International Journal of Engineering & Technology, 7 (4.35) (2018) 131-135

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Issues in Engineering Geological Classification of Weathered Sedimentary Rocks: Case Study of Kati Formation, Parit, Perak

Wong Jia Mang[1]*, Abdul Ghani Md Rafek[2], Goh Thian Lai[3]

[1 2] *Department of Geosciences, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia*
[3]*Centre for Earth Science and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia*
**Corresponding author E-mail: jia_16001961@utp.edu.my*

Abstract

Kati Formation consists of alternating layers of sandstone, siltstone and mudstone that results in non-uniform weathering. The presence of surficial features due to weathering such as iron bands, iron recementation, iron staining and lithobionts coating in an uneven distribution on the outcrop causing more complexity to the heterogeneous sedimentary rocks which are also tectonically deformed. The presence of iron recementation in highly weathered rocks causing the rock strength to be higher than the moderately weathered rocks. Thus, several laboratory tests are conducted in this study to characterise the weathered rocks which are uniaxial compressive strength (UCS), point load strength index, slake durability test, jar slake test and Schmidt hammer rebound test. Among the laboratory tests conducted in this study, slake durability index test, I_{d2} is the ideal test to characterise the rock samples of different weathering grades as it gives a large range of laboratory test results which is 0.3 % to 15.0 % for completely weathered, 22.0 % to 67.0 % for highly weathered, 68.0 % to 83.0 % for moderately weathered and 87.0 to 98.0 % for slightly weathered to fresh rocks. The values obtained are not affected by the uneven distribution of iron oxide present in the rock samples.

Keywords: *Engineering Geology; Kati Formation; Sedimentary rocks; Weathering; Weak Rocks*

1. Introduction

Weak rocks or soft rocks can be classified as young sedimentary rocks, weathered rocks and tectonically disturbed rock [1]. In term of rock mechanics, the rocks with the uniaxial compressive strength (UCS) of 0.5 MPa to 25 MPa are classified as extremely weak to weak rocks [2] while materials below 0.4 MPa behave more like soil [3].

Weathering of rocks causes the rocks to lost its strength characteristics. This causes several problems during construction projects in weak rocks due to difficulties in classifying the behavior of these materials accurately [4]. The main problem in determining the characterisation of weak rocks is that the rocks are too soft to be tested using rock mechanics equipment and too hard for soil mechanics equipment [5]. Besides that, the non-uniform weathering of the heterogeneous sedimentary rocks causes the rock strength and durability of the same rock type in a strata to be different. This is due to variations in weathering grade usually result in varying engineering properties of rock [6]. [7 & 8] determined that the geomechanical strength of the fresh rocks deteriorated by approximately 30 % to 40 % when the fresh rocks material reduced to slightly weathering.

However, literature study also reveals that more study of weathering conditions classification system on granitic rock [9, 10 & 11]. The existing weathering profile classification based on [2] with the consistent changes from fresh rocks to highly weathering with decreasing surface depth is more suitable to classify the homogeneous rock mass. This is due to the heterogeneous rock mass consists of variety rock types and composition that will undergone different weathering rate in addition to the tectonic deformation and some sedimentary structures that increase the complexity of the rock mass. Furthermore, the weathering classification of rocks [2, 12 & 13] are mostly based on visual inspections that are hard to be observed in sedimentary rocks.

Besides that, [14] stated that there is little knowledge of the fundamental engineering changes associated with the various grades of weathering that specifically developed for site investigation of weathered rocks. This is because the classification system is only applicable to the tropical areas that have significant weathering on rocks and less on sedimentary rocks. Futhermore, [15] also stated that in spite of the large number of classification and testing schemes for shales and other weak or weathered rock types, there exists no single accepted method for characterising these materials. In the study of sedimentary rocks in Johor, [16] includes the parameters of density, point load strength index, indirect tensile strength, UCS and slake durability for sandstone and shale to correlate with weathering grades. However, [17] stated that the similar testing method that produce a more reliable data for sandstone does not produce definite result for shale due to its intrinsic properties.

