http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 04 No 03 2019

RESEARCH ARTICLE

The Use of Disintegration Ratio in Evaluating Rock Durability in Selected Mudrock Samples in Indonesia

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Tel.: +62-858-1143-5418
Received: Oct 11, 2018; Accepted: July 31, 2019
DOI: 10.25299/jgeet.2019.4.3.2331

Abstract

Characterization of durability of mudrocks is important regarding its slaking behaviour within a short time when exposed to and or interact with water. Some relevant cases that occurred due to slaking are damage to roads and slope failures along the Cipularang and Cipali Toll Road. Current engineering activities related to the presence of mudrocks are being and will be held in several locations in Indonesia such as the construction of the Cisumdawu Toll Road in Ujungjaya District, Sumedang and building the National Observatory in Timau District, Kupang. This research is useful for providing engineering considerations related to those activities.

The methods used in this research included X-ray diffraction to obtain mineralogy of mudrock, laboratory testing of physical properties of rocks such as dry density, water content, porosity, absorption and mudrocks durability tests. Durability of rocks was determined by disintegration index test. Testing was carried out by wetting and drying of rock samples.

Test results showed that the average disintegration ratio of claystones, shales, mudstones and siltstones are 0.1035, 0.2183, 0.4942 and 0.9900. Slaking mode occurs to claystones, mudstones and shales is body slaking while dispersion slaking occurs to siltstones. Evaluation of the durability of mudrocks in this research indicates that siltstones have the highest durability characterized by very slow disintegration, followed by mudstones, shales and claystones at the lowest with very quick disintegration. Disintegration ratio from the disintegration index test characterizes the durability of mudrocks in more details. It can be concluded that porosity and absorption are incorporated into the main factors affecting the durability of mudrocks.

Keywords: *Disintegration Index Test, Disintegration Ratio, Durability, Mudrocks*

1. Introduction

In some engineering activities, mudrocks often have a negative impact. This is related due to its characteristics of easily slaked when exposed and or interacting with water in a short time. Some adverse effects that can be caused by the presence of these rocks are cases of slope failure, road damage, landfill problems, land subsidence, tunnel loading and instability in building foundations. Several types of rocks in mudrocks can consist of siltstones, mudstones, shales and claystones (Dick and Shakoor, 1992; Gautam, 2013).

Cases of failure or poor engineering buildings take place in several locations in Indonesia, such as the Cikampek-Purwakarta-Padalarang Toll Road (Cipularang), often found in landslides or subsidence both on the slopes and on the sides of roads. The Cikampek-Palimanan (Cipali) Toll Road also began to show similar characteristics on several sides of the road. The Training Center for Education and the National Sports School (P3SON) Hambalang has a disturbed foundation because of the shrinking nature of the material associated with mudrocks.

Other cases that could potentially be affected by the presence of mudrocks is the plan to make the Cileunyi-Sumedang-Dawuan Toll Road (Cisumdawu) which will be connection access between regions around Bandung and Cirebon. This road will pass through the Subang Formation in the Ujungjaya-Legok Section. The Subang Formation has distinctive properties which are often found in conditions slaked in a short time when exposed to the atmosphere and or when wet by water, triggering several significant problems in engineering activities (Sadisun *et al.*, 2005; Misbahudin and Sadisun, 2018).

Besides the claystone of the Subang Formation, there are also several rock formations with similar properties such as the Bobonaro Formation. The Timau National Observatory, Kupang, East Nusa Tenggara is planned to be built on this formation. Meanwhile, the Batuasih Formation in the form of shales was allegedly the cause of damage to some parts of the Saguling Dam (Misbahudin, 2017).

The vulnerability of rocks to disintegration is related to the low durability that rocks have. Rock durability is often measured by a test of slake-durability. This test was standardized by the International Society of Rock Mechanics (ISRM, 1981). Slake durability tests are widely used to assess physical changes as a result of wetting-drying processes (Franklin and Chandra, 1972; Koncagul and Santi, 1999; Gokceoglu and Aksoy, 2000).

Some researchers developed static durability tests through wetting-drying process. Sadisun *et al.* (2005) made a static slaking index test, then Erguler and Ulusay (2009) develop the method called the disintegration index test.

Regarding durability testing, some researchers characterize the reference material that is retained on a 2 mm (mesh no. 10) sieve as durable material. It should be noted that when rocks are disintegrated, rocks will be slaked or split into fragments that have different size ranges. This will depend on the type of rock itself. These rocks will differ in terms of mineralogical content and physical properties of rocks.

Based on the explanation above, the characterization of mudrocks durability to the process of disintegration by both weathering and other natural deterioration processes is important. This is useful for providing engineering considerations in the construction activities that will take place as well as those that have already been built.

1.2 Location and Geological Condition

The research locations are in Warungkiara, Sukabumi, Ujungjaya, Sumedang, West Java and Timau, Kupang, East Nusa Tenggara regions as shown in Fig. 1. The rock formations are related to the research focus on mudrocks in the Sukabumi area consisting of Rajamandala Formation (Sukamto, 1975). Martodjojo (2003) called it Batuasih Formation for rocks in this area. Subang Formation and Kaliwangu Formation cover the research area in Ujungjaya, Sumedang. Meanwhile, in Timau area, Kupang main rock formation is Bobonaro Formation (Fig. 2).

Based on Djuri (1973), Subang Formation in the study area consisted of claystone containing limestone layers, dark grey; sometimes there are intercalation of green glauconite sandstones. According to Martodjojo (2003) this formation consisted of blackish claystone-sandstone interbedding and claystone deposited in tidal plains environment.

Kaliwangu Formation contains clay intercalation of tuffaceous sandstones, conglomerates and sometimes found sandstones and calcareous sandstones (Djuri, 1973). This formation consists of sandstone and clay, tufaceous and is black grey with lignite intercalation. The most important characteristic is that it is rich in Mollusca fossil, conglomerates are often found as intercalation and depositional environments are the uppermost tidal environment (Martodjojo, 2003).

