EFFECT OF LIME ON STABILIZATION OF MINING WASTE FROM SABAH, MALAYSIA

Baba bin Musta[1], Khairul Anuar bin Kassim[2], Prasannan Pillai Rajeev Kumar[3*]

[1]*School of Science and TechnologyUniversity Malaysia Sabah, 88400, Kota Kinabalu, Sabah, Malaysia*
[2, 3]*Department of Geotechnics & Transportation*
Faculty of Civil Engineering
University Teknologi Malaysia
81310 Skudai, Johor, Malaysia

*Corresponding Author: *dr.prkumar@gmail.com*

Abstract : This paper deals with the effect of lime on stabilization of mining waste from Sabah, Malaysia. In this study, different percentages of lime as well as fine material were added as additive with the mining waste. The engineering properties were measured by compaction test, unconfined compressive strength tests and permeability tests. The mineral identification and microstructure were examined using X-ray diffraction (XRD) and Scanning Electron Microscopic (SEM). The compaction test indicated that the optimum moisture content varied with amount of lime content. The virgin mining waste showed low unconfined compressive strength value due to the very low cementing agent. The samples showed a rapid increase in shear strength when stabilized with lime content ranging from 2 to 8%. The rate of increase in strength is most rapid within two weeks of interaction. This is due to the pozzolanic reaction, which created more rigid - packed structure and small pore space at lime content as low as 2%. More addition of lime had increased the unconfined compressive strength due to the intensive pozzolanic reactions forming more cementitious mineral and created bridge-like structure. However the optimum percentage of lime required was 6% based on the unconfined compressive strength. Lime content in excess of the optimum (8% of lime) acted as filler or lubricant. Significant reduction in permeability to 1 x 10^{-7} m/s was observed at the end of the leaching test. This is due to the development of cementitious minerals and clogging of fine particle size in the pore spaces.

Keywords : *Lime, stabilisation, mining waste, shear strength, permeability*

1.0   Introduction

Due to the rapid development in the industrial, mining and power sector, environmental pollution is becoming a matter of great concern to engineers and planners. Among these, mine waste is a major concern to the remediation experts

because mine waste is a source of heavy metals and other toxic substances which will pose human health hazard.

Mining waste is finely ground rock particles from which most of the commercial ore has been extracted in extraction plant. The mining waste of sulfate mine normally contains a variety of content of residual sulfides, such as pyrite, pyrrhotite, galena, sphalerite, and chalcopyrite (Lin, 1997). When the sulfides are exposed to air and water, the rate of acid generation is accelerated, which resulted in the release of heavy metals. Stabilization is one of the remediation technique which is could improve strength and durability, and also can be used to modify the characteristics of the fine fraction or more granular soils (TRB, 1976). Stabilization processes designed to either improve waste handling and physical characteristics, decrease surface area across which pollutants can transfer or leach, or limit the solubility or to detoxify the hazardous constituents (Malone, *et al.*, 1982). The benefit of stabilization is the improved handling and geotechnical properties of the treated material compared with the original material. The modification of material by lime is attributed to two main groups of reactions viz-a-viz cation exchange capacity and pozzolanic reaction. It is believed that the exchanging of calcium ions onto the clay particle results in the zeta potentials of the particles being reduced considerably and therefore they are more inclined to flocculate. The pozzolanic reaction takes place between the calcium and the silica and alumina that are present in materials. The alumina ions (Al^{3+}) and silica ions (Si^{4+}) would react with calcium ions (Ca^{2+}) to produce the new cementitious minerals. The other possible sources of Al^{3+} and Si^{4+} are quartz, feldspars and mica. Lime and pozzolana are used as a stabilizing agents for the engineering purposes (Faisal, 1990; Indraratna, *et al.*,1995; Zou and Li, 1999). The strength is an important characteristic for assessing the success of the stabilization and potential reusability of the stabilized mining waste. Improvement in strength will enhance its managing and disposal capabilities in waste containment or as low cost aggregates in related applications. Development of sufficient strength will also allow the use of mining waste material for embankments with adequate slope in the waste containment.