In tropical counties, rainwater plays an important role in chemical, biological or physical weathering of rocks. However, the present of humidity and water content decrease the rock strength [18]. [19] mentioned that the variations are particularly pronounced for water saturation below 25%. At water saturation above 50 % the strength is less influenced by small changes in water content.

Thus, this research is done to determine the field characteristics besides of physical and mechanical parameters of the weathered sedimentary rocks in Kati Formation. The investigated outcrop

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

consists of heterogeneous rock mass that had undergone slight to complete weathering.

1.1. Geological Setting

The outcrop located along the road A164 from Parit to Kuala Kangsar (N04º32', E100º56') is composed of Kati Formation of Carboniferous to Permian age. According to [20] Kati Formation generally consists of weakly metamorphosed reddish brown carbonaceous shale, siltstone, sandstone with minor conglomerate and chert.

[21] stated that the strike of the sedimentary rocks are mostly to north or northwest while the dip angle is high. This is also proven by sedimentology study of Kati Formation at four outcrops in Seri Iskandar by [22] that the rocks has the strike of 325º and steep to almost vertical dipping.

[22] also stated that the rocks structures presence on the formation are burrow tracks, load structures, slump and graded sandstone beds. The clastic deposit of Kati Formation has good sorting of fine grain shale and siltstone and is characterized by lamination.

2. Methodology

The investigation methods are divided into field work and laboratory tests. Field observations are done to classify the rock types and preliminary weathering grades based on weathering classification of [2, 12, 13 & 23]. However, classification based on [21] is more concerned as the weathering grades classification are done based on the rock's physical strength since the discolouration of sedimentary rocks is difficult to observe and classify through [12]'s scheme. The presence of iron oxide plays an important role in the changes of rocks colour.

Rock samples were collected according to the changes of lithology from each strata of the outcrop. Due to the interbedded nature of the sedimentary rocks, different strata have undergone different degree of weathering. In order to characterise the weathering of each strata, different weathering grades within each strata were sampled for laboratory testing. Sampling of rocks was conducted using geological hammer at the depth of 20 cm from the slope surface. Schmidt hammer rebound (SH) test were carried out using a digital Schmidt hammer type L at the direction perpendicular to the rock surface. In this research the characterisation of rocks were determined based on the recommendation of [2 & 24]. The laboratory tests comprised the following:

(a) Point load strength index ($I_{S(50)}$)
(b) Uniaxial compressive strength (UCS)
(c) Slake durability index (I_{d2})
(d) Jar slake test

Durability of weak rocks are determined by slake durability index are classified through proposed classification system by [25]. Jar slake test was conducted based on modification standards of several researchers [26, 27 & 28].

3. Results and Discussion

3.1. Field Observations

The sedimentary rocks in the study area consists of interbedded sandstone and mudstone while chert can be found in another outcrop. The outcrop of the study area has the bedding and laminations almost vertically with the average dip direction and angle of 076°/78°. Tectonic deformation occurred causing some minor faults and folding can be observed in the roadcut. Thus, unlike homogeneous rocks such as granite, the weathering profile along the outcrop is not consistent either laterally or vertically.

Due to the weathering, some surficial features can be observed in the outcrop which are lithobionts coating, iron banding, iron staining that results in colour changes and iron recementation. The presence of the surficial feature in an uneven distribution in the outcrop causing more complexity to the heterogeneous sedimentary rocks in addition to the tectonic deformation. This causes very large variation of data obtained in the laboratory testing.

3.2. Schmidt Hammer Rebound Test

Schmidt hammer rebound tests were conducted to determine the rock strength on the rock surface. Thus, the presence of iron features and roughness of rock surface due to weathering affect the rebound values. According to modified weathering classification by [28], the Schmidt hammer rebound for unweathered and slightly weathered rocks exceed 25 while for moderately and highly weathered are less than 25. Results show that the overall Schmidt hammer rebound test values for the slope are in the range of 12 to 45 with the mode of 18. The mode value of Schmidt hammer rebound for fresh, slightly weathered and moderately weathered sandstone are 28, 24 and 18 respectively. The mode rebound values for moderately weathered mudstone is 18 while moderately weathered chert is 26. However, the Schmidt hammer rebound values cannot be obtained for highly to completely weathered rocks due to very low rock strength.

