Degradation of limestone exposed to drying and wetting cycles – experimental study

A M Al-Bared[1], I S H Harahap[1], N H Azuddin[1], A Marto[2], S V Alavi Nezhad Khalil Abad[3] M O A Ali[1] and B W Isah[1]

[1]Department of Civil and Environmental Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, 32610, Malaysia.
[2]Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia (UTM) Kuala Lumpur, 54100 Kulala Lumpur, Malaysia.
[3]Department of Civil Engineering, Birjand University of Technology, Birjand, Iran

E-mail: albared2009@yahoo.com

Abstract. Degradation of rock is the deterioration of the rock forming materials and the reduction of strength and stiffness within time. It is responsible for the failure of rock slopes and landslides as the drying and wetting cycles in long-term will extensively reduce the strength of the rock and eventually end up as a soil-like material. Weathering rate is very crucial, and it is the main parameter inducing and accelerating degradation of rock. This study focuses on investigating and evaluating the effect of degradation on cored samples of limestone. Limestone was collected from the state of Perak, Malaysia and the samples were cored, trimmed and cut into 50 mm diameter and 80 mm height. A total number of 30 samples were exposed to different number of drying and wetting cycles in the laboratory. A total number of 27samples were tested using the Uniaxial compression test after 0 – 14 cycles while three samples were exposed to exactly 14 cycles to observe the reduction in weight. The results showed the strength of limestone to decrease gradually with the increment of drying and wetting cycles. Besides, samples that were continuously exposed to 14 drying and wetting cycles experienced a weight reduction of approximately 1.12%.

1. Introduction

Slope failures along highways and other infrastructures are considered one of the most hazardous events for users, planners, and governments due to the great impact caused every year all over the globe. They result in the losses of human lives and economical crises that affects both governments and society [1]. Besides, landslides cause the disturbance of services of highways and railways, oil and gas pipelines and other important facilities. In this study, massive slope failures are referred to as landslides that can be defined as a disaster at which the weak fractured rock masses or weak soil move downward a slope by the influence of gravity. They can be either fast or slow, wet or dry, small or large depending on the influencing factors triggering their occurrence [2]. The failure of cut slopes is triggered by several factors including hydrological conditions, orientation and characterization of discontinuities, strength of the slope's materials, and geometry of the slope [3]. Most of the factors affecting the stability of the rock slopes have been investigated widely by various researchers. One of the factors that has high interest and being studied recently is the degradation of the strength of the slope forming materials within time.

Recently, various studies focus on the degradation of rock materials forming slopes as it is considered crucial to ensure the safety of communities living nearby and to avoid major losses of properties due to slope failure. Degradation of rock slope is described as the deterioration of the strength of the slope forming materials within time due to several natural and man-made factors. One of the most significant natural factors that triggers the degradation of rock is weathering that can be in the form of temperature (drying and wetting processes) and the rainfall events. Various studies had been conducted in order to investigate the weathering of rock in the field of engineering geology and soil mechanics (e.g. [4–7]). The man-made factors are mostly due to construction within or beside the rock slopes such as modifying the slope geometry for road construction, excavations, and road cuts which usually results in stress relief inducing degradation [8]. Weathering processes causes physical, chemical and geotechnical changes in the slope forming materials that create new discontinuities and enlarges the existing ones [9]. A study was conducted by Abdullah et al. [10] found that man-made activities are one of the significant factors causing the disturbance to the intact rock slopes. When the slope geometry is modified for construction purposes, weathering agents starts to deteriorate the fresh exposed surface and therefore the fractured rock will be converted into a soil-like material. Moreover, weathering process can be categorized into physical and chemical weathering as stated by Miscevic and Vlastelica [11]. The physical weathering is described as the process that results in the disaggregation of geologic materials without changing its mineralogical components, while the chemical weathering leads to modification of the mineralogical components of the material. An indication of chemical weathering is the formation of minerals which take place due to the reaction between the rock materials and water. Meanwhile, water penetration into rock masses leads to the development of pressure in between rock joints resulting in the cracks or discontinuities formation.

Although a lot of research had been conducted to analyse, model and suggest the best mitigation measures to stabilize rock slopes, failure of slopes is still considered as a threat to society from economical, social, and environmental point of view. The safety of the facilities located at the bottom or top of unstable slope is still threatened and the cost required for maintenance is relatively high. Therefore, this study is focused on investigating the degradation of rock slopes formed by limestone. To the author's best of knowledge, no effort has been undertaken to investigate the degradation of limestone in the laboratory by simulating the weathering drying and wetting processes. Hence, an experimental study was conducted in order to investigate the degradation of limestone under different drying and wetting cycles. The samples of limestone exposed to the drying and wetting cycles were tested using the uniaxial compression strength test.

