



IMPROVING OF BASE COURSE MATERIALS CHARACTERISTICS USING INDUSTRIAL WASTES

A Thesis

Submitted to the Public Works Department

Faculty of Engineering

Ain Shams University

For partial Fulfillment for the Requirements of

The Master of Science Degree

In Civil Engineering (Highways and Traffic)

Prepared by

Eyas Mohammed Eyad Almallouhi

B.Sc. in Civil Engineering, 2016

Higher Institute of Engineering and Technology El-Arish

Supervisors

Prof. Dr. Hassan Abdul Zaher Mahdy

Professor of Highway and Traffic Engineering

Faculty of Engineering, Ain Shams University, Cairo, Egypt

Prof. Dr. Khaled Anwar Kandil

Professor of Highway and Airports Engineering

Faculty of Engineering, Ain Shams University, Cairo, Egypt

Cairo, 2019



IMPROVING OF BASE COURES MATERIALS CHARACTERISTICS USING INDUSTRIAL WASTES

A Thesis For
The Master of Science Degree in Civil Engineering
(Highways and Traffic)

by

Eyas Mohammed Eyad Almallouhi

B.Sc. in Civil Engineering, 2016
Higher Institute of Engineering and Technology El-Arish

Thesis Approval

Examinar Committee

Signature

Prof. Dr. Hassan Tahssin Abdul Wahab

Professor of Highway and Airports Engineering
Faculty of Engineering, Cairo University

.....

Prof. Dr. Eissa Abdul Allah Srhan

Professor of Highway and Traffic Engineering
Faculty of Engineering, Ain Shams University

.....

Prof. Dr. Hassan Abdul Zaher Mahdy

Professor of Highway and Traffic Engineering
Faculty of Engineering, Ain Shams University

.....

Prof. Dr. Khaled Anwar Kandil

Professor of Highway and Airports Engineering
Faculty of Engineering, Ain Shams University

.....

Date: /..../ 2019

Dedication

This thesis is dedicated to those who contributed to educating, encouraging and supporting me to be able to fulfill this work...

To my Father and my Mother...

To my Brothers and my Sisters...

Researcher Data

Name:	Eyas Mohammed Eyad Almallouhi
Date of Birth:	1 / 1 / 1993
Place of Birth:	Homs – Syria.
Nationality:	Syrian.
Last Academic Degree:	B.Sc. in Civil Engineering
Awarding Date:	2016
Department:	Road and Airport
University issued the degree:	Higher Institute of Engineering and Technology El-Arish

Statement

This thesis is submitted for the partial fulfillment of Master of Science degree in Civil Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis and no part of it has been submitted for a degree or qualification at any other scientific entity.

Name

Eyas Mohammed Eyad Almallouhi

Signature

.....

Date

...../...../2019



IMPROVING OF BASE COURES MATERIALS CHARACTERISTICS USING INDUSTRIAL WASTES

Abstract

Phosphogypsum is a solid by-product waste generated from phosphoric acid industry. The worldwide amount of phosphogypsum is ranging between 100 and 280 million tons. Otherwise, iron and steel slag is a solid by-product waste resulted from iron and steel industry. The estimated worldwide amount of iron and steel slag is 400 million tons. Therefore, these solid wastes are causing negative effect on the environment and surrounding communities. On the other hand, the demand for road construction, widening and maintenance works also construction of other structures increased by time, which means increasing in demand for conventional aggregates that threatened by depletion. Therefore, many studies were conducted around the world by utilizing these solid by-product wastes in road construction which proved the ability to use these wastes either with underlying layers or asphaltic layers. This study aims to form and test mixtures of these wastes with locally available traditional base course aggregates to determine and evaluate the effect of adding these solid wastes on some of mechanical characteristics of the base course materials. Therefore, all used materials subjected to validation tests to determine some of its physical and mechanical characteristics. Seven percentages (0, 5, 10, 15, 20, 25 and 30%) of phosphogypsum were mixed with crushed limestone. Further,

three percentages (25, 50 and 75%) of crushed steel slag blended with crushed dolomite stone and six percentages (0, 5, 7.5, 10, 12.5 and 15%) of phosphogypsum at each percent of steel slag. These mixtures subjected to modified compaction test, un-soaked California bearing ratio penetration test, soaked California bearing ratio penetration test, California bearing ratio swelling test and California bearing ratio penetration test after a series of wetting-drying cycles. The results of tests demonstrated that using phosphogypsum and crushed steel slag improves some mechanical characteristics of traditional base course materials. Whereas, a mixture containing 20% phosphogypsum and 80% crushed limestone showed improving in some mechanical characteristics comparing with control mix 100% crushed limestone. Further, some mechanical characteristics of a mixture consisting 10% phosphogypsum from mixture dry weight, crushed steel slag and crushed dolomite stone with ratio 75%:25% were enhanced compared with control mix 100% crushed dolomite stone. Therefore, utilizing these solid by-product wastes in road base enhance the mechanical properties of conventional construction aggregates.

