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SHEAR AND COMPRESSION BEHAVIOUR OF CRUSHED MUDROCKS IN MALAYSIA

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By

ILI SYAZWANI BINTI CHE MOHD ROSLEY

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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March 2019

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Faculty : Engineering

Mudrocks is a type of rock that tends to deteriorate upon exposure to water. Studies have found mudrocks to be in low to medium durability in which its shear strength and compressibility were easily influenced by its resistance towards wetting and drying. However, in Malaysia, it is difficult to avoid mudrocks from exposure to water due to the tropical climate. When mudrocks were encountered on construction sites, they were often been excavated however, it is not a sustainable solution. Thus research on shear and compression behaviour of crushed mudrocks with detailed explanations on morphological changes that relate with mineralogical and chemical composition is required before suitable stabilisation or any advance solutions on working out crushed mudrocks as geotechnical material could be carried out. Hence this research implied direct shear tests, XRD, XRF and VPSEM to evaluate the shear and compression behaviour of crushed mudrocks in Malaysia. This study was conducted onto mudrocks in Malaysia from Putrajaya, Semanggol (Perak) and Durian Tunggal (Melaka). The materials were named as CM1, CM2, and CM3 respectively. These crushed mudrocks predominantly contained of swelling clays where CM1 contained 38.2%, CM2 contained 35.1% and CM3 contained 58% of swelling clays respectively. Three types of slaking tests were carried out; jar slake test, slake durability test, and slaking immersion test. Based on the results, CM2 was the most durable, followed by CM1 and lastly CM3. This pattern of sequence agrees with swelling clay minerals contents but went inversely with total mica contents in which CM2 has the highest with 34.7%, followed by CM1 with 29.4% and lastly CM3 with 25%. Shear and compression behaviour of crushed mudrocks were investigated at various compaction degree, various initial moisture content, and various terms of immersion in which the tests were accompanied with staged-loading process using direct shear box test. Higher compaction degrees caused crushed mudrocks to exhibit highest peak shear strength in

which decrease of subsequent 5% compaction degrees had caused 11% to 12% peak shear strength reduction and 2% compression to take place. Due to increment of initial moisture content from natural to optimum, peak shear strength of crushed mudrocks increased by 4.4% to 6.9% with reduced brittleness and about 0.6% to 1.2% compression took place since early loading stage. Upon immersions, direct shear tests revealed that all crushed mudrocks failed in brittle deformation when without immersion. Short term immersion had intensified crushed mudrocks brittle behaviour with peak shear strength reduction of 15% for CM1 and CM2, and 42% for CM3. Long term immersion, on the other hand had caused only 3% strength reduction with fully plastic straining behaviour after failure. In addition, short term immersion caused immediate compression of about 3% to crushed mudrocks while long term immersion caused CM1 and CM2 to show progressively reduced compression, and CM3 to show progressive compression along staged-loading process.VPSEM images shown that vigorous micro activities that took place during short term immersion had led to strength reduction and high compressibility of mudrocks while long term immersion had enabled prolonged micro-activities hence resulted into higher peak shear strength than that of recorded by short term immersion. As a result, micro flaws; micro holes, micro fracture and micro cracks were seen from VPSEM images of mudrocks after short term immersion. The micro flaws had caused mudrocks to experience strength reduction and high compression. However the micro flaws were seen resealed after long term immersion as prolonged micro activities had promoted healing to the flaws. Interestingly, these micro activities were able to occur due to presence of swelling clay minerals which seem to have increased aggregate’s ability to absorb water and to weave with each other. This study hence found that mudrocks are not only sensitive to moisture changes but to sudden moisture changes as pictured through short term immersion while pre-wetting effect through long term immersion had reduced mudrocks sensitivity towards moisture changes throughout staged-loading.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TINGKAHLAKU RICIH DAN MAMPATAN MUDROCKS TERHANCUR DI MALAYSIA

