REFERENCES

1. ชาญ จรรยาวนิชย์. สถานการณ์แร่ที่ใช้ในอุตสาหกรรมเซรามิกส์. วารสารเซรามิกส์ไทย 1 (พฤษภาคม 2528): 47-74.
2. Klinsukol, V. Effect of organic matter soluble salts and characteristics of ball clays on their rheological and casting properties. Master's Thesis, Department of Materials Science, Graduate School, Chulalongkorn University, 1998.
3. Glasson, N. P. Interceram 38 (1989): 1-4.
4. Lukasiewicz, S. J. Granulation and spray drying. Engineered material handbook. 3 rd ed. New York, 1979.
5. Lukasiewicz, S. J. Spray-drying ceramic powders. Journal of The American Ceramic Society 72 (1989): 617-624.
6. Masters, K. Spray drying handbook. 4 th ed. New York: John Wiley & Sons, 1985.
7. Masters, K. Applying spray drying to ceramics. The American Ceramic Society Bulletin 73 (1994): 63-73.
8. Lee, D. A. Comparison of centrifugal and nozzle atomization in spray dryers. Ceramic Bulletin 53 (1974): 232-233.
9. Shanefield, D. J. Organic additives and ceramic processing. Boston: Kluwer Academic, 1995.
10. Onoda, G. Y., Jr.; and Hench, L. L. Ceramic processing before firing. New York: John Wiley & Sons, 1978.
11. Onoda, G. Y., Jr. Theoretical strength of dried green bodies with organic binders. Journal of The American Ceramic Society 59 (1976): 236-239.

12. Whitman, D. W.; Cumbers, D. I.; and Wu, X. K. Humidity sensitivity of dry-press binders. The American Ceramic Society Bulletin 74 (1995): 76-79.

13. Nies, C. W.; and Messing, G. L. Effect of glass-transition temperature of polyethylene glycol- plasticized polyvinyl alcohol on granule compaction. Journal of The American Ceramic Society 67 (1984): 301-304.

14. Brewer, J. A.; Moore, R. H.; and Reed, J. S. Effect of relative humidity on the compaction of Barium Titanate and Manganese Zinc Ferrite agglomerates containing polyvinye alchhol. Ceramic Bulletin 60 (1981): 212-215,220.

15. Lewis, W. A. Jr. Dry pressing technical ceramics. The American Ceramic Society Bulletin 75 (1996): 103-106.

16. McEntire, B. J., Dry Pressing. Engineered material handbook. 3 rd ed. New York, 1979.

17. Lukasiewicz, S. J.; and Reed, J. S. Character and compaction response of spray-dried agglomerates. Ceramic Bulletin 57 (1978): 798-801.

18. Worrall, W. E. Clays and ceramic raw material. London: Elsevier Applied Science, 1975.

19. Shaw, D. J. Introduction to colloid and surface chemistry. 3 rd ed. London: Butter worth, 1980.

20. Olphen H. V. Clay colloid chemistry. New York: John Wiley & Sons, 1996.

21. Metler Toledo Analytical. Basic of rheology. Schwerzenbach (n.p.), 1992.

22. Brookfield Engineering Laboratories. More solutions to sticky problems. Massachusetts (n.p.), 1995.

23. Reed, J. S. Principles of ceramics processing. 3 rd ed. New York: John Wiley & Sons, 1995.

24. Grayson, M. ‹ Clays. Encyclopedia of composite materials and components (1983): 324-338.

25. Mitchell, D. Fortieth Mellor memorial lecture. British Ceramic Transactions 96 (1997): 66-73.

26. Chirdkiatisak, J., Sales director of MRD-ECC, Interview, 9 August 1998.

27. Olphen, H. V.; and Fripiat, J. J. Data handbook for clay materials and other non-metallic minerals. New York: Pergamon, 1979.

28. Bannon, L. S. Dictionary of Ceramic Science and engineering. New York: Plenum, 1984.

APPENDICES

APPENDIX A

Slip preparation for deflocculant test and flow measurement

Apparatus

1. Motor mixer, Heidolph RZR 2041
2. Beaker 600 ml.
3. Brookfield viscometer model LVT spindle No.2, 60 rpm.

Procedure

1. Calculate and weigh 1000 g. of desired sample (by dry weight).
2. Add DI water (in the proportion by dry weight of clay) and allow to slake for a while 15 min approximately.
3. Mix with motor mixer at speed of 650-700 rpm., add sodium silicate if necessary to obtain the flow, pass through 200 mesh.
4. Transfer to the container and measure slip density, solid content and amount of used sodium silicate.
5. Pass the slip to the magnet separator 2-3 times to eliminate ferromagnet in the slip. Age for 24 hr. before use.

Deflocculant test

1. Use 600 ml. of prepared slip (known solid content) to stir and gradually add Na_2SiO_3 (if the binder used, add the binder before adding sodium silicate), stir 2 min for each step.