2. Materials used and testing program

2.1. Materials used

Limestone was chosen as the testing material for this research due to its wide existence in Malaysia. Limestone blocks were collected from a quarry area located at Simpang Pulai, Ipoh, Perak. The physical properties of the tested limestone are shown in Table 1.

Table 1. Physical properties of tested limestone

Physical property	Value
Colour	Grey
Density	0.3-12%
Hardness	2.0 - 4.0 Mohs scale
Specific gravity	2.65-2.75
Bulk density	2000 - 2800 kgm-3

2.2. Experimental program

Samples of limestones were collected, transferred, and stored in the laboratory. The preparation of the samples started by coring the limestone blocks into a uniform size of 50 mm diameter and 80 mm height. The dimensions and weight of the samples were checked at the end of the coring processes and the cored limestone samples are shown in Figure 1. Following the coring of the samples, samples were saturated and submerged in water for a minimum period of 24 hours. This step is attempted to simulate the wetting process during the rainfall in the real environment. Then, the samples were oven-dried in the oven for another 24 hours at 105 °C in order to simulate the hot weather at the field. Samples were left to cool down in the room temperature for a period of 12 hours and then the processes was repeated for the required numbers of wetting and drying cycles. Figures 2 and 3 shows the samples exposed to the wetting and drying processes respectively.

Figure 1. Cored limestone samples

Figure 2. Wetting process of limestone cored samples

Figure 3. Drying process of limestone cored samples

The uniaxial compressive strength test was used to test the strength of the samples after being exposed to the required numbers of wetting and drying cycles. During the uniaxial compressive test, the load was applied vertically and the sample was loaded until failure and the peak strength was recorded. Figure 4 shows the uniaxial compressive strength machine used for the testing. Samples were tested under the uniaxial compression test at 0 wetting and drying cycles and also at 2^{nd}, 3^{rd}, 5^{th}, 6^{th}, 8^{th}, 9^{th}, 13^{th}, and 14 th cycles of wetting and drying. On the other hand, samples were also subjected to weight degradation test at which the reduction of weight after 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 cycles was recorded and analysed.

Figure 4. Uniaxial compressive test machine used for testing

3. Results and discussion

The results obtained from the uniaxial compressive strength test and the weight degradation observation are presented and discussed in this section.

3.1. Degradation of the strength

A total of 3 samples labelled as A, B, and C of limestones were subjected to 14 cycles of wetting and drying. The initial weight of samples A, B, and C was 457.00 g, 454.18 g, and 458.12 g, respectively. The final weight of the samples after being exposed to 14 wetting and drying cycles was 451.93 g, 449.09 g, and 453.26 g, respectively. It is clearly seen that the samples lost approximately 1.11, 1.12, and 1.08 % of its initial weight. This is due to the wetting and drying cycles that results in degrading the material forming the samples and reducing its weight. Table 2 lists all the recorded weight of sample A, B, and C at 0-14 wetting and drying cycles.

Table 2. Weight degradation data for sample A, sample B, and sample C

Cycle	Weight of sample A (g)	Weight loss of sample A (g)	Weight loss of sample A (%)	Weight of sample B (g)	Weight loss of sample B (g)	Weight loss of sample B (%)	Weight of sample C (g)	Weight loss of sample C (g)	Weight loss of sample C (%)
0	457	-	0	454.18	-	0	458.20	-	0
1	456.90	0.10	0.02	454.07	0.11	0.02	458.12	0.08	0.02
2	456.70	0.30	0.07	453.84	0.34	0.07	457.93	0.27	0.06
3	456.64	0.36	0.08	453.67	0.51	0.11	457.47	0.73	0.16
4	455.6	1.40	0.31	453.35	0.83	0.18	457.33	0.87	0.19
5	455.50	1.50	0.33	452.90	1.28	0.28	457.01	1.19	0.26
6	455.23	1.77	0.39	452.32	1.86	0.41	456.69	1.51	0.33
7	454.95	2.05	0.45	451.99	2.19	0.48	456.27	1.93	0.42
8	454.68	2.32	0.51	451.72	2.46	0.54	455.86	2.34	0.51
9	454.40	2.60	0.57	451.49	2.69	0.59	455.56	2.64	0.58
10	453.89	3.11	0.68	451.11	3.07	0.68	455.26	2.94	0.64
11	453.39	3.61	0.79	450.68	3.50	0.77	454.79	3.41	0.74
12	452.97	4.03	0.88	450.23	3.95	0.87	454.19	4.01	0.88
13	452.56	4.44	0.97	449.73	4.45	0.98	453.76	4.44	0.97
14	451.93	5.07	1.11	449.09	5.09	1.12	453.26	4.94	1.08