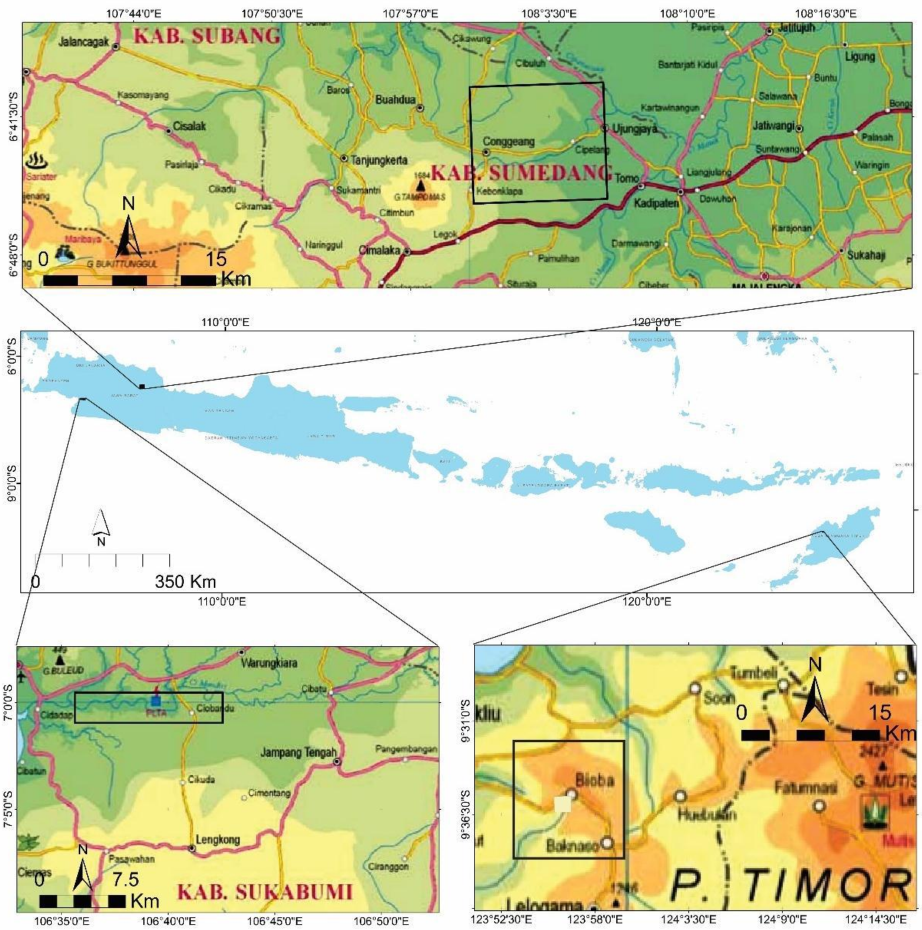

Fig. 1. The sampling location for the study is in three areas, Sukabumi and Sumedang, West Java and Kupang, East Nusa Tenggara.

