PERFORMANCE OF KAOLIN-TIRE DERIVED AGGREGATE MIXTURE AS A BACKFILL MATERIAL FOR RETAINING WALL

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PERFORMANCE OF KAOLIN-TIRE DERIVED AGGREGATE MIXTURE AS A BACKFILL MATERIAL FOR RETAINING WALL

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To my beloved parents and sister, your courage and
compassion have taught me humility

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ABSTRACT

Backfill material for retaining wall should be lightweight in order to reduce the lateral pressure behind the wall. In addition, high permeability backfill walls are designed to eliminate or minimize the development of pore water pressure. Tire Derived Aggregate (TDA) has low unit weight and high permeability. Moreover, reutilizing solid wastes like TDA with cohesive soil as backfill material may reduce sand mining and preserve the environment to achieve sustainable construction. Therefore, the aim of this study was to evaluate the performance of Kaolin-TDA mixtures as a backfill material for retaining wall. Geotechnical properties of Kaolin, TDA and Kaolin-TDA mixtures were determined in addition to compaction and hydraulic conductivity tests. A total of 13 scaled down 1:20 physical model tests on polymer concrete retaining wall using Kaolin and different mixtures of Kaolin-TDA as backfill material were performed. Footing settlements and wall displacements due to loading on fabricated steel as strip footing in the model test were measured. The results were verified using three numerical methods, namely PLAXIS 2D, Genetic Programming and Multiple Linear Regression. The maximum dry density of Kaolin-TDA mixture was in the range of 964 kg/m^3 to 1590 kg/m^3, lighter than the maximum dry density of Kaolin 1750 kg/m^3. Therefore, using Kaolin-TDA mixture as backfill material reduced the unit weight of backfill in a range of 9% to 45% resulted in a decrease in lateral pressure. Physical modeling and permeability tests results showed that mixture of Kaolin with 20% Granular (5-8 mm) TDA was the optimum mixture. The permeability of the optimum mixture was 2.56 times higher than that of the Kaolin. It was also observed from the physical modeling that by using the optimum mixture as backfill material, it resulted in footing stress roughly 3 times higher than using Kaolin without TDA. Thus, by mixing TDA with Kaolin, the weight of backfill decreases, permeability increases and footing stress increases compared to Kaolin as a backfill material for retaining wall.

ABSTRAK

Bahan kambus balik tembok penahan seharusnya ringan bagi mengurangkan tekanan sisi di belakang tembok. Di samping itu, kebolehtelapan yang tinggi bagi bahan kambus balik direka untuk menyahkan atau meminimumkan pembentukan tekanan air liang. Agregat Yang Didapati Daripada Tayar (TDA) mempunyai berat unit yang rendah dan kebolehtelapan yang tinggi. Disamping itu, penggunaan semula bahan-bahan buangan pepejal seperti TDA dengan tanah berjelekit sebagai bahan kambus balik dapat mengurangkan perlombongan pasir dan memelihara persekitaran bagi mencapai pembinaan lestari. Tujuan kajian ini ialah untuk menilai prestasi campuran Kaolin-TDA sebagai bahan kambus balik bagi tembok penahan. Sifat-sifat geoteknikal Kaolin, TDA dan campuran Kaolin-TDA telah ditentukan di samping ujian-ujian pemadatan dan keberaliran hidraulik ke atas campuran-campuran itu. Sejumlah 13 ujian model fizikal tembok penahan konkrit polimer yang telah diskala kecilkan 1:20 menggunakan Kaolin dan campuran Kaolin-TDA yang berlainan sebagai bahan kambus balik telah dilakukan. Enapan asas jalur dan pergerakan tembok penahan akibat pembebanan ke atas plat keluli yang difabrikasi sebagai asas jalur dalam ujian model telah diukur. Keputusan yang diperolehi daripada model fizikal telah disahkan menggunakan tiga kaedah berangka iaitu PLAXIS 2D, Pengaturcaraan Genetik dan Berbilang Regrasi Lelurus. Ketumpatan kering maksima bagi campuran Kaolin-TDA antara 964 kg/m^3 dan 1590 kg/m^3 adalah lebih ringan dari Kaolin yang mempunyai ketumpatan kering maksima 1750 kg/m^3. Oleh itu, penggunaan campuran Kaolin-TDA sebagai bahan kambus balik telah mengurangkan berat unit antara 9% hingga 45% menyebabkan penurunan tekanan sisi di belakang tembok. Model fizikal dan hasil ujian kebolehtelapan menunjukkan bahawa campuran Kaolin dengan 20% Granular (5-8 mm) TDA adalah campuran yang optima. Kebolehtelapan campuran optima tersebut adalah 2.6 kali lebih tinggi dari kebolehtelapan Kaolin. Kajian dari model fizikal juga menunjukkan bahawa penggunaan campuran optima sebagai bahan kambus balik telah menyebabkan tekanan penapak asas jalur 3 kali lebih tinggi dari menggunakan Kaolin tanpa TDA. Oleh itu, dengan campuran TDA dan Kaolin, berat kambus balik berkurangan, kebolehtelapan meningkat dan tekanan asas jalur meningkat berbanding dengan Kaolin sebagai bahan kambus balik bagi tembok penahan.