2. Pour in the 600 ml. beaker at 500 ml. level, measure the viscosity after rotating spindle 10 rounds.

3. Record the viscosity until flocculation occur or unchangeable ready.

4. Calculate the deflocculant use in each step and plot curve between % Na_2SiO_3 and viscosity.

Shear measurement by Brookfield small sample DVII+ (Degree of shear thinning and thixotropy)

1. Use one litre of slip already mixed with additives and stir with mixer for 2 min at 1000 rpm. (measure solid content)

2. Set rpm. for test, start at 0.3, 0.6, 1.5, 3.0, 6.0, 12.0, 30.0 and 60.0 rpm. and select spindle No. (No. 18 for lower viscosity, No. 31 for higher viscosity)

3. Pour in the sample container at the half level screw spindle on the shaft level and put in the sample.

4. Turn on the motor and start at 0.3 rpm. for 2 min, record cP (viscosity), SS (shear stress), SR (Shear rate)

5. Change to higher speed without turning off the motor and record each step until to 60 rpm.

6. Decrease the speed in steps to the slowest speed without turning off the motor and record each step.

7. Stop 5 min then turn on at 0.3 rpm. for 2 min and record the value.

(Only shear response in increasing shear rate step for rechecking.)

Slip preparation for Modulus of rupture

Apparatus

1. Plaster
2. Motor mixer

Procedure

1. Use the prepared slip for deflocculation 600 ml. at 50% solid.
2. Add Na_2SiO_3 in the amount of testing.
3. Mix for 10 min at speed 1050 rpm., screen through 40 mesh.
4. Cast in cylindrical plaster mould and dry at 110°C for 24 hr.
5. Keep in desiccator before breaking with 3-point bending tester (Hungta Instrument).
6. Calculate the MOR from equation (4.4), use 8-test pieces for average value.

APPENDIX B

JCPDS cards and diffraction data

Kaolinite 14-0164

14-0164 — Wavelength= 1.5418

Al2Si2O5(OH)4

Aluminum Silicate Hydroxide

Kaolinite-1A

Rad.: CuKa λ: 1.5418 Filter: Mono d-sp: 22.9

Cut off: Int.: Estimation I/Icor.:

Ref: Goodyear, Duffin, Mineral. Mag., 32, 902 (1961)

Sys.: Triclinic S.G.: C1

a: 5.155 b: 8.959 c: 7.407 A: 0.5754 C: 0.8268

α: 91.68 β: 104.9 γ: 89.94 Z: 2 mp:

Ref: Ibid.

Dx: 2.595 Dm: 2.645 SS/FOM$_{32}$=35(.022, 38)

εα: 1.559(6) ηωβ: 1.564(5) εγ: 1.565(5) Sign:- 2V:24-50

Ref: Deer, W., Howie, R., Zussman, J., Rock Forming Minerals, 3, 194

Color: White
Specimen from Scalby, Yorkshire, England, UK. Validated by calculated pattern Borg and Smith, GSA Memoir, 122. Kaolinite-serpentine group, dioctahedral subgroup.mC.D. Cell: a=5.166, b=7.407, c=5.155, α=104.90, β=119.87, γ=84.10, a/b=0.6974, c/b=0.6960, S.G.=P1(1). PSC: aP17. To replace 5-143 and 12-447. Mwt: 258.16. Volume[CD]: 165.22.

2θ	Int	h	k	l	2θ	Int	h	k	l
12.344	100	0	0	1	43.508*	5	0	2	3
19.826*	35	0	2	0	43.863*	20	2	2	2
20.340*	60	1	1	0	45.415*	35	2	0	3
21.225*	45	1	1	1	45.657*	35	1	3	2
21.468*	35	1	1	1	45.975*	20	2	2	1
23.120*	40	0	2	1	46.523*	20	2	2	1
23.758*	25	0	2	1	46.853*	35	1	3	2
24.877*	80	0	0	2	47.319*	20	0	4	2
26.054*	5	1	1	1	47.715*	5	1	1	3
26.400*	35	1	1	1	47.955*	25	1	3	3
28.286*	20	1	1	2	48.692*	20	0	4	2
28.732*	20	1	1	2	49.396*	25	1	3	3
32.511*	20	0	2	2	49.596*	35	2	2	3
34.967*	35	2	0	1	50.417*	20	2	2	3
35.151*	25	1	3	0	51.051*	25	0	0	4
35.408*	35	1	3	1	53.592*	25	2	2	2
35.641*	10	1	1	2	54.313*	25	1	5	0
35.995*	45	2	0	0	54.593*	25	1	5	1
37.717*	25	0	0	3	55.019*	40	2	4	0
38.351*	40	2	0	2	55.343*	40	2	4	0
38.504*	40	1	3	1	55.488*	10	0	4	3
39.078*	5	1	1	3	55.744*	40	3	1	2
39.291*	35	1	3	1	56.338*	30	3	1	0
40.018*	20	1	3	2	56.831*	70	1	3	3
40.316*	5	0	4	0	57.333*	30	0	4	3
40.677*	10	2	2	1	57.845*	10	1	5	2
41.083*	20	1	3	2	58.165*	60	1	3	4
41.299*	20	2	0	1	58.733*	10	2	4	1
41.558*	5	2	2	0	59.523*	30	2	2	4
42.003*	10	0	4	1	59.863*	40	1	1	4
42.374*	20	0	2	3	60.207*	40	2	0	3
42.731*	10	0	4	1	61.219*	5	3	1	1
43.224*	10	2	2	2	61.624*	5	2	4	3