3.3. Slake Durability Index

Slake durability index tests were conducted to determine the ability of rock to resist mechanical degradation. The average values of slake durability index of different weathering conditions and lithology were calculated and plotted in the graph as shown in Fig. 1 and Fig. 2. Although the durability tests were conducted up to five cycles, results shows that two cycles are more suitable in this study as there is constant changes in the slake durability graph. Furthermore, completely weathered rocks with high slaking cannot be determined up to five cycles as the total samples disintegrated during the third cycle. However, classification using first cycle values are not recommended as the first cycle values of the same type of rocks consists of large variation. Thus, slake durability index for second cycle, I_{d2} is more stable and suitable to use as the index of durability.

The second cycle slake durability index, I_{d2} obtained are in the range of 0.3 % to 98.0 % which are from completely weathered to fresh rocks. The summary of laboratory test results on the sedimentary rocks are shown in Table 1 and Table 2 which classify according to the slake durability classification system proposed by [25]. In this test, the presence of iron recementation, iron staining and recrystallisation of rocks produced stronger bonding between the rock grains hence, enhance the durability of the rocks. Lithobionts coating also slightly improve the rock durability for completely weathered rocks as it bounds the rock surfaces together (Fig. 3).

3.4. Jar Slake Test

Jar slake test is only applicable to rock of very weak durability. Completely weathered rocks with slake durability index less than 10% will completely break to mud or flakes rapidly while completely weathered rocks with slake durability index more than 10% breaks rapidly to develops several fractures or form chips. For sandstone, jar slake test shows no changes or little percentage loss for low to extremely high durability of rocks. For fine grain clastic sedimentary rocks, jar slake test shows no changes for high to extremely high durability rocks and breaks slowly to develops few fractures for medium durability. This can concluded that jar slake test is an ideal laboratory test to study the characteristic of completely weathered rocks. As similar to the observations shown by [27], shale and mudstone usually turns into flakes while sandstone would break into its grains.

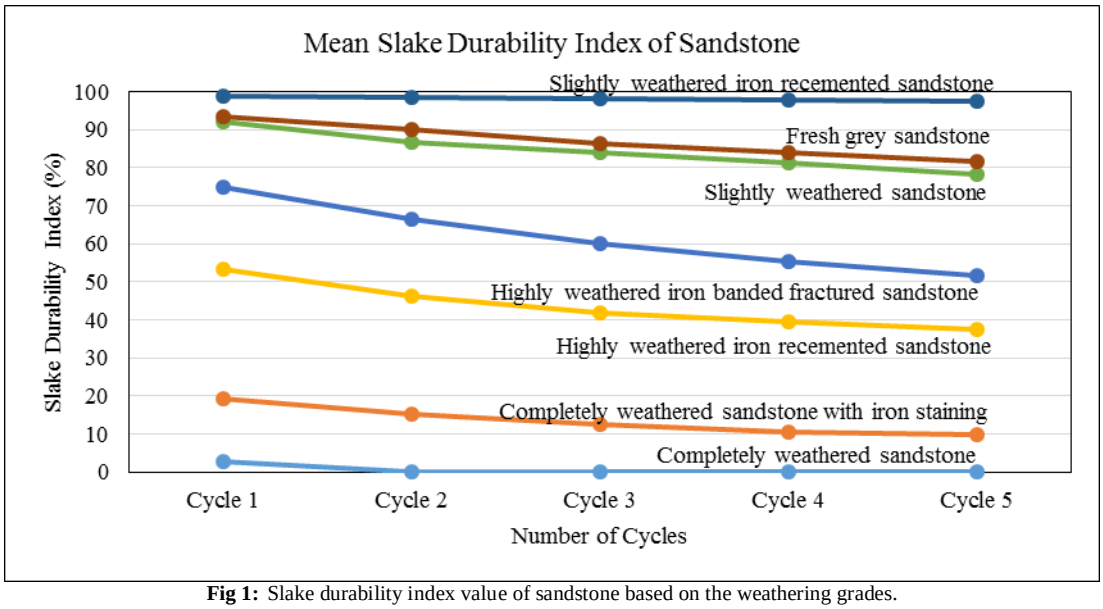


Fig 1: Slake durability index value of sandstone based on the weathering grades.

