CHAPTER V
TEST RESULTS

This chapter represents the results of three rock specimens during and after test through 80 cycles of slake durability index test. The obtained data includes (1) shape and size of specimens, (2) passing materials, (3) mineral compositions, and (4) fragment density measured for an interval of 20 cycles.

5.1 Specimen shape and size

The physical changes of PWSS, PPCS, and PPSS fragments under dry and wet tests are illustrated in Figure 5.1. The images show the representative of the specimens prepared before testing and those remaining in the drum after subjecting to the durability tests for 20, 40, 60 and 80 cycles. Under both conditions, all fragments become rounder and smaller as the test cycles progress. PPCS and PPSS specimens under dry tests are deteriorated less under than wet condition. However, it seem that PWSS specimens might be smaller in dry conditions than those subjected to water. Under wet condition, PPSS specimens significantly smaller than PPCS and PWSS specimens. By the test cycle 40, PPSS specimens are flattened, where their larger dimensions are parallel to the bedding planes. After 80 test cycles, fragments seem to be degraded normal to bedding plane and show more rounded pattern. PPCS specimens under wet condition show a rough surface on fragments within the first 20 cycles of durability testing. These fragments become smoother after 40 test cycles. Three dimensional models for a representative fragments under wet testing are available via QRcode. For each fragment visualization, figures are shown in Appendix A.

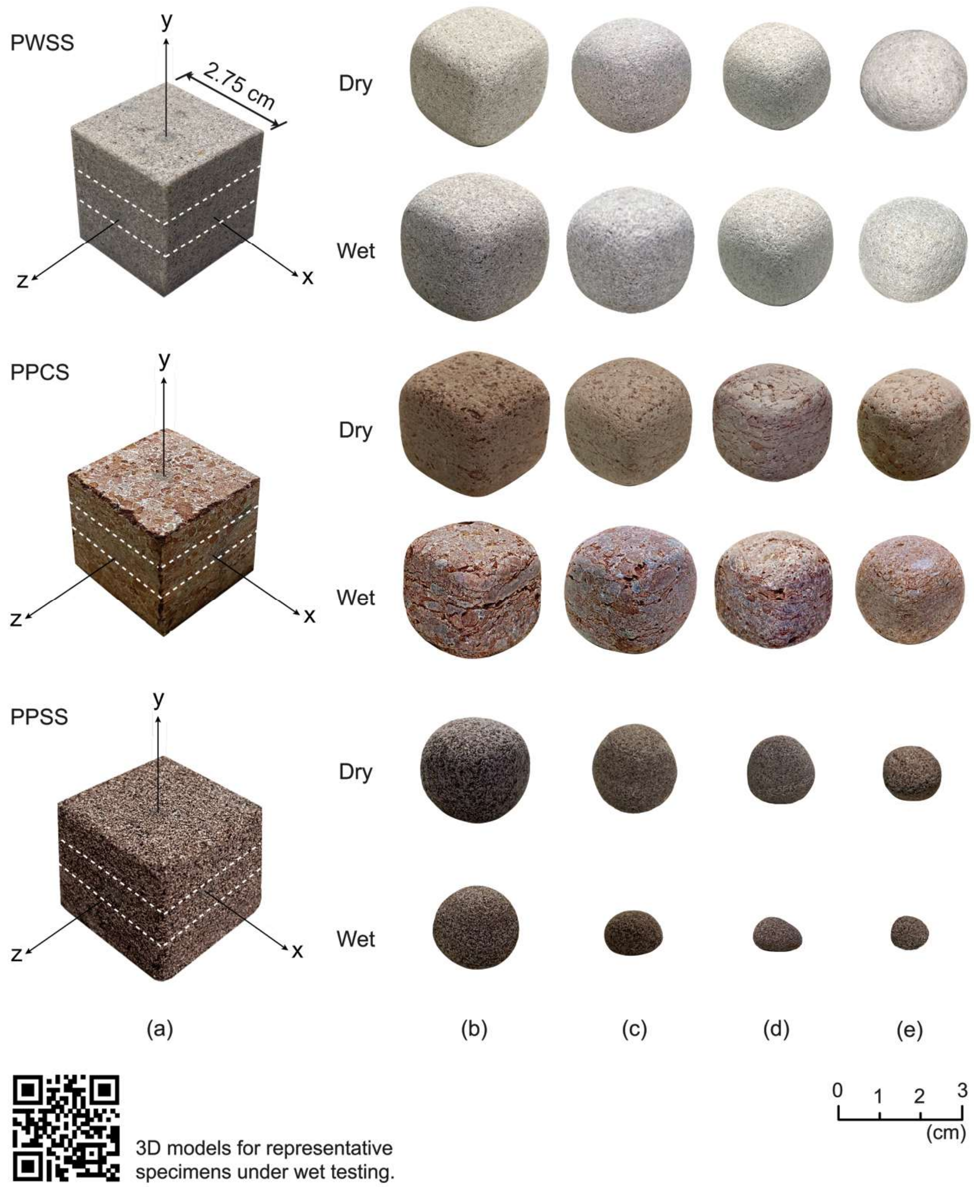


Figure 5.1 Initial cubical specimens (a) and representative images of specimens after subjected to 20 (b), 40 (c), 60 (d) and 80 (e) test cycles.