Oleh

ILI SYAZWANI BINTI CHE MOHD ROSLEY

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Mudrocks adalah sejenis batuan yang mudah merosot apabila terdedah kepada lembapan. Kajian telah banyak mendapati bahawa *mudrocks* berada dalam kelas ketahanan rendah ke sederhana di mana kekuatan ricih dan kemampatannya mudah dipengaruhi oleh daya rintangan *mudrocks* terhadap pembasahan dan pengeringan. Di Malaysia, ianya amat sukar untuk menghalang *mudrocks* daripada pendedahan kepada air oleh kerana cuaca tropikal di Malaysia iaitu panas dan hujan sepanjang tahun. Oleh itu, *mudrocks* digali dan dibuang dari tapak pembangunan. Namun, ini bukanlah suatu penyelesaian lestari. Maka kajian tentang tingkahlaku ricih dan mampatan *mudrocks* terhancur yang disokongi ileh penerangan perubahan morfologi bersertakan pengetahuan kandungan mineral dan kimia adalah diperlukan. Ini adalah bagi membolehkan kajian tentang kaedah penstabilan bersesuaian untuk dijalankan ke atas *mudrocks* dan seterusnya boleh melestarikan *mudrocks.* Kajian ini menggunakan ujian ricih terus, pembiasan x-ray (XRD), pendaflouor x-ray (XRF) dan ujian pengesanan imbasan mikroskop pelbagai tekanan (VPSEM) untuk menilai tingkahlaku ricih dan mampatan *mudrocks* terhancur di Malaysia. *Mudrocks* yang dikaji diambil dari Putrajaya, Semanggol (Perak) dan Durian Tunggal, Melaka yang dilabel sebagai CM1, CM2, dan CM3. Sampel-sampel *mudrocks* ini masing-masing mengandungi mineral tanahliat membengkak sebanyak 38.2%, 35.1%, dan 58% *Mudrocks* ini diuji ketahannnya melalui tiga jenis ujian kehancuran iaitu ujian kehancuran balang, ujian kehancuran dan ketahanan, dan ujian rendaman kehancuran. Menurut keputusan yang diperolehi, CM2 menunjukkan ketahanan paling tinggi, diikuti oleh CM1 dan CM3. Turutan ini dilihat selari dengan kandungan mineral tanahliat membengkak yang diperolehi melalui XRD tetapi terbalik dengan kandungan mica di mana CM2 mempunyai kadungan jumlah mica tertinggi dengan 34.7%, diikuti dengan CM1 sebanyak 29.4%, dan CM3 sebanyak 25%.Tingkahlaku ricih dan

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mampatan pula dikaji pada darjah padatan yang berbeza, kandungan lembapan awalan berbeza, dan penggal rendaman berbeza. Didapati bahawa darjah padatan yang lebih tinggi mempamerkan kekuatan ricih puncak yang lebih tinggi dan penurunan 5% darjah padatan menyebabkan penurunan kekuatan ricih puncak sebanyak 11% ke 12% dan 2% mampatan direkodkan. Apabila kandungan lembapan awalan meningkat daripada asli ke optimum, kekuatan ricih puncak meningkat sebanyak 4.4% ke 6.9% manakala mampatan menungkat sebanyak 0.6% ke 1.2% di peringkat awal bebanan. Ujian ricih rendaman pendek menyebabkan kerapuhan *mudrocks* makin jelas dengan penurunan nilai kekuatan ricih puncak sebanyak 15% bagi CM1 dan CM2, dan 42% bagi CM3. Manakala selepas ujian ricih rendaman panjang pula, kerapuhan tersebut hilang dan menyebabkan penurunan nilai kekuatan ricih puncak sebayak 3% sahaja. Malahan, selepas gagal, tingkahlaku terikan penuh plastic dapat diperhatikan. Ujian ricih rendaman pendek juga telah menyebabkan kenaikan nilai mampatan serta merta sebanyak 3% sebaik sahaja rendaman bermula ujian ricih rendaman panjang pula member kesan yang berbeza; CM1 dan CM2 telah menunjukkan penurunan mampatan secara beransur manakala CM3 menunjukkan mampatan sekata sepanjang proses bebanan berperingkat itu. Imej imbasan VPSEM menunjukkan bahawa ujian ricih rendaman pendek menyebabkan aktiviti mikro berlaku dengan cepat dan banyak pada masa rendaman yang pendek. Ia telah menyebabkan kekuatan ricih berkurang dan *mudrocks* mudah menerima mampatan manakala selepas ujian ricih rendaman panjang, aktiviti mikro dapat berlaku dalam masa yang lebih lama sambil dibebani oleh beban-beban berikutnya. Berdasarkan pemerhatian, cela mikro yang terlihat pada *mudrocks* selepas rendaman pendek telah ditutupi setelah rendaman panjang. Menariknya, aktiviti mikro ini boleh terjadi kerana kehadiran mineral tanahliat membengkak di mana kehadiran mineral-mineral ini telah meningkatkan kebolehan *mudrocks* dalam menyerap air lalu membolehkan jalinan antara aggregat. Jadi melalui kajian ini, *mudrocks* didapati bukan sensitif kepada perubahan lembapan tetapi ianya sensitif terhadap perubahan lembapan secara mengejut yang digambarkan melalui ujian ricih rendaman pendek. Sebagai inferens, ujian ricih rendaman panjang telah membuktikan sensitiviti *mudrocks* terhadap perubahan lembapan berkurang apabila direndam dan dibebani secara berperingkat.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and materials
BS	British Standard
C	Cohesion
CBR	Claifornia bearing ratio
Cc	Coefficient of curvature
Cu	Coefficient of uniformity
CM	Crushed mudrocks
E	Void ratio
EDX	Energy dispersive x-ray
ED-XRF	Energy dispersal x-ray fluorescence
EPMA	Electron microprobe analysis
ESEM	Environmental scanning electron microscopy
FESEM	Field emission scanning electron microscopy
I_d	Slake durability index
OM	Optical microscopy
PI	Plasticity index
SEM	Scanning electron microscopy
USCS	Unified Soil Classification system
VPSEM	Variable pressure scanning electron microscopy
W	Moisture content
WD-XRF	Wavelength dispersal x-ray fluorescence
w_L	Liquid limit
w_{nat}	Natural moisture content
w_{opt}	Optimum moisture content
w_p	Plastic limit
XRD	X-ray diffraction
XRF	X-ray fluorescence
γ_{dmax}	Maximum dry density
Δ	Shear displacement
E	Compressive settelement (strain)
σ’	Shear strength
Φ	Friction angle

