THE ENGINEERING PROPERTIES OF POLYURETHANE-CLAY COMPOSITE (PU-CC) DOPED WITH UNTREATED AND TREATED WASTE TREATMENT

AIDA ATIQAH BINTI ATIL

A thesis submitted
In fulfillment of the requirement for the award of the
Master in Engineering Technology

Faculty of Engineering Technology
Universiti Tun Hussein Onn Malaysia

SEPTEMBER 2023

DEDICATION

To my beloved father and mother,

For being the backbone of my life by supporting me from the very beginning

To my supervisor,
Ts. Dr. Nik Normunira binti Mat Hassan
For their consistent encouragement, guidance and support throughout the researchjourney

To my siblings, family

Close family members & true friends
For their trust, cooperation and motivation during this project
For their direct and indirect support in completing various stages of this research

ACKNOWLEDGEMENT

First and foremost, I praise the almighty God for blessing me strength and capability to complete my master research successfully. This thesis dissertation owes its presence to the inspiration, encouragement and assistance from several good souls. My sincere gratitude is extended to my parents, siblings, close family members and friends for their unconditional and genuine love through my thick and thin.

My greatest appreciation goes to my supervisor, Ts. Dr. Nik Normunira binti Mat Hassan who has been constant source of guidance and motivational factor to take up this Master challenge quality. I am grateful for financial assistance from The Ministry of Education Malaysia and Faculty of Engineering Technology (FTK), Universiti Tun Hussein Onn Malaysia (UTHM) during my research years.

ABSTRACT

The versatility of polyurethane (PU) properties has the potential to improve the compressive strength, shear strength, and buoyancy force in soil improvement applications. The PU waste materials were issued as disposal management that can impact environmental pollution when these materials were dumped into landfills. In this study, Polyurethane-Clay Composite (PU-CC) samples were prepared with different ratios of untreated and treated PU waste filler (PUF) loading (0 wt%, 2.5 wt%, 5 wt %, 7.5 wt%, and 10wt%) namely as Polyurethane-Clay Composite Untreated (PU-CCUN), Polyurethane-Clay Composite treated by the oven (PU-CCTO) and Polyurethane-Clay Composite treated by microwave (PU-CCTM). In accordance with ASTM standard, all the testing were successfully performed for fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM), thermogravimetric (TGA), water absorption, buoyancy, unconfined compressive strength (UCS) and direct shear strength). The PU-CCUN$_5$ exhibited the highest water absorption of 20 % followed by PU-CCTO$_{10}$ at 15% and PU-CCTM$_{2.5}$ at 5% respectively. The PU-CCTO gives the high buoyancy force at 10 wt% of PU-CCTO$_{10}$ samples at 50% followed by 45% of PU-CCTM$_{10}$, and the lowest at 2.5 wt% of PU-CCUN$_{2.5}$ at 8%. The UCS and shear strength shows obviously the highest at 300 kPa and 50 kPa of PU-CCTO$_{10}$ followed by PU-CCTM$_{2.5}$ at 130 kPa and 19 kPa and PU-CCUN$_{2.5}$ at 100kPa and 15kPa, respectively. PU-CCTO treated by drying oven has the highest buoyancy force at 10% of PU-CCTO$_{10}$ samples at 50%, followed by 45% of PU-CCTM$_{10}$ treated by microwave, and the lowest at 2.5 wt% of PU-CCUN$_{2.5}$ untreated at 8%. In conclusion, the 10 wt% of PU filler treated by drying oven method as an PU clay composite has the potential as an alternative material to improve the compressive strength, shear strength, and buoyancy force in the soil improvement.

ABSTRAK

Kepelbagaian sifat poliuretana (PU) berpotensi untuk meningkatkan kekuatan mampatan, kekuatan ricih, dan daya keapungan dalam bidang yang melibatkan kekuatan tanah.Bahan buangan PU mempunyaipengurusan pelupusan yang lemah dan pencemaran alam sekitar ketika bahan ini dibuang ke tapak pelupusan sampah. Dalam kajian ini, sampel komposit tanah liat telah disediakan dengan nisbah campuran yang berbeza bagi pemuatan pengisi PU (0% 2.5%, 5%, 7.5%, dan 10%) yang dinamakan komposit poliuretana-tanah liat tidak dirawat (PU-CCUN), komposit poliuretana-tanah liat yang dirawat oleh ketuhar (PU-CCTO) dan komposit tanah liat poliuretana yang dirawat oleh gelombang mikro (PU-CCTM). Sifat kejuruteraan sampel PU-CC diuji mengikut piawaian Bahan Penguji Standard Amerika (ASTM) iaitu spektroskopi inframerah transformasi fourier (FTIR), mikroskop elektron pengimbasan (SEM), termogravimetrik (TGA), ujian keapungan, ujian penyerapan air, kekuatan mampatan tidak terkurung (UCS), dan kekuatan ricih terus. PU-CCUN$_5$ menunjukan penyerapan air tertinggi sebanyak 20 % diikuti dengan PU-CCTO$_{10}$ pada 15% dan PU-CCTM$_{2.5}$ pada 5% disebabkan oleh saiz pori sampel yang berbeza. PU-CCTO memberikan daya keapungan yang tinggi pada 10 wt% bagi sampel PU-CCTO$_{10}$ iaitu 50% diikuti oleh PU-CCTM$_{10}$ sebanyak 45%, and yang paling rendah pada 2.5 wt% bagi PU-CCUN$_{2.5}$ iaitu sebanyak 8%. UCS dan kekuatan ricih bagi sampel menunjukkan paling tinggi pada 300kPa dan 50kPa oleh PU- CCTO$_{10}$ diikuti oleh PU-CCTM$_{2.5}$ pada 130 kPa dan 19 kPa and PU-CCUN$_{2.5}$ pada 100 kPa dan 15 kPa. PU-CCTO dirawat dengan pengeringan ketuhar mempunyai daya daya apungan tertinggi pada 10% sampel PU-CCTO$_{10}$ pada 50%, diikuti oleh 45% PU-CCTM$_{10}$ dirawat oleh gelombang mikro, dan yang terendah pada 2.5 wt% daripada PU-CCUN$_{2.5}$ yang tidak dirawat pada 8%. Kesimpulannya, 10 wt% pengisi PU yang dirawat dengan kaedah ketuhar pengeringan berpotensi untuk dijadikan bahan alternatif bagi meningkatkan kekuatan mampatan, kekuatan ricih dan daya apungan bagi meningkatkan kekuatan tanah.