Roundness (R), sphericity (S), and average size are given in Figure 5.2 through 5.4, respectively. Each rock fragment is determined and classified based on Hryciw et al. (2016), (See Appendix B). Mean and standard deviations of these values after subjecting to 20, 40, 60 and 80 test cycles are summarized in Table 5.1.

According to Figure 5.2, the values of all fragments from the initial condition though 80 test cycles show an increasing of fragment roundness from very angular ($R<0.17$) to different roundness values. After 80 test cycles, PPSS fragments under wet condition can be classified as well rounded ($R>0.7$), while PPCS fragments under dry and wet conditions show only subrounded characteristics ($0.35<R<0.49$). Figure 5.3 plots results with standard deviation of the sphericity values. Except PPSS fragments under wet testing, all rock fragments show linear increases of sphericity values from the initial condition with $S=0.58$ to the test cycle 80 with $S=0.60$-0.67.

The average sizes of ten specimens under dry and wet conditions after subjecting to 20, 40, 60, and 80 cycles are measured based on the narrowest and widest lengths across each side of specimen (detailed in section 4.5). The results are illustrated in Figure 5.4. PPSS specimens under wet tests are decreasing its sizes from 2.95 cm to 0.70 cm within 80 test cycles, which degraded further than those with dry condition and the others under both dry and wet conditions. After test through 80 cycles, the sizes of PWSS and PPCS specimens are slightly deceased with less than 0.50 cm from its initial condition. Excepted for PPCS specimens, the PWSS show a decreasing sizes of fragments under dry testing than those with wet condition.

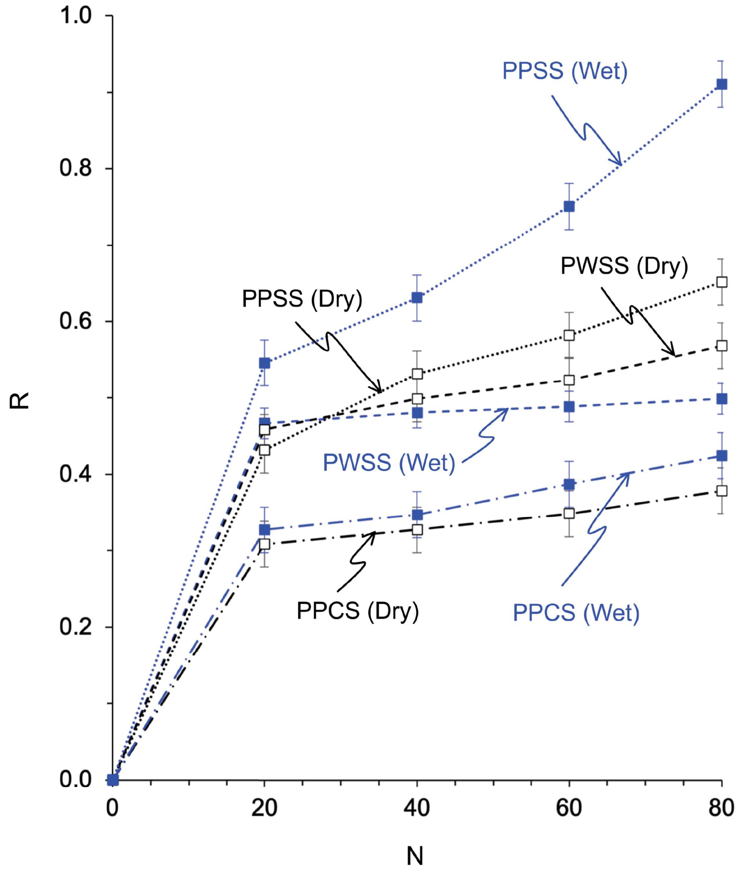


Figure 5.2 Fragment roundness as a function of test cycle (N) measured every 20 days, classified in accordance with Hryciw et. al. (2016). Open points represent dry testing and solid points represent wet testing.