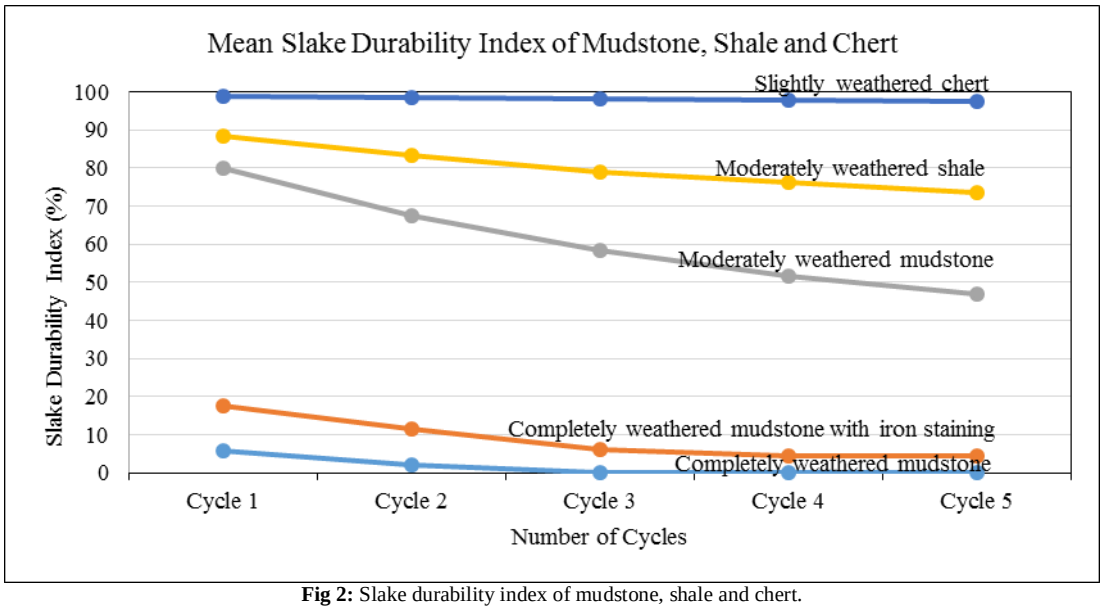


Fig 2: Slake durability index of mudstone, shale and chert.

Table 1: Laboratory test results for sandstone

Durability Classification	Average I_{d2} (%)	Weathering Conditions and Lithologies	Mean Is(50) (MPa)	Mean UCS (MPa)	Jar Slake Test	Mode Schmidt Hammer Rebound
Very low	0.3	Completely weathered sandstone	0.04	-	Completely breakdown to grains	-
	15.0	Completely weathered sandstone with iron staining	0.04	-	Breaks rapidly and form many chips/ develop new fractures	-
Low	46.0	Highly weathered iron banded fractured sandstone	0.34	-	No change	18
Medium	67.0	Highly weathered iron recemented sandstone	0.52	-	No change	18
High	87.0	Slightly weathered sand-stone	0.21	34.0	No change	24
Very high	91.0	Fresh grey sandstone	1.27	35.0	No change	28
Extremely high	98.0	Slightly weathered iron recemented sandstone	3.20	52.0	No change	28

Table 2: Laboratory test results for mudstone, siltstone and chert

Durability Classification	Average I_{d2} (%)	Weathering Conditions and Lithologies	Mean $I_{s(50)}$ (MPa)	Mean UCS (MPa)	Jar Slake Test	Mode Schmidt Hammer Rebound
Very low	2.0	Completely weathered mud-stone	0.08	-	Completely breakdown to flakes	-
	12.0	Completely weathered mud-stone with iron staining	0.24	-	Breaks rapidly and de-velops several fractures	-
	22.0	Highly weathered siltstone	0.12		Breaks rapidly and de-	

				-	velops several fractures	-
Medium	68.0	Moderately weathered mud-stone	0.30	9.0	Breaks slowly and devel-ops few fractures	18
High	83.0	Moderately weathered shale	0.24	-	No change	18
Extremely high	98.0	Slightly weathered chert	1.86	18.0	No change	26