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

EPS	-	Expanded polystyrene
FTIR	-	Fourier transform infrared spectroscopy
PU	-	Polyurethane
PU-CC	-	Polyurethane-Clay Composite
PU-CCTM	-	Polyurethane-Clay Composite Treated Microwave
PU-CCTO	-	Polyurethane-Clay Composite Treated Drying Oven
PU-CCUN	-	Polyurethane-Clay Composite Untreated
PUF	-	Polyurethane waste filler
PUF-TM	-	Polyurethane waste filler Treated Microwave
PUF-TO	-	Polyurethane waste filler Treated Drying Oven
PUF-UN	-	Polyurethane Waste Filler Untreated
SEM	-	Scanning Electron Microscopy
TGA	-	Thermogravimetric Analysis
UCS	-	Unconfined Compressive Strength

CHAPTER 1

INTRODUCTION

1.1 Background of research

Polyurethane (PU) is one of the polymeric materials that offers many potential applications in numerous industries including construction and manufacturing due to its versatility such as cost benefits, energy savings, and durability (Khaikade *et. al.*, 2023; Khalifah *et. al.*, 2020; Saleh *et. al.*, 2020; Saleh *et. al.*, 2019). However, PU generates significant amounts of waste in various forms, of which only 29.7% is recycled and 39.5% is recovered through energy recovery processes and unfortunately, the first choice in many countries such as United State, Denmark and Japan, accounting for 30.8% of total waste (Abrishamkar *et. al.*, 2023; Wu *et. al.*, 2021; Masykuri *et. al.*, 2021). Due to the increasing of PU amount waste, solutions have been taken to reduce the problem of polymer waste which is a cost effective and efficient method of recycling polymer waste through mechanical recycling. For many years, the various additives as fillers used in PU composite for various purposes and as an alternative to improve mechanical and physical properties of polymer materials.

Recently, many researchers have investigated the performance of the polymer composite materials including PU doped with various additive, such as recycled materials, plastic, fiber used to remediate problematic soil. Despite this discovery, more efficient additive must be presented to alleviate some of the issues. Installation and repair techniques based on PU foams have only been available for the last 25 years, and a deep lifting approach has been patented (Khalifa *et. al.*, 2020; Canteri *et. al.*, 2019). To alleviate problematic of soil, the PU foam is installed into the soil at discrete spots under an existing structure. Even though much research has been conducted on PU and its application in many areas of specialization, information on the use of PU in the improvement of clay soils is limited.

According to research by Saleh S. *et al.,* (2019) were explored the possibility of PU enhancing soil improvement strength. From this previous research discovered that installation method the soils with PU resulted in considerable soil improvement. Similar studies conducted by other researchers such as Saleh S. *et al.,* (2021) and M. A. *et. al.,* (2017), demonstrate that clay soil is a weak soil in the soil improvement. Various researchers have studied PU as a soil enhancement material (Zhou *et. al.,* 2023; Ghani *et. al.,* 2017; Ghani *et.al.*, 2017; Jais *et. al.,* 2019). Nawamooz *et al.*, (2016) conducted a study on resin installation in clay with high plasticity and discovered that pressure meter and cone penetration test results before and after installation of PU showed a significant increase in pressure limit and soil resistance for all depths studied close to the installation point. Ghani *et al.,*(2017) was researched the application of PU for soil flood damage reduction. This research was discussed the types of soil are hard soil and soft soil which is commonly utilized as soil in soil construction.

However, the demand for polymer materials in the construction of soil for soils and other purposes in an urban environment introduced numerous technical and social obstacles to civil engineering have been raised among researchers (Kiddel *et. al.,* 2023; Ghani *et. al.*, 2017; Ghani *et.al.*, 2017; Jais *et. al.*, 2019). The scope of work was developed and carried out with consideration for the potential interruption to people, existing buildings and infrastructure, and the environment. One of the polymeric materials, Expanded Polystyrene (EPS) or another name is geofoam, a form of polymer group has emerged as the material of choice for most earthworks that require a lightweight material and high strength and high stiffness (Horvath, 2019).

A study by Stuedlein and Negussey (2018) is on the application of lightweight materials using EPS geofoam where the approach experienced significant on soils while requiring constant grade maintenance. Replacement of fill with EPS geofoam samples successfully eliminate further soil. Buskowicz and Culpan (2014) considered the foam as inexpensive even inthe twentieth century and the high pay is due to fast work done and efficient construction material that offers significant schedule advantages to new structure especially in locations with poor soil conditions.

1.2 Problem statement

The large amount of solid waste reported by the Compendium of Environment Statistics, Malaysia (2020) is produced at 3,108.9 thousand tonnes in 2019 and the solid waste expected will increase year by year (Khalifa *et. al.*, 2020; Gomez-Rojo *et. al*., 2019; Jamaluddin *et. al.*, 2019). Solid waste associated with substantial environmental issues, as based primarily on non-renewable raw materials, are commonly used in short-lived product, and once discarded, are predominantly landfilled or incinerated (90%) and only small percentages (10%) is recycled (L. Chong *et al*., 2019). As reported by (Simon *et. al.*, 2018), PU make uproughly 8% of all PU produced, the world's sixth most common polymer. These processes consist basically of the waste mechanical transformation into flakes, granules, or powder to be used in new materials production including thermoplastic group which are plastic and rubber (Daigavane *et. al.*, 2015). The main advantages of these methods are their simplicity and their low cost with successful results for thermoplastic PU recovery. Furthermore, solid waste such as PU waste is a thermoset polymer that needs hundreds of years to degrade in normal environmental conditions (Singh *et al*., 2017).

