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EFFECT OF WEATHERING ON DISINTEGRATION AND SHEAR STRENGTH REDUCTION OF CLAY SHALE

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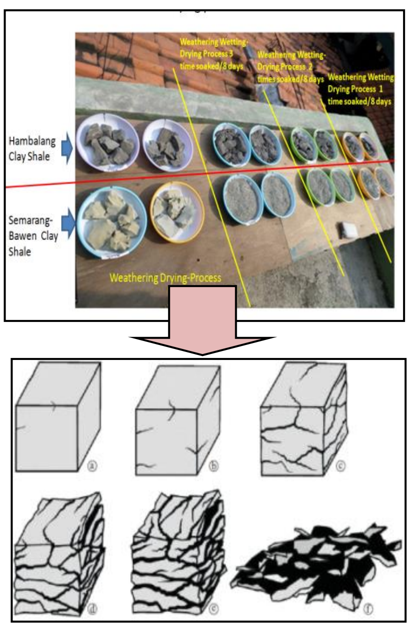
Graphical abstract



Abstract

Frequent and strong atmosphere and hydrosphere reactions accelerate weathering of clay shale. This study was carried out to determine the effects of frequent natural drying and wetting-drying cycles on clay shales in every 8 days until the value of disintegration ratio, D_R reached zero (completely non-durable). Clay shale samples from Semarang-Bawen and Hambalang were tested in the laboratory under four circumstances: (1) without soaking, (2) soaked once in every 8 days, (3) soaked 2 times in every 8 day and (4) soaked 3 times in every 8 days. Disintegration ratio, D_R was obtained from the change in grain size distribution of the clay shale due to weathering. Reductions in shear strength of the samples were observed after subjected to wetting-drying cycles. The D_R of Semarang-Bawen clay shale reached zero after 32 days, while the D_R of Hambalang clay shale showed a range of values between 0.09 and 0.147 on the 80th day. Wetting-drying cycles showed greater impact than natural drying on shear strength parameters reduction. Triaxial tests could only be performed on samples from Semarang-Bawen and Hambalang which were exposed to wetting-drying cycles up to 24 and 32 days of test, respectively beyond which the samples completely disintegrated.

Keywords: Clay shale; weathering; wetting-drying cycle; disintegration ratio; shear strength reduction

1.0 INTRODUCTION

Weathering is defined as a process of changes on rocks under the influence of atmosphere and hydrosphere. The changes can be in the form of physical disintegration and chemical decomposition.

In tropical climate such as in Indonesia, the process is generally more common and intense than in other climatic conditions [1]. Figure 1 shows an illustration of the disintegration caused by weathering of clay shale [2].

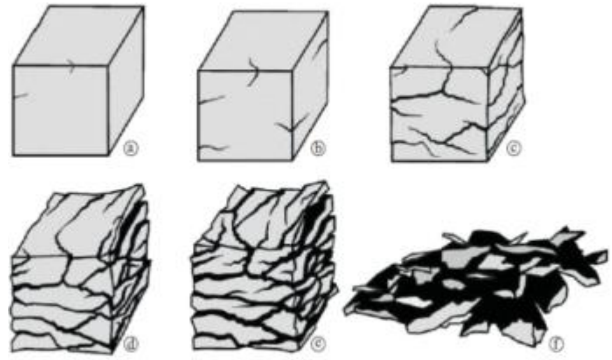
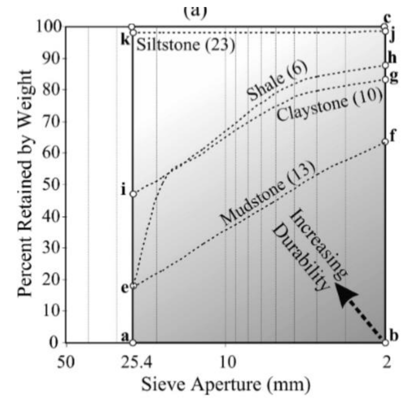


Figure 1 Illustration of general appearances of the body slaking mode of mudrocks under exposure condition clay shale behavior change over time due to drying process [2]