Fig. 3: Lithobionts rock coating left after first cycle of the slake durability test for completely weathered sandstone

3.5. Rock Material Strength

Uniaxial compressive strength can only be conducted for stronger rocks that can produce core samples. Due to highly fractured, slaking, presence of bedding, reduction of strength due to weathering, only fresh to moderately weathered rocks can be cut into standard size of core samples. The average UCS values obtained for slightly weathered sandstone is 34.0 MPa and fresh sandstone is 35.0 MPa. Recrystallised sandstone due to metamorphism increase the UCS value to average of 52.0 MPa. For moderately weathered mudstone, mean UCS value obtained is 9.0 MPa while moderately weathered chert has mean UCS value of 18.0 MPa.

For point load strength, the mean value decreases with increasing of weathering grades. However, the presence of iron band and iron recementation increase the mean point load strength, $I_{S(50)}$ of highly weathered rocks to 0.34 MPa and 0.52 MPa respectively which is higher than the mean point load strength of slightly weathered sandstone which is 0.21 MPa. However, the point load test values obtained from moderately to completely weathered sandstone and mudstone are less that 0.5 MPa which are considered as extremely weak rocks by [2]. Rock moisture content that is affected by the tropical weather in the country also affect the rock strength. The increment of water content in the rock decrease the rock strength. Uneven iron distribution of the weathered rocks causes the rock strength at different parts of the same rock mass to be different.

Among the laboratory tests conducted in this study, slake durability test is the ideal test to characterise the rock samples of different weathering grades as it gives a large range of laboratory test results which is 0.3 % to 98.0 % and the values obtained are not affected by the uneven distribution of iron oxide present in the rock samples. Schmidt hammer rebound cannot be tested for highly to moderately weathered rocks. The rock strength tested by using uniaxial compressive strength (UCS) is only limited to the core samples while point load strength is able to use to differentiate rock samples of every weathering grades. However, point load test, $I_{S(50)}$ values for completely weathered rocks which are less than 0.1 MPa are too low to be considered. Jar slake test only provide significant results for extremely weak durability rocks.

4. Conclusion

Throughout the research, it can conclude that slake durability test are able to characterise the rock mass by giving a large range of result besides considering the facts that regular shape and large samples size for other types of laboratory tests are hard to be obtained due to weak rock strength. For sandstone, completely weathered has the mean I_{d2} of 0.3 % to 15.0 %, highly weathered is 46.0 % to 67.0 %, slightly weathered is 87.0 % to 98.0 % depend on the presence of iron and fresh sandstone is 91.0 %. For mudstone, mean I_{d2} for completely weathered is from 2.0 % to 12.0 % while moderately weathered is 68.0 %. Jar slake test will be an advantage method to classify the sedimentary rocks of completely weathered into higher slaking properties which is either completely breakdown or break rapidly to form chips and fractures.

Acknowledgement

Authors would like to express the gratitude to the partners for their support and guidance in conducting this study. Besides that, authors would like to acknowledge the laboratory assistants and Geoscience Department, Universiti Teknology PETRONAS to provide laboratory testing equipment for the study. This research is support by the research grant FRGS/1/2016/STG08/UTP/01/1 of the Malaysia Government which is acknowledged.

References

[1] Zhai H, Canbulat I, Hebblewhite B & Zhang C, "Review of Current Empirical Approaches for Determination of the Weak Rock Mass Properties." *Procedia engineering*, Vol. 191, (2017), pp. 908-917.

[2] International Society for Rock Mechanics, *The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006*, ISRM Turkish National Group, Ankara, (2007), pp. 628.

[3] Terzaghi K & Peck RB, *Soil Mechanics in Engineering Pratice*, John Wiley & Sons Inc, New York, (1996).

[4] Klein S, "An Approach to the Classification of Weak Rock for Tunnel Projects", *Proceedings of the Rapid Excavation and Tunneling Conference* (2001), pp. 793-806.

[5] Ulusay R, *Rock Mechanics and Rock Engineering: From the Past to the Future*, CRC Press, London, (2016).