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LIST OF SYMBOLS

a	-	Area of cross section of standpipe tube
A	-	Area of the Mold
B	-	Number of Blows
C_u	-	Uniformity Coefficient
C_c	-	Coefficient of gradation
c	-	Cohesion
c′	-	Effective Cohesion
C_m	-	Meniscus correction
D	-	Particle Diameter
D_{10}	-	Effective Particle Size
D_{50}	-	Average Particle Diameter
D, d	-	Diameter
e	-	Void Ratio
e_0	-	Initial Void Ratio
E	-	Modulus Elasticity
E_{50}	-	Modulus Elasticity of soil
$E_{(oed)}$	-	Elasticity Modulus of Oedometer
F	-	Force
ft	-	foot
g	-	Gravity = 9.81 m/s
G	-	Shear Modulus
G_s	-	Specific Gravity
h	-	Height
h_1	-	Initial water level in standpipe tube
h_2	-	Secondary water level in standpipe tube
H	-	Height of Hammer

H_r	-	Effective Depth
I	-	Moment of inersia
$k, k_x\ k_y$	-	Hydraulic Conductivity, Permeability
K	-	Percent finer than D
K	-	Bulk Modulus
K_0	-	Lateral Earth Pressure Coefficient at Rest
K_a	-	Active Lateral Earth Pressure Coefficient
K_p	-	Pasive Lateral Earth Pressure Coefficient
L	-	Length of sample
l	-	Length
m	-	Mass
m	-	Dry mass of soil
m_o	-	Initial Dry mass of sample
M_{PW}	-	Mass of Pycnometer and Water
M_{PW}	-	Mass of Pycnometer, Water and Material
M_s	-	Mass of oven dry soil
N	-	Number of Layer
n	-	Porosity
P	-	Pressure
R_o'	-	Reading in Dispersant
R_d	-	Modified Reading
R_h	-	True Reading
R_h'	-	Hydrometer Reading
S_v	-	Volume Strain
t	-	Time
T	-	Tempreture
V	-	Volume of the Mold
V_a	-	Volume of Air
V_v	-	Volume of Voids
V_w	-	Volume of Water
V_s	-	Volume of solid
W	-	Weight of Hammer
W_a	-	Mass of Original sample
W_b	-	Mass of pycnometer filled with mixtures

W_c	-	Mass of pycnometer filled with alcohol
x	-	Displacement
σ	-	Stress
σ_h	-	Horizontal Stress
σ_v	-	Vertical Stress
ε	-	Strain
ε_h	-	Horizontal Strain
ε_v	-	Vertical Strain
η	-	Viscosity of Water at 24.5° C
φ	-	Internal Friction Angle
φ'	-	Effective Internal Friction Angle
φ_f	-	Interparticle Friction Angle
ρ	-	Density
ρ_d	-	Dry Density
ρ_s	-	Particle Density
ρ_{sat}	-	Saturation Density
γ	-	Unit Weight
$\gamma_{(d)}$	-	Dry Unit Weight
$\gamma_{(z.z.v)}$	-	Zero Air Unit Weight
υ	-	Poisson's Ratio
ω	-	Moisture Content
$\omega_{(opt)}$	-	Optimum Moisture Content
Ψ	-	Dilation Angle

LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BCR	-	Bearing Capacity Ratio
BS	-	British Standard
CCME	-	Canadian Council of Ministers of the Environment
CH	-	Clay Soil with High Plasticity
CL	-	Clay Soil with Low Plasticity
CU	-	Consolidated Undrained Test
EDX	-	Energy Dispersive X-ray
FSR	-	Free Swell Ratio
GP	-	Genetic Programming
GRM	-	Gravel Rubber Mixture
IPCs	-	Inorganic Polymer Concretes
K100	-	100 Percent of Kaolin
K80S	-	80 Percent of Kaolin mixed with 20 Percent Sand
K80G	-	80 Percent of Kaolin mixed with 20 Percent Gravel
K60S	-	60 Percent of Kaolin mixed with 40 Percent Sand
K60G	-	60 Percent of Kaolin mixed with 40 Percent Gravel
K40S	-	40 Percent of Kaolin mixed with 60 Percent Sand
K40G	-	40 Percent of Kaolin mixed with 60 Percent Gravel
K80-P20	-	80 % Kaolin mixed with 20 % Powdery TDA
K60-P40	-	60 % Kaolin mixed with 40 % Powdery TDA
K40-P60	-	40 % Kaolin mixed with 60 % Powdery TDA
K80-SH20	-	80 % Kaolin mixed with 20 % Shredded TDA
K60-SH40	-	60 % Kaolin mixed with 40 % Shredded TDA
K40-SH60	-	40 % Kaolin mixed with 60 % Shredded TDA
K80-G (1-4mm)20	-	80 % Kaolin mixed with 20 % Granular (1-4mm)TDA
K60-G (1-4mm)40	-	60 % Kaolin mixed with 40 % Granular (1-4mm)TDA

K40-G (1-4mm)60	-	40 % Kaolin mixed with 60 % Granular (1-4mm)TDA
K80-G (5-8mm)20	-	80 % Kaolin mixed with 20 % Granular (5-8mm)TDA
K60-G (5-8mm)40	-	60 % Kaolin mixed with 40 % Granular (5-8mm)TDA
K40-G (5-8mm)60	-	40 % Kaolin mixed with 60 % Granular (5-8mm)TDA
kPa	-	Kilo Pascal
LL	-	Liquid Limit
LRFD	-	Load and Resistance Factor Design
LVDT	-	Linear Variable Differential Transducer
MC	-	Mohr-Coulomb
MDD	-	Maximum Dry Density
MEKP	-	Methyl Ethyl Ketone Peroxide
MH	-	Silt Soil with High Plasticity
ML	-	Silt Soil with Low Plasticity
MLR	-	Multiple Linear Regression
NCHRP	-	National Cooperative Highway Research Program
OMC	-	Optimum Moisture Content
PC	-	Polymer Concrete
pcf	-	Per Cubic Foot
pH	-	Power of Hydrogen
PI	-	Plasticity Index
PL	-	Plastic Limit
RMA	-	Rubber Manufacturers Association
SEM	-	Scanning Electron Microscope
SRM	-	Sand Rubber Mixture
TDA	-	Tire Derived Aggregate
TEM	-	Transmission Electron Microscope
UU	-	Unconsolidated Undrained Test
XRD	-	X-ray Diffraction

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Tire Derived Aggregate (TDA) has a low unit weight, is highly permeable and insulating. These characteristics make it an excellent choice as fill material for embankments build on unstable ground and also for landslide stabilization. TDA can be a proper backfill material for retaining walls and bridge abutments. Moreover, it may be use for insulation against frost penetration beneath roads, and as a drainage layers in landfills. In addition, the reuse of waste tires avoids problems associated with their disposal as well as stockpiling as scrap tires.

