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# Physical Disintegration Characterization of Mudrocks Subjected to Slaking Exposure and Immersion Tests

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**Abstract**

In order to gain insights into the detailed physical disintegration characteristics of various types of mudrock, a series of static slaking exposure and immersion tests were carefully carried out in this study. The intent of this paper is to exhaustively describe and discuss the results of the tests, including slaking mechanism, mode and rate/intensity. In general, it can be obviously identified that there are significant different susceptibilities of each mudrock tested to slake-disintegration. These differences can not only be identified from the results of slaking exposure test but also from slaking immersion test. It seems that there is also an agreement in both testing results, which show that the most resistant mudrock to slaking was Ikeshima shales, and was comparatively, followed by Ombilin siltstones, Tanjung Enim mudstones-claystones, and Subang claystones as the worst slaking characteristic. The detailed differences in fundamental characteristics of physical disintegration characteristics will further widely be discussed in this paper.

**Keywords**: disintegration, mudrock, exposure, immersion, slaking test

***Sari***

*Dalam upaya untuk mengetahui secara mendalam sifat disintegrasi fisik berbagai jenis batulumpur, serangkaian pengujian dengan penyingkapan disintegrasi statis dan perendaman secara seksama dilakukan pada studi ini. Maksud penulisan makalah ini adalah untuk mendeskripsikan dan membahas hasil pengujian, termasuk mekanisme disintegrasi, cara (model), dan tingkat/intensitasnya. Pada umumnya dengan mudah dapat diidentifikasi bahwa ada berbagai macam kerentanan yang signifikan pada batulumpur yang diuji terhadap disintegrasi fisik. Keragaman ini tidak saja dapat diidentifikasi dari hasil uji penyingkapan disintegrasi, tapi juga dari uji rendam pelapukan. Tampaknya bahwa ada kesesuaian di antara kedua uji tersebut yang mengungkapkan bahwa batulumpur yang paling resisten terhadap disintegrasi adalah serpih Ikeshima, dan secara komparatif diikuti oleh batulanau Ombilin, batulumpur-batulempung Tanjung Enim, dan batulempung Subang yang mempunyai sifat paling buruk. Perbedaan fundamental terperinci dalam sifat disintegrasi fisik lebih lanjut akan dibahas dalam makalah ini.*

***Kata kunci:*** *disintegrasi, batulumpur, singkapan, perendaman, uji disintegrasi*

## Introduction

The mudrocks have been chosen as a particular interest in this study due to their peculiar behaviour of when they are contacting with water or being exposed to the atmosphere, they often present a considerable slaking within a short period of time. The susceptibility of mudrocks to slaking is definitely a main factor; if not it led to the deteriorating and softening of the rock deposits on the natural field condition.

Due to the consequences of numerous engineering problems where the mudrocks are exposed, these rocks have received extensive attention. An engineering problem, for instance, connected with the shallow landslides of Subang claystones

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has been described by Sadisun *et al.* (2005). In connection with the study on construction of Tulis Hydroelectric Power, Irsyam *et al.* (1999) found that the progression of mudrock slaking was responsible for numerous instabilities in the mountains of mid-northern Serayu between Tulis and Merawu Rivers.

In order to determine the slake-susceptibility of some mudrocks, a series of static slaking exposure and immersion tests were carefully carried out in this study. As a case study, some mudrock samples used in this study were obtained from Matsushima Colliery of Ikeshima Coal Mine (Japan), Ombilin and Tanjung Enim Collieries of Bukit Asam Coal Mines (Indonesia), and from an industrial estate development of the southern Karawang area of West Java Province (Indonesia).

## Materials and Methods

All mudrock samples were classified based on the composition of relative amounts of clay-silt and fissile or nonfissile structure (Blatt, 1982; Ferm *et al.,* 2002). For this classification, grain-size distribution was determined by wet sieving and hydrometer analyses after the samples were partially disaggregated by cycles of wetting and drying (Table 1). According to this classification, the samples collected can be classified as Ikeshima shales (IKS), Ombilin siltstones (OS), Tanjung Enim mudstones (TM), Tanjung Enim claystones (TC), and Subang claystones (SC). A brief description of each sample is given in Table 2.

