MODELLED MECHANISMS IN THE SLAKE-DURABILITY TEST FOR SOFT ROCKS

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ABSTRACT

The slake-durability test is regarded as a simple test for assessing weathering of rocks. This simple test has been accepted as a standard test by the Rock Mechanics Society. However, mechanisms into slaking processes have not been fully understood yet as many factors involved in the processes. The current research explored mechanisms performed by the test by conducting a series of slake-durability tests for four types of soft rocks taken from Coober Pedy, South Australia. Results show that the slake-durability index (I_{d2}) of weathered soft rocks was influenced by the degree of weathering. Distinctly weathered rocks had lower indeces compared to partly weathered rocks. Shapes also influenced the I_{d2} of these soft rocks. Different shapes displayed different mechanisms in the slaking processes. Samples that had irregular shapes tended to have a lower I_{d2} compared to samples that had rounded shapes. Thus, the slake-durability test might have simple procedures, but it could have complicated mechanisms in slaking processes that contribute to the result of the test.

Keywords: slake-durability, weathering, soft rocks, mechanisms and I_{d2}.

INTRODUCTION

The slake-durability test is regarded as a simple test for assessing the influence of weathering on rock [1]. The test has been standardised by the ISRM [2], and data of the test have been published over 25 years [3, 4]. However, mechanisms involved in this slaking test have not been fully understood yet. Franklin and Chandra [1] indicated that mechanisms in slake-durability tests are subject to ion exchange and capillary tension. For rock contains clay minerals, the exchange of cations and ions will take place due to the adsorption of water, which allows the rock to swell when it is wet. With the duration of the test of only ten minutes, the wetting process may only take for parts of the rock, particularly for the surface part.

When the rock becomes more saturated, water menisci within the rock pores increase, which then causes the reduction of capillary tension at grain contacts and the tips of cracks [1]. This mechanism seems to dominate the durability behaviour of porous rock. Water certainly influences the mechanical characteristics of rock. However, in the slake-durability test, not only wet-dry con ditions are given to the rock specimen, but also mechanisms correspond to the drum rotation are involved. These mechanisms have not been explored.

Such mechanisms may be influenced by the shape and weight of the specimen. Therefore, the main objective of the current study is to determine the slake-durability mechanisms, which are then used as the basis for analysing the slake-durability index of the rock.

METHOD

As mentioned above, the slake-durability test was intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting [2]. Rock samples were put into an apparatus that comprises two sets of drums of the length of 100 mm and the diameter of 140 mm, as can be seen Figure 1.

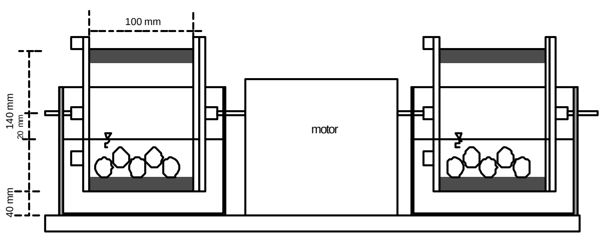

Figure 1. The slake-durability test apparatus.

Note: Discussion is expected before November, 1st 2003. The proper discussion will be published in "Dimensi Teknik Sipil" Volume 6 Number 1 March 2004.

The two drums rotated in water that had a level of about 20 mm below the drum axis. The rotation was driven by a motor capable of rotating the drums at a speed of 20 rpm, which was held constant for a period of 10 minutes. Ten rock lumps, each had a mass of 40-60 g, were placed in the drums. After slaking for the period of 10 minutes, these rock samples were then dried in an oven at a temperature of 105^{0}C for up to 6 hrs. Finally, the mass of dried samples was weighted to obtain the first cycle. The test was conducted over two cycles, in which the weight of particles of 10 rock lumps retained in these wet-dry cycling tests were therefore determined [2].

For the current research, samples were taken from four locations at Coober Pedy, South Australia, which are McCormack dugout (MC), Desert View Motel (DV), Old Timers Mine Museum (OTM) and Gunther Wagner dugout (GW). These four sites had different types of argillaceous weathered soft rocks. Samples were therefore labelled with these notations to differentiate one type to the other.