Literatures have shown that combining TDA and cohesive soil brings about additional benefits. For instance, adding TDA to cohesive soil reduces the need for sand mining and creates more sustainable construction. Kaolin-TDA mixtures are lightweight and create less horizontal pressure against the back of a retaining wall. In addition to that, the mixture may sustain and provide effective drainage, reduce water pressure, and insulation against frost damage to walls. Interestingly, TDA has been tested by the University of Maine and used in the construction of the Merrymeeting Bridge in Maine (Whetten *et al.*, 1997; Humphrey *et al.*, 1998; Tweedie *et al.*, 1998; Cosgrove and Humphrey, 1999). However, the use of shredded tires as a way to reduce pressure on rigid frame bridges remains largely untested.

In one study, series of triaxial tests were conducted on a mixture of tires chips and Ottawa sand (Ahmed, 1993). The results of this study demonstrated that apparent cohesion was increased while friction angle decreased when more tire chips were added to the mixture. According to Edil and Bosscher (1994) a formulation consisting of 25% chips (size 20 to 80mm) and 75% sand resulted in a mixture with superior shear strength at low normal stresses. More so, Lee *et al.* (1999) found that dilatancy behavior in TDA-sand was influenced by the stress strain relationship between pure sand and pure chips. In a similar study, Rao and Dutta (2006) discovered that the stress strain volumes of sand and tire chip mixtures exhibited various responses in triaxial compression tests. The results of their study also indicated that adding tire chips to sand mixtures may lead to a slight increase in frictional angles. The work of Dutta and Rao (2009) showed that triaxial testing on TDA mixed with soil was better able to absorb energy and decrease stress when the aspect ratio, chip content and confining pressure were increased.

Other researchers have also investigated on the performance of mixtures composed of sand and waste tires. For instance, Yoon *et al.* (2008) conducted plate load tests on sand reinforced with TDA. The sand samples used in Yoon's study had relative densities of 40%, 50%, and 70%. They found that the Bearing Capacity Ratio *(BCR)* of loose sand improved when the volume of TDA was added. However, they also found that *BCR* decreased when density increased. According to the study of Tafreshi and Norouzi (2012), the results of plate load tests on square footing resting on soil mixed with TDA was also significantly improved. Overall, direct shear tests on material containing scrap tire chips demonstrate that the addition of tire chips increases shear strength (Naval *et al*., 2013).

This study investigates Geotechnical properties of Kaolin-TDA mixture as backfill material. Also, it compares the effect of various TDA shapes and percentages in Kaolin. Physical modeling of the retaining wall is conducted in the laboratory using normal and modified soil as backfill. The result of physical modeling was verified by the numerical modeling (PLAXIS 2D) for retaining wall using the modified soil as backfill. Tables and charts of modified soil properties are established that may be used in retaining wall design.

1.2 Problem Statement

Backfill material with poor permeability used in reinforced structure is of great concern as it has resulted in maintenance issues and structural failures (Mitchell and Zornberg, 1995). Often, materials with low permeability are used in inexpensive wall systems. These systems are vulnerable to deformation and may fail. If fine materials such as silt or clay are used as backfill, then any water pressure in the regions in front of, behind, or underneath the backfilled area must be collected and removed through proper filtration and drainage methods. Moreover, the region above the backfilled area must be waterproofed using geomembrane or a geosynthetic clay liner. The process is necessary so as to prevent surface water from entering the backfilled area (Koerner and Soong, 2001). On the other hand, clay soils have a plastic behavior. Therefore, combining the elastic properties of shredded tires with the plastic properties of clay soil in a single mixture creates a perfectly Elasto-plasticity backfill material for retaining walls.

Moreover, reutilizing solid wastes like TDA with cohesive soil as backfill material would reduce sand mining and preserve the environment to achieve sustainable construction. The proper disposal of waste tires is a global issue as an environmental problem as the secondary problem statement of this study. Scrap tires cannot be easily disposed of by burning because they release pollutants into the water and air when they are set alight. When disposed of in landfills, waste tires float to the surface and compromise the surface of the landfill providing a way for rodents, insects and water to enter the landfill (Figure 1.1). Stockpile of scrap tires represents a threat to environment and public health. Fortunately, scrap tires can be reused in several ways such as creating tire chips for lightweight fill (Humphrey and Manion, 1992; Foose *et al.*, 1996; Yoon *et al.*, 2008). In this study, the benefits of Kaolin-TDA mixtures as a backfill material for retaining walls were examined.