Extensive geotechnical researches on the clay shale shear strength behavior in peak pressure conditions and residual pressure have been performed with variety of test instruments in the laboratory. However, detailed studies have not been conducted to investigate the effects of climate change in term of frequency and intensity of wetting and drying clay shale weathering and its implications on shear strength reduction. Weathering that occurs due to the influence of various processes will result in changes of the clay shale behavior through its disintegration ratio parameter. This study uses disintegration ratio, D_R to quantify the amount of disintegration under natural drying and wetting-drying cycle conditions. The D_R is defined as ratio of the area under the grain size distribution (GSD) curve of slaked material for a given rock sample to the total area encompassing entire GSD curves of the tested samples as shown in Figure 2 [3] . Most importantly, the D_R provides a better quantification of the amount of disintegration by taking into account the GSD of entire slaked material from a sample [4].

Research on shear strength reduction at peak stress conditions on clay shale in unsoaked and soaked samples, as well as under the condition of residual stress has been done previously [5]. The decrease in shear strength of unweathered clay shale under different conditions of weathering grade and residual stress also have been studied with recommended shear strength parameters [6]. The correlation between the weathering grade occurred in the field with the reduction in effective internal angle friction and effective cohesion have been investigated in 2014 as shown in Figure 3 [7]. This paper presents the effects of natural drying and wetting-drying cycles on clay shale through determination of disintegration ratio, D_R and changes in shear strength.



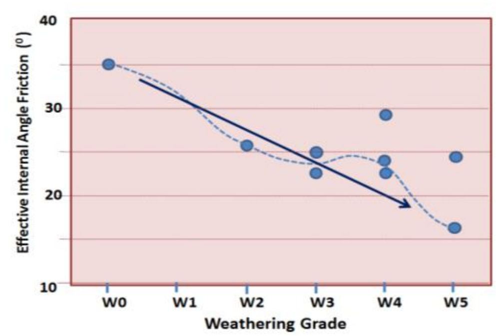
(a)

Rock Type	Disintegration Ratio (D_R)
Claystone (10)	$D_R = \frac{Area(abge)}{Area(abcd)} = 0.571$
Mudstone (13)	$D_R = \frac{Area(abfe)}{Area(abcd)} = 0.329$
Siltstone (23)	$D_R = \frac{Area(abjk)}{Area(abcd)} = 0.983$
Shale (6)	$D_R = \frac{Area(abhi)}{Area(abcd)} = 0.634$

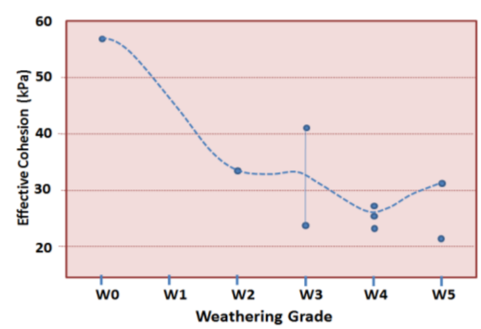
□ Completely durable (D_R=1)
■ Completely non-durable (D_R=0)

(b)

Figure 2 (a) Fragment size distribution curves for some clay-bearing rocks and (b) mathematical derivation of the disintegration ratio [3]



(a)



(b)

Figure 3 (a) Reduction of effective internal angle friction grade of clay shale and (b) reduction of effective cohesion grade of clay shale [7]

2.0 METHODOLOGY

Figure 4 illustrates the methodology to determine the disintegration ratio, D_R due to the influence of weathering processes on clay shale and its effects on reduction in shear strength through respective laboratory tests.