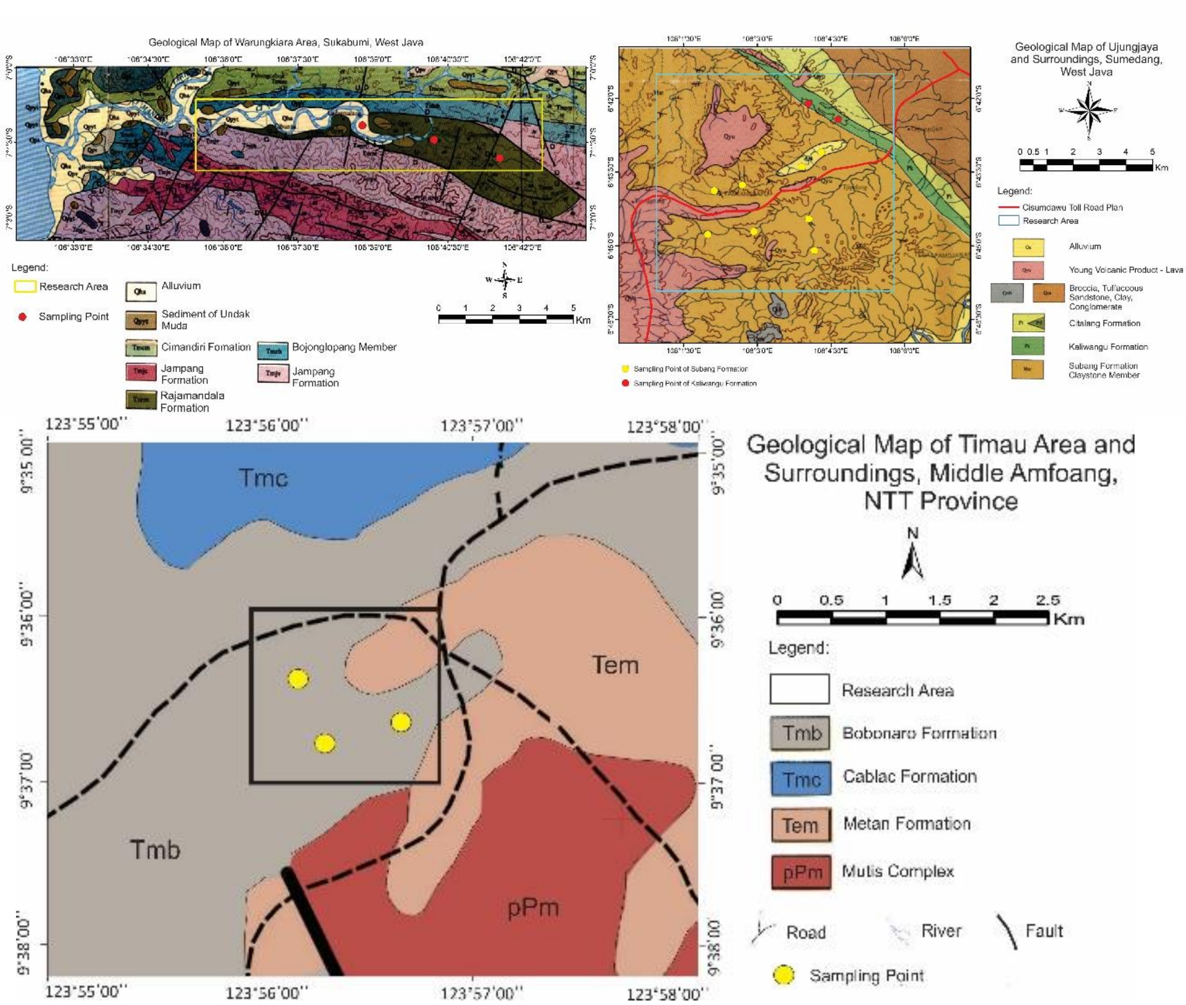

Fig. 2. The geological map of sampling location (Djuri, 1973; Sukamto, 1975; and Rosidi et al., 1996)

Batuasih Formation consists of stiff, dense and often wet clays. Several thin intercalations of sandy silt were also found and sometimes sand was also found. This sandy silt generally consists of quartz and chert; does not contain volcanic fragments. Pyrite is common. The upper part, especially more calcareous; many contain fossils of foraminifera and gastropods besides echinoid and bryozoa fragments. The colours are generally blackish-grey, brittle and shaly. Baumann (1972) op cit. Martodjojo, 2003 considers that Batuasih Formation is an oceanic facies of Upper Bayah Formation. Deposition environment of Batuasih Formation is a transitional sea with reduced conditions at the bottom.

Rosidi *et al*. (1996) suggested that Bobonaro Formation in this study was Miocene, consisting of fragments of boulder size with clay matrixes containing different types of foraminifera. The lithology consists of two main parts, namely scaly clay with soft consistency, dark red, greenish, greyish green, brownish-red and grey. This scaly clay is a matrix of exotic blocks that originate from older rock formations. These blocks have a variety of sizes derived from Cablac Formation limestones, chert, ultrabasic rocks, pillow lava, chrinoide limestone of Maubisse Formation and rocks from the Mutis Complex.

2. Methods

2.1 Rock Sampling

In general, the sampling process follows the procedure made by Clayton *et al*. (1987). Mudrocks samples are taken as undisturbed samples. This is related to the release potential of stress from the overburden stress received by the sample during the deposition process. This release of stress can cause disintegration of the sample earlier. Therefore, sampling is carried out first with a depth of 0.5 - 1 m or up to the depth of the sample which does not show any symptoms of cracking due to stress release.

Samples are then carefully formed into dimensions of 20 cm x 20 cm x 20 cm and as soon as possible coated with wrap plastic and aluminium foil. This layer aims to avoid samples from changes in natural water content and temperature as well as maintain the natural conditions of the sample. After being coated with the material, the sample is put into a sample box arranged from the multiplex slab and guarded against mechanical shocks using bubble wrap or other damper material.

2.2 Laboratory Examination

2.2.1 Disintegration Index Test

Wetting-drying tests are referred to as disintegration index tests following static durability tests on mudrocks carried out by Erguler and Ulusay (2009). This test also takes into consideration the research that has been done by Sadisun *et al.* (2005). The main procedure for disintegration index test is preparation of rock samples weighing 450 - 550 g which are dried in the oven for 24 h at 105 °C.

After being cooled at room temperature, the sample is then immersed in a container filled with water for 24 h (Fig. 3). Most rock samples will experience physical disintegration into small fragments because of the interaction between rock samples with water.

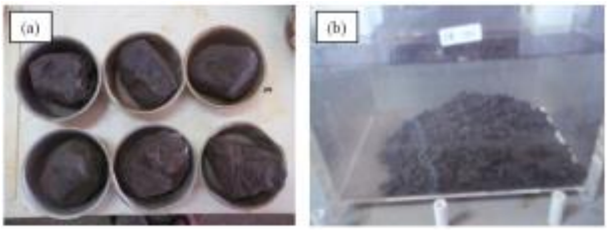

Fig. 2. (a) Preparation of testing samples (b) Samples immersion as a wetting process.

Fig. 3. Wet sieving with varying opening sizes.

The durability index produced from the disintegration index test is total disintegration index declared through Eqn. (1).

$$Di_t = \frac{W_t}{W_o} \times 100 \qquad (1)$$

with, Di_t as total disintegration index (%), W_t as the sample dry weight retained on the sieve 2 mm (g) and W_o as the initial dry weight of the sample (g).

Fragment Size Analysis and Disintegration Ratio

Fragment size analysis was carried out to determine the fragment size distribution of the disintegration material. Wet sieving is used in conducting material distribution on each sieve (Fig. 4). The wet sieve is done manually so there is no disintegration mechanics during the sieving process. The size of the sieve used is maintained to remain consistent during the implementation of testing. The sieves used have an opening size of 76.2 mm, 38.1 mm, 25.4 mm, 19 mm, 13.4 mm, 9.5 mm, 6.35 mm, 4.76 mm and 2 mm.

In order to present characteristics that are more responsive to disintegration material, disintegration ratio is used following the research conducted by Erguler and Shakoor (2009). Disintegration ratio defined follows Eqn. (2).

$$D_R = \frac{A_c}{A_t} \qquad (2)$$

with, D_R is Disintegration Ratio, A_c as area under the sample fragment size distribution curve and A_t as overall area of the fragment size distribution curve that covers all samples.