In soil constructions, the EPS has an established lightweight material used since a long time ago and has a good ability to resist water flow due to closed cell structure and low water absorption. However, there is the major concern of the buoyancy property of lightweight materials such EPS as a soil improvement application (Stephen *et. al.*, 2016; Jamaludin *et. al.*,2019). This buoyancy issue reported a few failure cases of founded on lightweight geofoam reported by Jamaludin *et. al.*, 2019. The buoyancy problems were also reported in the real incident cases occurred in Thailand in 2019 where the unexpected water level washed away the soil filled with EPS as low compressive strength and low shear strength (Gao *et. al.*, 2019). Due these issues, EPS may have a bad effect of buoyancy and weak of water absorption as consideration on clay (Daigavane *et. al.*, 2015).

The clay soil in the soil structure is found among the weak soils. The main finding shows that the clay soil was allowed to absorb large amounts of water, thereby increasing the volume of water and a tendency to low compressive strength (Sharma *et. al.*,2015; Ahmed *et. al.*, 2015; Maliza *et. al.*, 2018; Kianimehr *et. al.*, 2019) and low shear strength. The presence of high water contents affects the structure of clay and causes a higher chance of collapse. However, in the soil structure, the drainage clay was provided between the EPS geofoam fill and the clay soils to reduce potential uplift forces and buoyancy issues.

Furthermore, PU foam is a lightweight material that could minimize additional load contribution to the underlying soil and therefore minimize further soil improvement (Lu *et. al.*, 2019). The uplift behavior of the foam can be controlled by providing adequate overburden on the PU foam. Due to its lightweight property, the soil problem can be overcome by using PU materials as filler. Through the concern to overcome the several issues in waste polymer and problematic soil, the idealized in this study was proposed to produce a Polyurethane-Clay Composite (PU-CC) samples doped with untreated and treated Polyurethane waste filler (PUF) by different drying method via microwave and drying oven exposure. The physical and mechanical properties of PU-CC samples doped PUF filler were examined to reduce the buoyancy force, increase shear strength, high compressive strength, and low water absorption in order to enhance the soil improvement (Jafar *et. al.*, 2016; Mohamed *et. al.*, 2017; Masykuri *et. al.*, 2021).

1.3 Objectives of the research

The objectives of this research are:

1) To determine the polyurethane waste filler (PUF) untreated and treated by different drying methods.
2) To fabricate the polyurethane-clay composite (PU-CC) at different ratios of untreated and treated polyurethane waste filler (PUF) loading.
3) To characterize the engineering properties of polyurethane-clay composite (PU-CC) untreated and treated of polyurethane waste filler (PUF) for soil improvement.

1.4 Scopes of the research

The scopes of this study are:

Objective 1:

i. Polyurethane waste was obtained from Jiang Ji Cushion, Johor Bahru. The PU waste was cut at the sizes of 25 cm x 10cm.
ii. The treated PUF was conducted at different drying apparatus such drying oven and microwave. The drying parameter was set up at a temperature 60°C, PUF size of 300µm, and left to dry for 3 hours.
iii. There are three samples of PUF untreated and treated which are Polyurethane waste filler untreated (PU-FUN), Polyurethane waste filler treated by drying oven (PU-FTO) and Polyurethane waste filler treated by microwave (PU-FTM).

Objective 2:

i. The PU-CC was prepared with polyol and isocyanate ration of 1:1, 0.2 mm expanded polystyrene (EPS) bead, soft clay sizes at 4.75 mm to ASTM 4221-18, 25 wt% fly ash and 60 wt% distilled water, and different ratio of untreated and treated PUF.
ii. The PU-CCUN, PU-CCTO and PU-CCTM was doped at different ratio 0 wt%, 2.5 wt%, 5 wt%, 7.5 wt% and 10 wt% with untreated and treated of PUF

Objective 3:

Table 1.1 shows the physical and mechanical testing was conducted in this study according to ASTM Standards.

Table 1.1: Testing outline for materials characterization

Testing	Function	Parameter	Standard
Fourier Transform Infrared spectroscopy (FTIR)	To identify the functional group of material	4000 cm^{-1} to 650 cm^{-1} spectral range sample scans is 32.	ASTM D6342-12
Scanning Electron Microscope (SEM)	To observe the morphological structure of thespecimen surface	The structural analysis of the surface an acceleration of 15 kV, average 500 µm scans. The images of these samples were taken by using optical microscope with scanning image 500x magnifications	ASTM D3576
Thernogravimetric Analysis (TGA)	To determine a material's thermalstability and its fraction of volatile components by monitoring the weight changes.	The flow 25 mil/min in the temperature range from 0°C to 800 °C. Samples mass was approximately 10 mg. The sample tested samples with sizes 300µm	ASTM E1131
Buoyancy	To determine the floating of material asaccording to Archimedes Principle	38mm x 75mm	ASTM F2682
Water Absorption	To determine the amount of water absorbed under specified conditions.	50mm x 50mm	ASTM-994 M11-2016
Unconfined Compressive Strength (UCS)	To determine maximum stress.	38mm x 75mm	ASTM D2166/D2166M-16
Shear Strength	To identify the maximum resistance to the shearingstress.	60mmx60mmx25mm	ASTM D3080

1.5 Significant of study

In this study represent the various contributions towards furthering the understanding of the innovation of a new PU-CC doped with different ratios of PUF untreated and treated method. This alternative to produce a new PUF is one of the ways to reduce the abundance of polymer waste dumped to landfill and at the same time gives a better environmental impact to society. The improvement of the different ratios of PUF mixed with EPS was successfully proven to reduce the buoyancy force in soil improvement soil. This also influences the PU waste as a filler will accelerate the prolonged decomposition of PU of soil improvement.

The addition of PUF into the soil also contributed a large effect on the mass and volumetric properties of the resulting modified soil mixtures and their influence on mechanical properties are scarce in the literature (Formela *et. al*., 2017). The PU-CC samples have an intentioned to reduce the buoyancy force, increase shear strength, high compressive strength, and low water absorption soil improvement in applications. The PU-CC samples evidently helped to control the movement of water flow by controlling the interconnected cell shape structure between EPS, clay, fly ash and PUF, at the same time uplift force in the soil improvement soil.