Samples were described qualitatively for their degree of weathering, which are PW (partly weathered) and DW (distinctly weathered). The descriptions of rocks and weathering followed the suggested method given by ISRM [2].

RESULTS AND DISCUSSIONS

Results of slake-durability tests can be seen in Table 1. In this table, the slake durability index, I_{d2}, varied from 50% to over 96%. A significant finding is that the index could decrease up to 40% for the same rock type taken from the same location. For example, the OTM rocks had an I_{d2} of 55% - 92%. A similar range of results was also obtained from the DV rocks.

The decrease in the index seems to be due to an increase in the degree of weathering of the rock. A low index for the OTM rocks, for example, belongs to the rock which is classified as distinctly weathered dark brown sandstone; while a higher index was displayed by partially weathered, light brown sandstone from the same site. The DV rocks show a similar result. The MC rock seemed, however, to have a better resistance in the slake-durability test as it had relatively higher indexes than other rocks. This porous white siltstone had an index of above 90%.

Table 1. Slake durability testing results.

							Index class	
Rock	Sample	Shape	Weathering	I_{d1} (%)	I_{d2} (%)	Ave	(1)	(2)
MC	MC-SD6	R-Irr	PW	93.5	87.1	92.3	H	MH
	MC-SD4	R-Irr	PW	94.2	90.5		VH	MH
	MC-SD7	S-Shpr	PW	96.4	92.0		VH	MH
	MC-SD5	R-Irr	PW	94.7	92.0		VH	MH
	MC-SD8	S-Rtngl	PW	96.1	92.6		VH	MH
	MC-SD2	S-Shpr	PW	98.8	95.5		EH	H
	MC-SD3	S-Shpr	PW	98.7	96.5		EH	H
DV	DV3.2	R-Irr	DW	68.0	49.8	69.7	L	L
	DV-DW2	R-Irr	DW	75.2	65.8		M	M
	DV-DW1	R-Irr	DW	77.7	69.0		M	M
	DV3.1	R-Irr	DW	83.0	70.2		M	M
	DV2.1	R-Irr	DW	83.5	70.3		M	M
	DV-DW4	R-Irr	DW	87.1	72.2		M	M
	DV-SD5	R-Irr	DW	84.5	78.0		H	M
	DV-DW3	R-Irr	DW	89.6	81.8		H	M
	DV-SD2	R-Irr	PW	90.9	84.2	86.1	H	M
	DV-PW1	R-Irr	PW	91.7	84.7		H	M
	DV-SD1	S-Shpr	PW	88.4	85.5		H	MH
	DV-SD4	R-Irr	PW	90.9	85.9		H	MH
	DV-PW2	R-Irr	PW	92.7	87.7		H	MH
	DV-SD3	R-Irr	PW	93.9	88.7		H	MH
OTM	OTM-SD2	R-Irr	DW	73.0	55.1	55.1	M	L
	OTM-SD1	S-Shpr	PW	94.9	88.1	92.0	H	MH
	OTM-SD3	R-Irr	PW	94.8	91.8		VH	MH
	OTM-SD4	R-Irr	PW	96.1	92.9		VH	MH
	OTM-SD5	R-Irr	PW	96.3	93.4		VH	MH
	OTM-SD6	R-Irr	PW	96.0	93.7		VH	MH
GW	GW-SD1	R-Irr	DW	57.3	51.61	64.3	M	M
	GW-SD2	R-Irr	DW	56.2	53.4		M	M
	GW-SD3	R-Irr	DW	61.0	59.2		M	M
	GW-SD4	R-Irr	DW	68.8	61.9		M	M
	GW-SD5	R-Irr	DW	75.1	68.3		M	M
	GW-SD6	R-Irr	DW	80.3	72.3		M	M
	GW-SD7	R-Irr	DW	76.4	72.6		M	M
	GW-SD8	R-Irr	DW	81.2	74.7		M	M

Note: see Appendix for notations.

Five samples were tested in five slake-durability cycles to assess the samples in five cycles (Figure 2). Three samples (DV, OTM and GW) disintegrated severely over three cycles. The GW distinctly weathered samples, had the lowest slake-durability index of the five cycles (I_{d5}), of 25.8%. From Figure 2, the deterioration of rock in a longer cycle seems to depend on the degree of weathering.