At a fundamental level to understand detailed characteristics of slake-deterioration, manifestations of common slaking modes were investigated by slaking exposure and immersion tests, involving qualitative observations of the slaking process in order to identify the principle mechanism of the deterioration. All samples were then described in terms of any crack development or rock disintegration that might occur and the extent of slaking. In order to gain a better visual characterization, a loupe having a magnification of 10X and 30X was used.

X-ray diffraction (XRD) analysis was applied to this study in order to get a better detailed min-

Table 1. Summary of Grain-size Analysis Results

| Sample Type | Sample# | Grain size | | |
|---|---|---|---|---|
| | | **% Sand*** | **% Silt*** | **% Clay*** |
| IKS shale | IKS-1 | 12.1 | 47.2 | 40.7 |
| | IKS-2 | 9.3 | 54.8 | 35.9 |
| | IKS-3 | 7.4 | 49.5 | 43.1 |
| OM siltstones (OS) | OM-1 | 1.2 | 68.3 | 30.5 |
| | OM-2 | 3.0 | 65.2 | 31.8 |
| | OM-3 | 4.8 | 65.8 | 29.4 |
| | OM-4 | 1.2 | 68.2 | 30.6 |
| | OM-7 | 1.1 | 70.5 | 28.4 |
| | OM-8 | 2.2 | 66.2 | 31.6 |
| | OM-9 | 0.4 | 67.1 | 32.5 |
| TE mudstones (TM) | TE-2 | 6.4 | 35.2 | 58.4 |
| | TE-4 | 0.2 | 46.1 | 53.7 |
| TE claystones (CT) | TE-1 | 2.1 | 21.5 | 76.4 |
| | TE-3 | 2.2 | 26.3 | 71.5 |
| SC claystones | SC-1 | 1.7 | 25.8 | 72.5 |
| | SC-2 | 4.6 | 11.3 | 84.1 |
| | SC-3 | 6.6 | 24.9 | 68.5 |

Table 2. A brief Description of Mudrocks used in this Study

| Rock Type | Geological Formation | Brief Description |
|---|---|---|
| IKS Shale | Sakito | Light gray to dark gray shales, mostly coaly and slickensided, with occasionally contains some sand nodules. |
| OM Siltstone (OS) | Sawah Lunto | Gray to dark gray mottled siltstones, finely interbedded with ripple cross-laminated fine-grained sandstone. |
| TE Mudstone (TM) | Muara Enim | Light gray to gray mudstones, having massive structure, which contains some carbonaceous silt insertions and fine-grained sandstone intercalations. |
| TE Claystone (TC) | Muara Enim | Gray to dark gray claystones, mostly contains carbonaceous silt insertion, with some silicified siltstone nodules. |
| SC Claystone | Subang | Greenish gray to dark gray claystones, mostly having massive structures, intercalated with some fine-grained sandstone. |

eralogical composition of the rocks, due to the fact that overwhelming majority of the rocks consist of very small grain-sized minerals. XRD analysis was performed using a computer-driven Rigaku X-ray diffractometer. A semiquantitative analysis obtained from diffraction patterns was also performed by a reference intensity ratio (RIR) method based on measuring the intensity one or more peaks for each mineral present and the added internal standard from bulk specimens (Table 3), following the method suggested by More and Renolds (1997) and Hillier (2000).

## Results and Discussions

### Slaking Exposure Test

Exposure slaking characteristics of each mudrock specimen are specific (Table 4). The testing results show that all Ikeshima shales were unaffected by short exposure. The initial processes of slake-deterioration in these shales could be observed after 42 to 92 days, by revealing some minor hairline cracking processes, particularly on the edges of the specimens. The progression on cracking continued through the shale specimens in mostly smooth shapes, which tends to form along any fissile or slickenside present.

Meanwhile, hairline cracking processes in the Ombilin siltstones could be observed firstly after their 4 to 35 days exposure. Rugged shapes of the cracks were dominantly found in these siltstones, and they had a certain orientation that might be related to the bedding orientation of the rock formation. In this case, the cracks orientations were relatively parallel to the bedding orientation.

In Tanjung Enim mudstones, initial hairline cracking processes could be observed after 3 to 9 days, with incremental growth in rugged shapes, quite similar to those found in the Ombilin siltstones. A certain orientation of the crack progression relatively parallel to the bedding orientations was also observed.