Moreover, Figure 5 shows the degradation of strength by the increase of the wetting and drying cycles. The Figure reveals almost linear relationship between the weight lost and the number of wetting and drying cycles. When the number of cycles was increased, the reduction of weight was increased. When comparing the weight reduction of samples A, B, and C, it is clearly seen that they had a similar trend and the difference was very minor. Those results simulate the degradation of limestone rock at site due to the rainfall and high temperatures events. Similar observations were found by Labus and Bochen [12] who tested the degradation of sandstone under accelerated weathering. It was found that the sandstone samples were deteriorated as a result of the experiment and was associated by weight reduction.

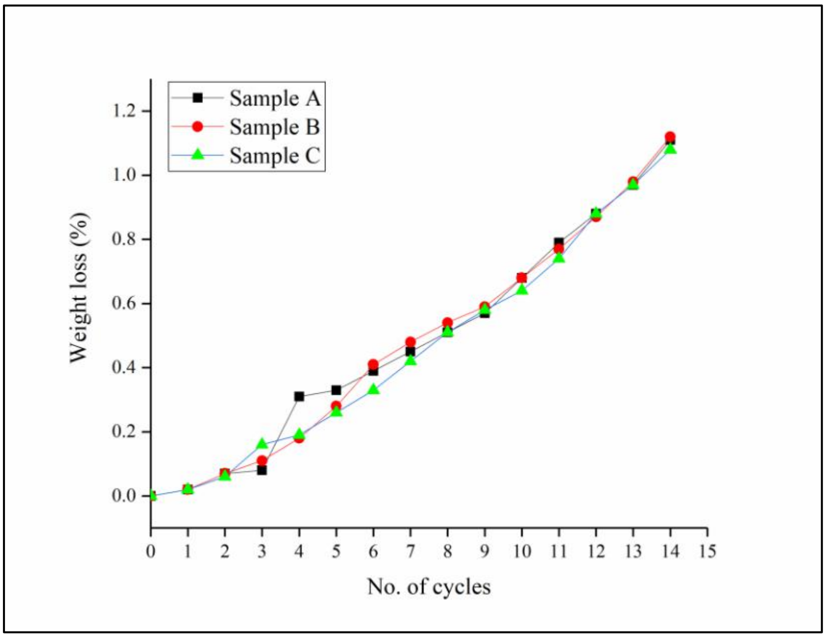

Figure 5. Weight loss of limestone samples versus the number of wetting and drying cycles

3.2. Uniaxial compressive strength tests

The uniaxial compressive strength test was used in this study to assess the reduction of the strength in samples subjected to various numbers of wetting and drying cycles compared to the control samples which was not subjected to any cycle. Table 3 shows the testing program and detailed results of all the limestone samples tested in this study. A total of 27 limestone samples were tested under the uniaxial compressive strength test as shown in Table 3. Samples subjected to higher number of wetting and drying cycles had a significant weight loss due to degradation. Three samples were subjected to the same number of cycles in order to have an average value of the strength and weight reduction. Figure 6 shows the average compressive strength of all the limestone samples versus the number of cycles. It can be observed from the Figure that the average compressive strength of the control samples that were not subjected to the weathering cycles was 108.28 kPa. The average compressive strength of samples subjected to weathering cycles was reduced with the increased number of cycles. Similar results were obtained by Qin et al. [13] who investigated the damage of rock under drying and wetting cycles. Besides, Figure 7 shows the strength reduction versus the number of weathering cycles. It can be seen that the strength was decreased with the increased number of cycles until reaching cycle number 8 where the rate of the strength reduction was decreased rapidly. This can be explained as the surface of the rock sample is considered severely weathered due to the increased number of cycles and the surface materials are degraded when subjected to the weathering cycles ranging from 1 to 8. Weathering cycles after the cycle number 8 started to affect deeper surface material that is still considered strong and require higher number of cycles in order to degrade it. Therefore, long term degradation can only be achieved by applying higher number of weathering cycles. Figure 8 shows a comparison between the strength reduction and the average weight loss of samples. The reduction of the strength and also the weight loss were increased with the increased number of cycles until cycle number 8 at which the rate of strength reduction was decreased while the weight loss continued to increase. This explains the reason behind the reduction of strength after cycle number 8. As the weight continued to decrease, this proof that the surface layers were degraded at the earlier 8 cycles and further cycles started to degrade new core layer. This new layer will require another round of wetting and drying cycles in order to deteriorate its materials. Yang et al. [14] tested the effect of weathering cycles on rock samples and found continuous decrease of the strength with the increased number of cycles.

