CHAPTER VIII

DISCUSSIONS AND CONCLUSIONS

This chapter presents discussions and conclusions of the experimental and analytical studies and recommendation for future study.

8.1 Discussions

Modifications of the slake durability index test parameters of ASTM D4644-16 by increasing the drum revolutions from 200 to 2,000 per test cycle and from 2 to 80 cycles provide a clear trend of deterioration for the three sandstones used in this study. The results not only show different deterioration characteristics among different sandstone types, but also allow deriving mathematical representations to predict the number of test cycles required to completely reduced the rock fragment sizes from 28×28×28 mm^3 (gravel, ASTM D2487-17) to 2 mm (medium sand) or less. Such extreme modifications have never been attempted elsewhere.

As the test cycles progress, Phu Phan bedded sandstone (PPSS) shows higher roundness values and smaller fragment sizes, as compared to those of PPCS conglomeratic and PWSS sandstones, suggesting that it is more susceptible to erosion than the other two sandstones. All sandstone types and test conditions show the increases of sphericity values, except for the PPSS under wet condition. The reduction of PPSS sphericity is probably due to the separation of bedding planes, which occurs more easily when the fragments are in contact with water. This is supported by the fragment images given in Figure 5.1(b), where the larger dimensions are parallel to the bedding planes, and by the fragment size reductions shown in Figure 5.4.

Slaking test induces slightly more deterioration to the PWSS sandstone under dry condition than under wet condition, and results in a higher percentage of passing materials (Figure 6a). This is because scrubbing and colliding effects between fragments are more severe under dry condition. Submersion of the fragments under water in the trough makes them lighter due to their buoyancy forces and reduces fictional resistance between their surfaces. These processes also occur for the PPCS and PPSS sandstones under both test conditions. For these two sandstones, however, water may penetrate into their intergranular boundaries and cementing materials more easily, and subsequently reduce bonding between the grains. The effect of water penetration for PPCS and PPSS sandstones are predominant over the scrubbing and colliding effects, and hence leading to a higher percentage of accumulated passing materials even under wet condition (Figures 6.5b through c). This agrees with the conclusions drawn by Torsangtham et al. (2019) who perform a slake durability testing on the same sandstones in Khorat group.

The mineral compositions of remained fragments are more suitable to correlated with others physical properties than those of passing materials passing through the drums. No distinctive change of mineral compositions of the PWSS and PPCS specimens has been observed from their initial condition to the end of 80 test cycles. This is due to the fact that the slaking test performed here in relatively short-term, and hence chemical alterations are unlikely to occur. Small differences of mineral compositions between their initial and test conditions may be due to the intrinsic variability of the rocks. The water sensitive and soft PPSS sandstone, however, shows notable increases of porosity and reduction of density under both wet and dry conditions (Table 5.3). This is caused by dislodging of feldspar grains and the initiation of micro-cracks and fissures, particularly along bedding planes during slaking test. The easy separation of bedding planes results in relatively flat fragments with lower sphericity values (Figure 5.2).

It is recognized that a variety of sandstone types and textures exists in the northeast of Thailand, only three sandstones have been selected for this study. This is limited by research duration and instrumentation. The presented test series require nearly 500 days (3 sandstones × 2 test conditions × 80 test cycles). The test results, nevertheless, provide a clear trend of erosion behavior for each sandstone type and test condition.

It should be noted that the test results obtained here for the Phu Phan and Phra Wihan formations do not represent the erosion behavior of the entire formations. As reported by Murray et al. (1993), sandstone formations in Khorat group contain a variety of textures, densities, and compositions, depending upon the depth and location.

The porosity determined here is called "calculated porosity" to avoid confusing with the effective porosity as measured by water saturation method specified by ASTM D7263-21. The calculated porosity combined connective and non-connective voids in the rock matrix, while the effective porosity represents only connective voids where they can be penetrated and filled by water.

Even though rock fragments are oven-dried at 105°C for 20 hours for each test cycle, the elevated temperature is excluded from the energy calculation. This is based on the experimental results conducted by several researchers, who conclude that temperatures of less than 200°C have little effect on rock deterioration and mineral alterations, particularly for sandstones (Brotons et al., 2013; Sirdesai et al., 2019; Li & Liu, 2022). Temperature induces thermal expansion to the minerals composing rocks. Sandstones contain mostly quartz and feldspar whose thermal expansion coefficients are similar (Somerton, 1992). For rocks containing minerals with different thermal properties, such as igneous rocks, the effect of elevated temperature becomes significant.

Under in-situ condition the applied kinetic energy to rock fragments can come under different forms, for examples, falling down from hillside, rolling on stream bed by water flow or on desert floor by wind blow, colliding and scrubbing between fragments, and blasting by water or wind-carried particles. For long-term deterioration (e.g. decades or centuries) chemical energy due to weathering, and mineral alteration and thermal energy by repeating heating and cooling cycles would become more significant. Even though the law of energy conservation is valid, the magnitudes and rates of energy consumption to reduce sandstone fragment sizes under in-situ condition would be difficult to predict. In addition, the site-specific environment where the rock fragments are situated, can change from one period to another. The results obtained here, nevertheless, reveal significant findings that the magnitude and rate of kinetic energy consumption by sandstone fragments depend on fragment size, density, porosity, and rock texture. Large fragments can utilize the applied energy more efficiently than smaller ones, as evidenced by the accumulated passing materials in Figure 6.5, and by the energy diagrams in Figure 7.1. Water penetration into fragment matrix helps reducing kinetic energy consumption by weakening the bonding between grains (PPCS specimen) or between bedding planes (PPSS specimen).

8.2 Conclusions

Conclusions drawn from this experimental and analytical investigation can be summarized as follows.

1) Water insensitive PWSS sandstone erodes more quickly under dry condition than under wet condition. Even though it requires longer period to erode under water submersion, due to buoyancy force, it consumes less energy than those under dry condition to reach the same fragment sizes.

2) Sandstone with coarser grains and higher density (e.g. PPCS) tends to be more durable than that with finer grains and lower density (e.g. PWSS), providing that water penetration has insignificant effect during erosion process.

3) For sandstones with comparable mineral compositions as tested here, their erosion characteristics are mainly governed by textures, grain sizes, densities, and structures (bedding planes).

4) Sandstone fragment roundness and sphericity increase as fragment size decreases. The decrease of fragment sphericity can occur during erosion if bonding along bedding planes is weaker that across the beds, particularly when water penetration occurs.

5) Larger fragments use energy more effectively to reduce their size than the smaller ones.

6) The main mechanisms of sandstone erosion under kinetic energy are scrubbing and colliding processes. These physical processes can, however, be predominated by water penetration, depending upon the rock porosity, density, and bonding between grains.

8.3. Recommended for future studies

To understand a more complete erosion behavior of sandstones, more studies are needed as follows:

1) A diverse types of sandstone should be tested. They should have different textures, grain sizes, type of cementing materials and mechanical properties.

2) Long-term deterioration of the rocks under dry and saturated conditions should be integrated, in particular under the consideratives of mineral alterations and their related chemical energy.

3) The long-term testing should also consider the impact of thermal cyclic loading and the thermal energy imposed on the rock fragment.