Identification of Clay Mineral

X-ray diffraction (XRD) is a method often used to identify clay minerals. Particles smaller than 0.002 mm are used for this analysis. Preparation of samples includes use of glass or ceramic for that sample oriented. A coarse powder sample is prepared on a metallic glass to extract clay material.
Characteristics of diffraction peaks and relative intensity were used to identify clay minerals. The mineral standard used in this identification follows International Center for Diffraction Data (ICDD, 2002).

2.2.2 Physical Properties of Rocks

Based on Dick *et al.* (1994) rock durability can have a high value because it is related to degree of induration of rocks is high and is reflected by the value of dry density and void ratio whereas low durability is related to the size of the expansive mineral content such as the smectite group indicated by the value of absorption and specific gravity. Therefore, to evaluate characteristics disintegration by the physical properties of rocks carried out a series of tests following the testing standards of ISRM (2007). This standard is used to determine natural water content, dry density, porosity and absorption of rock. The standard for determining porosity and absorption passes through the immersion process in water.

When the immersion test continues, the mudrocks sample will split into small fragments. To avoid these conditions, immersion liquid is replaced with ethylene glycol in order to minimize deteriorate interactions between rocks and water.

3. Results and Discussion

3.1 Characteristics of Mudrocks in Field

3.1.1 Claystones and Mudstones of Subang Formation

Subang Formation outcrops have weathering levels from fresh rock to residual soil. Fresh rocks are widely exposed which are found on river slopes. Description of claystones is color of grey to blackish grey, clay grain size and found several sizes of silt, low-medium compactness, brittle, locally present pyrite, iron oxide concretion and conchoidal texture with flaked surface.

Claystones are prone to cracks in a short time when exposed. Cracks that occur can take place naturally and rapidly. Cracks show an orientation that is relatively parallel to the direction of rock bedding (Fig. 5).

Fig. 4. (a) Kaliwangu Formation claystone show mollusca fossil (b) Natural crack not well developed.

3.1.2 Claystones of Kaliwangu Formation

The outcrop of Kaliwangu Formation has a narrow spread. At the study site, rock outcrops were only found on one river which is a small valley between two hills. Most of the outcrops are fresh. Description consists of greenish-grey colour, soft consistency, there are abundant fossils of Mollusca with a size of 0.1 - 2 cm, low compactness and locally limestone nodules.

Outcrops of claystones are generally found in a fresh rocks and undergo a process of wetting which is quite intensive. Rocks are sticky if peeled. Some cracks are filled with weathering soil. Cracks that occur due to disintegration are not well developed in a short period. However, it can be observed that there is a natural crack orientation following the rock bedding (Fig. 6).

3.1.3 Siltstones and Mudstones of Bobonaro Formation

Rock outcrops are found on hill slopes with the appearance of rocks slaked. Outcrops are generally found in fresh conditions with some parts experiencing slightly to moderate weathering. River flows that pass through rocks cause gully erosion. Description of these rocks is siltstone, grey to white color, silt grain size and high compactness (Fig. 7). Mudstones, a mixture of sizes of silt and clay with medium compactness. In the claystones, found a scaly structure with a darker color. At the time of observation, no natural cracks that are formed or are difficult to find when exposed to the surface, the existing cracks are oxidized and there are limestone boulders.

3.2 Characteristics of Mineralogy of Mudrocks Samples

X-Ray Diffraction (XRD) is useful for identifying mineral compositions from rocks that have fine grain size. XRD test was carried out on 13 samples. Table 1 summarizes the semi-quantitative analysis result of clay minerals identified through XRD test. The table shows that claystones have varying amounts for illite, kaolinite and montmorillonite. Quartz, plagioclase and calcite are the most common minerals for each rock samples with a percentage of 28.0 %, 11.5 %, and 10.3 % of the overall composition of the samples. Siltstones contain a maximum of quartz minerals of 67.0 %.

3.3 Physical Properties of Rocks

Table 2 shows a summary of the physical properties of mudrocks samples consisting of natural water content, dry density, porosity and absorption. Natural water content ranges from 2.26 % to 32.71 % for all samples. Claystones have the highest natural content with an average value of 20.19 % and siltstones have the lowest natural water content with an average value of 4.18 %. Mudstones and shales have an intermediate value for average water content. Natural water content of mudrocks is a reflection of the clay content and composition of clay minerals. Mudrocks which have a percentage of clay content and expansive clay minerals will have a large value for higher natural water content. It should also be noted that natural water content can vary depending on season or weather conditions (Gautam, 2013).

Dry density ranges from 1.77 % to 3.02 % for all samples. Claystones have the lowest average dry density value of 1.88 % and the highest porosity value with an average of 31.48 %. This indicates the low degree of compacting and induration of claystones. The average dry density for siltstones, mudstones and shales are 2.39 %, 2.19 % and 2.20 % respectively while average porosity values for these rocks are 7.07 %, 16.80 % and 20.87 % respectively.

The average absorption value is 18.63 % for claystones, 8.26 % for mudstones, 3.41 % for siltstones and 11.08 % for shales. Claystones have the highest average absorption value and siltstones have the lowest one. The average absorption value of all samples is 12.31 %. Mudstones and shales have varying absorption values. High absorption values indicate low degree of induration and abundance of clay material (Gautam, 2013).

3.4 Characteristics of Mudrocks Durability with Disintegration Index Test

3.4.1 Visual Observation of Mudrocks

After going through the disintegration index test, claystone shows cracks and intensive fragmentation. After the drying process, through the oven, cracks develop well in almost all claystone samples. When the wetting process through immersion for 24 hours can be observed symptoms of body slaking on claystones (Fig. 8). This occurs in all claystones samples. Some fragments on the edge of the samples begin to fall after being preceded by grains of sand and mud falling.

Table 1. Semi-quantitative analysis result of X-ray diffraction test.