The addition of lightweight EPS particulates has the potential to produce a modified soil with improved performance and a wide range of practical applications. EPS modified soils could be used as lightweight fill-in soil with significant strength. A modifying soil with reduced unit weight and significant void space could produce a sample material with beneficial applications. Hence, the finding of this study also contributed as a reference or beneficial information to the geotechnical engineering towards the recycling PU materials as a filler approached as an alternative solution to decrease problematic soil and as the stabilizing material by applying the PU through the soil improvement.

1.6 Thesis organization

The present thesis comprised of five chapters that were organized to address the objectives as referred to in section 1.3 which are:

- Chapter 1: The description of research overview is discussed. The problem statements, research objective, scope of the research and the research contributions are described. The justification of this study is discussed under the problem statement. The objectives are mentioned about which aspect should be considered.
- Chapter 2: The basic theory to support the implementation of the background research work is discussed in this chapter. It includes a general review on the polyurethane waste filler (PUF) untreated and treated, a detailed review on previous research studies and literature findings on application of PUF in soil improvement layer.

- Chapter 3: The details of the experimental approaches on materials, experimental techniques, equipment, and methods used in the study, including the polyurethane waste filler (PUF) untreated and treated methods, fabrication procedures of polyurethane-clay composite (PU-CC) using PUF solution, EPS, and fly ash and the physical and mechanical characterization techniques for testing PU-CC. The samples preparation, fabrication method and equipment used in the research activities are described. The parameter or the specific experiment such as FTIR, SEM, TGA, buoyancy, unconfined compressive strength (UCS) test and direct shear test are explained.
- Chapter 4: Discusses the results of the PUF and PU-CC untreated and treated samples.
- Chapter 5: Highlighted the general conclusions derived from the experimental and investigations are presented. The summary of all the major findings from this thesis and future works that could be done to sustain and improve the knowledge in PU-CC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review relevant to this research. The supportive information presented in this chapter is comprehensive. It covers the preparation the polyurethane waste filler (PUF) untreated and treated with different drying method. The fabrication of the polyurethane-clay composite (PU-CC) at different ratios of untreated and treated polyurethane waste filler (PUF) loading and the last of this research is to analyze the engineering properties of polyurethane-clay composite (PU-CC) untreated and treated of polyurethane waste filler (PUF) for soil improvement.

2.2 Polyurethane (PU)

Polyurethanes (PU) are versatile materials and have many applications in the manufacturing industry due to their wide range of densities, stiffness, and hardness. The materials include flexible foams used in upholstery and bedding and rigid foams used for thermal insulation. Globally over three-quarters of the PU are consumed in the form of foams, either flexible foams or rigid foams. In 2015, the worldwide consumption of PU was over 12 million metric tons and is continuously increasing at an average annual growth rate of 5 % (Samarth and Mahanwar, 2015; Wang and Schuman, 2012). The two essential components to produce PU are isocyanate containing isocyanate group (-N=C=O) and hydroxyl group (-OH) from polyol. A urethane linkage is produced by reacting an isocyanate group with a hydroxyl group, and therefore, PU are manufactured from the reaction between isocyanate and a polyol in the presence of catalysts and other additives. The generalized PU reaction is shown as follows (Klempner and Senijarevic, 2004) in the PU industry, where both isocyanate and polyols are usually made from petroleum derived feedstocks. However, in recent decades, various factors spur researchers to explore alternative resources for the feedstock of polyol, such as the increasing costs of petroleum, the increasing global consumption of PU, the unstable supplyof petroleum market partially due to political factors, and the enhanced public desire for environmentally friendly green products (Mahmood*et al.*, 2016; Jamdar *et. al.*, 2017; Kemona *et. al.*, 2020). Furthermore, there is potential for vegetable-oil derived polyols to replace petrochemical-based polyols exists (Mahmood*et al.*, 2016).

Initially, PU foams were developed early in the 1930s and has since grown in numerous and extensive, applications, after World War II. The main characteristic of PU foams revolves in its ability to deliver a wide range of cell structures, densities, rigidity,and foam morphologies (Saleh *et. al.*, 2020; Cong *et. al.*, 2018; Clark *et. al.*, 2018). PU foams are excessively predictable inperformance and known for their strength, durability, and surface feel (Hussein, 2016). The main classification of PU foams is rigid, flexible, and semirigid/flexible foams. Rigid PU foams have high insulation ability along with its rigidity, therefore, there are essentially used in automotive, construction,recreation, and appliance applications (Xie *et al.*, 2015; Zhang *et al.*, 2015). On the other hand, flexible PU foams reveal excellent deformation and elastic recovery characteristics since the PU are made with a less functional groups and shorter polyol. Flexible PU foams are suitable for packaging, furniture, and flexible hoses (Dos Santos *et al.*, 2012; Wu *et al*., 2009)

Economically, PU foams market occupies a massive sector because of their applications in a wide range of industrial processes. For example, the spray PU foam (SPF) industry was projected to grow at 13 % per year from about $800 million in 2013 to $1.1 billion in 2015. Growth will surpass overall construction industry expansion based on increased penetration of SPF in key residential and commercial applications (Xu *et al.*, 2014). However, the industry faces some challenges, including concerns about improper installations. In residential construction, walls and

REFERENCES

Abdul Salam S, Azzam S. Reduction of lateral pressures on retaining walls using geofoam inclusion. 2016. 23(6): 395 – 407.

Amri Fakhar, A. Asmaniza. Soil maintenance experience using polyurethane (PU) Foam installation system and geocrete soil stabilization as soil rehabilitation. 2016. 136 (1): 568 - 574.

Aghileh Khajeh, A., Jamshidi Chenari, R., & Payan, M. A review of the studieson soil-EPS composites: beads and samples. *Geotechnical and Geological Engineering*. 2020. *38*(4), 3363-3383.