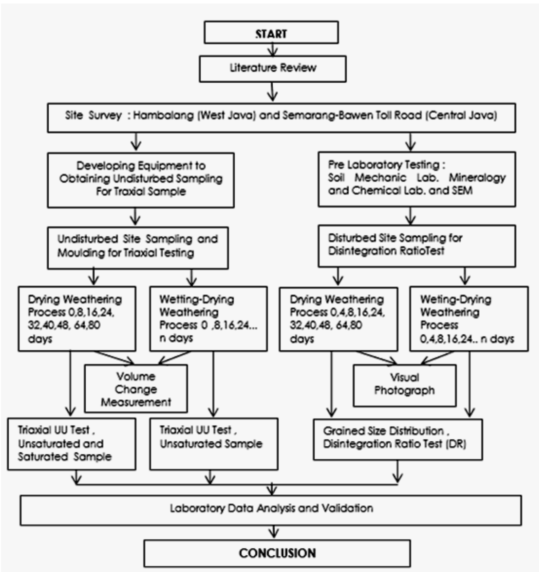


Figure 4 Flow chart of research methodology

2.1 Clay Shale Properties and Mineralogy

Table 1 shows some engineering properties of the Semarang-Bawen and Hambalang clay shales. It can be seen that the bulk density of Hambalang clay shale is greater than Semarang-Bawen clay shale. From the results of mineral composition, the Semarang-Bawen clay shale is dominated by smectite clay minerals (50%). Meanwhile, Hambalang clay shale is dominated by kaolinite clay minerals (30%) as tabulated in Table 2.

2.2 Natural Drying and Wetting-Drying Cycles

A room with transparent walls and roof with sufficient air circulation was used for the sun-drying process and to protect the samples from rain (Figures 5 and 6) [10].The clay shale samples were dried naturally for 0, 4, 8, 16, 24, 32, 40, 48, 64 and 80 days. In the wetting-drying cycle, the frequency and intensity of wetting and drying were repeated following a schedule shown in Figure 7. For wetting process, the clay shale samples were soaked for 5 minutes and then left for sun-drying. Three frequencies of soaking (i.e., one, two and three) were used in every 8 days of sun-drying to obtain different disintegration ratio, D_R in assessing the shear strength behavior of the collected clay shale [11].

Table 1 Index properties and mechanical properties of Semarang-Bawen and Hambalang clay shale [8]

No	Item of Properties	Semarang Value	Hambalang Value	Unit
1	Bulk density	20.3 ~ 21.6	23.4 ~ 24.7	kN/m^3
2	Water content	15.3 ~ 18.5	3.50 ~ 5.11	%
3	Specific Gravity (Gs)	2.65 ~ 2.68	2.70 ~ 2.79	
4	Dry density	17.6 ~ 18.6	22.1 ~ 23.7	kN/m^3
5	Liquid Limits (LL)	59.12	25.12	%
	Plastic Limits (PL)	29.89	14.12	%
	Plasticity Index (PI)	29.23	11	%
6	Sand	0.92	32.98	%
	Silt	45.08	27.02	%
	Clay	54	40.00	%
7	Cohesion undrained (Cu)	700	450	kN/m^2
	Internal angle friction (Øu)	59.4	78.4	Degree
	Res. Cohesion undraned (Cur)	285	270	kN/m^2
	Res. internal angle friction (Øur)	46	45	Degree

Table 2 Mineralogy of Semarang and Hambalang clay shale [9]

LOCATION	CLAY MINERAL (%)				TOTAL (%)
	Smectite	Illite	Kaolinite	Chlorite	
Semarang	50	3	2	1	56
Hambalang	-	12	30	20	62
	CARBONATE MINERAL (%)				TOTAL (%)
	Calcite	Dolomite	Siderite	-	
Semarang	30	-	2	-	32
Hambalang	-	-	4	-	4
	OTHER'S MINERAL (%)				TOTAL (%)
	Quartz	K-Feldsfar	Plagioclase	Pyrite	
Semarang	8	-	3	1	12
Hambalang	30	-	4	-	34

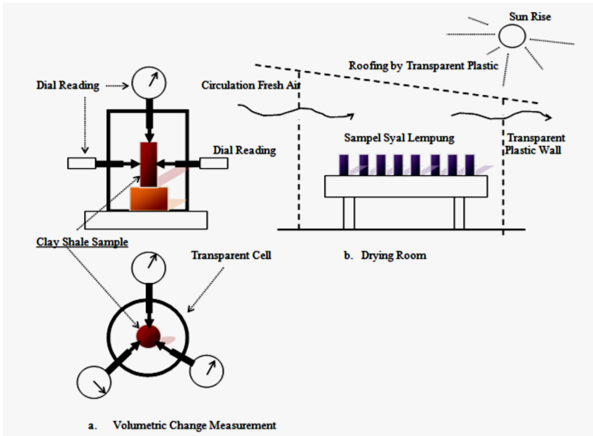


Figure 5 Volumetric volume change (free swell apparatus) and illustration for drying room