Clay minerals may influence the slake-durability index. Moon and Beattie [4] found that the clay minerals of Waikato Coal Measures mudrocks offered the principal control over the durability of the rocks. However, for Coober Pedy argillaceous rocks, microstructures and the presence of gypsum seem to play an important control over the slake-durability of the rocks, as for example the DV rocks. This finding contradicts the findings obtained by Moon and Beattie [4] that microstructures have only a minor influence over the durability of mudrocks.

The low index of the DV sandstone might be due to the loss of cohesion. This particular rock lacks clay minerals, and when it is saturated, water provides tension to its particles. In accordance with the loss of cohesion, the drum rotation exacerbates the break down of particles in the DV samples. Due to the fine grains of this sandstone, grain pieces pass through the drum mesh of 2 mm. In the second and subsequent cycles, gypsum is already heated, and so becomes friable and powdery. This powdery mineral is easy to break into pieces in water.

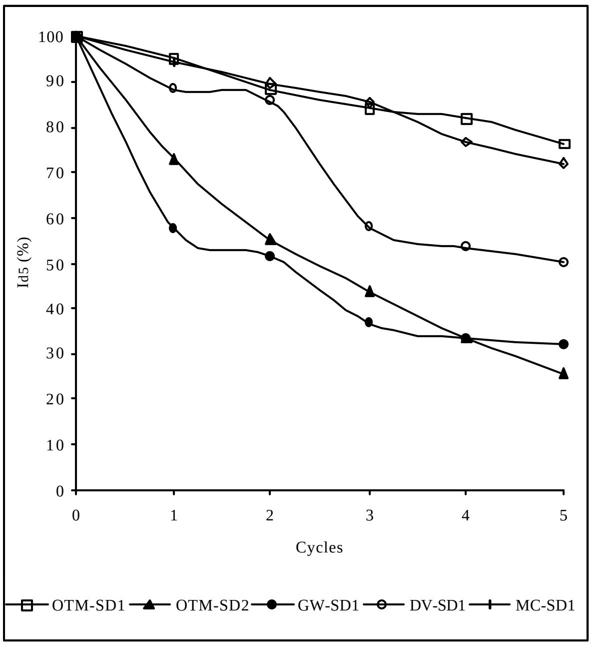

Figure 2. Five-cycle slake-durability tests.

Franklin and Chandra [1] have suggested index classes for I_{d2}, as can be seen in Table 1. The index classes have a range from Low (L) to Extremely High (EH). Unfortunately, this classification does not really represent rock conditions. As the aim of the test is to assess the weathering of the rock, weathering characteristics should be represented in the classification. Based on data obtained from Coober Pedy samples, a modification of the index class was therefore required to accommodate the degree of weathering of the rock.

The modification was developed, between I_{d2} values and the weathering classification (Table 1), and changes can be seen in Table 2. Even so, the divisions are based on a limited number of samples, chosen from the characteristics typical of weathered rocks in Coober Pedy. I_{d2} values in the range of 0-25% and 95-100% were not encountered amongst the available samples. So, both classes are assumed to be extreme cases, at the lowest and the highest ends, respectively. Only one sample for the I_{d2} class of 25-50% that is, the DV3.2 sample (Table 1), was encountered during the tests.

Based on Table 2, an unweathered rock is expected to have an extremely high I_{d2} (higher than 95%), whereas, for residuals, the I_{d2} will be less than 25%. This type of rock may be found at the very top layer of Coober Pedy rock masses, which may have a thickness of less than 0.1m [5].

Table 2. Slake-durability index classification.

(1)		(2)		
I_{d2} (%)	W- class	I_{d2} (%)	DoW	W-class
0-25	Very low	0-25(?)	Residual	E
25-50	Low	25-50	Destructed	D
50-75	Medium	50-70	Distinctly weathered	C
75-90	High	70-80	Distinctly/Partially weathered	C/B
90-95	Very High	80-95	Partially weathered	B
95-100	Extremely high	95-100(?)	Unweathered	A

Note:
(1) Franklin and Chandra [1]
(2) Modified classification

FURTHER DISSCUSSIONS ON SLAKE-DURABILITY MECHANISMS

As suggested by Franklin and Chandra [1], the aim of the test is to assess the durability of rock in association with engineering activities. Such activities may include road engineering and underground excavation, which involve the interaction between rock, weathering and equipment. Thus, the mechanisms involving these three aspects are important in slake-durability tests.