The biggest copper mining in Malaysia is located in Ranau, Sabah. There was not much mineable reserve left when the mines ended its production in the year 2000. The production of waste and haul ore average rate was 10 million tonnes and 6 million tonnes a year respectively. The mining waste is dumped in the eastern part of the mining area located at Lohan Dam, Ranau, Sabah, which is covers an area of $3.88km^2$. This paper provides geotechnical information of lime stabilised mining waste. Mineralogical identification and micro-structural study could give more closed feature through the scanning electron microphotographs.

2.0   Materials and Methods

2.1   Materials

The representative samples of mining waste were collected from the Lohan Dam site, situated about 8kms from the Mamut Copper Mine, Sabah, Malaysia. These samples are denoted as Lohan Dam Ash (LDA). The fine material (FM) samples, as an additive into the mining waste, originated from the weathered of fine particle size of Sedimentary rock that are shale and mudstone, were obtained from Telipok, Sabah. The sample was taken at the depth of 0.5 m to 3.0m of the soil profiles. Hydrated lime [$Ca(OH)_2$] was used as a stabilization agent into the LDA samples. The physico-chemical properties of the LDA and FM are presented in Table 1. Figure 1 shows the particle size distribution of LDA and FM. Based on the particle size distribution, LDA is best classified as silty sand, whereas FM is clayey sand. The Atterberg limit of the FM is as follows: liquid limit of 53% and plastic limit of 23%.
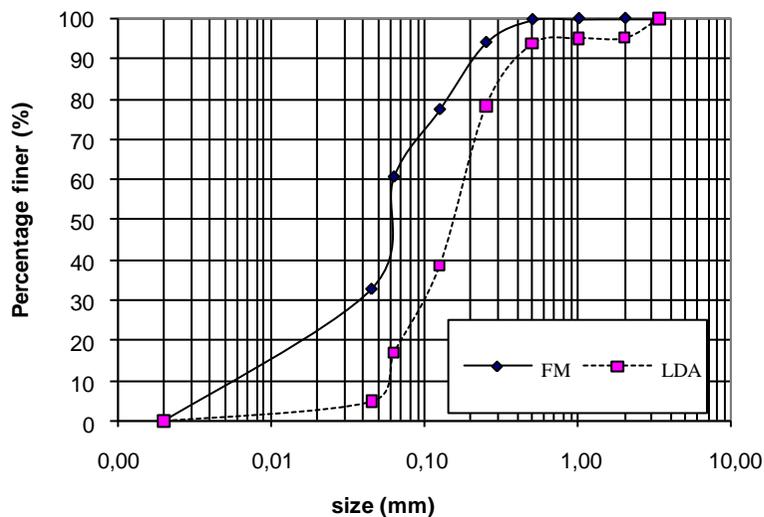
Figure 1: Particle size distribution curves of LDA and FM

It was found that the dry density for LDA is in the range of $1.72 - 1.74$ Mg/m^3, whereas the optimum moisture content (OMC) is 12.8% to 13%. The unconfined compressive strength is in the range of 10.6 to 14.9 kPa. The low value of strength was due to the absence or very low chemical cementation between grains in quartz and feldspar minerals, which resulted in the loose structure. The permeability of LDA is slightly high i.e at the range of 3.67×10^{-4} cm/s $- 1.67 \times 10^{-6}$ cm/s, this due to the high percentage of pore space in mining waste samples

Table 1: Physico-chemical characteristics of samples.