Figure 6 Natural drying process of clay shale and measurement of volume change in drying room

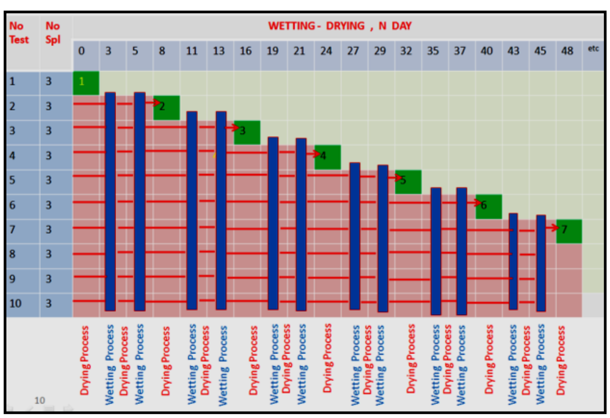


Figure 7 Wetting-drying cycle schedule for two times soaking in every 8 days sun drying [11]

3.0 RESULTS AND DISCUSSION

The relationship between changes of clay shale particles and the wetting-drying cycles can be observed through the decreasing disintegration ratio, D_R, which was initially equal to one (i.e., completely durable). The D_R became smaller until it reached zero (i.e., completely non-durable) [4]. The change in D_R occurred due to several causes related to weathering and different mineral compositions of the clay shale. Consequently, the decreasing D_R reduced the shear strength of the clay shale. Clay shale samples that were subjected to sun-drying only (Figure 8) have shown different effects compared to the wetting-drying cycles (Figure 9).

Figure 8 Disintegration of Hambalang and Semarang-Bawen clay shale up to 80 days due to natural drying process

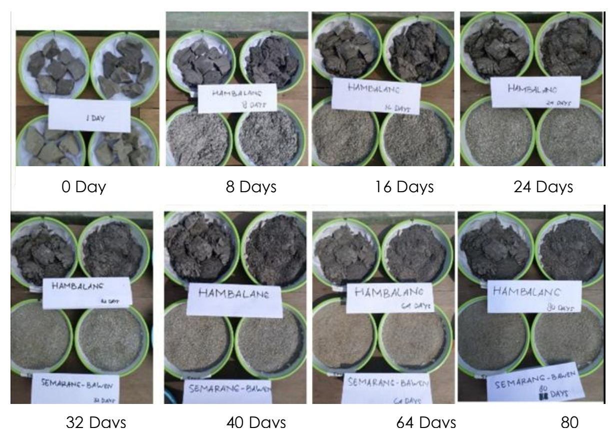


Figure 9 Disintegration of Hambalang and Semarang-Bawen clay shale up to 80 days due to wetting drying process twice soaked in every 8 days

The GSD results of Semarang-Bawen and Hambalang clay shale during the weathering process up to 80 days are shown in Figures 10 and 11. It can be seen that frequent soaking has accelerated the weathering process on both types of the clay shale samples. However, the effects of weathering process on the Semarang-Bawen clay shale with high smectite content was faster than that of the Hambalang clay shale. The smectite clay minerals has been widely recognized as minerals that cause high swelling.

