SEWAGE SLUDGE AND RED GYPSUM COMPOSITE APPLICABILITY AS ALTERNATIVE MATERIALS FOR INTERMEDIATE LANDFILL COVER

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by

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LIST OF SYMBOLS

		Unit
a	Cross-sectional area of standpipe	cm^2
A	Cross-sectional area o sample	cm^2
C_u	Uniformity coefficient	-
C_c	Curvature coefficient	-
d	Spacing between the planes for XRD	-
D_c	Degree of compaction	-
DO_{Bf}	Final Dissolved oxygen of blank	mg/L
DO_{Bi}	Initial Dissolved oxygen of blank	mg/L
DO_{Sf}	Final Dissolved oxygen of sample	mg/L
DO_{Si}	Initial Dissolved oxygen of sample	mg/L
h	Head difference	mL
h_0	The water level at t is zero	mL
h_t	The water level at the time, t	mL
λ	Wavelength of Xray	-
k	Coefficient of hydraulic conductivity	cm/s
L	Length of sample	cm
L_0	Length of the sample before drying	cm
L_D	Length of the sample after drying	cm
m	Mass	g
n	Order of diffraction	-
n	Number of pores	-
η	Porosity	%
P	Dilution factor	-
ρ	Density	g/cm^3
ρ_d	Dry density	g/cm^3
ρ_{dmax}	Maximum dry density	g/cm^3
ρ_{ds}	Density of particles	g/cm^3
S	Standard deviation	-
S_w	Weight of sample before drying	g
S_D	Weight of sample after drying	g
t	Time interval	s
V	Volume	m^3
x	Pore size	mm
$\bar{x}$	Average pore size	mm
γ_{dmax}	Maximum dry weight	g/cm^3

LIST OF ABBREVIATIONS

ASR	Activated Sludge Reactor
Al	Aluminium
B	Bentonite
BOD	Biochemical Oxygen Demand
C	Cement
CH	Portlandite
CH_4	Methane
C_2S	Belite
C_3S	Alite
CSH	Calcium Silicate Hydrate
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
CP	Coir Pith
CS	Construction Sludge
Ca	Calcium
Cu	Copper
DW	Distilled Water
FA	Fly Ash
FAS	Ferrous Ammonium Sulphate
Fe	Iron
HC	Hydraulic Conductivity
HL	Hydrated Lime
IO	Inorganic
ICP	Inductively Couple Plasma
L	Lime
LL	Liquid Limit
LOI	Loss on Ignition
MDD	Maximum Dry Density
N	Nitrogen
NH_3-N	Ammoniacal Nitrogen
NSWD	Natural Solid Waste Department
OMC	Optimum Moisture Content

P	Phosphorus
PI	Plasticity Index
PL	Plastic Limit
PMS	Paper Mill Sludge
Pb	Lead
QL	Quicklime
RG	Red Gypsum
RAS	Return Activated Sludge
S	Sulphur
SAC	Sulphoaluminate Cement
SEM	Scanning Electron Microscopy
Si	Silica
SL	Synthetic Leachate
SMW	Stone Material Waste
SS	Sewage Sludge
SSA	Sewage Sludge Ash
TC	Tire Chips
TDA	Tire Derived Aggregate
UCS	Unconfined Compressive Strength
VOA	Volatile Organic Acid
WAS	Waste Activated Sludge
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
Zn	Zinc

LIST OF APPENDICES

KEBOLEHLAKSANAAN KOMPOSIT SISA KUMBAHAN DAN GIPSUM MERAH SEBAGAI BAHAN ALTERNATIF UNTUK PENUTUP PERANTARA TAPAK KAMBUS TANAH

