

PAPER • OPEN ACCESS

## Geotechnical properties of unprocessed soil from abandoned Mamut mine in Sabah, Borneo

To cite this article: J Makinda *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **708** 012021

View the [article online](#) for updates and enhancements.

### You may also like

- [Effect of Long-Distance Earthquake from Philippines and Sulawesi to Sabah Region](#)  
N S H Harith, F Tongkul, M I Adiyanto et al.
- [Probabilistic seismic hazard assessments of Sabah, east Malaysia: accounting for local earthquake activity near Ranau](#)  
Amin E Khalil, Ismail A Abir, Hanteh Ginsos et al.
- [Seismic vulnerability assessment in Kota Kinabalu, Sabah](#)  
V Jainih and N S H Harith



The Electrochemical Society  
Advancing solid state & electrochemical science & technology

242nd ECS Meeting

Oct 9 – 13, 2022 • Atlanta, GA, US

Abstract submission deadline: **April 8, 2022**

Connect. Engage. Champion. Empower. Accelerate.

**MOVE SCIENCE FORWARD**



Submit your abstract



# Geotechnical properties of unprocessed soil from abandoned Mamut mine in Sabah, Borneo

J Makinda<sup>1,2</sup>, K A Kassim<sup>1</sup>, C C Siong<sup>3</sup>, M U Zango<sup>1</sup> and A S Muhammed<sup>1</sup>

<sup>1</sup>School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia

<sup>2</sup>Faculty of Engineering, Universiti Malaysia Sabah, 88400, Kota Kinabalu, Sabah

<sup>3</sup>Faculty of Bioscience and Medical Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia

Corresponding author: jodin@ums.edu.my

**Abstract.** The issue related to the geotechnical stability of land mining area in Malaysia had become more critical after a strong earthquake struck Sabah, Borneo in 2015 centred in Ranau District where Mamut copper mine is located. As part of safety assessment and future planning, knowledge of soil characteristics in this risky area is necessary. This paper presents some findings on geotechnical properties of unprocessed soil obtained from the abandoned mine. Results found that Mamut soil can be classified as SW and has higher coarse-grained percentage (97.4%) compared to other copper mines elsewhere. The soil also has higher permeability ( $3.61 \times 10^{-3}$  m/s), lower organic content (0.15%), lower pH (4.53), higher specific gravity (2.75) and higher maximum dry density ( $1780 \text{ kg/m}^3$ ). Mamut soil is found to be cohesionless, while the angle of friction shows a variation with the relative compaction. Chemical analysis shows that  $\text{SiO}_2$  and  $\text{C}_{12}\text{H}_{10}\text{MgO}_6\text{S}_2$  are the two predominant compounds of the soil. Morphologically, Mamut soil appears to be composed of powdered and hardened particles with dark brown colour. They contain higher amount of irregular-shaped particles but well-rounded and spherical shapes are also observed. Smooth surfaces with no agglomeration between particles indicates that the strength value of the soil is low due to the weak bonding between the loose grain structure. These findings suggest that Mamut soil is suitable for chemical stabilisation or remediation method such as microbiologically induced calcite precipitation (MICP).

## 1. Introduction

Mining industries generate large quantity of wastes or tailings, include inert solid and toxic materials present in heavy metals. In some cases, the hazardous chemicals may present due to the addition during extraction process. This has led to various environmental issues because of their subsequent severe hazard to the surrounding ground and surface water, and are known to pose health risk to the community living in the nearby area.

Ranau in Sabah, Borneo is home to Mamut, the biggest copper mine in Malaysia located about 68 kilometers from the state capital, Kota Kinabalu. It was in operation from 1975 to 1999 and generated about 350 Mt of waste, of which 250 Mt are rocks and overburden materials and over 100 Mt of tailings. The wastes from this mine were dumped at Lohan Dam ( $6^\circ 0' 45.936'' \text{ N}$ ,  $116^\circ 44' 20.004'' \text{ E}$ ), an area of 400 hectares located about 15 kilometers away from the mine [1]. Since the mine operation ceased in



1999, some studies have been conducted in this area include river contamination [2], acid drainages [3] and peat stabilization [4].