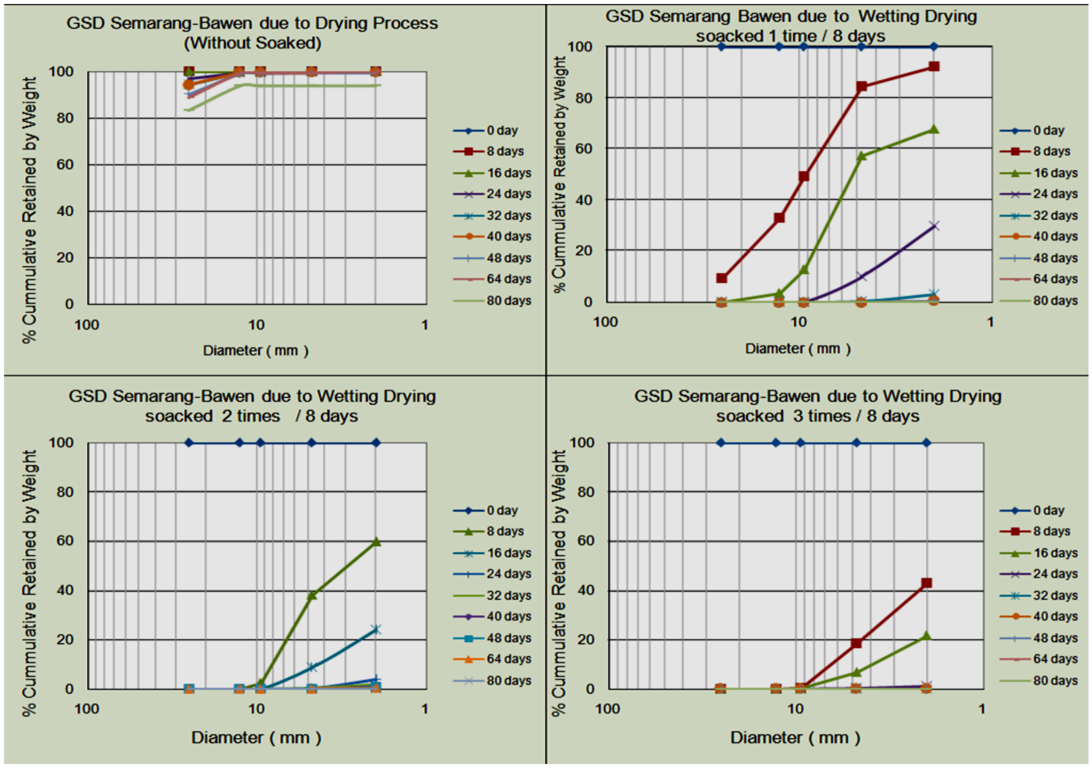


Figure 10 GSD curves of Semarang-Bawen clay shale after natural drying and wetting-drying cycles