Table 3. The average compressive strength of samples subjected to wetting and drying cycles

Sample No.	Cycle No.	Initial weight (g)	Final weight (g)	Weight loss (g)	Average weight loss (g)	Compressive strength (kPa)	Average compressive strength (kPa)	Strength reduction (kPa)
1	0	454.98	-	-	-	108.53	108.28	0
2		453.63	-	-	-	108.32		
3		452.78	-	-	-	107.99		
4	2	453.50	453.30	0.2	0.2	107.44	107.30	0.98
5		454.00	453.81	0.19		107.35		
6		453.70	453.49	0.21		107.12		
7	3	457.20	456.83	0.37	0.34	103.25	103.21	4.09
8		455.40	455.08	0.32		103.10		
9		457.52	457.18	0.34		103.28		
10	5	444.20	443.11	1.09	1.20	98.63	98.68	4.53
11		449.20	447.96	1.24		98.41		
12		458.50	457.23	1.27		99.01		
13	6	456.1	454.67	1.43	1.50	91.69	91.68	7.01
14		452.10	450.46	1.54		91.44		
15		452.40	450.87	1.53		91.90		
16	8	456.30	454.12	2.18	2.32	83.63	83.45	8.23
17		458.50	456.09	2.41		83.44		
18		455.00	452.62	2.38		83.27		
19	9	457.60	454.99	2.61	2.63	78.96	79.63	3.81
20		456.00	453.36	2.64		80.05		
21		457.10	454.36	2.64		79.89		
22	13	456.40	451.65	4.75	4.44	77.23	77.11	2.53
23		457.20	452.96	4.24		77.11		
24		448.70	444.36	4.34		76.98		
25	14	456.90	451.32	5.58	5.17	75.89	75.80	1.30
26		458.93	453.96	4.97		75.46		
27		455.89	450.93	4.96		76.06		

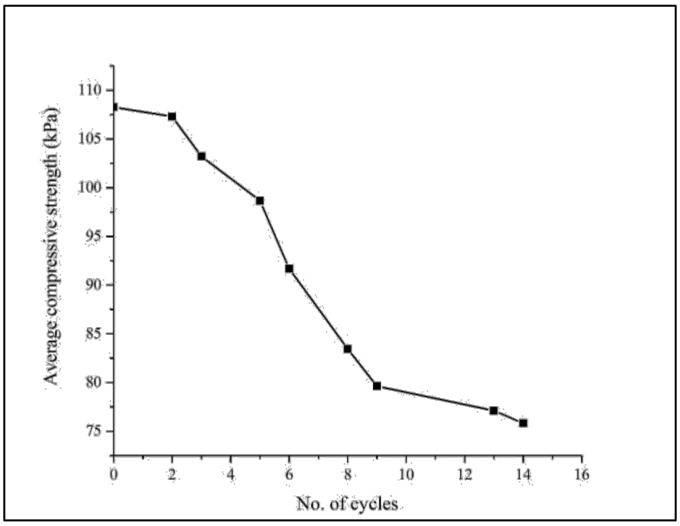

Figure 6. Average compressive strength of limestone samples versus the number of wetting and drying cycles

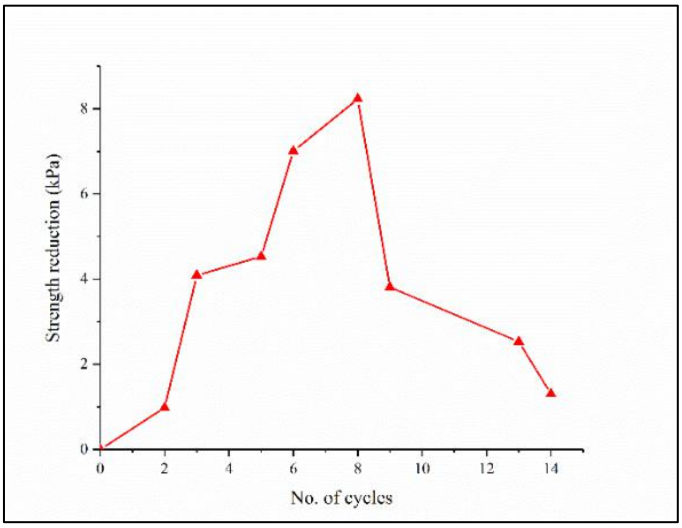

Figure 7. Strength reduction of limestone samples versus the number of wetting and drying cycles