Franklin and Chandra [1] have also discussed factors that influence the test. However, Crosta [3] argued that the test is insensitive for some types of rock, particularly soft rocks. Some soft rocks may have particles that are larger than a standard sieve mesh #10, or 2 mm, which may result in overestimating the slake-durability index. The test may also be insensitive to soil-like materials due to the equipment factor [3]. This argument may find supporting data from the current research, as data show that rocks classified into distinctly weathered with sharp, irregular shapes had low indexes, and some had a very low I_{d2}. Different shapes can contribute to different indexes, thus they may perform different mechanisms.

Main mechanisms associated with the slake-durability test are caused by water [1, 3]. These mechanisms may be subject to ion exchange and capillary tension [1], both of which depend on the permeability, porosity and mineralogy of the rock. The rock is expected to disintegrate in water over a number of wet and dry cycles, in which the exchange of cations and ions will take place due to the adsorption of water by clay minerals. The process allows the rock to swell when it is wet, and to shrink when it is dry. The process then deteriorates the bonding resistance of the particles.

As the rock becomes more saturated, the diameter of the water menisci within the rock pores increases (Figure 3), which then causes a reduction of capillary tension at grain contacts and the tips of cracks [1]. However, these mechanisms merely involve rock and water. Without the necessity of drum rotations in the slake-durability test, such mechanisms may occur as long as the rock is in contact with water. Hence, Franklin and Chandra [1] fail to address the mechanisms of slaking during drum rotation.

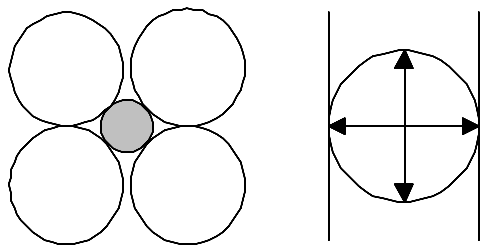

Figure 3. Water within the rock pores.

When the drums are rotating, three mechanisms may be working simultaneously, initiated by sliding. In Figure 4, as the drums rotate in a clockwise direction, the rock balls move from position 1 to position 2. During the movement, the rock will offer sliding resistance against the drum rotation until it reaches position 2. At position 2, the sliding resistance may vanish, and the rock balls will fall back to position 1. During the falling, these rock balls may also experience some rotations. These two mechanisms will occur in turn.

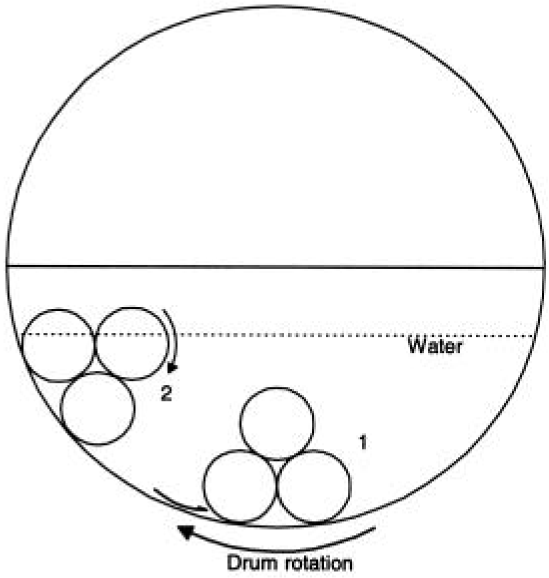

Figure 4. Rounded rock specimen in the slake-durability drum.