However, on 5<sup>th</sup> June 2015, a 6.0 magnitude earthquake occurred in Sabah, Borneo centered in Ranau near Mamut, causing ground failure and fear of open pit breaking and acidic drainages to flow out into the water resources utilised by nearby residents [5]. The earthquake was the strongest to affect Malaysia since 1976. 18 people died and most areas nearby Mount Kinabalu have to be closed until the situation was cleared. As a result, new studies include movement of heavy metal contaminants and chemical stabilisation of mine waste are now being considered as urgency.

As the movement of contaminants especially in soils and aquifers occurs along the hydrogeological parameters, investigation on using stabilisation method such as microbiologically induced calcite precipitation (MICP) to reduce the hydraulic conductivity is beneficial. Since MICP is considered as newer, more inventive and environmentally sustainable compared to the other methods, a wider application of this technique in geotechnical engineering should be explored. Most of the current researches on MICP deal with improving the strength of either organic, clayey or sandy soils. Limited available data on how the method can be applied in mine waste management, thus the necessity of this research.

This research is divided into several parts. For the first part, the research focuses on investigating the geochemical evaluation of the contaminated mine soil include heavy metals elements of samples obtained from several collection points and have been reported in previous publication [6]. As a continuation, this paper reports and discusses some geotechnical properties of Mamut soil compared to past studies in other countries, particularly similar unprocessed soil sampled from copper mines, as well as the morphology and their major chemical compounds. The results of this investigation will be used to assess the suitability of the materials for stabilization using MICP.

## 2. Background

Studies on engineering properties of mine soil or tailings provided varied characteristics when different tailings are investigated. This is why researchers comparing iron mine in Yuhezhai, Yunnan, China and copper mine in Bahuerachi, Mexico may find the differences in their basic geotechnical properties, permeability, compression and cyclic response dependent on their ore type, clay mineralogy and physical and chemical process used during extraction stages [7]. Similarly, a study on geotechnical properties of clay soil from abandoned mines at Sungai Lembing, Pahang, Malaysia showed variances in consistency index, compaction behaviour, hydraulic conductivity and undrained shear strength attributed to the different percentages of tin tailings [8].

In investigating copper mine soils collected from Sarcheshmeh, Iran, several studies have been compiled on properties of tailings from Canada, Philippines and United States. The comparison made include their grain size distributions, Atterberg's Limits, specific gravity, maximum dry density and optimum water content, pulp density, shear strength parameters, coefficient of consolidation and hydraulic conductivity. The study found that on the average, the value of geotechnical parameters of Sarcheshmeh fall within the parameters of others copper mine except for the coefficient of consolidation [9].

In addition, researches conducted in Philippines, British Columbia, Michigan and throughout United States found that the gradation curves of copper mine soils show relatively coarse particles with high permeability. The soils have non-plastic to low plasticity characteristics and of wide range of activity. The soils appear to have higher maximum dry density above 1750 kg/m<sup>3</sup> closer to that of rock tailings. The cohesion varies within the range of 0.1–0.24 kg/cm<sup>2</sup> and shows a strong increasing trend with the relative compaction [9].



**Figure 1 (a).** Mamut copper mine in operation 1999 [10] and **(b).** Abandoned Mamut mine in 2019

The geotechnical properties of tailings from copper mine at Ranau shown in Figure 1 are relatively unknown particularly in term of their compaction, hydraulic conductivity, coefficient of consolidation, shear strength and morphological characteristics. A geochemical study in 2003 indicated that heavy metals contamination still occurs even after the operation ceased in 1999 [11], some with level higher than Malaysia's Ministry of Health and United Nations' Food and Agricultural (FAO) standards. Even more worrisome, the metal contents, As, Cr, Cu, Fe, Ni and Pb are higher at nearby Kampung Bongkud and Lohan Dam [12] where tailings were piped, routed and deposited [13]. While recent environmental studies indicated that the contamination level of river water and soils have dropped over the years, no recent geotechnical study on mine soils were conducted in the area.

### 3. Methodology

#### 3.1 Location and sampling

The samples were collected at depth of 0.5 m to 3.0 m of the soil profile upon approval from local authorities. A total of three collection points were selected at each sampling locations ( $6^{\circ}1'37.7''$  N,  $116^{\circ}39'21.0''$ E).