Physico-chemical	LDA	FM
Liquid Limit, LL (%)	28.5	53
Plastic Limit, PL (%)	28	23
Plasticity Index (%)	~0	30
Specific Gravity, SG	2.65	2.2
Clay (%)	4.84	32.88
Silt (%)	12.11	27.82
Sand (%)	83.05	39.3
pH	6.84	4.79
Dry Density (Mg/m^3)	1.70	1.73
Opt.moisture content W_{opt} (%)	12.0	14.5
Shear strength (kPa)	12	200
Permeability (cm/s)	7.00×10^{-7}	1.56×10^{-9}

Table 2: Composition of major elements in mining waste (LDA), fine material (FM) and lime.

Major Elements (%)	Materials		
	LDA	*FM*	*LIME*
SiO_2	74.85	77.18	0.00
TiO_2	0.22	0.48	0.00
Al_2O_3	7.25	11.38	0.10
$Fe_2O_3(T)$	6.04	4.77	0.10
MnO	0.07	0.00	0.02
MgO	2.63	-	2.04
CaO	1.74	0.01	65.82
Na_2O	0.06	-	0.00
K_2O	3.22	0.82	0.02
P_2O_5	0.13	0.02	0.02
LOI*	3.77	5.35	31.88

LOI: Loss On Ignition

The composition of major elements in LDA, FM and lime are summarized in Table 2. The mineralogy of LDA samples mainly originated from the rock forming minerals i.e., quartz, feldspar. Low peaks of muscovite and pyrite were observed in LDA samples. FM samples mainly consists of quartz and kaolinite with small amount of Montmorillonite. The x-ray diffractogram peaks indicate the appearance of portlandite and calcite in lime.

2.2   Methodology

For the stabilization purposes, 20% of fine material (FM) was added into LDA to act as a pozzolana before adding lime. About 20% addition to the LDA samples was considered enough to enhance the strength and provide enough Silica (Si) and Alumina (Al) to react with the lime. The chemical compositions in the 20% fine material consist of SiO_2 15% and Al_2O_3 1.4%. Moreover, the particle distribution shows it consists of 6.5% clay particle, 5.6% silt and 7.8% sand.

Because strength is directly related to density, the samples were compacted at the maximum dry density and optimum moisture content (OMC). Light compaction test described in BS 1377: Part 4: 1990: 3.3 is followed in this study. In this test, about 6 kg dried soil was prepared. The moisture content was adjusted to the desired starting values before being placed into the 1000 cm^3 volume of mould. Then the soil is compacted in three equal layers by applying 27 blows of the 2.5 kg rammer dropping from the controlled height of 300 mm. The excess soil was cut away and leveled off to the top of the mould before measuring the weight. The moisture content of the compacted soil was measured immediately after the compaction test. The sample was then cured for 1, 14, 28, 45 and 100 days at room temperature (25^oC). The samples were placed in a PVC cylinder, closed tightly and wrapped with plastic to avoid any moisture loss and to maintain the moisture constant during the curing process. At the end of the curing period, the unsterilized and stabilized soil samples were tested for unconfined compressive strength.

The measurement of the unconfined compressive strength (UCS) parameters of the soil was obtained by unconfined compression test or 'quick' test. This test is done according to ASTM D2166 section 13.5.1. For preparation of sample the maximum dry density and optimum moisture content of soils were obtained from the compaction test. The specimen with 100 mm height and 50 mm diameter or a height: diameter ratio of 2:1were used in this test. A motorized Triaxial Instrument was used to compress the soil with driven platen speeds adjusted at

1% specimen length per minute or 1mm/min. Each set of test consists of three samples to ensure the reliability of the test result.

The permeability was measured using falling head method. The procedures of falling head test followed the generally accepted use of permeability mould with a standard rigid wall compaction mould as suggested by Head (1992).

Soils mineralogy was measured by X-ray diffraction (XRD) method using XRD instrument Model Diffractometer D 5000 Siemens. Kristalloflex 710/710 H with Diffrac/AT software was used for the mineralogical identification. The surface micromorphology of soil were studied using scanning electron microscopes (SEM) model Philips XL40. Before scanning, the fresh surfaces of dried soil were spattered with a thin film of gold to carry away any excess charge from the electron beam. Energy dispersive X-ray spectra (EDAX) were obtained when necessary to confirm the identification of the minerals.