Mineral	Samples Code												
	Bobonaro Fm.			Subang Fm.								Kaliwangu	
	BS-01	BS-02	BM-03	SM-02	SC-03	SC-04	SC-05	SC-06	SC-07	SM-08	SC-09	KC-02	KC-03
Quartz	67	31	8	24.4	19.6	30.2	23.5	24	30.7	37	33.4	21.3	14.8
Montmorillonnite	-	24	8.3	11.1	8.6	4.4	10.4	9.3	3.1	7.2	5.5	-	3.3
Kaolinite	4.3	-	2.5	23.5	26	28.8	24.3	16.9	16.6	10.7	11	17.7	4.8
Illite	8	-	19	-	21	18.9	20	20.4	26.2	24.9	28.9	35.8	53.3
Pyrite	-	-	-	6.4	5.2	3.4	4.4	4.5	4.6	2.8	5.7	-	1.8
Siderite	0.6	-	-	3.8	2.7	2.1	3.6	2	3.6	2.5	1.9	-	-
Calcite	8.1	2.2	43.5	18.4	10	5.6	7.6	15.5	8.5	6.8	7	6.2	10.6
Plagioclase	7.1	38	14.5	12.4	6.9	6.6	6.2	7.4	6.7	8.1	6.6	10.7	3.2
Nontronite	2	-	4.2	-	-	-	-	-	-	-	-	8.3	-
Beidellite	-	-	-	-	-	-	-	-	-	-	-	-	8.2

Slightly different conditions occurred in the KC-02 and KC-03 sample which showed slightly more intensive of dispersion slaking before forming a body slaking. The results of body slaking are rock breakdown in all rock bodies for KC-02 and KC-03 sample and also have larger disintegrated fragments than other samples. Fig. 9 shows the difference in disintegration fragments for both samples as a comparison.

Mudstones show hairline cracks and other samples have experienced cracks and intensive fragmentation such as claystones. When the oven drying process is complete, the BM-03 sample shows a fairly large crack formation along the horizontal plane of the layer. These cracks then continue to become more open during the wetting process. Some muds are dispersed and there are few broken and falling rock fragments (Fig. 10).

Sample SM-02 and SM-08 show different characteristics with BM-03 sample. Sample SM-02 and SM-08 showed symptoms of body slaking as the final result of the wetting process as is the case with claystone samples. This is estimated due to the clay mineral content in the SM-02 and SM-08 sample which are relatively higher compared to other mudstone samples. When going through the process of wetting the water can interact with clay minerals and urge the air in the pore to produce stresses that deteriorate rocks (Gautam, 2013).

Shales with the dominant lamination tend to disintegrate following fissility. Water entering along the lamination plane is a way for the development of cracks and disintegration of rock. All shales samples in the disintegration index test show similar characteristics. After going through drying process, samples showed no significant change. Some hairline cracks are formed apart from the shales fissility. In this condition, the sample still shows the appearance of rocks with high compactness. Different things are shown when the sample begins to be immersed in water. The sample disintegrated into small fragments with the appearance of body slaking. This disintegration takes place following fissility. Other fine cracks formed are not as dominant as their effects on disintegration compared to fissility of shales which are the main triggers for water to deteriorate rocks. Fig. 11 shows the state of shale samples after drying and during immersion.

Siltstones show a characteristic that is difficult or absent from disintegration. BS-02 sample after going through drying process shows formation of hairline cracks while other samples do not show crack formation. BS-02 sample was then slaked and did not show significant disintegration. Some mud may be dispersed even though it is difficult to observe and no fragments on the edge of the samples. Fig. 12 displays BS-02 samples after drying and immersion in water.

3.5 Mudrocks Durability Parameters

The characteristics of mudrocks durability in this study can be represented as a whole through the fragment size distribution curve. Fig. 13 shows the fragment size distribution curve for all samples. On the curve, it can be seen that each sample has a different percentage of material retained in each sieve. In evaluating the mudrocks durability characteristics of the fragment size distribution curve, two durability indices are used. Table 3 summarizes disintegration index test data.

3.5.1 Total Disintegration Index (Di_t)

Total disintegration index (Di_t) shows the percentage of material retained in a 2 mm sieve. Based on average value of Di_t for all rock samples, siltstones are the most durable rock compared to other rock samples. Siltstones have an average Di_t of 99.42 % while claystones have an average value of 36.75 %. Some claystones are completely disintegrated after undergoing a process of wetting and drying. Shales and mudstones show degree of intermediate deterioration with average value of Di_t 51.19 % and 83.99 % respectively.

Table 2. Data of physical properties of mudrock samples

Lithology	Formation	Samples Code	Natural Water Content (%)	Dry Density (g/cm³)	Absorption (%)	Porosity (%)
Claystone	Kaliwangu	KC-01	30.43	2.43	6.70	14.66
Claystone	Kaliwangu	KC-02	29.10	1.58	34.10	48.68
Claystone	Kaliwangu	KC-03	32.71	1.61	34.92	50.72
Claystone	Kaliwangu	KC-04	21.58	1.97	5.15	9.16
Claystone	Subang	SC-01	14.62	1.80	17.87	29.00
Claystone	Subang	SC-03	16.39	1.72	18.89	29.33
Claystone	Subang	SC-04	17.02	1.95	24.67	43.38
Claystone	Subang	SC-05	18.09	1.79	23.37	37.64
Claystone	Subang	SC-06	15.10	1.95	22.99	40.34
Claystone	Subang	SC-07	16.41	1.81	19.27	31.33
Claystone	Subang	SC-09	15.27	1.70	18.34	28.09
Claystone	Subang	SC-10	15.57	1.91	17.57	30.23
Mudstone	Bobonaro	BM-03	15.70	2.20	1.63	3.23
Mudstone	Bobonaro	BM-06	6.76	1.77	7.49	11.92
Mudstone	Subang	SM-02	12.85	2.48	15.10	33.80
Mudstone	Subang	SM-08	7.47	2.29	8.82	18.23
Shale	Batuasih	ASH-01	6.98	2.13	10.17	19.50
Shale	Batuasih	ASH-02	4.43	2.43	6.40	14.01
Shale	Batuasih	ASH-04	2.26	2.46	4.63	10.25
Shale	Batuasih	ASH-06	14.66	1.96	17.50	30.95
Siltstone	Batuasih	ASL-03	5.28	2.62	2.22	5.25
Siltstone	Batuasih	ASL-05	2.45	2.08	4.17	7.79
Siltstone	Batuasih	ASL-07	27.82	1.54	36.88	51.10
Siltstone	Bobonaro	BS-01	3.95	3.02	1.84	5.02
Siltstone	Bobonaro	BS-02	7.23	2.19	5.25	10.37
Siltstone	Bobonaro	BS-04	2.27	2.17	3.97	7.78
Siltstone	Bobonaro	BS-05	3.90	1.91	11.20	19.32