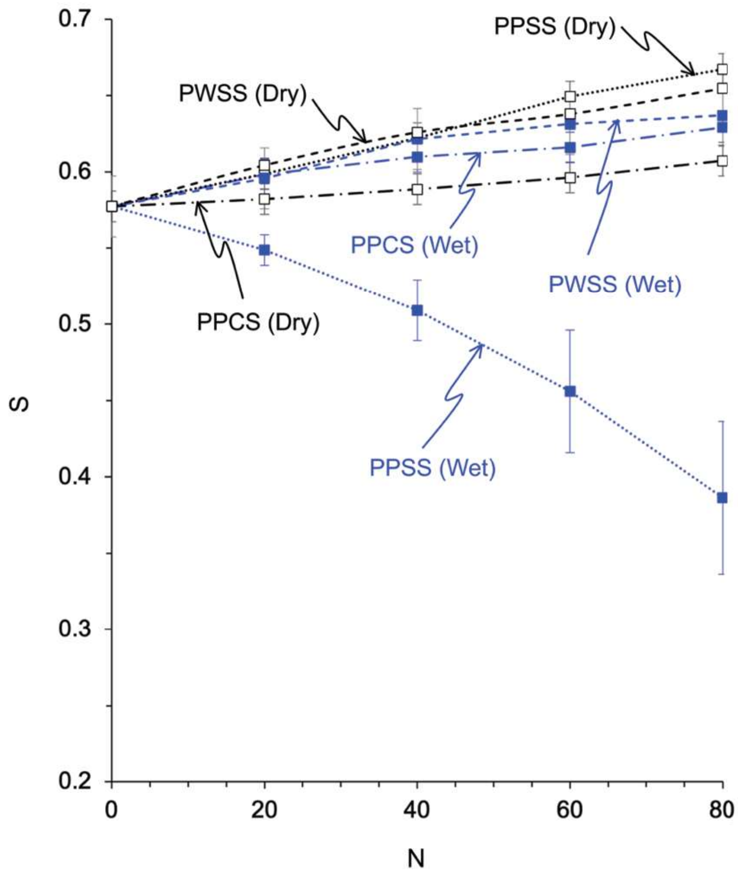


Figure 5.3 Fragment sphericity as a function of test cycle (N) measured every 20 days, classified in accordance with Hryciw et. al. (2016). Open points represent dry testing and solid points represent wet testing.