Claystones, of whether from Tanjung Enim or Subang suffered initial hairline cracking processes mostly before one day exposure. Some Tanjung Enim claystones that comparatively more durable than the Subang are those claystones could survive even until 2 days exposure. On the contrary, some Subang claystones showed more susceptible to initially hairline crack varied between 5 hours to 1 day exposure. In both claystones, the progression of cracks through the specimens tended to form parallel to the bedding orientation with generally possesses conchoidal shapes.

It should be noted on these testing results that swelling (volume expansion) of mudrock specimens always coincidentally occurred during the crack progression. Furthermore, it could be inferred from the aforedescribed exposure slaking characteristics that the body slaking mode was dominant in most mudrocks. The general appearance of the

Table 3. Results of semiquantitative Analysis of XRD Data: Q (quartz), P (plagioclase), Py (pyrite), R (rutile), G (Gypsum), C (Calcite), Si (Siderite) K (kaolinite), I (illite), Cl (Chlorite), and S (smectite)

| Sample# | Mineral Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q | P | Py | R | G | C | Si | K | I | Cl | S |
| IKS-1 | 24.94 | 13.08 | 10.29 | 6.78 | – | – | – | 11.11 | 16.46 | – | 5.60 |
| IKS-2 | 22.59 | 14.54 | 11.02 | 4.73 | – | – | – | 13.01 | 18.39 | Tr | 4.37 |
| IKS-3 | 24.69 | 12.65 | 11.08 | 6.28 | – | – | – | 12.66 | 16.82 | Tr | 7.81 |
| OM-1 | 39.75 | 16.48 | – | 8.81 | – | – | – | 16.44 | 9.61 | Tr | 3.48 |
| OM-2 | 37.99 | 14.91 | – | 10.35 | – | – | – | 17.84 | 8.87 | Tr | 3.62 |
| OM-3 | 35.02 | 15.08 | – | 13.93 | – | – | – | 12.34 | 10.46 | Tr | 4.61 |
| OM-4 | 39.20 | 15.31 | – | 9.58 | – | – | – | 15.88 | 9.69 | Tr | 3.25 |
| OM-7 | 37.99 | 14.87 | – | 10.39 | – | – | – | 16.94 | 6.88 | Tr | 4.51 |
| OM-8 | 48.01 | 3.12 | – | 12.80 | – | – | – | 17.32 | 9.42 | Tr | 2.67 |
| OM-9 | 35.05 | 14.26 | – | 12.72 | – | – | – | 15.30 | 10.48 | Tr | 5.63 |
| TE-1 | 31.24 | 2.16 | 25.70 | – | – | – | – | 25.43 | 2.11 | – | Tr |
| TE-3 | 27.62 | 1.51 | 27.20 | – | – | – | – | 38.03 | Tr | – | 1.37 |
| TE-2 | 39.51 | 2.87 | 17.03 | – | – | – | – | 31.40 | 6.91 | – | 2.05 |
| TE-4 | 37.18 | 1.93 | 27.25 | – | – | – | – | 25.38 | 5.51 | – | 2.55 |
| SC-1 | 25.03 | 13.78 | 5.22 | – | 4.03 | – | – | 12.51 | – | – | 39.43 |
| SC-2 | 17.40 | 8.82 | 13.58 | – | – | 10.70 | 12.31 | 17.41 | 6.67 | Tr | 13.10 |
| SC-3 | 14.60 | 8.91 | 12.70 | – | 6.87 | – | – | 20.51 | 6.62 | – | 29.79 |

Table 4. Summary Results of slaking Exposure and immersion Tests

| Sample# | Time needed to initially slake | |
|---|---|---|
| | Exposure (day) | Immersion (hour) |
| IKS-1 | 55 | 17 |
| IKS-2 | 92 | 31 |
| IKS-3 | 42 | 13 |
| OM-1 | 26 | 14 |
| OM-2 | 4 | 2 |
| OM-3 | 12 | 6 |
| OM-4 | 31 | 11 |
| OM-7 | 21 | 9 |
| OM-8 | 35 | 13 |
| OM-9 | 16 | 7 |
| TE-2 | 9 | 3 |
| TE-4 | 3 | 1 |
| TE-1 | 2 | 1 |
| TE-3 | 1 | < 1 (30 min) |
| SC-1 | <1 (12hours) | < 1 (4 min) |
| SC-2 | 1 | < 1 (5 min) |
| SC-3 | 1 | < 1 (4 min) |

body slaking mode was sketched during the exposure test, as shown in Figure 1. Another slaking mode that could also be recognized during this test was surface slaking mode, which was only present in the Subang claystones.

