid global population growth and development in the civil infrastructure have arisen the need of developing knowledge to enhance the strength properties of the existing soils or waste for civil and geotechnical engineering purposes. Since the beginning of human civilization, several different techniques and materials have been employed to stabilize the soil/waste. The use of a conventional method such as cement binders are associated with many environmental problems, so materials described as environmentally friendly called microbial biopolymers have been developed for application in engineering purposes.

Over the years, environmental issues have forced engineers and researchers to focus on new methods that use biological processes in soil/waste stabilization techniques. This research focuses on the application of biopolymer, xanthan, and guar gum, to bauxite residue and coal mine overburden waste to enhance mechanical and hydraulic properties. The primary potential application of waste stabilization with biopolymer is the construction of various engineered structures such as roads, embankments, impervious barriers, etc., to control erosion, permeability and enhance biodegradation of contaminants as they seep through the structure.

The thesis entitled” **A Study on utilization potential of microbial biopolymer treated wastes in civil engineering**” comprises five chapters. The research begins with an introduction, which briefly describes biopolymer, industrial waste (bauxite residue), and coal mine overburden waste in **Chapter 1**. The literature review on the potential application of biopolymer in stabilizing soil/waste is advocated by numerous researchers for various engineering purposes. This chapter also covers the scope and objective of this study.

In **Chapter 2**, description of the materials used in this research and their physical and chemical properties. This chapter also explains the preparation of samples and its methodology for the various test performed in this study.

The results and discussions of all the laboratory tests performed on bauxite residue and coal mine overburden waste treated with xanthan and guar gum is presented in **Chapter 3**. The experiments include the Compaction test, Tri-axial compression test, Unconfined compressive, Durability test (Freezing and thawing), Permeability test, Colorimeter analysis, Mineralogical and morphological test have been performed at different biopolymer concentrations and curing time.

Chapter 4 describes the potential application of biopolymer treated waste in civil and geotechnical engineering. A case study on the biopolymer application for slope and surface stabilization is reviewed. This chapter also explains the environmental, economic, social benefits, and future challenges of biopolymer application.

Finally, **Chapter 5** includes a conclusion based on all the experiments and discussion.