ABSTRAK

Penggunaan tanah sebagai penutup kambus tanah adalah tidak mampan dari segi ekonomi dan tidak lestari kepada persekitaran. Tambahan, tanah tersebut boleh digunapakai untuk tujuan lain seperti pertanian dan pembinaan. Kajian terdahulu telah menggunakan sisa kumbahan dan abu terbang untuk menggantikan tanah sebagai penutup kambus tanah, tetapi kebanyakannya adalah untuk kawasan yang menerima hujan sederhana. Kajian ini cuba untuk menggunakan sisa kumbahan (SS) dan gipsum merah (RG) sebagai bahan komposit penutup kambus tanah, berbanding pelupusan di tapak kambus tanah terkawal sebagai amalan semasa di Malaysia ketika ini. Kajian ini melibatkan penyiasatan rekabentuk campuran yang optimum berdasarkan kekonduksian hidraulik (k), kekuatan mampatan tidak terkurung (UCS) dan indeks keplastikan (PI), termasuk juga meneliti peranan SS dan RG dalam komposit. Kajian ini juga menyiasat kesan pemadatan ke atas komposit dari segi k, UCS dan tingkah laku lesapan. Sisihan piawai dan bar ralat dibuat pada setiap bacaan serta analisis regresi dilakukan untuk mengkaji perkaitan antara parameter menggunakan perisian Minitab 17. Ujian turus menggunakan kaedah turus tetap telah dilakukan dengan mengalirkan air suling (DW) atau cecair sintetik larut lesap (SL) melalui komposit yang telah dipadatkan kepada 60, 70, 75, 80 dan 85 % secara berat. Kualiti cecair larut lesap dari segi pH, BOD, COD, Cu, Fe dan Zn telah dipantau pada hari yang telah ditentukan terlebih dahulu. Komposit SS:RG bernisbah 1:1, yang juga merujuk kepada Ca:Si bernisbah 2.5:1, adalah nisbah yang paling ideal untuk pembentukan kalsium

silika terhidrat (CSH), dengan merekodkan UCS sebanyak 520 kPa, k pada 10^{-5} cm/s dan PI pada 28.5 %, dan sesuai untuk digunakan sebagai penutup kambus tanah. Ciri-ciri keplastikan adalah disebabkan pengaruh penggumpalan oleh ferum (Fe) dalam RG yang membolehkan pembentukan agregat mikro. Tahap pemadatan adalah berkadaran terus dengan keliangan awal, tetapi, tidak mempengaruhi k bagi DW. Walau bagaimanapun, k menunjukkan perbezaan pada 75 % pemadatan apabila SL melalui komposit. k menunjukkan penurunan dalam tiga peringkat; dua peringkat pertama adalah didominasikan oleh penyusunan semula partikel dan penghidratan oleh CSH, diikuti oleh pengstabilan k di peringkat ketiga. Penurunan k adalah satu magnitud lebih pantas apabila dilalukan dengan SL, disebabkan oleh pemerangkapan mendakan logam berat di antara matrik CSH. Komposit tidak menunjukkan sebarang potensi untuk mencemarkan alam sekitar dan pemadatan pada tahap 75 % dapat mengurangkan kepekatan larut lesap sebelum memasuki sistem rawatan larut lesap. Pemadatan minimum 80 % adalah disyorkan untuk operasi di tapak kambus tanah. Hasil penemuan dari kajian ini sangat berguna sebagai rujukan untuk penghasilan komposit alternatif untuk penutup tapak kambus tanah di kawasan tropikal seperti Malaysia.

SEWAGE SLUDGE AND RED GYPSUM COMPOSITE APPLICABILITY AS AN ALTERNATIVE MATERIALS FOR INTERMEDIATE LANDFILL COVER

ABSTRACT

Application of soil as landfill cover is not economical nor environmentally sustainable; instead, soil can be more beneficial in agricultural and construction sectors. Past studies replaced soil as landfill cover with waste such as sewage sludge and fly ash, primarily for application in a temperate climate. This study attempts to apply sewage sludge (SS) and red gypsum (RG) as a composite for landfill cover, which is currently disposed of as scheduled waste in secured landfills in Malaysia. The study investigated the optimum design mix based on the characterization of hydraulic conductivity (k), unconfined compressive strength (UCS) and plasticity index (PI), as well as scrutinizing the role of SS and RG in the composite. The study also examined the effect of compaction on the characteristics of composite in terms of k, UCS and leaching behaviour. The standard deviation and error bar was reported for the measurement, and regression analysis was conducted to study the correlation between parameters using Minitab 17 software. A series of column test using the constant head method was carried out by percolating distilled water (DW) or synthetic leachate (SL) through composites compacted to 60, 70, 75, 80 and 85 % by weight. The leachate quality was monitored at pre-determined days for pH, BOD, COD, Cu, Fe and Zn. The SS:RG composite of 1:1 corresponds to Ca:Si ratio of 2.5:1 was found ideal for calcium silicate hydrate (CSH) formation, recorded a UCS of 520 kPa, k of 10^{-5} cm/s, and PI of 28.5 %, favourable for application as landfill cover. The plastic behaviour was attributed to the coagulating performance of iron (Fe) in RG, contributing to the