Akindoyo, J. O., Beg, M. D. H., Ghazali, S., Islam, M. R., Jeyaratnam, N., & Yuvaraj, R. Polyurethane types, synthesis and applications – a review. 2016. 6(115), 114453–114482

Akbarimehr, D., Eslami, A., & Aflaki, E. Geotechnical behaviour of clay soil mixed with rubber waste. *Journal of Cleaner Production*. 2020. *271*, 122632.

American Standard Testing Method D6342-12. Standard Practice for Polyurethane Raw Materials: DeterminingHydroxyl Number of Polyols by Near Infrared (NIR) Spectroscopy. 2012

American Standard Testing Method D3576. Standard Test Method for Cell Size of Rigid Cellular Plastics. 2016

American Standard Testing Method E1131. Standard Test Method for Compositional Analysis byThermogravimetry. 2008

American Standard Testing Method C642-2013. Standard Test Method for Density, Absorption, and Voids inHardened Concrete 2012

American Standard Testing Method D2166-06. Standard Test Method for Unconfined Compressive Strength ofCohesive Soil. 2012

American Standard Testing Method D3080-04. Standard Test Method for Direct Shear Test of Soils UnderConsolidated Drained Conditions. 2018

American Standard Testing Method 4221-18. Standard Test Method For Dispersive Characteristics Of Clay Soil By Double Hydrometer. 2019

Bazmara, B., Tahersima, M., Behravan, A. Influence of thermoplastic polyurethane and synthesized polyurethane additive in performance of asphalt . Construct. Build. Mater. 2018. 166, 1e11.

Chen, J., Yin, X., Wang, H., Ding, Y. Evaluation of durability and functional performance of porous polyurethane mixture in porous. J. Clean. Prod. 2018. 188, 12e19.

Chen, S., Zhang, Y., Guo, C., Zhong, Y., Wang, K., Wang, H. Separation ofpolyvinyl chloride from waste plastic mixtures by froth flotation after surface modification with sodium persulfate. 2019. 218, 167e172.

Chenari, R. J., Fatahi, B., Ghorbani, A., & Alamoti, M. N. Evaluation of strength properties of cement stabilized sand mixed with EPS beads and fly ash. *Geomechanics and Engineering*. 2018.

Chin, C., Damen, P. Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications. 2019. Austsoils Publication No. AP-T351-19

Chuanyang Liang, C., Wu, Y., Liu, J., Wu, H., Chen, D., Liu, H., & Song. Effect of Expanded Polystyrene Particle Size on Engineering Properties of Clayey Soil. 2021. *Advances in Civil Engineering*, *2021*.

Clark, J.H. Farmer, T.J.; Ingram, I.D.V. Lie, Y. North, M. Renewable self- blowing non-isocyanate polyurethane foams from lysine and sorbitol. 2018. *Eur. J. Org. Chem.*, *2018*, 4265–4271.

Cong, L., Wang, T., Tan, L., Yuan, J., Shi, J. Laboratory evaluation on performance of porous polyurethane mixture sand OGFC. Construct. Build. Mater. 2018. 169, 436e442.

Cong, L., Yang, F., Guo, G., Ren, M., Shi, J., Tan, L. The use of polyurethanefor asphalt engineering applications: a state-of-the-art review. Construct.Build. Mater. 2019. 225, 012e1025.

Deng, Y., Dewil, R., Appels, L., Ansart, R., Baeyens, J., & Kang, Q. Reviewing the thermo-chemical recycling of waste polyurethane foam. *Journal of Environmental Management*, 2021. *278*, 111527.

Department of Statistic Malaysia, Compendium of Environment Statistic (2020) Retrieved on January 2021, from https://www.dosm.gov.my.

Formela, K., Hejna, A., Zedler, Ł., Przybysz, M., Ryl, J., Saeb, M.R., Piszczyk, Ł., Structural, thermal and physico-mechanical properties of polyurethane/brewers' spent grain PUF foams modified with soil tire rubber. Ind. Crops Prod. 2017. 108, 844–852.

Francis, R. Recycling of Polymers: Methods, Characterization and Applications. 2017.

Gao, Wang, H., Chen, J., Meng, X., You, Z. Laboratory evaluation on comprehensive performance of polyurethane rubber particle mixture. 2017

Ghani, A. N. A., Radzi, S. M., Ismail, M. S. N., Hamid, A. H. A. A. Study onthe use of polyurethane for soil flood damage control. *Int. J.* 2017

Gómez-Rojo, R., Alameda, L., Rodríguez, Á., Calderón, V., & Gutiérrez-González, S. Characterization of polyurethane foam waste for reuse in eco-efficient building materials. *Polymers*, 2019. *11*(2), 359.

Guo L, Wu DQ. Study of recycling Singapore solid waste as land reclamation filling material. Sustainable Environment Research. 2017. 27(1):1-6

Guo L, Wu DQ. Study of leaching scenarios for the application of incinerationbottom ash and marine clay for land reclamation. Sustainable Environment Research. 2018. 28(6):396-402.

Hassan, Nik Normunira, Anika Zafiah Mohd Rus. Thermal degradation and damping characteristic of UV irradiated biopolymer. *International Journal ofPolymer Science*, *2016*

Hassan, Nik Normunira , Anika Zafiah Mohd Rus, and M. F. L. A. Functionalized Waterborne Polyurethane Based Graphite Reinforced Composites, *2019*.

Jafar, J.J. Utilization of waste plastic in bituminous mix for improved performance of soils. KSCE J. Civ. Eng. 2016. 20 (1), 243e249.

Jais, I. B. M., Lat, D. C., and Endut, T. N. D. T. Compressiblity of peat soil improved with polyurethane. *Malaysian J. Civ. Engin.* 2019. 31: 35-41.

Jais, I. B. M., Mohammed, K., Baharom, B., Samat, N., and Zainuddin, A. N. Evaluation of strength characteristics for palm kernel oil-based Polyurethane (PKO-P) as a soil improvement method. *Mal. J. Fund. Appl. Sci.* 2016. 12: 126-129.

Jamaludin N, Mohd Yunus NZ, Jusoh SN, Pakir F, Ayub A, Zainuddin NE, Hezmi MA, Mashros. Potential and future: Utilization of waste material on strength characteristics of marine clay. IOP Conference Series: Materials Science and Engineering. 2019. 527:012003.