Figure 1.1: Stockpiling and burning the waste tire (Environmental Engineering and Contracting, 2002)

1.3 Objectives of the Study

The aim of this study is to evaluate the performance of Kaolin-TDA mixture as a backfill material on reinforced polymer concrete retaining wall. The following objectives are identified in order to achieve this aim:

i. To identify material characteristics of Kaolin-TDA mixture including different shapes, sizes and amount of the TDA.
ii. To determine the performance of the polymer concrete retaining wall using different backfill material prepared from the Kaolin-TDA mixtures based on physical modeling.
iii. To verify the physical modeling test results with numerical simulation using PLAXIS 2D, Genetic Programming (GP) and developing an equation based on Multiple Linear Regressions.

1.4 Scope of the Study

The study investigates the geotechnical properties of Kaolin pre-admixed with the TDA, for the purpose of use as a backfill material for polymer concrete retaining wall. The scopes of the study are as follows:

i. Test samples were mixed at optimum moisture content obtained from compaction test
ii. The basic tests were performed based on the ASTM (1992) and BS 1377-(1990).
iii. Physical modeling tests of the retaining wall were performed in the laboratory using Kaolin and Kaolin-TDA mixtures as backfill material.
iv. The results of physical modeling were verified using commercial numerical modeling program PLAXIS 2-D (based on Mohr-Coulomb model), Genetic Programming and Multiple Linear Regression while, active force was considered for retaining wall and backfill.
v. Physical modeling tests were conducted in dry condition because the main reason for conducting the physical modeling was investigating the use of lightweight material as backfill. However, permeability tests were conducted to show the increase in permeability for different mixtures.
vi. In this study the mixing ratio of 0:100, 20:80, 40:60 and 60:40 were chosen to conduct the laboratory tests, physical modeling tests and numerical modeling.

1.5 Significance of the Study

Consideration of the performance of Kaolin-TDA mixture as backfill material on the prepared polymer concrete retaining wall is the most important purpose of this investigation. TDA is a light weight material while the use of this waste in geotechnical engineering may decrease weight of structures. Hence, Kaolin-TDA mixtures prevent overturning in retaining wall because of low horizontal pressure. In addition, removal of waste tire as integral parts of solid waste of a nation is a good solution for saving the environment. The removal can result in because of preventing of burning and stockpiling the tire while, thus adding economic value to it.

1.6 Thesis Organization

The thesis consists of five chapters. Chapter 1 presents the background, problem statements, objectives, scope, and significance of this research. Chapter 2 reviews previous studies related to this study. Topics such as clay soil properties, shredded tire properties, soil-shredded tire applications, fill materials, recycled materials, backfill material and retaining wall, polymer concrete, physical modeling and numerical modeling were discussed. Chapter 3 describes the research methodology including various laboratory tests carried out. The tests included compaction test, permeability test and triaxial test on Kaolin mixed with different percentages and shapes of Tire Derived Aggregate (TDA). Besides physical modeling, equipment and procedures of the loading were illustrated. The design of the box and steel strip footing dimensions and instrumentation were addressed. In Chapter 4, laboratory test results and the results from the physical modeling tests and numerical simulations are presented and discussed. The results cover several issues such as the settlement of the improved ground, retaining wall displacement at failure and backfill failure modes. The results from triaxial tests on the backfill materials were also presented. The effects of shape of TDA, percentage of TDA and arrangement of the material particles in mixtures were presented. Furthermore, comparison between the Load-displacement of experimental tests with numerical are performed. Consequently, the equations were created for predicting the footing settlement and wall displacement. Finally, Chapter 5 lists the conclusions and recommendations for future research on Kaolin-TDA mixture as a backfill material.

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