Table 3. The parameters resulted from disintegration index test.

Lithology	Formation	Samples Code	Total Disintegration Index, Di_t(%)	Disintegration Ratio, D_R
Claystone	Kaliwangu	KC-01	0.17	0.0031
Claystone	Kaliwangu	KC-02	62.98	0.4462
Claystone	Kaliwangu	KC-03	27.50	0.1552
Claystone	Kaliwangu	KC-04	13.41	0.0152
Claystone	Subang	SC-01	68.08	0.1077
Claystone	Subang	SC-03	64.09	0.1692
Claystone	Subang	SC-04	1.04	0.0031
Claystone	Subang	SC-05	1.34	0.0038
Claystone	Subang	SC-06	8.23	0.0154
Claystone	Subang	SC-07	58.94	0.0769
Claystone	Subang	SC-09	54.57	0.0769
Claystone	Subang	SC-10	80.58	0.1692
Mudstone	Bobonaro	BM-03	98.60	0.9688
Mudstone	Bobonaro	BM-06	92.56	0.9242
Mudstone	Subang	SM-02	60.33	0.1231
Mudstone	Subang	SM-08	84.49	0.2154
Shale	Batuasih	ASH-01	71.18	0.3077
Shale	Batuasih	ASH-02	74.72	0.2308
Shale	Batuasih	ASH-04	62.62	0.2879
Shale	Batuasih	ASH-06	32.84	0.0758
Shale	Batuasih	ASH-07	14.60	0.0769
Siltstone	Batuasih	ASL-03	99.05	0.9846
Siltstone	Batuasih	ASL-05	99.62	0.9970
Siltstone	Bobonaro	BS-01	99.55	0.9844
Siltstone	Bobonaro	BS-02	98.63	0.9844
Siltstone	Bobonaro	BS-04	99.78	0.9924
Siltstone	Bobonaro	BS-05	99.86	0.9970

3.5.2 Disintegration Ratio (D_R)

Disintegration ratio (D_R) represents the level of durability of mudrocks. Based on Erguler and Shakoor's research (2009), D_R value about 0 indicates low rock durability and high value represents high durability. Claystones have lowest average D_R of 0.1035 while siltstones have highest value with an average value of 0.9900. D_R for mudstones and shales are at an average value of 0.5579 and 0.1958. When claystones interact with water, rocks will rapidly disintegrate because existing clay tends to absorb water. In siltstones, influence of water which causes disintegration is not significant if it takes place in a short time.

3.5.3 Relationship between Total Disintegration Index and Disintegration Ratio

The bivariate analysis between total disintegration index (Di_t) and disintegration ratio (D_R) indicates a statistically significant relationship. The relationship between Di_t and D_R follows an exponential curve (Fig. 14). Small changes in Di_t value can make drastic changes to D_R values. In this curve, it can also be concluded that rocks with a high value of Di_t can have a low D_R value. This is related to size distribution of fragments through process of wetting and drying.

As a representation, Sample SM-02, SC-03, KC-02 and ASH-04 have a relatively similar or Di_t value but D_R is different (Fig. 15). This can also be drawn from fragment size distribution curve of these samples with curves at 2 mm sieve having same percentage of retained material but overall curve area is different (Fig. 13). In general, claystones have low total disintegration index and disintegration ratio contrast with siltstones.

Fig. 5. (a) Iron oxide concretion in Subang Formation claystones (b) Natural crack on surface as a slaking process.


Fig. 6. Disintegration appearance and cracks on surface of Bobonaro Formation siltstone.


Fig. 7. Disintegration on mudstones samples, dispersion with crack (left) and body slaking result (right).

Fig. 8. The difference of disintegration fragment size between KC-02 (Kaliwangu Fm.) and SC-03 (Subang Fm.) sample.

Fig. 9. Body slaking on claystones sample.

Fig. 11. Body slaking on shales sample.

Fig. 12. Hairline cracks that formed on siltstones sample, no significant disintegration.