CHAPTER 1

INTRODUCTION

1.1 Research background

Mudrocks are sedimentary rocks that are very sensitive to changes in moisture content. It has a great tendency to slake when contacted with water. Mudrocks are also often categorized as problematic rocks by researchers (Yagiz 2001; Bell and Survey 2005; Adewuyi and Festus 2015) and has given rise to numerous construction problems. Mudrocks, including all the subgroups it hold; siltstone, claystone, mudstone, and shale are enlisted as problematic geo-material due to low durability and its high clay mineral content. Due to that, mudrocks have been remarked by researchers as a type of rock that has a great tendency to deteriorate when in contact with water (Olivier and Yagiz, 2001; Yoshida *et. al.*, 2002).

Aforetime, Franklin and Chandra (1972) reported that in India, mudrocks were instantaneously rejected the second it is found in construction area, even as subgrade material. Upon acceptation, many construction problems that occurred including slope failure, embankment failure, and road settlements were found to have been related to mudrocks' behaviour (Sharma, 2013). Also, Putra and Kikumoto (2016) stated that mudrocks often deposed as waste disposal due to mudrocks behaviour when exposed to water. The term `behaviour' connotes the high clay mineral content which had been regarded as key factor that influenced mudrocks water absorption (Na *et al.*, 2014) and hence water been described as a harmful role for mudstone's stability (Jiang *et al.*, 2014). Relatively, Koralegedara and Maynard (2017) found that in absence of swelling clay minerals, correlation between mudrocks mineralogy and its durability did not exist.

A threefold classification of mudrocks proposed siltstone comprising less than 25% clay fraction, claystone containing more than 40% clay fraction and mudstone restricted to the intermediate materials. The mudstone category can also refer to those rocks which would be difficult in the field to classify as either siltstones or claystones.

Classification of mudrocks depends on the grain size of the minerals making up the rock and whether or not the rock is fissile or non-fissile. Fissile or laminations are parallel layers less than 1 cm thick. Such laminations can be seen as differences in grain size of the clasts in different laminate, due to changes in current velocity of the depositing medium, or could be due to changes in the organic content and oxidation conditions at the site of deposition of the different layers. They often represent anisotropic over a

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range of length scales, which Horne (2012) claimed that at the microscopic level mudrocks often possess aligned clay platelets and low-aspect ratio horizontal pores.