#### 3.2 Geotechnical test

A series of laboratory experiments were carried out to investigate the basic engineering properties of the mine soil include grain size distribution, Atterberg's Limits, specific gravity, natural moisture content, pH and organic content followed by hydraulic conductivity, compaction and shear strength. Laboratory testing were conducted according to BS EN ISO 17892-12:2018, BS 1377: Part 2: 1990 and other relevant standards.

#### 3.3 Major compounds

The air dried and powdered samples were then made into pressure pellets and fuse discs and analysed using inductively coupled plasma optical emission spectrophotometer (ICP-OES) to determine the concentration of heavy metals and major compounds.

#### 3.4 Morphology

A scanning electron microscope (SEM) with a maximum magnification of about 300x and 5000x was used to generate high-resolution images and precisely measures very small features on the surface of the

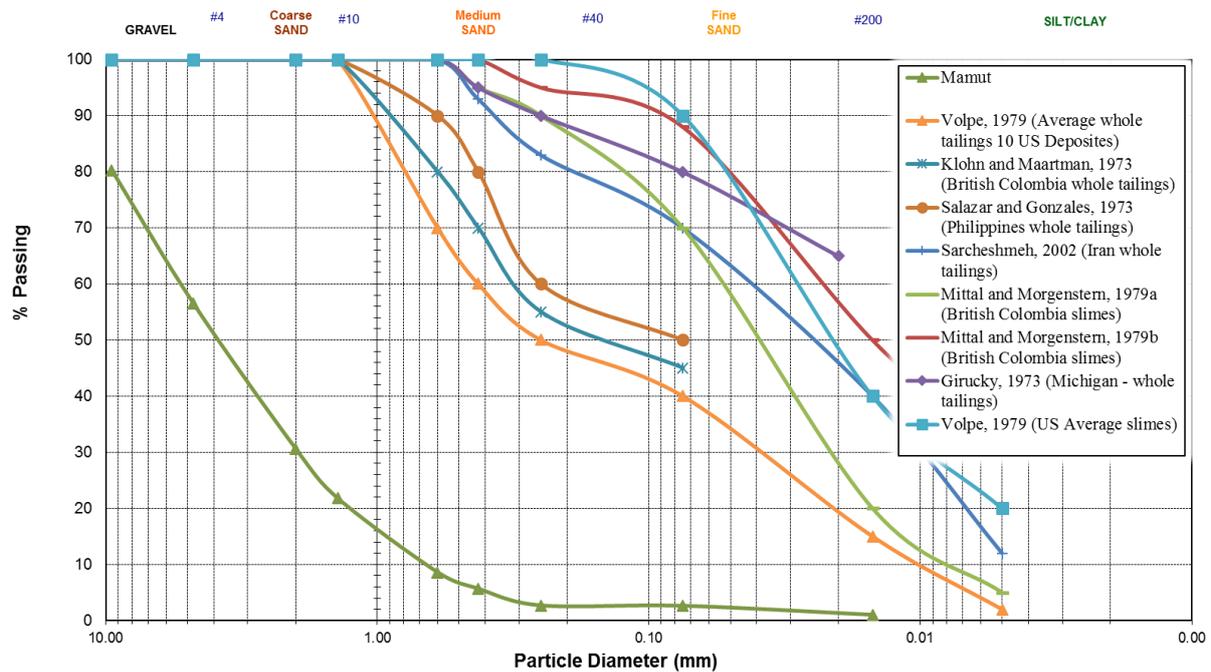
soil sample. A two-dimensional image is generated on selected points and chemical characterization, texture and orientation of materials were assessed.

## 4. Result and discussion

### 4.1 Grain size distribution

The grain size distribution of the soil is shown in Figure 2 and detailed percentage and classifications are shown in Table 1. When compared to the wastes from some other copper mines of Philippines [14], British Columbia [15], Sarcheshmeh, Iran [9], Michigan [16], US average slimes [17] and British Columbia slimes [18], it was found that Mamut soils found to have higher coarse-grained percentage ((7.4%) with gravel and sand of 43.5% and 53.9% respectively. This may be attributed to the fact that Mamut samples are of unprocessed original materials and not in slime conditions. On average, copper tailings are relatively coarse but they depend on the milling size, feeding materials, hydrocyclone pressure, slurry density and presence of water during the extraction process [9].