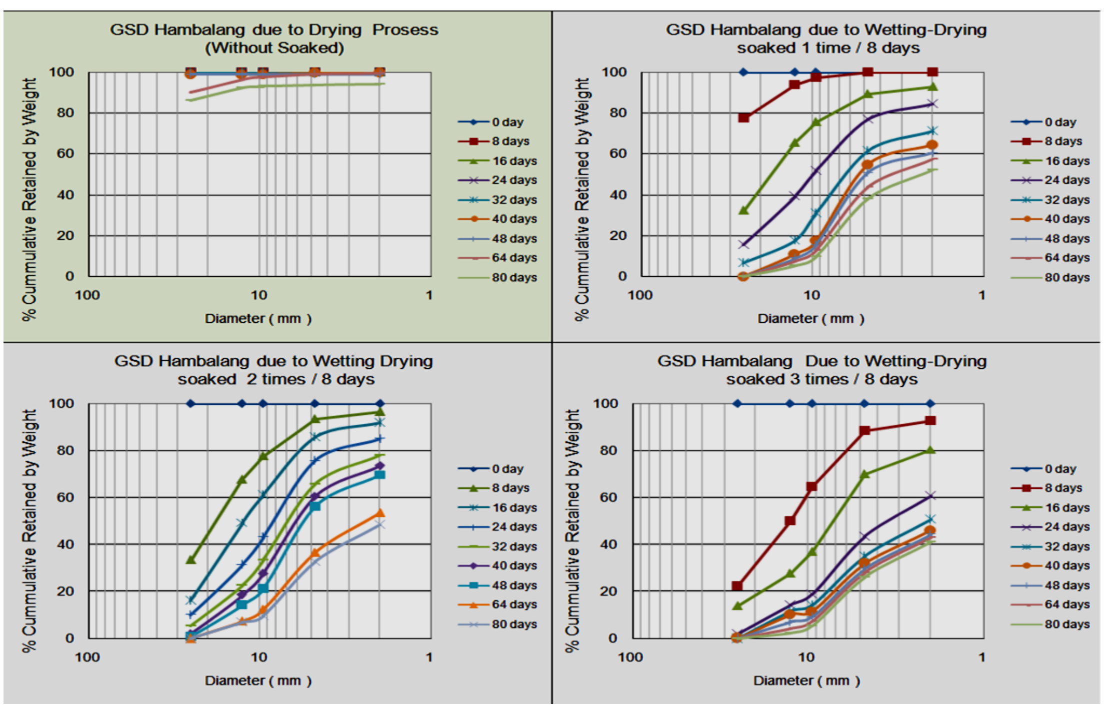


Figure 11 GSD curves of Hambalang clay shale after natural drying and wetting-drying cycles

The decrease in D_R due to the weathering process variations on Semarang-Bawen and Hambalang clay shales are shown in Figures 12 and 13. In comparison, the D_R of Semarang-Bawen clay shale decreased faster than that of the Hambalang clay shale. This result reveals that the Semarang-Bawen clay shale is less durable than the Hambalang clay shale. In 80 days of testing, the Hambalang clay shale has not completely non-durable (refer to Figure 13).

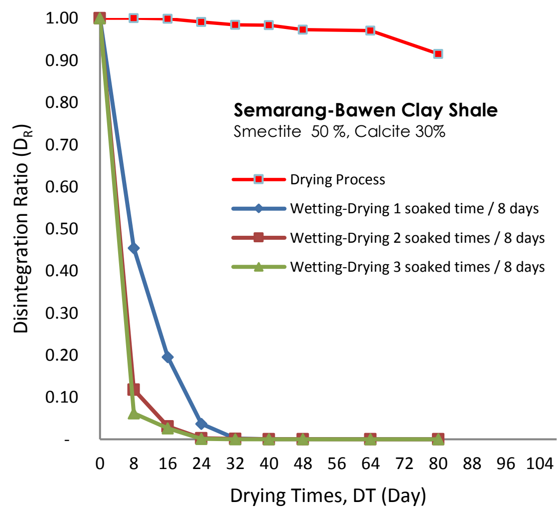


Figure 12 Decrease in disintegration ratio, D_R of Semarang-Bawen clay shale due to variations of weathering processes up to 80 days

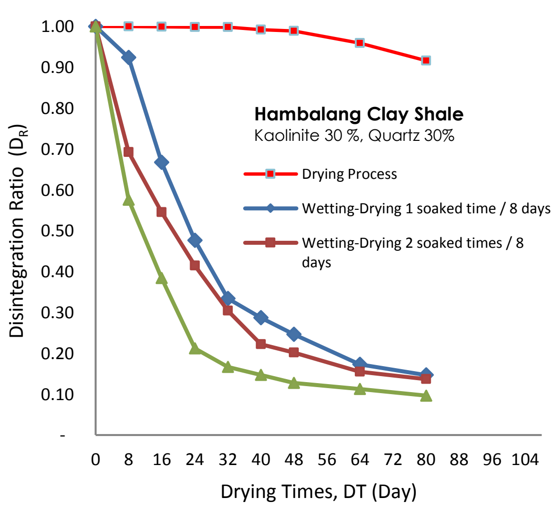


Figure 13 Decrease in disintegration ratio, D_R of Hambalang clay shale due to variations of weathering processes up to 80 days

The decreasing D_R is used as an important indicator for reduction in shear strength parameters. Residual internal friction angle decreased faster due to wetting-drying cycles than due to natural drying. In addition, reduction in residual internal friction angle increased with frequencies of wetting-drying cycles. Reduction in the internal friction angle results for unsaturated Semarang-Bawen clay shale due to weathering process variations can be seen in Figure 14.

Similarly, the residual cohesion reduced as the residual internal angle friction decreased. However, the trend of residual cohesion with stress release due to wetting-drying process is almost similar to the case of natural drying condition (refer to Figure 15).