micro-aggregation in the composite. The degree of compaction was linearly correlated with initial porosity but did not affect k in the case of DW. However, k changed at 75 % when SL percolated through the composite. The k decreased in three stages; the first two stages were predominated by the rearrangement of particles and hydration of CSH, followed by stabilization of k in the third stage. The faster reduction of k by about one magnitude order in the case of SL was attributed to the entrapment of heavy metal precipitated within the matrices of CSH gel. The composite did not exhibit potential environmental pollution, and compaction at 75 % reduced the strength of leachate for the receiving leachate treatment system. This study recommended a minimum of 80 % compaction for a landfill operation. These findings will be a useful reference for developing alternative composite for landfill cover in tropical climates, such as Malaysia.

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Landfilling remains the main method of waste disposal to date in Malaysia. Based on National Solid Waste Department (NSWD), there are 146 of 296 landfills in Malaysia active as of 2019. A significant amount of earthen materials is being used as landfill covers to control odours, vectors, fires, litter and scavenging and to minimize the emissions of landfill gas into the atmosphere and vertical infiltration of water into waste, which subsequently control the leachate yield (Vinitha et al., 2019; Aziz et al., 2016; Travar et al., 2015). Generally, there are three types of landfill cover, namely daily cover, intermediate cover and final cover. Each type of cover have different function and required different thickness of soil.

Malaysia is generating about 10 million tonnes of sewage sludge per year (Zakaria et al., 2015) from the existing 3 million wastewater treatment facilities that are in operation (SPAN, 2019). Besides that, the sludge is also generated from the existing communal septic tank, which requires desludging every 2 to 5 years. The facilities to treat and dispose of this sludge are limited, and currently, sewage treatment plants with excess capacity are being used to treat septic tank sludge as temporary means. Most of the sludges are dumped at secured landfills because it is still considered the cheapest option being practised by most of the existing wastewater treatment plant operators (Roslan et al., 2013). Modern sludge treatment facilities are only available at the recent plant; nevertheless, the dried sludge is still sent to landfills as a final disposal route.

1.2 Problem statement

Every landfill cover layer typically consists 6 to 12 inches of earthen materials (Vallero and Blight, 2019; NSWEPA, 2015), which makes up about 25 % of total landfill volume (Ng and Lo, 2007). The majority of landfill sites in Malaysia have inadequate soil cover, which makes the sanitary condition of the landfill inferior (MHLG, 2004). For landfills where suitable soil is insufficient, there is a need to transport suitable soil from an off-site source which increases the price of the soil and the risk of erosion at the off-site source. This practice is not economically and environmentally sustainable, and therefore motivated the study for alternative landfill cover materials to conserve the natural resources.

There have been many studies conducted to find alternative materials for landfill cover, in which sewage sludge is one of the common waste materials used (Fan et al., 2019a; Balkaya, 2019; Fan et al., 2019b; Vinitha et al., 2019; He et al., 2015a; Na, 2015; Li et al., 2014). Sewage sludge is classified as scheduled waste, SW204 under Schedule 1, in the EQA 1974 (ILBS, 2019) because it contains one or several metals, including copper, zinc, chromium, nickel, lead, cadmium, aluminium and tin. Therefore, it is required to be incinerated and disposed to secured landfills (Roslan et al., 2013; Bradley and Dhanagunan, 2004). This method is not economically and environmentally sustainable, considering Malaysia is producing an estimated 10 million tonnes of sewage sludge in 2020 (Zakaria et al., 2015). Therefore, it is worth considering sewage sludge as an alternative material for landfill cover as it will address issues of soil scarcity and optimize the filling of the landfill, as well as a potential financial offset for premises to the sewage sludge disposal. The government is now aiming to reclassify sludge as non-scheduled waste. It is anticipateded that Malaysia