### Slaking Immersion Test

Similar results to the slaking exposure test were also shown when the mudrock specimens were subjected to slaking immersion test. However, during water immersion, all specimens showed rapid initial hairline cracks, mostly less than one day.

In Ikeshima shales, hairline cracking processes could be observed firstly after their 13 to 31 hour immersion. Besides body cracking, a little sign of collapsing (mainly just at the edges) had been recognized, resulting into an angular piece of rock fragment, without any cloudiness presented.

The occurrence of hairline cracking processes in the Ombilin siltstones could be observed after 2 to 14 hour immersion. Body cracking and a few small flakes were mostly appeared in these siltstones which were occasionally followed by a very little cloudiness. In this case, it was quite difficult to pry

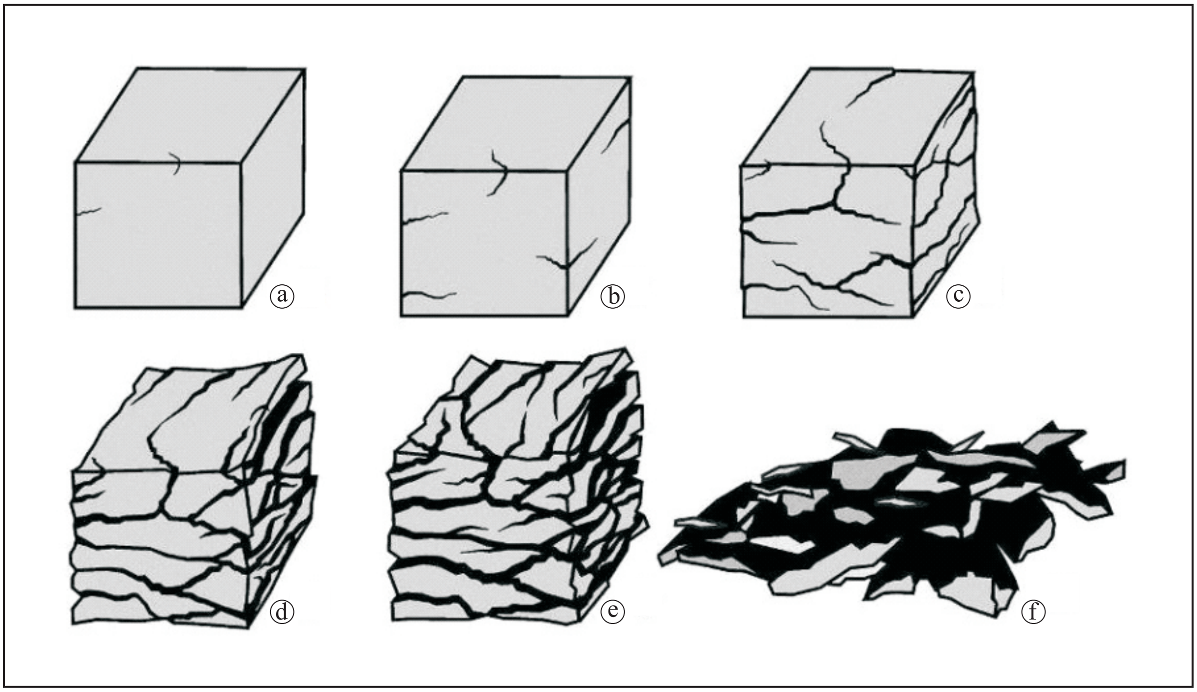


Figure 1. General appearances of the body slaking mode of mudrocks under exposure condition.

up some further flakes which developed due to the progression on cracking.

Tanjung Enim mudstones suffered initial hairline cracking after 1 to 3 hour immersion. The progression on cracking continued through the mudstones resulting in some body cracks and small flakes. Some cloudiness was appeared as soon as following the progression on cracking, which indicated that dispersion slaking had taken part in the deterioration processes of the mudstones.