Classification by Unified Soil Classification System (USCS) indicates that Mamut soil which has coefficient of uniformity,  $C_u \geq 6$  and coefficient of curvature,  $1 < C_c < 3$ , falls within SW group (well-graded sand) where wide range of sizes are distributed in well manner over the gradation curve. Using American Association of State Highway and Transport Officials (AASHTO), Mamut is classified as A-1-a due to the significance presence of stone fragments, gravel and sand and indicative of excellent rating as subgrade materials.



**Figure 2.** Grain particle distribution of Mamut and other copper mine soils

### 4.2 Geotechnical characteristics

The consistency behaviour of tailings can be grouped into coarser and finer than 0.074mm (Sieve No 200). The coarser group, also known as ‘sand tailings’ exhibit non-plastic (NP) behaviour while the finer group, also known as ‘tailings slimes’ may exhibit low plasticity. As shown in Table 2.0, Mamut which is predominantly gravel and sand, is non-plastic while copper mines wastes from Sarcheshmeh, Iran [9] and British Columbia, Canada [18] exhibits low plasticity with a reported range of 26-30%.

**Table 1.** Grain size distribution of Mamut

Properties	Mamut
D <sub>10</sub> , mm	0.7
D <sub>30</sub> , mm	2
D <sub>50</sub> , mm	4
D <sub>60</sub> , mm	5.4
Coefficient of uniformity	7.71
Coefficient of curvature	1.06
Particle size distribution (%)	
Coarse	97.4
Gravel	43.5
Sand	53.9
Fine	2.6
Silt	2.1
Clay	0.5
Classification	
USCS	SW
AASHTO	A-1-a

**Table 2.** Geotechnical characteristics of Mamut soil

Properties	Mamut
Consistency Index	
Liquid Limit, LL (%)	NP
Plastic Limit, PL (%)	NP
Plasticity Index, PI (%)	NP
Activity (A)	N/A
Natural water content (%)	11.04
Specific Gravity, G <sub>s</sub>	2.75
pH	4.53
Organic content, (%)	0.15
Permeability, m/s	3.61 x 10 <sup>-4</sup>

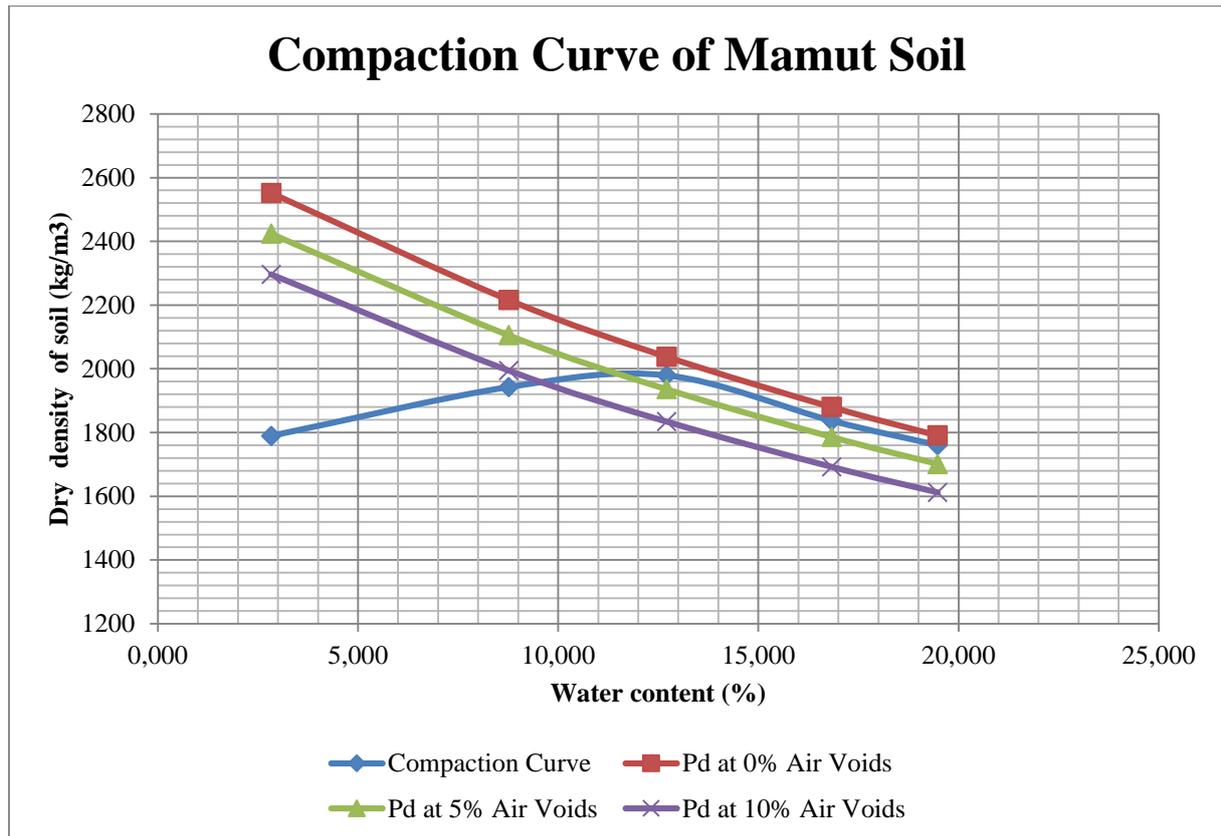
The measured permeability is  $3.607 \times 10^{-4}$  m/s approximately corresponding to that of dense sand to gravelly sand. The acidic nature of the of the mine is evident in the pH value recorded of 4.53. Previous research in 2008 focusing on water quality parameters, studied samples from 12 discharge points in Mamut area and discovered a pH range of 2.90-3.75 attributed to the high and variable total acidity (176 – 1697 mg CaCO<sub>3</sub>/L), high TDS (302 – 2673 mg/L), high sulphate (292 – 2808 mg/L) and elevated concentrations of dissolved metals Al, Mn, Fe, Cu and Zn [3].