Mudrocks are most abundant of all sedimentary rocks, constituting about 45% to 55% of stratigraphic sequences (Hajdarwish *et. al.,* 2006), thus they are often encountered in engineering construction. Mudrocks are widely found in various areas of construction such as, subgrade, base, aggregate and foundation (Aghamelu and Okogbue, 2011; Adewuyi and Festus, 2015; Maduka *et. al.,* 2016; Tuffour *et. al.,* 2016; Hartono *et. al.,* 2018). For instance, tertiary sedimentary soft rock namely mudstone, have been undertaken in many construction sites and is the most often encountered geologic material. According to Shima and Imagawa (1980), mudstone was also reported to have caused poor performance of highway embankment in Japan which required drastic measures due to an excessive pavement cracks, rutting, and longitudinal roughness. In addition, massive landslides occurred in central Hokkaido, Japan and Shiaolin, Taiwan were also related with mudrocks abundance in the area (Tsou *et. al.,* 2011; Yoneda *et. al.,* 2014). Also, Sakai and Nakano (2018) found that slaking progression of mudstone in embankment near Makinohara service area had caused failure. These failures were reported as the effect of mudrocks-water interaction whether it was triggered by earthquake or weathering.

Based on the problems stated, it is clear that mudrocks when expose to water will cause slaking and consequently result into reduction of mechanical strength. This study is aiming to evaluate the shear and compression behaviour of mudrocks in Malaysia when in different contact with water. There are numerous of past researches that have explained the shear and compression behaviour of mudrocks (Petley, 1999; Nygård and Gutierrez, 2002;Yoshida *et. al.,* 2004; Hajdarwish and Shakoor, 2006; Nahazanan *et. al.,* 2013; Li and Wong, 2015; Liu *et al.,* 2016). However, the explanations available are only in physical prospective whereby the analysis and description of the behaviour were based wholly on results obtained from physical testings. There are also a number of researchers that have studied mudrocks through microstructural investigation (Blatt and Schultz, 1976; Lashkaripour and Ghafoori, 2002; Hildenbrand and Urai, 2003; Jiang *et al*., 2014; Nooraiepour *et. al.,* 2017), however, the findings were mainly concerning the mineralogical alteration and mudrocks sensitivity towards moisture but not to what happen to mudrocks during the failure. The discussion and explanation on microstructural changes and the corresponding mechanism prior to its shear and compression behaviour is somehow lacking. This is because the studies that have been conducted on studying mudrocks shear and compression behaviour were mainly on degree of settlement that may be caused due to swelling behaviour of mudrocks and its brittle-ductile transition (Nygård *et. al.,* 2006; Amann *et. al.,* 2012; Farid, 2016; Yin *et. al.*, 2016). This study is hence point to describe shear and compression behaviour of mudrocks based on microstructural viewpoint

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observed through VPSEM images, mineralogical analysis from XRD analysis and chemical composition obtained from XRF analysis. The microstructural testing were carried out and analysed to infer the problem of mudrocks governed by results of physical testing carried out beforehand.

1.2 Problem statements

Mudrocks including mudstone, shale, siltstone and claystone which comprised of mud-sized particles are one of major geological features of Malaysia occurring widely in Sabah and some parts of Peninsular Malaysia. In Sabah, series of landslides occurred at Kampung Mesilou, Kundasang were reportedly triggered by Kinabalu earthquake and followed by heavy rainfall (Rahim *et. al.*, 2017). Also due to heavy rainfall, a landslide at forest reserve in Bukit Nanas, Kuala Lumpur occurred and it is found that the area was underlained by Kenny Hill Formation rock which comprised of sandstone, siltstone, and shale (Osman *et. al.*, 2014).