3.0   Result And Discussions

The analyses of engineering properties in this research consist of compaction, compressibility and permeability. The result of the engineering properties is discussed as follows:

3.1   *Compaction Curve*

The unstabilized mining waste shows the maximum dry density and OMC of lime stabilized LDA samples show irregular trend with lime content (Figure 2). Although, lime with additive pozzolana could increase the strength of the soil as reported by previous researchers (Faisal, 1990; Locat, et al., 1990; Bell, 1996, and Indraratna, et al., 1995), the irregular distribution of coarse grain particles in the samples may affect the strength. In this test, the highest strength of LDA stabilized with 6% of lime was due to the intensive pozzolanic reaction with sufficient lime added, which produced cementitious mineral.

3.2   *Unconfined Compressive Strength*

The unstabilized mine waste showed the low unconfined compressive strength due to the low cementing agent within the particle. In contrast, there is a rapid increase in strength with age when LDA samples were stabilized with lime ranging from 2 to 8% (Figure 3). The rate of increase in strength is most rapid within two weeks. In is noted that addition 2% of lime and cured for 28 days has increased the strength about 7.0 times compared to the unstabilized sample.
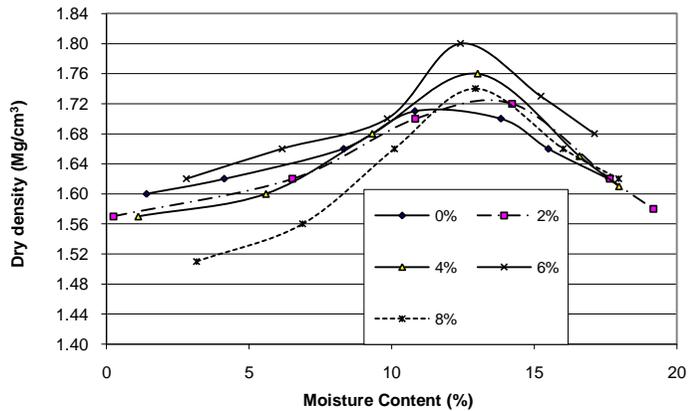
Figure 2: The compaction curves on lime stabilised LDA samples.
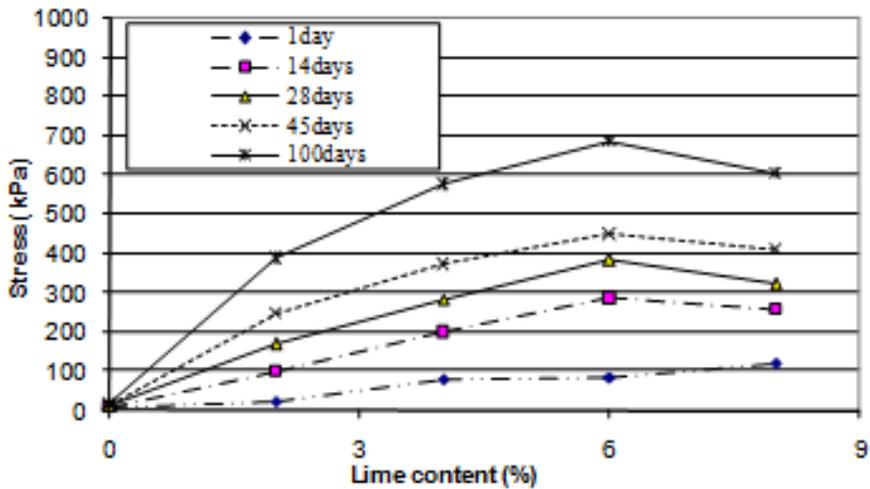
Figure 3 : The compressive strength of stabilized LDA samples with age.