The average of organic content is relatively low with value of 0.15%. As the organic content comes primarily from plant roots, this value may indicate that the soil is not conducive for vegetation and hence a challenge for stabilisation method using phytoremediation method. This is supported by the fact that there are fewer high trees and plants observed here compared to the nearby area.

Specific gravity test showed that on average, Mamut materials have G<sub>s</sub> of 2.75, associated with heavy grained soil.

#### 4.3 Compaction properties

AASHTO standard method for compaction have been performed on the samples to determine the maximum dry density (MDD) and optimum moisture content (OMC). The test yielded MDD of 1980 kg/m<sup>3</sup> and OMC of 13%. Previous study on Iran copper mine indicated lower MDD of 1780 kg/m<sup>3</sup>. On the other hand, it is also interesting to note that the while Mamut's OMC falls within the range of hard rock tailings (13.0-15.2%), the MDD is relatively higher than the reported range of 1750-1830 kg/m<sup>3</sup> for hard rock mines [19].



**Figure 3.** Compaction curve of Mamut unprocessed soil

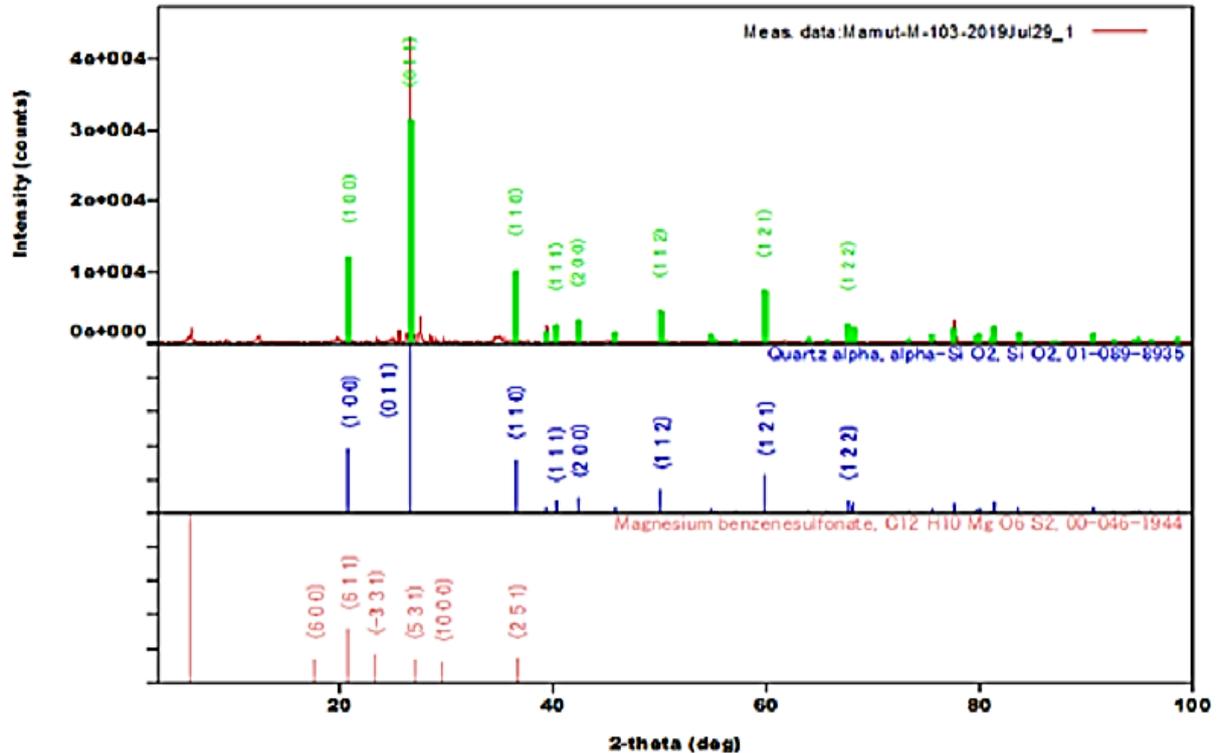
#### 4.4 Shear strength parameters

Direct shear test was conducted using small shear box (6 cm x 6 cm) on dry compacted mine waste materials passing through sieve 4.75 mm were sheared under three different normal stresses. The soils exhibit low cohesion value of 0.04 kN/mm<sup>2</sup> and angle of frictions is