Meanwhile in other countries, mudrocks has been widely used in construction such as highway embankment, as subgrade material, base course, aggregate and fill material around the world (Yoshida *et al.,* 2002; Aghamelu and Okogbue, 2011). In UK and US for instance, crushed mudrocks were heavily used to backfill opencast coal mine (Nahazanan *et al.*, 2013). Most of the times an area of mudrocks were crossed by road schemes, embankments and engineered slope due to its abundance in Japan (Yoshida *et. al.*, 2002; Kimura *et al.*, 2010; Putra and Kikumoto, 2016; Nakano and Sakai, 2017). The main problem in utilizing mudrocks as the construction material is that they tend to deteriorate when in contact with water. According to Wang *et al.*(2015), the self-sealing property of mudrocks has led to their volume variation upon wetting. Mudrocks is a moisture sensitive materials that can change from a brittle crushable nature when dry to a ductile clay material when subjected to inundation (Nahazanan *et al*., 2013). The deterioration or softening with time after construction had resulted into shear strength reduction and high compressibility (Putra and Kikumoto, 2016; Sharma *et al.*, 2017) which had caused settlement of fill, slope instability, damages to road pavement and foundations. In spite of its poor engineering behaviour, mudrocks is extensively used because often there are no other sources of suitable and economical construction material available (Bryson *et. al.,* 2012). Studies on shear and compression behaviour of crushed mudrocks had been done on several countries by researchers (Kimura *et al.*, 2010; Aghamelu and Okogbue 2011; Nahazanan *et al.*, 2013; Sakai and Nakano 2018) however, studies on crushed mudrocks in Malaysia is lacking. The understanding on shear and compression behaviour of crushed mudrocks in Malaysia is important as Malaysia is a tropical country with tropical climate which exposed the crushed mudrocks to very dry season and heavy raining season. The exposure then increase crushed mudrocks susceptibility to fail in performing as industrial application such as subgrade or backfill material.

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Hence to understand the mechanism of the softening, disintegration and deterioration of mudrocks which took place during the failure due to shear and compression from morphological prospective is of a vital importance in order to understand the root problem upon the failure. Through the understanding, further study and measurements that should be taken in overcoming the microscopic problem could be conducted in future with the advancing technologies.

1.3 Aim and objectives

The overall aim of this research is to investigate the shear and compression behaviour of crushed mudrocks in Malaysia as civil engineering construction materials. The following measures were carried out to achieve the aim:

i. To study shear and compression behaviour of crushed mudrocks with various compaction degrees.
ii. To study shear and compression behaviour of crushed mudrocks with various initial moisture contents.
iii. To study shear and compression behaviour of crushed mudrocks with various terms of immersion.

1.4 Scope of work

This research is conducted to investigate the microstructural changes occured during which the mudrocks failed when dry and when subjected to different term of submersion. The materials of mudrocks were collected from Putrajaya, Melaka (Durian Tunggal) and Perak (Semanggol).

The study focuses on the geotechnical and geological properties of samples including clay content, clay mineralogy, moisture content, specific gravity, liquid limit, plastic limit and plasticity index. The samples obtained from the sites were crushed into aggregate form and were made sure to be well graded before been tested to further tests. The Proctor Compaction Test was performed to determine the relationship between dry density and optimum moisture content of crushed sample. All samples from the sampling sites were compacted to three different compaction degrees (90%, 95%, and 100%). All procedures of laboratory tests were carried out by following a standard from BS 1377 (1990). Crushed samples were then made ready to be tested with direct shear test.

Despite the standard direct-shear test, a staged compression-immersion-direct shear test was implied in this research from which not only its compressive behaviour but also shear strength change during staged loading and due to immersion can be evaluated. Each sample was tested under five

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different values of normal stresses by applying the loadings of 50 kPa, 100 kPa, 150 kPa, 300 kPa and 600 kPa. The five loadings were applied stage by stage, after settlement increment caused by each loading became negligible. Immersion was done onto samples to illustrate both short term immersion and long term immersion condition. Short term immersion is when the sample been immersed during the last stage (at 600 kPa loading) of the staged-loading process whilst long term immersion is when the sample been immersed since the second stage (at 100kPa loading) of staged-loading process. Detailed procedure is as described in Chapter 3.

Properties of mudrocks, such as durability, compressive strength, and shear strength were obtained and evaluated from the physical testing. Meanwhile, the mineralogical content, chemical composition, and morphological changes of the samples were analyzed and evaluated from XRD, XRF, and VPSEM.

1.5 Limitations of study

The crushed mudrocks used in this study were collected from Putrajaya, Semanggol (Perak), and Durian Tunggal (Melaka) in which the crushed mudrocks from the first two sampling sites were classified as mudstones while the other one was classified as claystone. The sampling works were limited to certain season (taken during April to May). This is to ensure the homogeneity of samples condition (not too dry and not too wet). Samples' crushing were conducted outdoor (due to lab's rule), was made sure to be conducted during right season too to reduce moisture escape. Moreover, due to limitation of the apparatus, it is recommendable that modification of the drum mesh is made as suggested by Heidari *et al.*(2015)

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