[6] Mohamad ET, Komoo I, Kassim KA & Gofar N, "Influence of moisture content on the strength of weathered sandstone", *Malaysian Journal of Civil Engineering*, Vol. 20, No. 1, (2008), pp. 137-144.

[7] Goh TL, Simon N, Hussin A & Serasa AS, "Weathering related rock material strength reduction: the Malaysian granites", *Journal of Engineering Geology*, (2015), pp. 1445-1450.

[8] Goh TL, Simon N, Hussin A & Rafek AG, "Impact of weathering on rock material strength of granite", *Journal of Geology & Geophysics*, Vol. 4, No. 3, (2015), pp. 45.

[9] Irfan TY & Dearman W, "Engineering classification and index properties of a weathered granite", *Bulletin of the International Association of Engineering Geology*, Vol. 17, No. 1, (1978), pp. 79-90.

[10] Lee SG & de Freitas M H, "A revision of the description and classification of weathered granite and its application to granites in Korea", *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 22, (1989), pp. 31-48.

[11] Dearman W, "Weathering classification in the characterisation of rock for engineering purposes in British practice*", Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur*, Vol. 9, No. 1, (1974), pp. 33.

[12] International Association of Engineering Geology (IAEG), "Soil description and classification for engineering geological mapping", *Eng. Geol. Mapping. Bull. of the IAEG*, Vol. 24, No. 1, (1981), pp. 235-274.

[13] British Standard (BS), Code of Practice for Site Investigations (5930), British Standards Institution, London, (1981) pp. 204.
[14] Fookes PG, Dearman WR & Franklin JA, "Some engineering aspects of rock weathering with field examples from Dartmoor and elsewhere", *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 4, No. 3, (1971), pp. 139-185.
[15] Santi PM, "Field Methods for Characterizing Weak Rock for Engineering", *Environmental & Engineering Geoscience*, Vol. 12, No. 1, (2006), pp. 1–11.
[16] Liang M, Mohamad ET, Komoo I & Ma CK, "An excavatability classification system for surface excavation in sedimentary rocks", *Bulletin of Engineering Geology and the* Environment, (2015) pp. 1-11.
[17] Mohamed Z, Rafek AG & Komoo I, "Characterisation and classification of the physical deterioration of tropically weathered kenny hill rock for civil works", *Electronic Journal of Geotechnical Engineering*, Vol. 12, (2007), pp. 16.
[18] Kanji MA, "Critical Issues in Soft Rocks", *Journal of Rock Mechanics and Geotechnical Engineering*, 6 (2014), pp. 186-95.
[19] Franklin JA, "Suggested Method for Determining Point Load Strength", *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, Elsevier, (1985), pp. 51-60.
[20] Foo KY, "Geology and Mineral Resources of the Taiping-Kuala Kangar Area Perak Darui Ridzuan", *Geological Survey of* Malaysia, Vol. 1 (1990), pp. 145.
[21] Hutchison CS & Tan DNK, "Geology of Peninsular Malaysia", *The University of Malaya and the Geological Society of Malaysia, Kuala Lumpur* (2009), pp. 479.
[22] Alkhali HA & Chow WS, "The Kati Formation: A Review", *ICIPEG 2014*, Springer, (2015), pp. 303-12.
[23] Geotechnical Control Office (GCO), *Guide to Rock and Soil Descriptions (Geoguide 3)*, Geotechnical Control Office, Hong Kong (2017).
[24] ASTM Standard, D4644 (2004) Standard Test Method for Particle-Size Analysis of Soils, *ASTM International, West Conshohocken*, (2004), pp. 816-818.
[25] Franklin J & Chandra R, "The slake-durability test", *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, Vol. 9, No. 3 (1972), pp. 325-328.
[26] Santi PM, "Improving the Jar Slake, Slake Index, and Slake Durability Tests for Shales", *Environmental & Engineering Geoscience*, Vol. 4 (1998), pp. 385-96.
[27] Czerewko M & Cripps J, "Assessing the durability of mudrocks using the modified jar slake index test," *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 34, (2001) pp. 153-163.
[28] Mohamad, ET, Saad R & Abad SK, "Durability assessment of weak rock by using jar slaking test." *Electron J Geotech Eng*, Vol. 16, (2011), pp. 1319-1335.