observed at 37°. By comparison, the cohesion of dry copper mine soil varies from 0.07 kg/m<sup>2</sup> to 0.15 kg/m<sup>2</sup> [9], 0-0.98 kg/m<sup>2</sup> [17] and 0-0.64 kg/m<sup>2</sup> (Wahler, 1974). Due to the lower values of the cohesion, mine soils are considered as cohesionless, while the angle of friction shows a variation with the relative compaction.

#### 4.5 Major compounds

As previously reported by the authors [6], the levels of heavy metals in soil from Mamut were found to have higher average contents in Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cp), Iron (Fe), Manganese (Mn), Nickel (Ni), Lead (Pb) and Zinc (Zn). Compared to the standard of Department of Environmental Malaysia (DOE) and Food and Agriculture Organization of the United Nations (FOA), the concentration (in mg/L) of As (0.712), Co (0.071), Cp (24.396) and Ni (1.175) are

beyond the safe levels. However, when further chemical test is performed, it was determined that  $\text{SiO}_2$  and  $\text{C}_{12}\text{H}_{10}\text{MgO}_6\text{S}_2$  are the two predominant compounds as shown in Figure 4 (a) and (b).



**Figure 4 (a)** Major compounds of Mamut soils

#### Qualitative analysis results

Phase name	Formula	Figure of merit	Phase reg. detail	DB card number
Quartz alpha, alpha-Si O <sub>2</sub>	Si O <sub>2</sub>	0.666	ICDD (PDF-2 Release 2015 RDB)	01-089-8935
Magnesium benzenesulfonate	C <sub>12</sub> H <sub>10</sub> Mg O <sub>6</sub> S <sub>2</sub>	0.887	ICDD (PDF-2 Release 2015 RDB)	00-046-1944