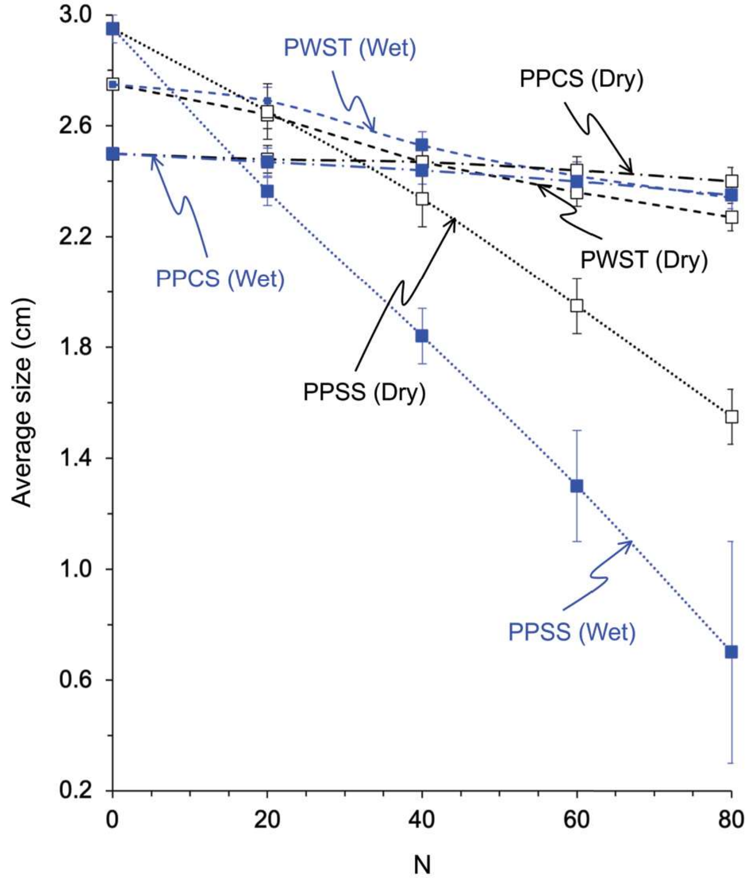


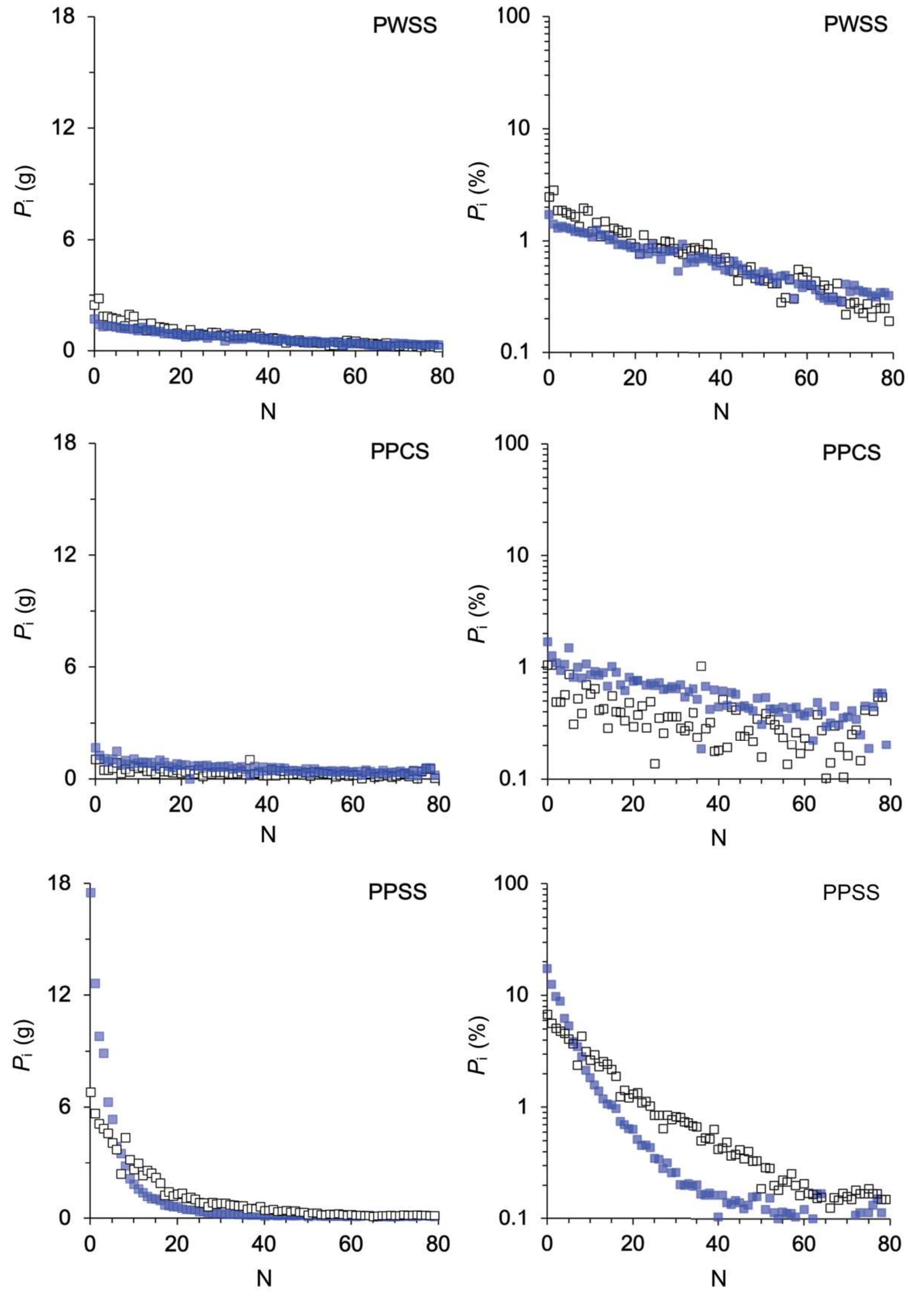
Figure 5.4 Average size of fragments remaining in drum after subjecting under dry and wet tests as a function of test cycle (N). Open points represent dry testing and solid points represent wet testing.

Table 5.1 Mean roundness, sphericity, and average sizes with standard deviation for PWSS, PPCS and PPSS specimens under dry and wet tests.

	N	PWSS		PPCS		PPSS	
Roundness		Dry	Wet	Dry (cm)	Wet	Dry	Wet
	0	-		-		-	
	20	0.46± 0.02	0.47± 0.02	0.31± 0.05	0.33± 0.02	0.43± 0.03	0.55± 0.03
	40	0.50± 0.03	0.48± 0.02	0.33± 0.05	0.35± 0.02	0.53± 0.03	0.63± 0.03
	60	0.52± 0.03	0.49± 0.02	0.35± 0.05	0.39± 0.02	0.58± 0.03	0.75± 0.03
	80	0.57± 0.03	0.50± 0.02	0.38± 0.05	0.42± 0.02	0.65± 0.03	0.91± 0.03
Sphericity	N	PWSS		PPCS		PPSS	
		Dry	Wet	Dry	Wet	Dry (cm)	Wet
	0	0.58		0.58		0.58	
	20	0.60± 0.01	0.60± 0.01	0.58± 0.01	0.60± 0.01	0.60± 0.02	0.55± 0.08
	40	0.62± 0.01	0.63± 0.01	0.59± 0.01	0.61± 0.01	0.62± 0.02	0.51± 0.12
	60	0.63± 0.01	0.64± 0.01	0.60± 0.01	0.62± 0.01	0.65± 0.02	0.45± 0.17
	80	0.64± 0.01	0.65± 0.01	0.61± 0.01	0.63± 0.01	0.67± 0.02	0.39± 0.17
Size (cm)	N	PWSS		PPCS		PPSS	
		Dry	Wet	Dry	Wet	Dry	Wet
	0	2.75		2.50		2.95	
	20	2.64 ± 0.1	2.69 ± 0.1	2.48 ± 0.05	2.47 ± 0.1	2.65 ± 0.1	2.36 ± 0.05
	40	2.47 ± 0.1	2.53 ± 0.1	2.47 ± 0.05	2.44 ± 0.2	2.34 ± 0.1	1.84 ± 0.1
	60	2.36 ± 0.1	2.42 ± 0.1	2.44 ± 0.05	2.40 ± 0.1	1.95 ± 0.1	1.30 ± 0.2
	80	2.27 ± 0.1	2.34 ± 0.1	2.40 ± 0.05	2.35 ± 0.1	1.55 ± 0.1	0.70 ± 0.4