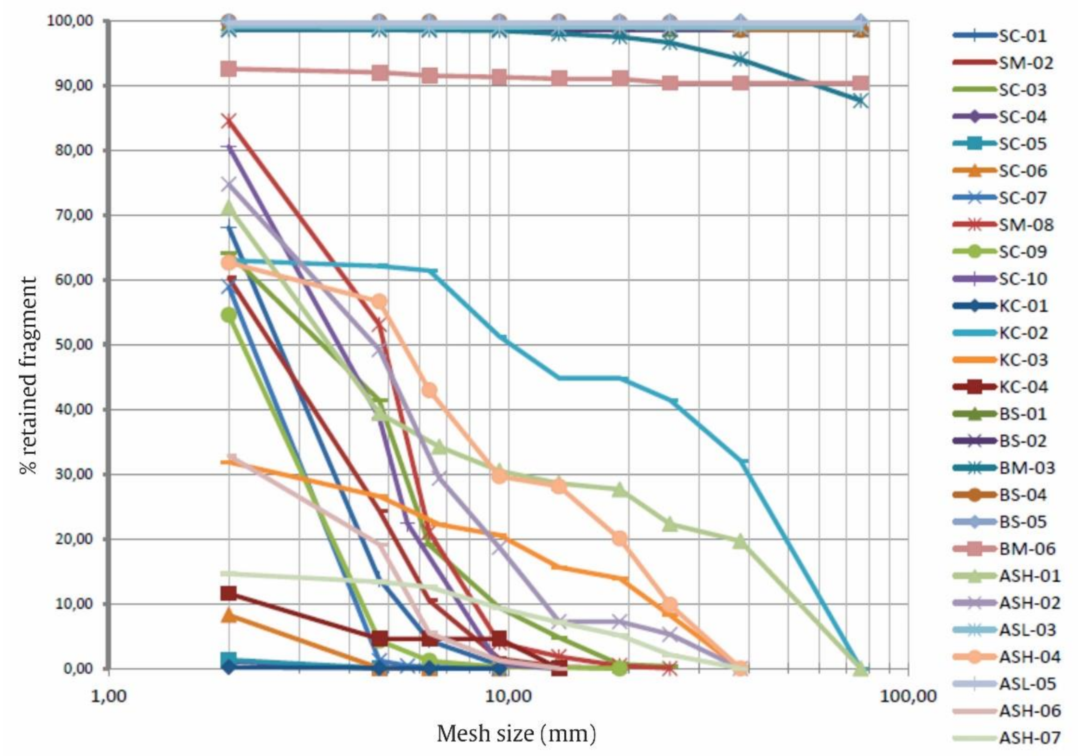

Fig. 13. Fragment size distribution curve resulted from disintegration index test.

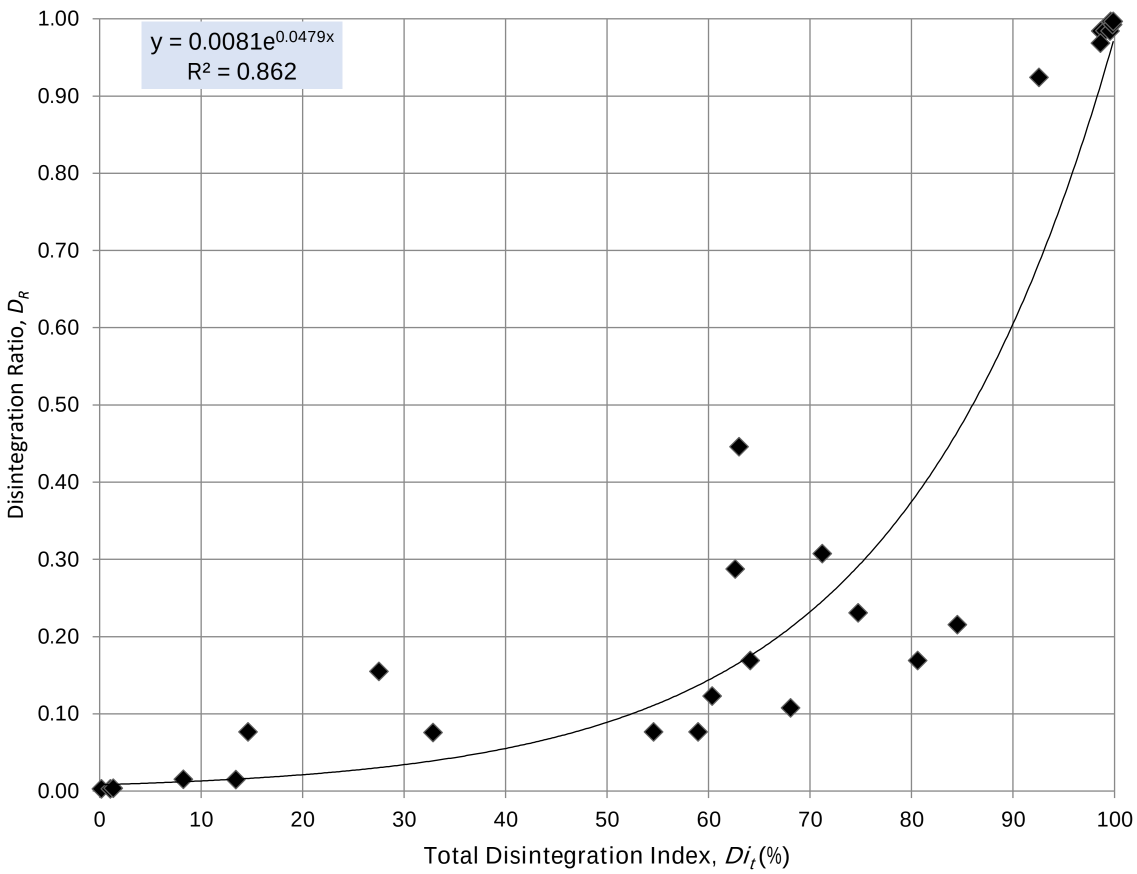

Fig. 14. Correlation between total disintegration index and disintegration ratio.

Samples Code	SM-02	SC-03	KC-02	ASH-04
Total Disintegration Index (%)	60,33	64,10	62,98	62,62
Disintegration Ratio	0,1231	0,1692	0,4462	0,2879
Fragment of Disintegration				

Fig. 15. Samples showing similar Di_i values but different D_R.