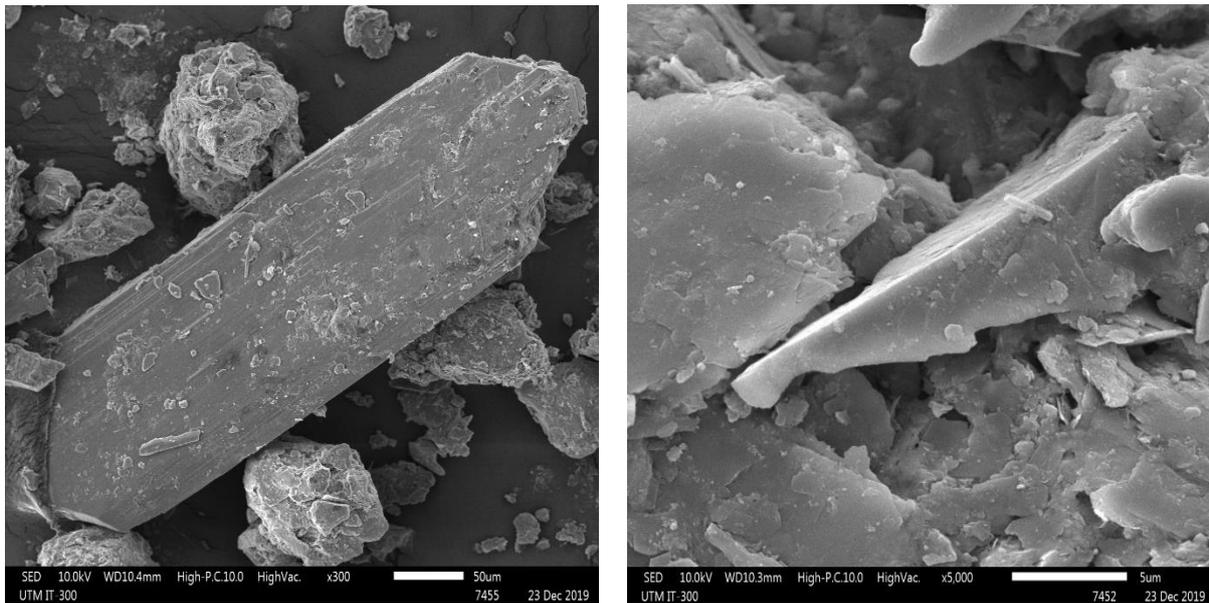
  

Phase name	Formula	Space group	Phase reg. detail	DB card number
Quartz alpha, alpha-Si O <sub>2</sub>	Si O <sub>2</sub>	154 : P3221	ICDD (PDF-2)	01-089-8935
Magnesium benzenesulfonate	C <sub>12</sub> H <sub>10</sub> Mg O <sub>6</sub> S <sub>2</sub>	10 : P12/m1,unique-b	ICDD (PDF-2)	00-046-1944

**Figure 4 (b)** Major compounds of Mamut soils

#### 4.6 Morphology

The SEM analysis of Mamut shown in Figure 5 (a) and (b) are for x300 and x5000 times respectively. They appear to be composed of powdered and hardened particles with dark brown colour. Mamut soil contains higher amount of larger particles and with well-rounded and spherical in shapes but some irregular-shaped particles are also observed. Their surfaces appear to be very smooth with no agglomeration between particles. This may indicate that without treatment, the strength value of mine waste is low due to the low bonding between the loose grain structure. Previous study found that particle size and shape notably influence the mechanical response of soils treated and stabilized chemically where an increase of 35%, 50%, and more than 100% in shear strength for round coarse, angular coarse and round fine particles respectively [20].



**Figure 5 (a).** Mamut morphology (x300) and **(b).** Mamut morphology (x5000)

## 5. Conclusion

A series of geotechnical tests has been performed on unprocessed soils from Mamut mine in Sabah as part of the assessment on the suitability of the materials for stabilisation using MICP. The geotechnical properties are then compared to similar copper mines in several countries. Based on the investigations, following conclusion can be derived;

- i. Mamut soil is classified as SW, has higher coarse-grained percentage compared to other copper mines. The soil also has higher permeability. These two attributes, and the fact that the contamination level in the area is above the national health standard made Mamut suitable for chemical stabilisation or remediation.
- ii. Mamut soil has low organic content, acidic in nature, higher specific gravity and maximum dry density. Due to the lower values of the cohesion, Mamut soil can be considered as cohesionless, while the angle of friction shows a variation with the relative compaction.  $\text{SiO}_2$  and  $\text{C}_{12}\text{H}_{10}\text{MgO}_6\text{S}_2$  are the two predominant compounds of the soil.
- iii. Mamut soil appears to be composed of powdered and hardened particles with dark brown colour. They contain higher amount of irregular-shaped particles but well-rounded and spherical are also observed. Their surfaces appear to be very smooth with no agglomeration between particles which indicates that without treatment, the strength value of the soil is low due to the weak bonding between the loose grain structure.