Jamdar, V., Kathalewar, M., Dubey, K.A., Sabnis, A. Recycling of PET wastes using electron beam radiations and preparation of polyurethane coatings using recycled material. Prog. Org. Coating. 2017. 107, 54e63.

Jia, M., Zhang, Z., Liu, H., Peng, B., Zhang, H., Lv, W., Zhang, Q., Mao, Z.The synergistic effect of organic montmorillonite and thermoplasticpolyurethane on properties of asphalt binder. Construct. Build. Mater. 2019. 229, 116867.

Jianguo Wang, Hu, B., & Soon, J. H. Physical and mechanical properties of abulk lightweight concrete with expanded polystyrene (EPS) beads and soft marine clay. *Materials*, 2019. *12*(10), 1662.

Jiao, L.; Xiao, H.;Wang, Q.; Sun, J. Thermal degradation characteristics of rigid polyurethane foam and the volatile products analysis with TG-FTIR-MS. Polym. Degrad. Stab. 2018. 98, 2687–2696

Jin, X., Guo, N., You, Z., Wang, L., Wen, Y., Tan, Y. Rheological properties and micro characteristics of polyurethane composite modified asphalt. Construct. Build. Mater. 2020. 234, 117395

Jouyandeh, M., Hadavand, B. S., Tikhani, F., Khalili, R., Bagheri, B., Zarrintaj, P, Saeb, M. R2. *Thermal-Resistant Polyurethane/Nanoclay Powder Coatings: Degradation Kinetics Study. Coatings*, 2020. *10(9), 871*..

Kemona, A., & Piotrowska, M. Polyurethane recycling and disposal: Methods and prospects. *Polymers*, 2020. *12*(8), 1752.

Khalifa, M., Anandhan, S., Wuzella, G., Lammer, H., & Mahendran. Thermoplastic polyurethane composites reinforced with renewable and sustainable fillers–a review. Polymer-plastics technology and materials. 2020. 59(16), 1751-1769.

Khairuddin, F.H., Alamawi, M.Y., Yusoff, N.I.M., Badri, K.H., Ceylan, H., Tawil, S.N.M. Physicochemical and thermal analyses of polyurethane modified bitumen incorporated with Cecabase and Rediset: optimizationusing response surface methodology. 2019. 115662.

Kim, J. K., Lee, S. H., & Balasubramanian, M. A. Comparative Study of Effectof Compatibilization Agent on Untreated and Ultrasonically Treated Waste Soil Rubber Tire and Polyolefin Blends, 2016. *16*, 263–268.

Kirpluks, M., Cabulis, U., & Avots, A. Flammability of Bio-Based Rigid Polyurethane

Foam as Sustainable Thermal Insulation Material. Insulation Materials in Context of Sustainability. 2016.

Kolar, V., & Muller, M. Research on Influence of Polyurethane Adhesive Modified by Polyurethane Filler Based on Recyclate. *Manuf. Technol*. 2018. *18*(3), 418-423.

Leng, C., Lu, G., Gao, J., Liu, P., Xie, X., Wang, D. Sustainable green using bio-based polyurethane binder in tunnel. 2019.

Leng, L., Sreeram, A., Padhan, R.K., Tan, Z. Value-added application of wastePET based additives in bituminous mixtures containing high percentage of reclaimed asphalt (RAP). J. Clean. Prod. 2018. 196, 615e625.

Li, J., Xiao, F., Zhang, L., Amirkhanian. Life cycle assessment and life cycle cost analysis of recycled solid waste materials in highway are view. 2019. 233, 1182e1206.

Liu, M., Han, S., Shang, W., Qi, X., Dong, S., Zhang. New polyurethane modified coating for maintenance of asphalt potholes in winter rainy condition. Prog. Org. Coating. 2019. 133, 368e375

Lu, G., Renken, L., Li, T., Wang, D., Li, H., Oeser. Experimental study on the polyurethane-bound pervious mixtures in the application of permeables. Construct. Build. Mater. 2019. 202, 838e850.

Lu, B., Zhao, Y., Li, N., Yu, Y., Wu, Y., & Gu, M. Triaxial Mechanical Properties and Mechanism of Waterborne Polyurethane-Reinforced Soil Demolition Waste as Soil Bases. *Polymers*, 2022. *14*(13), 2725.

Masykuri, M., & Widyasari. Surface Morphology and Biodegradation Test of Polyurethane/Clay Rigid Foam Composites *Journal of Chemical Technology & Metallurgy*, 2021. *56*(4).

Min, S., Bi, Y., Zheng, Chen. Evaluation of a cold-mixed high performance polyurethane mixture. 2019.

Mohamed Al-Atroush, Shabbir, O., Almeshari, B., Waly, M., & Sebaey. A Novel Application of the Hydrophobic Polyurethane Foam: Expansive Soil Stabilization. *Polymers,* 2021. *13*(8), 1335.,

Mohamed Jais IB. Rapid remediation using polyurethane foam/resin grout in Malaysia. Geotechnical Research . 2017. 4(2):107-117.

Mohammed Al-Bared MA, Marto. A review on the geotechnical and engineering characteristics of marine clay and the modern methods of improvements. Malaysian Journal of Fundamental and Applied Sciences. 2017. 13(4):825-831.

Shafiq, Aniqa, Shaharudin. An Acoustic Study OF Shorea leprosula Wood Fiber Filled Polyuretane Composite Foam, 2017. *22*(6), 1031–1039.

Shinko, Amika. Introduction to Mechanical Recycling and Chemical Depolymerization. In Recycling of Polyurethane Foams. 2018. 45-55.

Murmu AL, Jain A, Patel. Mechanical properties of alkali activated fly ash geopolymer stabilized expansive clay. KSCE Journalof Civil Engineering. 2019. 23(9):3875-3888.

Mogha. Hybrid polyurethane nanocomposites reinforced with clay and multiwalled carbon nanotubes: Synthesis and characterization. 2020.