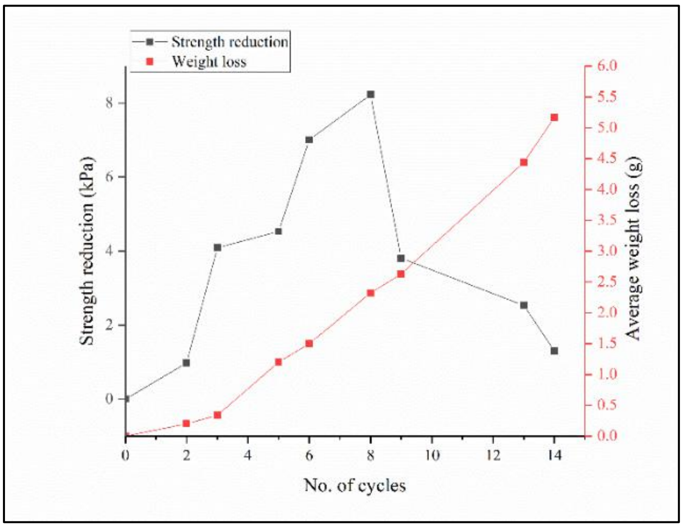

Figure 8. Strength reduction and average weight loss of limestone samples versus the number of wetting and drying cycles

4. Conclusion

Rocks such as limestone are greatly affected by the weathering processes when they are being exposed to different atmosphere. They have these evolutive behaviours that make them vulnerable to degradation due to weathering process. Rocks degrade within time and lose its self-retain ability and eventually fail resulting in massive landslides. This experimental study simulated the weathering processes in the laboratory by applying accelerated wetting and drying cycles for limestone cored samples. The following conclusions could be drawn:

1. Limestone rock is affected by the fluctuations of temperature and its strength is highly influenced.
2. The increase of the number of wetting and drying cycles resulted in degrading the strength of the limestone samples. The results of the compressive strength tests showed lower compressive strength after the first weathering cycle.
3. The weight of the tested samples was reduced with the increased number of weathering cycles due to the degradation of its materials. The loss of weight ranged between 0.2 – 5.17g for total number of weathering cycles between 1 – 14 cycles.
4. The rate of the strength reduction was significantly reduced after cycle number 8 and this is due to the exposure of new core layer as the surface layer is degraded by the previous 7 weathering cycles.

Acknowledgments

The authors would like to express their gratitude to Universiti Teknologi PETRONAS (UTP) for the generous support given for the publication of this paper using the Graduate Assistantship Scheme (GA). The authors would like to express their gratitude to UTP for their generous support.

References

[1] Al-Bared M A M, Abdullah R A, Mohd Yunus N Z, Mohd Amin M F and Awang H 2015 *J. Teknol.* **72** 1–7.
[2] Alsubal S, Sapari N, Harahap I SH and Al-Bared M A M 2019 I*OP Conf. Ser. Mater. Sci. Eng.* **513** 1–12. doi:10.1088/1757-899X/513/1/012009.
[3] Kainthola A, Singh P K and Singh T N 2015 *Geosci. Front* **6** 837–845
[4] Abad S V A N K, Mohamad E T, Komoo I and Kalatehjari R 2015 *J. Teknol.* **72** 71–75
[5] Arikan F and Aydin N 2012 *ISRN Soil Sci.* **2012** 1–15
[6] Miscevic P and Vlastelic G 2014 *J. Rock Mech. Geotech. Eng.* **6** 240–250
[7] Mukhlisin M and Taha M R 2009 *Eur. J. Sci. Res.* **30** 36–44

[8] Al-Bared M A M , Harahap I S H , Marto A , Mustaffa Z , Ali M O A , Al-Subal S 2019 *Malaysian Constr. Res. J.* **6** 215–226
[9] Huisman M, Hack H R G and Nieuwenhuis J D 2004 *EUROCK 2004 53rd Geomech. Colloquium. Schubert*
[10] Abdullah R A, Rosle Q A , Al- Bared M A M , Haron N H , Kamal M and Ghazali M 2015 *Int. Conf. Slopes Malaysia*: 1–16.
[11] Miscevic P and Vlastelica G 2014 *J. Rock Mech. Geotech. Eng.* **6** 240–250
[12] Labus M and Bochen J 2012 *Environ. Earth Sci.* **67** 2027–2042
[13] Qin Z, Chen X and Fu H 2018 *Adv. Civ. Eng.* **2018**
[14] Yang X, Wang J, Hou D, Zhu C and He M 2018 Effect of dry-wet cycling on the mechanical properties of rocks: A laboratory