## References

- [1] Van der Ent, A. and M. Edraki. 2016. Environmental geochemistry of the abandoned mamut copper mine (Sabah) Malaysia. *Environ geochem health*. **40**(1): p. 19.
- [2] Mohammad Ali, B.N., et al. 2014. Assessment of heavy metals contamination in Mamut river sediments using sediment quality guidelines and geochemical indices. *Environmental monitoring and assessment*. **187**(1): p. 4190.
- [3] Jopony, M. and F. Tongkul. 2009. Acid mine drainage at mamut copper mine, Sabah, Malaysia. *Borneo science*. **24**(Mac): p. 12.

- [4] Makinda, J., et al. 2018. *Compressibility behaviour of borneo tropical peat stabilized with lime-sand column. International journal on advanced science, engineering and information technology.* **8**: p. 172.
- [5] Star, T. 2015. *Strong earthquake strikes sabah.* [cited 2020 3rd February ].
- [6] Jodin Makinda, Kassim K.A., Ahmad. K, AS Muhammed, M.U Zango. 2020. Geochemical evaluation of contaminated soil for stabilisation using microbiologically induced calcite precip. *TEST engineering and management.* **83**(May-June 2020): p. 2236-2244.
- [7] Hu, L.-m., et al. 2016. *Geotechnical properties of mine tailings. journal of materials in civil engineering.* **29**: p. 04016220.
- [8] Ali Rahman, Z., et al. 2012. Influence of Amang (Tin Tailing) on geotechnical properties of clay soil. *Sains Malaysiana.* **41**: p. 303-312.
- [9] Shamsai, A., et al. 2007. Geotechnical characteristics of copper mine tailings: A case study. *Geotechnical and geological engineering.* **25**(5): p. 591-602.
- [10] Bhd, M.C.M.S., Mamut Pit, M. Pit. 1999. Editor. The Star: The Star.
- [11] Lee Yook Heng and R. Wickneswari. 2004. Metal distribution and contamination of the mamut river, Malaysia, caused by copper mine discharge. *Bulletin of environmental contamination and toxicology.* **73**: p. 8.
- [12] Baba Musta and K.A. Kassim. 2000. Geochemical evaluation of contaminated soil for soil stabilisation with lime. in annual geological conference. *Penang: Geological society of Malaysia*
- [13] Mohd. Azizli, K., Y. Tan Chee, and J. Birrel. 1995. Design of the lohan tailings dam, mamut copper mining sdn. bhd., Malaysia. *Minerals engineering.* **8**(6): p. 705-712.
- [14] Salazar R. 1973. G.R. Design, construction, and operation of the tailings pipelines and underwater tailings disposal system of Atlas consolidated mining and development corporation in Philippines. in *Proceeding of the 1st international tailing symposium.* Miller Freeman, San Francisco.
- [15] Klohn, E., Maartman, 1973. C. Construction of sound tailings dam by cycloning and spigotting. in *proceeding of the 1st international tailing symposium.* Miller Freeman, San Francisco.
- [16] Girucky, F. New tailings dam construction at White Pine. in *Proceeding of the 1st international tailing symposium.* 1973. Miller Freeman, San Fransisco.
- [17] Volpe, R. 1979. Physical and engineering properties of copper tailings, in *American Society of Civil Engineers.* ASCE: New York. p. 19.
- [18] Hari K. Mittal, N.R.M. 1975. *Parameters for the design of tailings dams. Canadian geotechnical journal.* **12**(2): p. 27.
- [19] Aubertin, M., B. Bussière, and R. Chapuis. 2011. *Hydraulic conductivity of homogenized tailings from hard rock mines. Canadian geotechnical journal.* **33**: p. 470-482.
- [20] Nafisi, A., et al. 2018. The effect of grain size and shape on mechanical behavior of MICP sand I experimental study.

### Acknowledgement

This work was supported by the Ministry of Education Malaysia's Fundamental Research Grant Scheme [R. J130000.7851.5F256] and the High Impact Research Grant [Q.J130000.2451.04G57].