LDA with 6% of lime proved to be the most effective of stabilization, followed by 8%, 4%, and 2% (Figure 4). It is found that with addition 6% of lime and cured 28 days the strength is increased from 85 kPa to 383 kPa. However, with

the same age the addition 8% of lime, the strength is only 322 kPa. It indicates lime content in access of the optimum (8% of lime) will acts as lubricant, which has little or no bonding. This may cause some detrimental effect to the overall strength of the sample causing the strength to reduce a little as compared to the sample with 6% of lime.
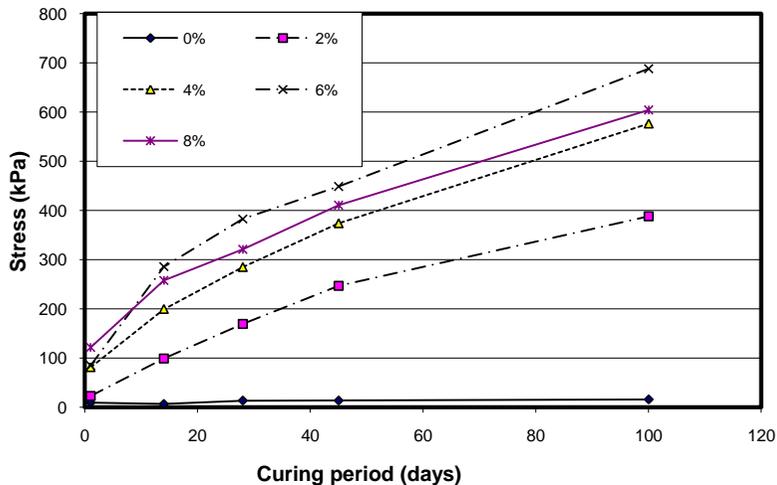
Figure 4: The compressive strength of stabilized LDA samples with different percentages of lime.

3.3   *Mineralogical and microstructure study*

3.3.1 *XRD analysis*

The XRD pattern of the lime treated mining waste with 2% of lime shows the formation of cementitious minerals namely ettringite, gismondine, and calcium silicate hydrate (CHS). Ettringite (calcium sulphoaluminate hydroxide hydrate) was formed at the early stage of reaction with the presence of sulfate compounds. According to Means, *et al.*, (1995) the early formation of minerals in the pozzolanic reactions was due to the high content of water thus increased the hydration, where the mineral increased the volume of solids. Therefore, if

the same pozzolanic reaction occurred in this study, it could be concluded that both the needle like shape mineral and the sub-angular shape minerals (cementitious minerals) were formed in the early process of crystallization. The reaction involved Ca^{2+} from lime, Al^{3+} from the fine material and SO_4^{2-} sulfate compound from the dissolution of pyrite in mining waste. Gismondine (calcium silicate aluminate hydrate) and calcium silicate hydrate showed low peaks with the addition of lime. However, the development of calcium silicate hydrate with 20% of fine material showed high peaks of intensity compared to the unstabilized sample. This suggests the intensity formation of cementitious minerals with sufficient availability of clay minerals from the fine materials.