These mechanisms may, however, be influenced by the size and shape of the specimen. For instance, relatively bigger specimens may slide back from position 2 to position 1, rather than falling down to position 1. For rectangular or blocky shapes, sliding may dominate the mechanism, as can be seen in Figure 5

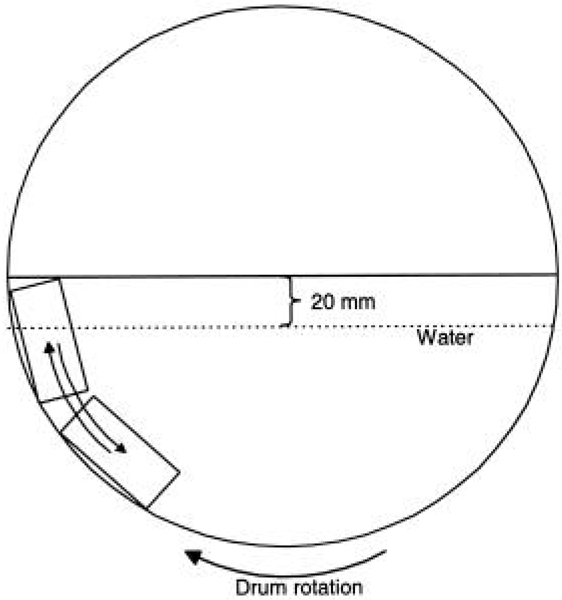

Figure 5. Rectangular specimens in the slake-durability drum.

During these mechanisms, the specimen will suffer from wearing and crushing, which leads to the loss of its weight. However, the roughness of the rock surface may influence the results of this test. As can be seen Figure 4, irregular rough specimens may suffer differently from smooth specimens. Irregularities on the rough specimens may bump each other during the drum rotation, which may cause these irregularities to break away from the body. Bumping and breaking of irregularities occurs mainly in the first cycle, which may then cause samples to be rounded in subsequent cycles.

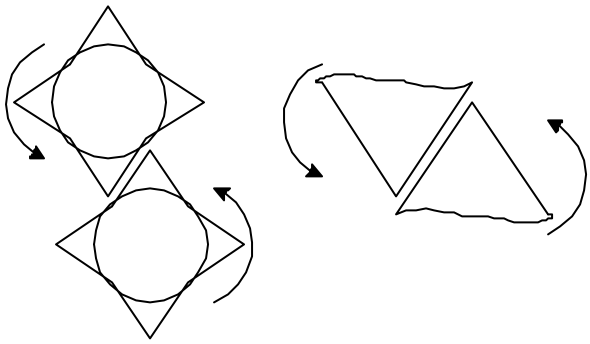

Figure 6. Irregular rock lumps in slake-durability tests of soft rocks.

The size of broken irregularities may be smaller than the sieve mesh size, which would then allow these broken chips to pass through the mesh and into the water. In this case, the deterioration due to wet-dry conditions and slaking has not yet taken place. This is because the process of breaking irregularities might be quicker than the work done by water to deteriorate the rock. With a rotation speed of 20 rpm over a 10-minute slaking, the crumbling of irregularities would be a quick process for soft rocks.

In addition to mechanisms related to drum rotations, mechanisms due to the work done by water may also be present during the slake-durability test. The presence of water within the rock pores gives tension to the particles, since the diameter of water menisci increases. An increase in the diameter of water menisci causes a reduction in the shear resistance of particle surfaces, which then deteriorates the bonding strength of the rock. This deterioration may occur simultaneously with the sliding, rotation and crushing of the irregularities.

The subsequent stage of the slake-durability test is to put the specimens in an oven with a temperature of 105^0C for a certain period [2]. During this stage, the specimens may obtain compression effects from the heat. Thus, the change in environment may further deteriorate the rock. The resistance of rock due to changes in environment and mechanisms is assessed in this test. A different degree of weathering is expected to have a different response to this assessment.

CONCLUSION

Mechanisms in a slake-durability test are a complex feature involving a number of mechanisms working simultaneously. For soft rocks, mechanisms related to drum rotations might significantly contribute into the reduction of the slake-durability index of the rocks. This reduction is particularly substantial for samples that have an irregular shape. From the test, it can also be concluded that microstructures, clay minerals and gypsum play an important part in controlling the slake-durability index.

APPENDIX

Notation:

MC	=	McCormack dugout (underground home)
DV	=	Desert View motel
OTM	=	Old Timers Mine museum
GW	=	Gunther Wagner dugout (underground home)
PW	=	partly weathered
DW	=	distinctly weathered
R	=	round
Irr	=	irregular
S	=	sharp
Shpr	=	spherical
Rtngl	=	rectangular
EH	=	extremely high
VH	=	very high
H	=	high
M	=	medium
L	=	low
W-class	=	weathering class
DoW	=	degree of weathering

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