Key words: phosphogypsum, steel slag, limestone, dolomite stone, California bearing ratio, wetting-drying cycles and base course.

Acknowledgement

All thanks and praise be to **Allah**, the Almighty, for his unnumbered and countless blessing and gifts, the thanks is attached to my **father** and my **mother** for every things they gave it to me, the thanks is linked to my **brothers** and my **sisters** for their endless encouragement and support.

Further, I grant Great thanks to my supervisors Prof. Dr. Hassan Abdul Zaher Mahdy Professor of Highway and Airports Engineering, Ain Shams University and Prof. Dr. Khaled Anwar Kandil Professor of Highway and Airports Engineering, Ain Shams University, for their help, cooperation and instructions during preparing of this study.

Table of Contents

Thesis Approval	II
Dedication.....	III
Researcher Data	IV
Statement.....	V
Abstract	VI
Acknowledgement	VIII
Table of Contents	9
List of Tables	11
List of Figures	13
List of abbreviations	15
1- Introduction:.....	17
1-1- Background:	17
1-2- Problem statement:	18
1-3- Objectives:.....	20
1-4- Dissertation organization:	21
2- Literature review:.....	23
2-1- Phosphogypsum:.....	23
2-1-1- Applications of phosphogypsum in road construction: ...	23
2-1-2- Formation, production and disposal of phosphogypsum:	28
2-1-3- Physical, chemical and radioactive characteristics of phosphogypsum:	30
2-2- Iron and steel slag:	34
2-2-1- Applications of iron and steel slag in roads:	34
2-2-2- Formation, types and production of iron and steel Slag:	45
2-2-3- Physical, chemical and mechanical characteristics of iron and steel slag:	49
3- Methodology and Materials:	56
3-1- Methodology:	56
3-2- Materials:	60
3-2-1- Crushed Limestone:	60

3-2-2- Crushed Dolomite stone:.....	61
3-2-3- Phosphogypsum:	62
3-2-4- Crushed steel slag:	64
4- Results and discussion:.....	67
4-1- Results of materials characterization tests:	67
4-2- Limestone mixtures tests results:.....	76
4-3- Dolomite Mixtures tests results:	84
4-4- Practical Implications:	93
5- Conclusion and recommendations:	97
5-1- Conclusion:	97
5-2- Recommendations:	99
References	101

List of Tables

Table 1: Amount of phosphogypsum produced in some countries.	29
Table 2: Phosphogypsum chemical analysis in some countries.	31
Table 3: Phosphogypsum radioactive analysis in some countries.	32
Table 4: Production of iron and steel slag in some countries.	50
Table 5: Iron and steel slag physical properties in some countries.	52
Table 6: Iron and steel slag chemical properties in some countries.	53
Table 7: Iron and steel slag mechanical properties in some countries.	54
Table 8: Characterization tests conducted on different materials.	56
Table 9: Ratios of different materials used to form limestone mixtures. .	58
Table 10: Ratios of different materials used to form dolomite mixtures. .	59
Table 11: Chemical analysis of phosphogypsum sample as received.	63
Table 12: Chemical analysis of the steel slag sample as received.	65
Table 13: Results of AASHTO T-255 conducted on different materials. .	67
Table 14: Results of AASHTO T-89 and AASHTO T-90 conducted on different materials.	68
Table 15: Results of AASHTO T-11 and AASHTO T-176 conducted on different materials.	69
Table 16: Results of BS 812-105.1 and BS 812-105.2 conducted on different materials.	71
Table 17: Results of AASHTO T-84 and AASHTO T-85 conducted on different materials.	71
Table 18: Results of AASHTO T-96 conducted on different materials. .	72
Table 19: Results of AASHTO T-104 conducted on different materials. .	72
Table 20: Fraction percentages used in CDS and CSS mixtures according to fraction size and according to grading F in the Egyptian code.	73
Table 21: Results of AASHTO T-180 conducted on different materials. .	73
Table 22: Results of AASHTO T-193 conducted on different materials. .	74