3.3.2　SEM analysis

Figure 5 shows the lime treated mining waste with 2% of lime (LDA2%) cured for 28 day with 20% of fine material.
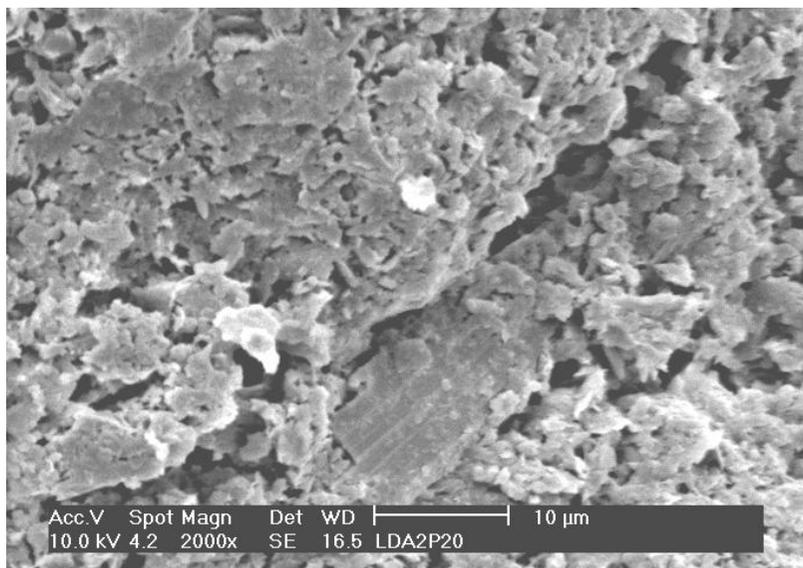
Figure 5: Photomicrograph of LDA2% with 20%FM cured for 28 days.

The photomicrograph illustrated the distribution of lime particle on the surface and at the edge of the feldspar mineral. The flocculation and linked within the soil particle were observed.

The addition of 4% of lime (LDA4%) cured for 28 days has created more like a bridge structure (Figure 6), rigid- packed structure and small pore space. This resulted in the increased of the unconfined compressive strength.
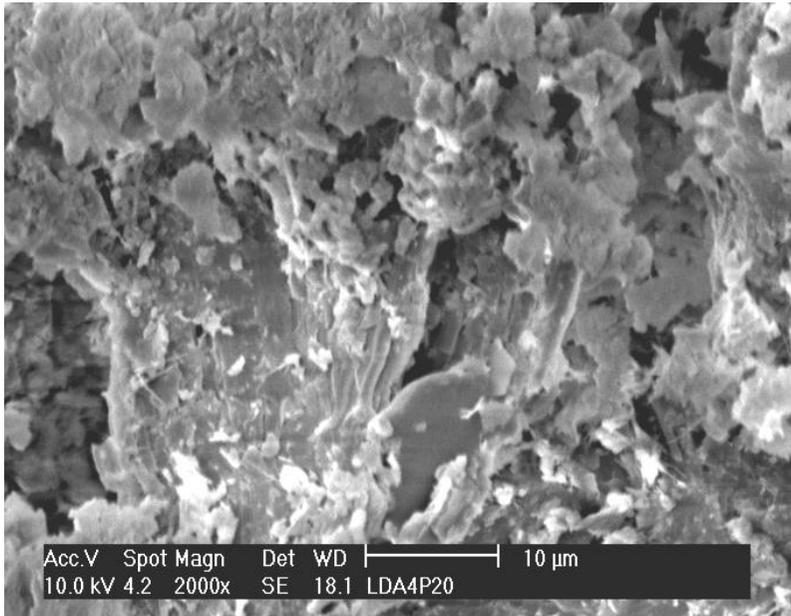
Figure 6: Photomicrograph of LDA4% with 20%FM cured for 28 days.