Nawghare, S. M., & Mandal, J. N. Effectiveness of expanded polystyrene (EPS) beads size on fly ash properties. International Journal of Geosynthetics and Soil Engineering, 2020. 6(1), 1-11.

Nian Tiwari, Jiao H, Fan N, Guo. Microstructure analysis on the dynamic behaviorof marine clay in the South China Sea. Marine Georesources & Geotechnology. 2019. 1-14.

Nitin Tiwari, Satyam, N., & Shukla. An experimental study on micro- structural and geotechnical characteristics of expansive clay mixed with EPS granules. *Soils and Foundations*, 2020. *60*(3), 705-713.

Özer AT, Akay O. Interface shear strength characteristics of interlocked EPS-Samples Geofoam. J Mater Civ Eng. 2015. 28(4):04015156

Indiramma, C. Sudharani, and S. Needhidasan. Utilization of fly ash and lime to stabilize the expansive soil and to sustain pollution free environment-An experimental study. 2018.

Past, P. F., Gama, N. V, Ferreira, A., & Barros-timmons. Polyurethane Foams: Past, Present, and Future. 2018.

Phetchuay C, Horpibulsuk S, Arulrajah A, Suksiripattanapong C, Udomchai A. Strength development in soft marine clay stabilized by fly ash and calcium carbide residue based geopolymer. 2019. 127(128):134-142.

Chenari, B. Fatahi, A. Ghorbani. Evaluation of strength properties of cement stabilized sand mixed with EPS beads and fly ash. *Geomechanics and*

Engineering, 2018. vol. 14, no. 6, pp. 533–544.

Ragab, A. A., & Mohammedy. Simple preparation method of asphalt polyurethane foam for various insulating purposes. *Egyptian Journal of Petroleum.* 2020

Ramesh S, Punithamurthy. The effect of organoclay on thermal and mechanical behaviours of thermoplastic polyurethane nanocomposites. Digest Journal of Nanomaterials and Biostructures. 2017. 12(2):331-338

Ragaert, K., Delva, L. and Geem. Mechanical and chemical recycling of solid plastic waste. 2017.25-34.

Reza Chenari, R. J., Fard, M. K., Maghfarati, S. P., Pishgar, F., & Machado. An investigation on the geotechnical properties of sand–EPS mixtureusing large oedometer apparatus. *Construction and Building Materials*, 2016. *113*,773-782.

Salas, M.A., Perez-Acebo. Introduction of recycled polyurethane foam in mastic asphalt. Gradevinar. 2018. 70 (5).

Salas, M.A., Perez-Acebo, H., Calderon, V., Gonzalo-Orden, H., (2018). Bitumen modified with recycled polyurethane foam for employment in hot mix asphalt. Ing. Invest. 38 (1).

Saleem, J., Adil, M., & Mckay, G. (2018). Oil sorbents from plastic wastes and polymers: A review. *Journal of Hazardous Materials*, *341*, 424–437.

Saleh S, Asmawisham Alel MN, Mohd Yunus NZ, Ahmad K, Ali N, Abang Hasbollah DZ, Asnida Abdullah R (2019a) Geochemistry characterisation of marine clay. IOP Conference Series: Materials Science and Engineering 527:012023,

Saleh, Mohd Yunus N Z, Ahmad. Stabilization of Marine Clay Soil Using Polyurethane, *MATEC Web Conf. . 2018.* 250 01004

Saleh, Mohd Yunus NZ, Ahmad K, Ali. Improving the strength of weak soil using polyurethane grouts: A review. Construction and Building Materials. 2019. 202:738-752.

Saleh, Ahmad K, Mohd Yunus N Z and Hezmi M A. Evaluating the toxicity of polyurethane during marine clay stabilization *Environ. Sci. Pollut.Res.* 2020. 27 21252–21259

Saleh, Mohd Yunus N Z, Ahmad K, Ali N and Marto. Micro-Level Analysis of Marine. 2020

Shaharuddin Kormin, A. Z. M. R. Liquefaction of Oil Palm Fruit Waste and Its Application for The Development of Polyurethane Foams. 2018.

Sheng, X., Wang, M., Xu, T., Chen, J. Preparation, properties and modification mechanism of polyurethane modified emulsified asphalt. Construct. Build. Mater. 2018. 189, 375e383

Sidek N, Bakar I A A, Azman A A, Rahman A S A and Austin W A. Strength Characteristic of Polyurethane with Variation of Polyol to Isocyanate Mix Ratio: A Numerical Analysis *IEEE 2nd International Conference on Automatic Control and Intelligent Systems.* 2017. pp 31–34

Silva, A. L. P., Prata, J. C., & Walker, T. R. Rethinking and optimising plasticwaste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. 2020.

Simón, D.; Borreguero, A.M.; de Lucas, A.; Rodríguez. Recycling of polyurethanes from laboratory to industry, a journey towards the sustainability. 2018.

Sojobi, A.O., Nwobodo, S.E., Aladegboye, O.J. Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete. Cogent Engineering. 2016. 3 (1), 1133480

Sun, M., Zheng, M., Qu, G., Yuan, K., Bi, Y., Wang, J. Performance of polyurethane modified asphalt and its mixtures. 2018. 191,386e397.

Syahril, Somantri, A. K., & Febriansya. The effect of EPS addition to soilstabilized with fly ash as lightweight fill materials for embankment construction. In *Journal of Physics: Conference Series . 2019.* Vol. 1364, No. 1, p. 012077.

Taciroğlu, M. V., Ergezer, F., Baykal, T., Eriskin, E., & Terzi. Investigationof waste quartz sand as filler in hot-mix asphalt. *Construction and Building Materials*. 2022. *342*, 128004.

Valentino R, Stevanoni. Behaviour of reinforced polyurethane resin micropiles. Proceedings of the Institution of Civil Engineers - Geotechnical Engineering. 2016. 169(2):187-200.

Wei, Kong, Liu, Chen, Kanungo, Lan, Jiang, Shi. Effect of sisal fiber and polyurethane admixture on the strength and mechanical behavior of sand. *Polymers.* 2018

Wei Y, Wang F, Gao X, Zhong Y. Microstructure and fatigue performance of polyurethane grout materials under compression. Journal of Materials in Civil Engineering. 2017. 29(9):04017101.