Table 23: Results of CBR tests conducted on CLS+PG mixtures.....	83
Table 24: Results of CBR tests conducted on 20%PG+80%CLS mixtures and 100% CLS mixtures subjected to wetting-drying cycles.....	83
Table 25: Results of CBR tests conducted on mixtures containing soaked- dried PG and mixtures containing soaked-dried CLS according to no. of wetting-drying cycles.	83
Table 26 : Ratios of different materials used to form mixtures according to ratios of corresponding sieves stated in intermediate grading of granular base course in the Egyptian Code.	85
Table 27: Results of tests conducted on dolomite mixtures.	92

List of Figures

Figure 1: Phosphogypsum sample (Source: International Atomic Energy Agency IAEA).	30
Figure 2: Samples of different types of iron and steel slag (Source: Australasian Slag Association ASA).	45
Figure 3: Iron and steel making processes and types of slag produced (Indiana Department of Transportation Office of Research and Development).	47
Figure 4: Research flow-chart.	57
Figure 5: Crushed limestone sample.	60
Figure 6: Crushed dolomite stone sample.	61
Figure 7: Sample of phosphogypsum in fresh state.	62
Figure 8: Phosphogypsum dry stack and wet stack in Cairo.	63
Figure 9: Steel slag stacks in Alexandria.	65
Figure 10: Results of AASHTO T-27 conducted on dolomite and slag. .	70
Figure 11: Results of AASHTO T-27 conducted on limestone.	70
Figure 12 : Moisture-density relationships of dolomite, limestone, steel slag and phosphogypsum, respectively.	74
Figure 13: Swelling-time relationship of different materials mixtures according to AASHTO T-193.	75
Figure 14: Moisture-density relationship of mixtures containing limestone and phosphogypsum.	76
Figure 15: Relationship between MDD and PG % of prepared limestone mixtures.	77
Figure 16: Relationship between OMC and PG % of prepared limestone mixtures.	77
Figure 17: Relationship between CBR % and soaked CBR and PG % of prepared limestone mixtures.	79

Figure 18: Relationship between swelling % and PG % of prepared limestone mixtures.	79
Figure 19: Relationship between CBR % and no. of wetting-drying cycles of 80L20P and 100L samples.	80
Figure 20: Relationship between CBR % of mixture containing soaked-dried PG, mixtures containing soaked-dried CLS and no. of wetting-drying cycles.	81
Figure 21: Moisture-density relationship of mixtures containing dolomite, steel slag and phosphogypsum.	86
Figure 22: Relationship between MDD and SS % of prepared dolomite mixtures.	87
Figure 23: Relationship between OMC and SS % of prepared dolomite mixtures.	87
Figure 24: Relationship between MDD and PG % of prepared dolomite mixtures.	88
Figure 25: Relationship between OMC and PG % of prepared dolomite mixtures.	88
Figure 26: Relationship between SS % and un-soaked CBR % / soaked CBR % of prepared dolomite mixtures.	90
Figure 27 : Relationship between PG % and un-soaked CBR % / soaked CBR of prepared dolomite mixtures.	91

List of abbreviations

PG	Phosphogypsum
CLS	Crushed limestone
CSS	Crushed steel slag
CDS	Crushed dolomite stone
CBR	California bearing ratio
W-D	Wetting - drying
BT	Billion ton
MT	Million ton
DHPG	Dehydrate phosphogypsum
HHPG	Hemihydrate phosphogypsum
TENOM	Technologically enhanced naturally occurring material
UCS	Unconfined compressive strength
AASHTO	American association of state highway and transportation official
Psi	Pascal per square inch
Kpa	Kilo Pascal
Mpa	Mega Pascal
USGS	United States geological survey
BF	Blast furnace
LF	Ladle furnace
BOF	Basic oxygen furnace
EAF	Electric arc furnace
IS	Iron slag
SS	Steel slag
BFS	Blast furnace slag
BOFS	Basic oxygen furnace slag
EAFS	Electric arc furnace slag
LFS	Ladle furnace slag
ACBFS	Air cooled blast furnace slag
EBFS	Expanded blast furnace slag
PBFS	Pelletized blast furnace slag
GBFS	Granulated blast furnace slag
GGBFS	Ground granulated blast furnace slag
LA	Los Angeles
OMC	Optimum moisture content
MDD	Maximum dry density