3.6 Influential Factors on Durability of Mudrocks

The characteristics of mudrocks durability to the disintegration process represented by the wetting and drying process are influenced by variations in geological and engineering factors (Dick *et al*., 1994 and Gautam, 2013). The two variable regression method is applied to identify factors that affect durability. Regression analysis is the method most often used to determine the tendency of changes in two variables (Davis, 1973 and Czajka, 1994). Through deterministic coefficients (R^2) it can be determined how strongly the influence of independent variables on the dependent variable. The independent variables in this analysis are clay mineralogy of smectite group: montmorillonite, beidellite, nontronite, saukonite, hectorite, saponite (Chamley, 1989), physical properties of rock which include natural water content, absorption, dry density and porosity while the dependent variable is disintegration ratio. The independent variable plotted as the x-axis is rock mineralogy and physical properties of rocks while the dependent variable is plotted as the y-axis is disintegration ratio (D_R).

Table 4 displays the deterministic coefficient value (R^2) for regression variables. Fig. 16 shows selected plots based on the results of regression analysis of two variables for absorption, porosity, natural water content, dry density, and smectite group clay minerals. The plots show that absorption and porosity have a better correlation with D_R than natural water content, dry density and the percentage of smectite group clay minerals.

Fig. 16 shows the condition of rocks with porosity of less than 20 % will have value of D_R greater than 0.2. When rock porosity has a value of less than 20 %, there is a drastic increase in D_R. In line with absorption of rocks is more than 10 %, D_R has a value of less than 0.2. If absorption is less than 10 %, there is a drastic increase in D_R value.

High value of R^2 = 0.7894 indicates a strong influence of porosity on changes in D_R values. The relationship between porosity and D_R follows a negative exponential curve. A small change in the porosity value will cause a drastic change in D_R value. Absorption versus D_R for rock samples has a value of R^2 = 0.7759 which indicates that absorption has a strong influence on changes in D_R value. Claystones with a greater value of absorption variable has a larger pore space. When pores are filled with water, it produces pressure against grains, develops cracks or progressively deteriorates rocks (Olivier, 1979; Dick *et al*., 1994; Czerewko and Cripps, 2001). Siltstones have lower absorption, high dry density and higher durability. Rocks with large porosity are positively related to high absorption values. Both of these variables are negatively related to the amount of disintegration.

Analysis of two variables for the percentage of smectite group clay minerals, dry density and natural water content was correlated and had a moderate to weak influence on D_R. Although the relationship of each variable to D_R follows a certain trend curve, namely logarithmic for natural water content and percentage of smectite group clay minerals and exponential curves for dry density, the influence is weak.

The value of R^2 = 0.4325 for the relationship of natural water content and D_R indicates the condition of 43.25% variability in D_R value can be explained by the presence of natural water content variables but the remainder is influenced by other variables. The same is true for dry density and the percentage of smectite group clay minerals with values of R^2 = 0.2759 and 0.0145 respectively.

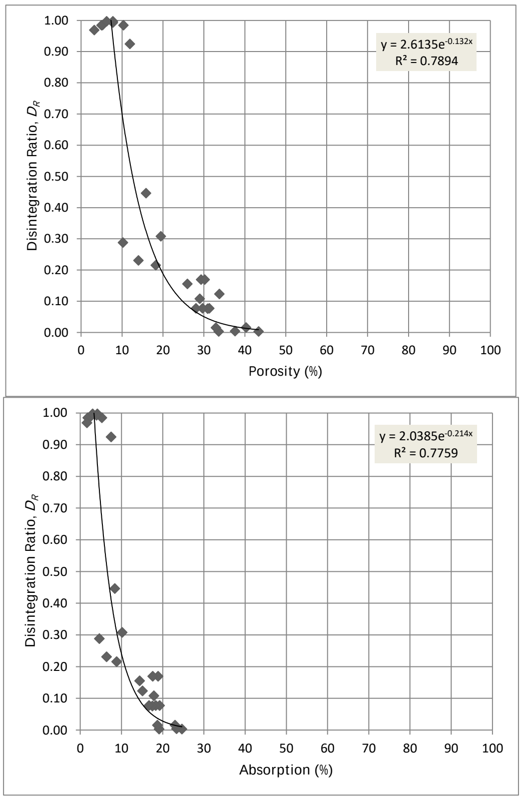

Fig. 16. Correlation between porosity and absorption with disintegration ratio.

Table 4. Deterministic coefficient value (R^2) for correlation between disintegration ratio with physical properties and rock mineralogy.

	Porosity	Absorption	Water Content	Dry Density	% Smectite Group Clay
D_R	0,7894	0,7759	0,4325	0,2759	0,0145

4. Conclusion

Disintegration index test can evaluate durability characteristics of mudrocks with qualitative and quantitative data. Visual observation and durability parameters can be obtained representatively. The total disintegration index and disintegration ratio have high variations of value for different types of mudrocks. Claystones are found to be the lowest durability rock, while siltstones are the highest durability one. The average disintegration ratio for claystones, shales, mudstones and siltstones is 0.1035, 0.1958, 0.5579 and 0.990, respectively. Claystones disintegrate rapidly become small fragments while siltstones disintegrate slowly and remain as larger fragments.

The relationship between total disintegration index and disintegration ratio is the exponential curve. This relationship indicates that rocks with a high total disintegration index can have a low disintegration ratio based on the fragment size distribution. Based on regression analysis of two variables, porosity and absorption have a strong influence on changes in disintegration ratio values. Both variables are related in the form of negative exponential curves. Small changes in the value of porosity and absorption will have a drastic effect on the value of the disintegration ratio.

Regarding this study, the characteristics of mudrocks in Indonesia have different durability properties. Mudrock with low durability and rapid disintegration can have a detrimental effect on engineering activities such as causing slope failure or foundations in road and building construction. On the other hand, there are also mudrocks with different characteristics with high durability and slow disintegration which, in a longer period of time, can only be seen to interfere with engineering activities.

Acknowledgement

The author would like to thank for the help and support of Laboratory of Metallurgy ITB in conducting the disintegration index test. In addition, thank you also to Laboratory of Hydrogeochemistry ITB for conducting X-Ray Diffraction testing.

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