Wu, S., & Montalvo, L. Repurposing waste plastics into cleaner asphalt materials : A critical literature review. *Journal of Cleaner Production*. 2021. *280*, 124355.

Yang Z, Zhang X, Liu X, Guan X, Zhang C, Niu Y. Flexible and stretchable polyurethane/waterglass installation material. Construction and Building Materials. 2017. 138:240-246.

Yu, R., Zhu, X., Zhang, M., Fang, C. Investigation on the short-term aging resistance of thermoplastic polyurethane-modified asphalt binders. Polymer. 2018. 10 (11), 1189.

Zhang M, Zhao M, Zhang G, Sietins JM, Granados-Focil S, Pepi MS, Xu Y, Tao M. Reaction kinetics of red mud-fly ash based geopolymers: Effects of curing temperature on chemical bonding, porosity, and mechanical strength. Cement and Concrete Composites. 2018. 93:175-185.

Zhang, Y., Xiao, R., Jiang, X., Li, W., Zhu, X., & Huang, B. Effect of particlesize and curing temperature on mechanical and microstructural properties of waste glass-slag-based and waste glass-fly ash-based geopolymers. *Journal of Cleaner Production*, 2020. *273*, 122970.

Zhao, F., Hu, J., Yang, D., Kuang, Y., Xiao, H., Zheng, M., & Wang, X. Studyon the Relationship between Pore Structure and Uniaxial Compressive Strength of Cemented Paste Backfill by Using Air-Entraining Agent. *Advances in Civil Engineering*, *2021*.

Zhou N, Ouyang S, Cheng Q, Ju F. Experimental study on mechanical behaviorof a new backfilling material: Cement-treated marine clay. Advances in Materials Science and Engineering. 2019.:1-8

Zhou Z, Du X and Wang S. Strength for Modified Polyurethane with ModifiedSand *Geotech.Geol. Engineering*. 2018. 36 1897–906

LIST OF PUBLICATION

i. Aida Atiqah Atil, Nik Normunira Mat Hassan, Fernandez Anak Julius Tungkiong, Tengku Nur Azila Raja Mamat, Fatimah Mohamed Yusop, Abdul Mutalib Leman1, Izuan Amin Ishak, Najibah Abd Latif, Adyla Illyana Roseli (2021) Physical Properties of Flexible Polyurethane waste as filler by difference Preparation Method, ICME 21, International Conference On Mechanical & Engineering.

ii. Aida Atiqah Atil, Nik Normunira Mat Hassan,Adyla Illyana Roseli, Fatimah Mohamed Yusop, Anika Zariah Mohd Rus, Noraini Marsi, Tuan Noor Hasanah Tuan Ismail, Nur Faezah Yahya (2022). Effect of Buoyancy, Compressive Strength, and Shear Strength of Polyurethane-Clay Composite (PU-CC) Doped with Polyurethane Filler Waste in Soft Clay Application, ICME Tech 2022. Journal of Advanced Research in Applied Sciences and Engineering Technology 31, Issue 3 (2023) 106-114. ISSN: 24621943

iii. Aida Atiqah Atil , Nik Normunira Mat Hassan , Fatimah Mohamed Yusop , Anika Zafiah M. Rus , Abdul Mutalib Leman , Noraini Marsi and Nor Afzanizam Samiran (2021). Preliminary Study On Different Materials Of Geogrid By Using Finite Element Model, Journal of Physics: Conference Series 1, ISBN:17426588.

iv. Aida Atiqah Atil , Nik Normunira Mat Hassan, Adyla Illyana Roseli , Fatimah Mohamed Yusop, Anika Zafiah Mohd Rus, Noraini Marsi, Tuan Noor Hasanah Tuan Ismail and Nur Faezah Yahya. Physical Characterization of Polyurethane-Clay Composite Doped With Treated and Untreated PU Waste as Filler for Subgrade Layer Applications. Malaysian Construction Research Journal (MCRJ). ISSN: 1985-3087.

v. Nik Normunira Mat Hassan, Aida Atiqah Atil, Adyla Illyana Roseli, Tengku Nur Azila Raja Mamat, Fatimah Mohamed Yusop, Anika Zafiah Mohd Rus, Noraini Marsi, Nurulsaidatulsyida Sulong, Hafsa Mohammad Noor (2022) Chapter 8:

Determination Of Vibration Transmissibility On Slab Track-Bridge Lrt Railway Structure, Multidisciplinary Engineering Science And Advanced Technology Series 1, UTHM , 81, ISBN:9789672817406.

vi. Aida Atiqah Atil, Nik Normunira Mat Hassan, Fatimah Mohamed Yusop, Anika Zafiah Mohd Rus, Noraini Marsi, Razlin Abdul Rashid, Tuan Noor Hasanah Tuan Ismail, Nurul Saidatul Syida Sulong and Hafsa Mohammad Noor (2021) Chapter 2. A Review Study On Pre-Treatment Method For Recycling Polymer Waste, Recycling Of Municipal Solid Waste (Msw) As A Resource For Bioproducts Development, UTHM , 19, ISBN:9789672817109.

viii. Adyla Illyana Roseli, Nik Normunira Mat Hassan, Nofrizalidris Darlis, Mohd Nazrul Roslan, Hafsa Mohammad Noor, Najibah Abd Latif, Aida Atiqah Atil (2021) Chapter 9: A Review On Treatment Method Of Natural Fibre As A Polyurethane Composite Filler, Construction Material And Technology Series4, UTHM , 101, ISBN:9789672817055.

VITA

The author was born on March 1st, 1995, in Segamat, Johor. She first obtained her Diploma in Mechanical Engineering, located in Kuantan, Pahang. She further pursued his bachelor's degree and master's degree at the same university which is Universiti Tun Hussein Onn Malaysia (UTHM),Pagoh, Johor, and graduated with the B.Eng. (Hons) in Mechanical Engineering Technology (Plant) and M.Eng in Mechanical Tehnology respectively.