5.2 Passing materials

The passing materials are represented by those smaller than 2 mm (mesh no.10 used for drum openings). As a result from the slake durability test, the weight amount of passing materials obtained from each test cycle is shown in Figure 5.5a through c. For standardized comparison between these results. The passing wight percents from each test cycles are plotted in a semi-log diagram in Figure 5.5d through f. The passing rate is varied with test cycle. The significant reduction of passing materials are suggested from all rock specimens and test conditions. The passing weight percents for PWSS specimens under wet and dry conditions tend to be similar. Both PPCS and PPSS specimens show slightly different percentages of passing materials between wet and dry conditions. The passing of PPSS materials are relatively high within the first 20 cycles. For PPCS specimens, fragments with dry testing tends to show a slightly less of passing materials than those under wet testing.



(a) (b)

Figure 5.5 Passing weight (a) and passing weight percent (b), as a function of test cycle (N). Open points represent dry testing and solid points represent wet testing.

5.3 Mineral compositions

X-ray diffraction (XRD) analysis are performed on PWSS, PPCS, and PPSS specimens under initial condition and on those remaining in the drum after 80 cycles of slake durability test. The passing materials of these specimens from test cycle 40 and 80 are also obtained for the analysis. The significant relationship are observed for the compositions of fragments at initial condition and after test cycle 80. Except for those of PPCS specimens that dominantly have calcite minerals, all rock fragments tend to have the same minerals including quartz, feldspars, chlorite, and clays. The weight percent for each mineral is summarized in Table 5.2.

The weight percent obtained from mineral analysis is used for calculation the volumatic percent of each mineral content. The volumatic percent (V_i) for each mineral can be expressed by following equation:

$$V_i = \{\rho \cdot (W_i/100)/\rho_i\} \cdot 100 \tag{5.1}$$

where V_i is volumatic percent of each mineral (%), W_i is weight percentage of each mineral obtained from XRD analysis (%), ρ_i is density of each mineral (g/cc), i is number of minerals, and ρ is density of fragments (g/cc). Table 5.3 gives the results. Figure 5.6 plots PPCS specimens under dry condition. The volumatic percent of mineral contents are represented as a grouping of feldspars, chlorite, mica, calcite, ferrous oxide, and clay minerals. The results show a slightly decreased proportions on feldspars, chlorite, and ferrous oxide minerals. The significant reduction are spotted on clay minerals. These mineral contents are decreased nearly 6% through the end of 80 test cycles. For PPSS specimens, calcite, feldspars, clay mineral, and mica are observed as a decreasing minerals under wet tests as illustrated in Figure 5.7.

Table 5.2 Mineral compositions in terms of weight percent (W_i) for retained fragments before testing and after 80 test cycles.

			W_i (%)								
Rock types			PWSS			PPCS			PPSS		
Test cycle			Initial	80		Initial	80		Initial	80	
Condition				Dry	Wet		Dry	Wet		Dry	Wet
Mineral composition	Quartz		78.58	84.43	85.09	14.13	15.90	11.10	60.60	67.47	65.37
	Plagioclase		1.99	1.13	1.00	6.81	6.81	6.70	5.93	4.21	2.20
	K-feldspars		3.00	2.71	2.85	2.86	1.87	2.30	0.74	0.57	0.14
	Biotite (Mg-Fe)	Mica	1.89	1.56	1.37	2.31	2.45	2.80	0.26	0.00	0.17
	Muscovite (K)		0.97	0.33	0.27	0.45	0.32	0.39	2.21	2.14	1.08
	illite	Clays	0.64	0.54	0.30	5.36	3.20	4.21	1.30	1.60	2.10
	Kaolinite		5.74	5.32	4.10	2.37	0.44	2.28	1.70	1.20	0.08
	Montmorillonite		0.58	0.27	0.13	0.61	0.08	0.22	0.31	0.07	0.00
	Chlorite		4.32	3.18	4.18	2.01	1.81	1.45	9.22	8.62	14.02
	Calcite		0.23	0.20	0.21	58.28	64.86	62.84	11.32	11.30	8.61
	Dolomite		0.00	0.00	0.00	0.77	0.09	5.21	0.80	0.00	0.00
	Gypsum		0.81	0.23	0.30	1.97	2.10	0.40	2.54	0.00	1.80
	Siderite		0.00	0.00	0.00	0.29	0.07	0.10	0.36	1.56	3.10
	Goethite		0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.43	0.40
	Hematite		0.22	0.10	0.02	1.86	0.70	0.30	1.54	0.83	0.93

Table 5.3 Mineral compositions in terms of volumatic percent (V_i) for retained fragments before testing and after 80 test cycles.