The effect of curing period with the development of cementitious mineral and needle like mineral in lime stabilized LDA with 6% of lime were illustrated in Figure 7. The quartz mineral was recognized as the coarse grain particle in the microphotograph. The photomicrographs also showed the kaolinite layer originated from fine material (FM samples) react with the lime particle to form cementitious mineral. The edge part of kaolinite mineral is the more reactive site, where it stimulated the formation of cementitious mineral. The needle like mineral called ettringite was developed due to the reaction between lime, clay and sulfate. In this stage sufficient addition of lime has increased the unconfined compressive strength again because of the intensive pozzolanic reactions.
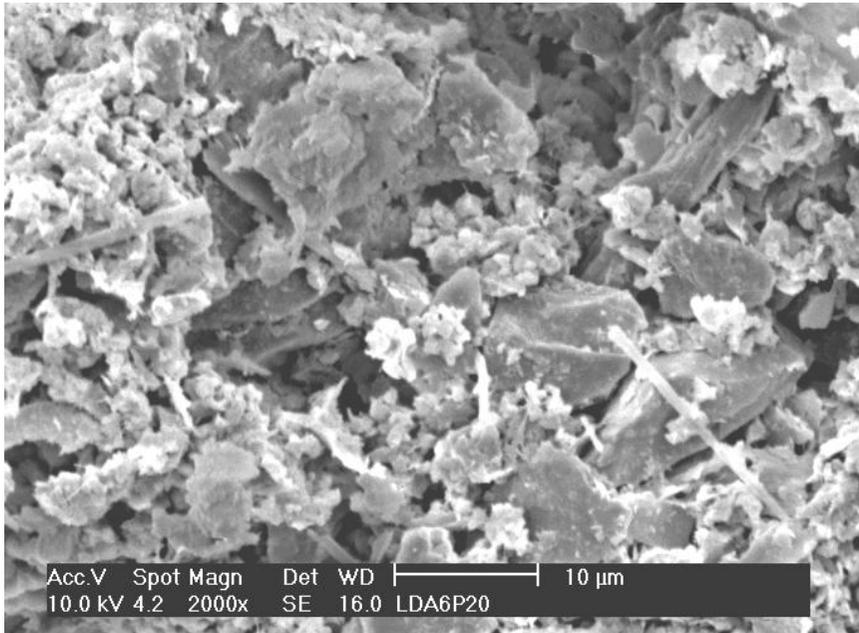
Figure 7: Photomicrograph of LDA6% with 20%FM cured 28 day.
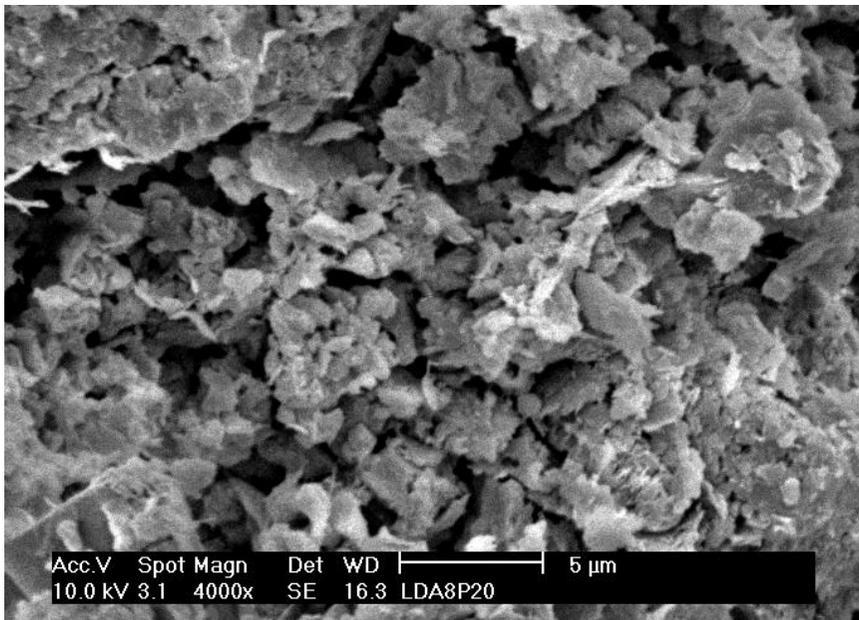
Figure 9: Photomicrograph of LDA8% with 20%FM cured for 28 days.

The LDA samples added with 8% of lime (LDA8% samples) and with 20%FM show the flocculated-agglomerated process (Figure 8). This is due to the gradual crystallization of new reaction products, which bind the particles together. The photomicrograph also indicated that further addition of lime has increased the cementitious mineral. However at the same time the agglomerate could increase the pore spaces of the mixtures. The unreacted lime will act as filler or lubricant. This is the reason for the decreased of the unconfined compressive strength. The high pore space also indicates the high water retention at the inter particle mineral.