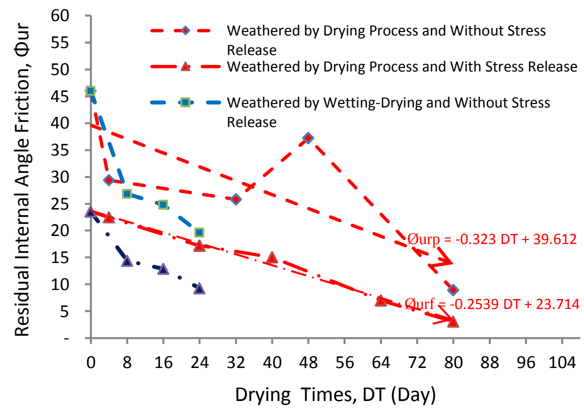


Figure 14 Residual internal friction angle reduction of unsaturated Semarang-Bawen clay shale due to natural drying and wetting-drying cycles (soaked twice in every 8 days)

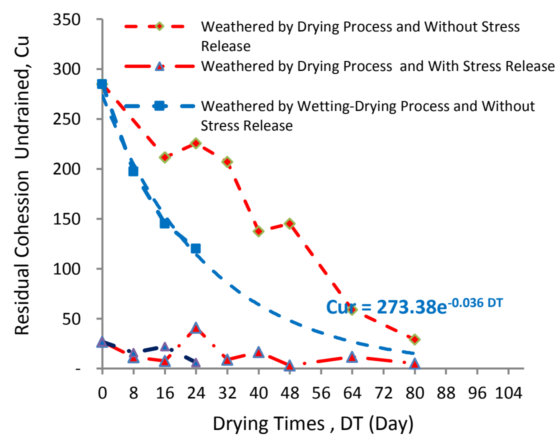


Figure 15 The residual cohesion reduction of unsaturated Semarang-Bawen clay shale due to natural drying and wetting-drying cycles (soaked 2 times in every 8 days)

The residual shear strength reduction of the Hambalang clay shale showed a similar pattern with the Semarang-Bawen clay shale. It was observed that the impact of weathering process by wetting-drying cycles on residual cohesion reduction was faster than the weathering process by natural drying. The reductions in residual cohesions due to natural drying and wetting drying cycle is shown in Figure 16.

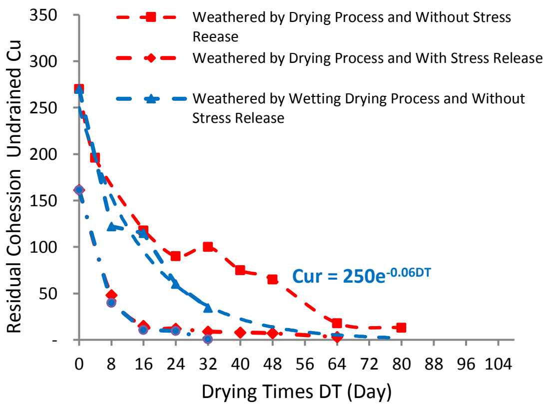


Figure 16 The residual cohesion reduction on unsaturated Hambalang clay shale due to natural drying and wetting-drying cycles (soaked 2 times in every 8 days)

4.0 CONCLUSION

Disintegration ratio, D_R and shear strength parameters of clay shale samples from Semarang-Bawen and Hambalang subjected to different weathering conditions were determined in the laboratory. The D_R of Semarang-Bawen clay shale reached zero (completely non-durable) after 32 days, while the D_R of Hambalang clay shale showed a range of values between 0.09 and 0.147 on the 80th day. Wetting-drying cycles showed greater impact than natural drying on shear strength parameters reduction. Triaxial tests could only be performed on samples from Semarang-Bawen and Hambalang which were exposed to wetting-drying cycles up to 24 and 32 days of test, respectively beyond which the samples were completely disintegrated. The Hambalang clay shale that did not contain smectite minerals but high in quartz content was more durable than the Semarang-Bawen clay shale with smectite mineral.

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