V_i (%)											
Rock types			PWSS			PPCS			PPSS		
Test cycle			Initial	80		Initial	80		Initial	80	
Condition				Dry	Wet		Dry	Wet		Dry	Wet
Mineral composition	Quartz		69.68	73.60	74.49	14.24	15.72	11.02	57.86	58.56	56.00
	Plagioclase		1.77	0.99	0.88	6.87	6.75	6.66	5.67	3.66	1.89
	K-feldspars		2.76	2.45	2.59	2.99	1.92	2.37	0.73	0.51	0.12
	Biotite (Mg-Fe)	Mica	1.53	1.24	1.10	2.13	2.21	2.54	0.23	0.00	0.13
	Muscovite (K)		0.79	0.26	0.22	0.42	0.29	0.36	1.94	1.71	0.85
	illite	Clays	0.55	0.45	0.25	5.20	3.05	4.03	1.20	1.34	1.73
	Kaolinite		5.16	4.70	3.64	2.42	0.44	2.29	1.64	1.06	0.07
	Montmorillonite		0.55	0.25	0.12	0.65	0.08	0.23	0.31	0.06	0.00
	Chlorite		3.74	2.71	3.57	1.98	1.75	1.40	8.59	7.30	11.72
	Calcite		0.20	0.17	0.18	57.42	62.71	60.98	10.57	9.59	7.21
	Dolomite		0.00	0.00	0.00	0.72	0.08	4.81	0.71	0.00	0.00
	Gypsum		0.82	0.23	0.30	2.27	2.37	0.45	2.77	0.00	1.76
	Siderite		0.00	0.00	0.00	0.20	0.05	0.07	0.24	0.93	1.83
	Goethite		0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.24	0.22
	Hematite		0.10	0.05	0.09	0.97	0.36	0.15	0.76	0.37	0.41

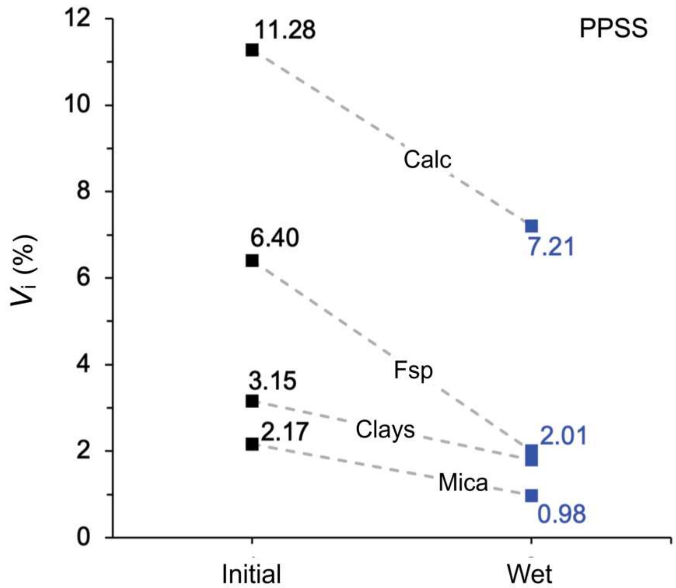


Figure 5.6 Volumatic percent of decreasing minerals for PPSS fragments under wet condition after subjecting to 80 test cycles (Cal=calcite, Fsp=feldspar group, Clays=clay minerals, and Mica=biotite and muscovite)

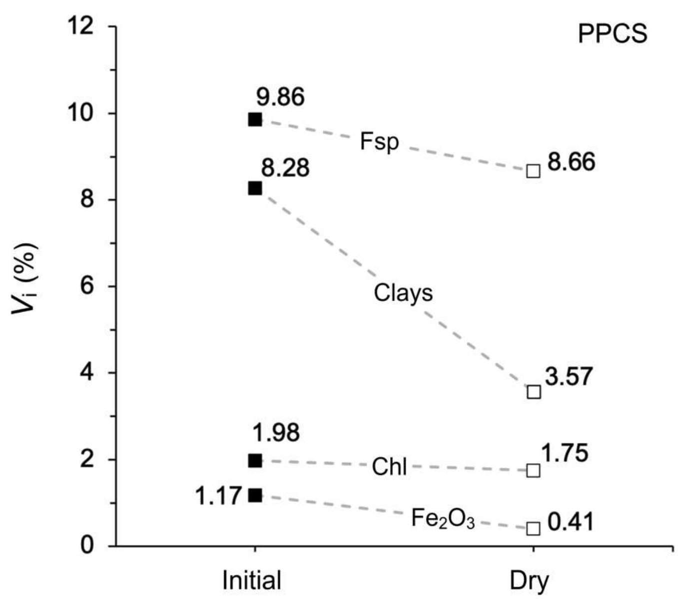


Figure 5.7 Volumatic percent of decreasing minerals for PPCS fragments under dry condition after subjecting to 80 test cycles (Cal=calcite, Fsp=feldspar group, Clays=clay minerals, and Mica=biotite and muscovite).