All claystone specimens, whether from Tanjung Enim or Subang, showed initial hairline cracks within less than or during 1 hour immersion. Again, it can be recognized that the Tanjung Enim claystones were relatively more durable than the Subang claystones (see Table 4). In both claystones, severe hairline cracks easily developed through the body specimens. They were easy to separate and flake, which were simultaneously followed by the development of a dense cloudiness (dispersion slaking), as sketched in Figure 2.a. Some of flakes were parallel to sample surfaces, which revealed typical evidences for surface slaking (Figure 2.b).

It is important to note that almost in every specimen, air bubbles were emitted either from the specimens or developed cracks during slaking immersion test which seemed to result in slaking acceleration.

## Mineralogical factors affecting slake-deterioration processes

The differences in slake-deterioration characteristics of mudrocks might be explained in terms of their inherent mineralogical characteristics as well as the environmental conditions where the slake-deterioration processes occurred.

General mineralogy of mudrocks is mainly composed of fine-grained particles, *i.e.* clay minerals and rock flours. It is already well known that the rocks containing smectite and pyrite minerals may disintegrate when they are exposed to the air and water, such as stated by Taylor and Spears (1970), Madsen (1979), Hopkin and Deen (1984), Bratti and Broch (1995), and Sadisun *et al.* (2004). As both minerals were found in these studied rocks, it was suggested that they might be possible factors influencing in the slaking processes of these rocks. Another mineral that might also affect the

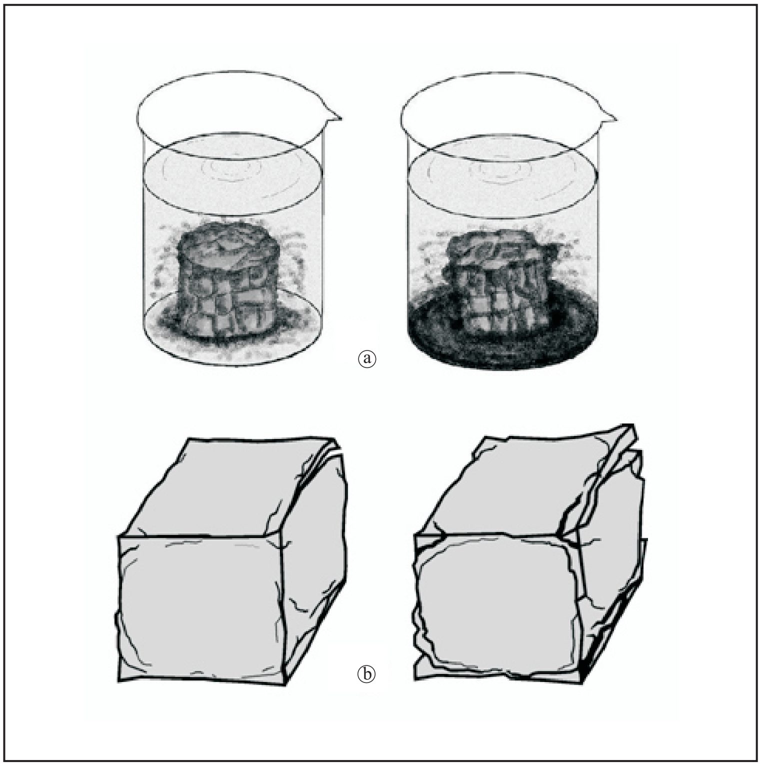


Figure 2. Typical appearances for: a) dispersion slaking, and b) surface slaking.

slaking processes is soluble calcareous minerals as also noted by Taylor and Spears (1970) and Hopkin and Deen (1984), *i.e.* calcite and siderite, notwithstanding this could have taken place for a long period of time.

## Conclusions

Series of slaking exposure and immersion tests were appropriately carried out for detailed characterizing of mudrock slaking. Under a free air exposure condition, most mudrocks were characterized by an appearance of initial hairline cracking or already existing microcracks were opened, which varied in terms of time needed to initially cracking and the shape of developed crack. Meanwhile, in the wetting phase, slake-deterioration processes were seen to occur rapidly, mostly less than one hour, as the entrapped air, particularly in the capillary paths, was sucked by water resulting in high pressure capillary forces. It seems that there is an agreement in both testing results, which shows that the most resistant mudrock to slaking was Ikeshima shales, and was comparatively followed by Ombilin siltstones, Tanjung Enim mudstones-claystones, and Subang claystones as the worst slaking characteristic.

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