3.4   Permeability study

Figure 10 shows the permeability patterns of unstabilized and stabilized samples leached with 7 pore volume (PV) of solution. PV is measured as the porosity of the sample under consideration. Water is the leaching media in this study and it is used to fill the voids in the sample. Details of the leaching study is explained by Musta 2003. The stabilized samples were cured for 28 days. Significant reduction of permeability for both unstabilized and stabilized samples were observed. The stabilized samples show permeability less than 1.00
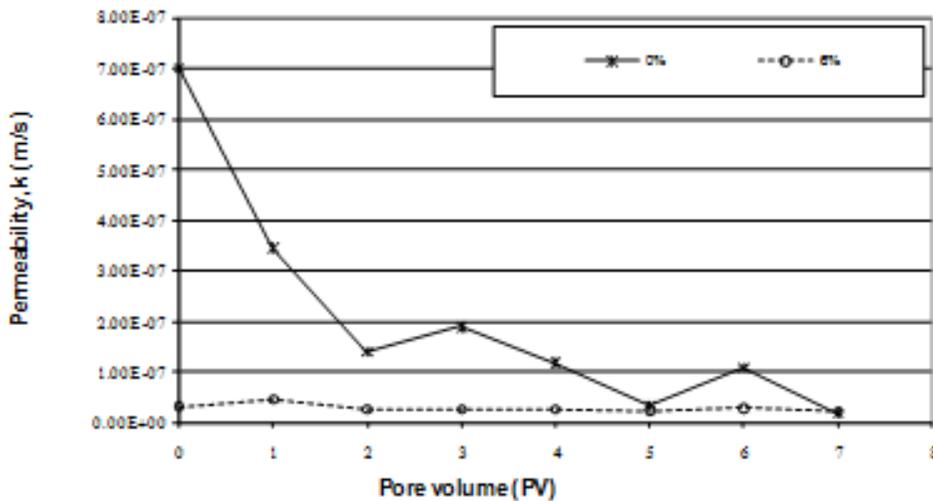
Figure 10 : Permeability of unstabilised and stabilised LDA samples with leaching of water.

x 10^{-7} m/s at the early process. This indicates the sufficient of lime to form cementitious minerals, which was capable to fill up the pore space in the mining waste. Rowe *et al*. (2000) found that solution flowing through the smaller particle sizes quickly reduces the porosity, while the coarse particle sizes showed

a much more consistent reduction in permeability over time. Although the unstabilized LDA showed the permeability is fluctuated, however generally it was decreased with PV of leaching. This is due to the clogging of fine particle from the FM samples as well as from the lime.

4.0   Conclusions

The dry density and optimum moisture content (OMC) of lime stabilized LDA samples show irregular trend with lime content. This is due to the irregular distribution of coarse grain particles in the stabilized samples. The unconfined compressive strength of unstabilized samples is between 11 and 15 kPa. It indicates the absence or very low ~~of~~ chemical cementation between grains in quartz and feldspar minerals resulted in the low of strength. The high pore space resulted in the high permeability of LDA samples. It is concluded that the intensive pozzolanic reactions with the addition of lime produce cementitious minerals, eventually creating bridge-like structures, and cementing the original minerals and creating high inter-particle contact orientations. As a result, the unconfined compression strength ~~is~~ increases ~~d~~ immediately. The continuation of the pozzolanic reaction produces more cementitious minerals with time, hence increases the maximum unconfined compressive strength. The random structural arrangement of the clay particle and high pore spaces in the unstabilized samples as compared to the stabilized samples is the reason for the high permeability of the unstabilized samples at the early process of permeability test. However after leaching, the fine particle were washed out from the top part of soil, which clogged the pore spaces towards the bottom part, hence decreased the permeability. For the stabilized samples pozzolanic reaction formed more cementing agent resulted to the low of permeability. The microstructure of the soil becomes packed, clogged with fine particles as well as cementitious material, hence reducing the permeability.

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