The results of mineral contents for passing materials of PWSS, PPCS, and PPSS specimens after test cycle 40 and 80 are shown in Table 5.4. The mineral compositions of these particles seem to have a good correlation with the dominant minerals within rock fragments at initial condition. However, the results between test cycle 40 and 80 for all rock fragments are shown that there is no significant relationships. The percentage of dominant minerals are likely having the same amount, which are not correlated with the mineral compositions obtained from the retained fragments after 80 test cycles.

Figure 5.8 plots a peak patterns of each mineral intensity with two theta degrees. The diagrams are illustrated the results of passing materials for PPSS under dry condition from test cycle 40 and 80. The major minerals include quartz, feldspars, chlorite, mica, and clay minerals are observed with a variation of relative two theta. The discrepancy for each mineral content between these test cycles tends to be less than 0.2%.

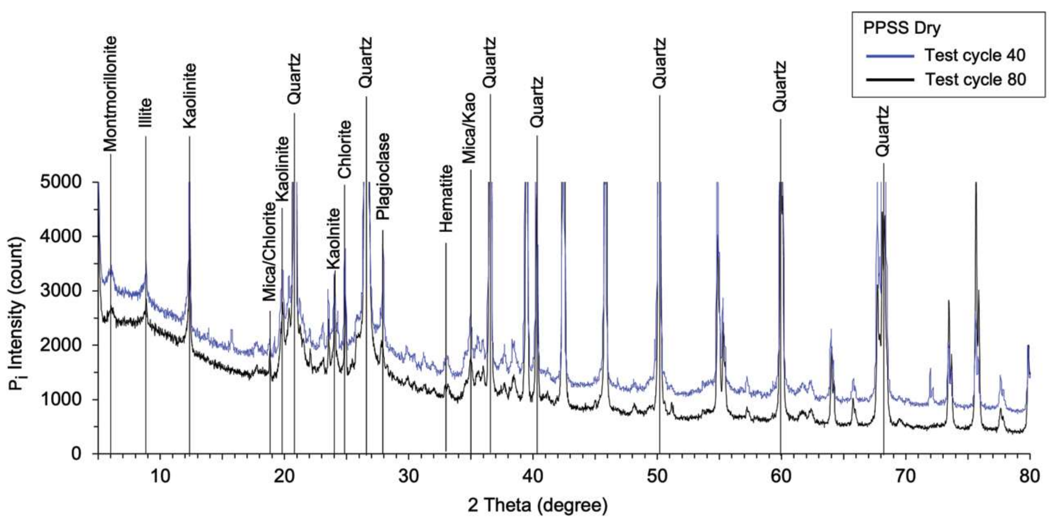


Figure 5.8 Peak patterns of each mineral intensity with two theta degrees of passing materials for PPSS specimens under dry condition after test cycle 40 and 80.

Table 5.4 Mineral compositions in term of weight percent (W_i) for passing materials after 40 and 80 test cycles.

			w_i of passing materials (%)											
Rock types			PWSS				PPCS				PPSS			
Condition			Dry		Wet		Dry		Wet		Dry		Wet	
Test cycle			40	80	40	80	40	80	40	80	40	80	40	80
Mineral composition	Quartz		84.37	85.64	86.63	87.95	13.97	15.81	14.60	14.48	75.18	74.49	73.70	73.65
	Plagioclase		2.12	2.41	2.03	2.55	6.78	6.48	6.97	7.80	3.22	3.72	4.11	3.97
	K-feldspars		2.47	1.99	2.45	2.01	2.87	2.76	2.88	3.04	1.47	0.71	0.99	0.58
	Biotite (Mg-Fe)	Mica	0.55	0.03	0.13	0.11	2.42	0.50	1.38	0.30	0.19	0.29	0.37	0.10
	Muscovite (K)		0.36	0.10	0.19	0.25	0.54	0.22	0.33	0.10	0.96	0.81	0.11	0.62
	illite	Clays	1.17	0.95	1.55	1.22	4.68	6.88	5.82	6.37	4.33	3.10	7.09	6.90
	Kaolinite		3.24	2.49	2.37	2.41	2.14	1.77	1.99	1.67	5.32	4.42	1.50	1.17
	Montmorillonite		0.21	0.10	0.08	0.08	0.63	0.63	0.62	0.61	0.28	0.27	0.53	0.20
	Chlorite		2.64	2.05	2.09	0.76	2.90	1.72	2.46	3.22	1.59	1.66	0.25	1.18
	Calcite		1.32	3.12	0.97	1.61	55.37	55.74	55.95	54.42	2.04	2.13	5.83	7.02
	Dolomite		0.43	0.63	0.55	0.65	3.88	4.73	3.58	4.94	0.69	1.84	0.16	0.70
	Gypsum		0.76	0.39	0.41	0.36	1.80	1.32	1.72	1.78	2.43	3.94	1.56	0.53
	Siderite		0.00	0.00	0.00	0.00	0.32	0.29	0.31	0.33	1.67	1.67	2.41	2.57
	Goethite		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.66	0.78	0.34
	Hematite		0.36	0.10	0.55	0.04	1.70	1.15	1.41	0.94	0.41	0.29	0.61	0.47

5.4 Density

The densities are measured for PWSS, PPCS, and PPSS specimens follow the standard specification of ASTM D7263-21 (detailed in section 4.4). Ten rock fragments under dry and wet conditions after test cycle 20, 40, 60, and 80 are tested. The results of the specimens densities are summarized in Table 5.5. Figure 5.9 plots the results obtained for this study. The diagram shows a reduction trend lines of densities after increasing the test cycles for all rock conditions. PPSS specimens after subjecting to wet tests, their fragments tend to have a significant reduction of density than those under dry testing and the others rocks under both dry and wet testing. The densities from initial condition through 80 test cycles are reducing by 0.26 g/cc for PPSS specimens. However, the fragments of PWSS and PPCS are slightly loss the density after testing through 80 cycles. Excepted for those of rock specimens under dry condition, PWSS specimens show a decreasing of density more than wet tests.

Table 5.5 Densities for PWSS, PPCS and PPSS specimens before testing and after test cycle 20, 40, 60, and 80.

	N	PWSS		PPCS		PPSS	
		Dry	Wet	Dry	Wet	Dry	Wet
Density (g/CC)	0	2.35		2.67		2.53	
	20	2.34	2.35	2.66	2.66	2.47	2.43
	40	2.33	2.34	2.65	2.64	2.38	2.34
	60	2.32	2.33	2.64	2.63	2.33	2.30
	80	2.31	2.32	2.63	2.62	2.30	2.27

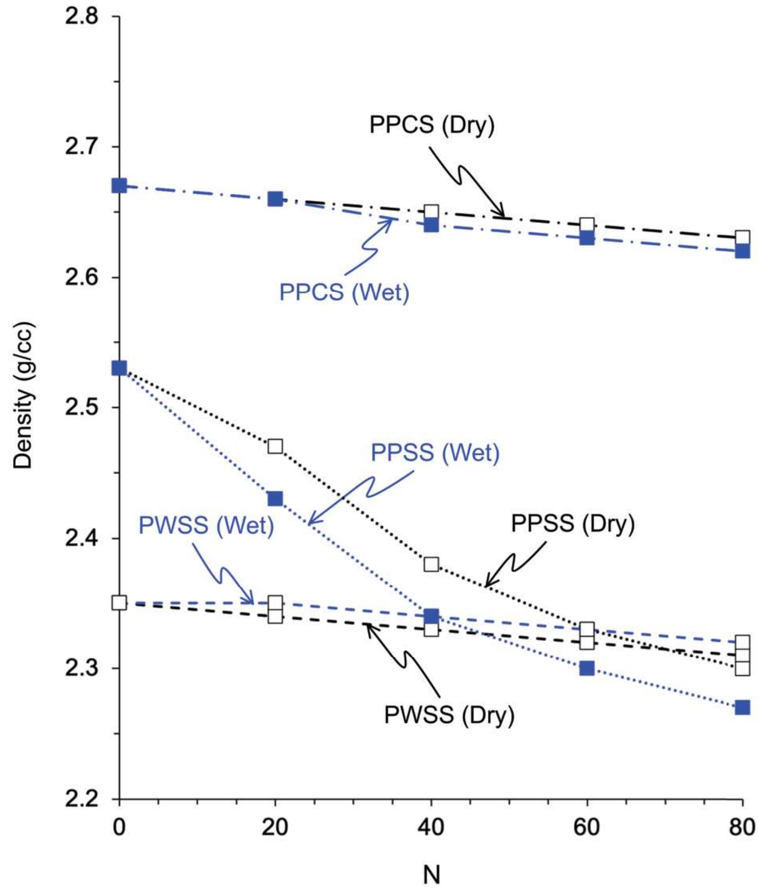


Figure 5.9 Densities of fragments as function of test cycle (N) for PWSS, PPCS, and PPSS specimens after subjecting to 20, 40, 60, and 80 test cycles. Open points represent dry testing and solid points represent wet testing.