2θ	Int	h	k	l
62.360*	90	3	3	1

Quartz 05-0490

05-0490 Wavelength= 1.54056

α-SiO2

Silicon Oxide

Quartz, low

Rad.: Cu λ: 1.5405 Filter: d-sp:

Cut off: Int.: I/Icor.: 3.60

Ref:

Sys.: Hexagonal S.G.: $P3_121$ (152)

a: 4.913 b: c: 5.405 A: C: 1.1001

α: β: γ: Z: 3 mp:

Ref: Ibid.

Dx: 2.649 Dm: SS/FOM$_{31}$=78(.0125, 31)

PSC: hP9. To replace 1-649. Deleted by 33-1161. Mwt: 60.08. Volume[CD]: 112.98.

2θ	Int	h	k	l	2θ	Int	h	k	l
20.835°	35	1	0	0	81.186°	4	1	1	4
26.643	100	1	0	1	81.486°	4	3	1	0
36.526°	12	1	1	0	83.836°	2	3	1	1
39.455°	12	1	0	2	84.941°	<1	2	0	4
40.283°	6	1	1	1	87.451°	<1	3	0	3
42.443°	9	2	0	0	90.823°	4	3	1	2
45.788°	6	2	0	1	92.808°	1	4	0	0
50.166°	17	1	1	2	94.650°	2	1	0	5
50.643°	<1	0	0	3	95.127°	2	4	0	1
54.864°	7	2	0	2	96.236°	2	2	1	4
55.330°	3	1	0	3	98.747°	2	2	2	3
57.244°	<1	2	1	0	102.224	2	1	1	5
59.981°	15	2	1	1	102.570	2	3	1	3
64.029°	3	1	1	3	103.910	<1	3	0	4
65.806°	<1	3	0	0	104.195	1	3	2	0
67.748°	7	2	1	2	106.603	2	3	2	1
68.140°	11	2	0	3	112.206	<1	4	1	0
68.309°	9	3	0	1					
73.460°	3	1	0	4					
75.654°	4	3	0	2					
77.697°	2	2	2	0					
79.891°	5	2	1	3					
80.084°	2	2	2	1					

Quartz 46-1045

46-1045 Wavelength= 1.5405981

SiO2

Silicon Oxide

Quartz, syn

Rad.: CuKα1 λ: 1.5405 Filter: Ge Mono d-sp: Diffractometer

Cut off: Int.: Diffract. I/Icor.: 3.41

Ref: Kern, A., Eysel, W., Mineralogisch-Petrograph. Inst., Univ. Heidelberg, Germany, ICDD Grant-in-Aid, (1993)

Sys.: Hexagonal S.G.: $P3_221$ (154)

a: 4.91344(4) b: c: 5.40524(8) A: C: 1.1001

α: β: γ: Z: 3 mp:

Ref: Ibid.

Dx: 2.649 Dm: 2.660 SS/FOM$_{31}$=539(.0018, 31)

ε: ηωβ: 1.544 εγ: 1.553 Sign:+ 2V:

Ref: Swanson, Fuyat, Natl. Bur. Stand. (U.S.), Circ. 539, 3, 24 (1954)

Color: White

Integrated intensities. Pattern taken at 23(1) C. Low temperature quartz. 2θ determination based on profile fit method. O2 Si type. Quartz group. Silicon used as an internal stand. PSC: hP9. To replace 33-1161. Mwt: 60.08. Volume[CD]: 113.01.

2θ	Int	h	k	l	2θ	Int	h	k	l
20.860°	16	1	0	0	95.119°	<1	4	0	1
26.640	100	1	0	1	96.238°	1	2	1	4
36.544°	9	1	1	0	98.751°	1	2	2	3
39.465°	8	1	0	2	102.231	<1	1	1	5
40.300°	4	1	1	1	102.567	<1	3	1	3
42.450°	6	2	0	0	103.877	<1	3	0	4
45.793°	4	2	0	1	104.203	<1	3	2	0
50.139°	13	1	1	2	106.593	<1	3	2	1
50.622°	<1	0	0	3	112.114	<1	4	1	0
54.875°	4	2	0	2	114.061	<1	3	2	2
55.325°	2	1	0	3	114.467	2	4	0	3
57.235°	<1	2	1	0	114.639	2	4	1	1
59.960°	9	2	1	1	115.885	<1	2	2	4
64.036°	2	1	1	3	117.537	<1	0	0	6
65.786°	<1	3	0	0	118.313	<1	2	1	5
67.744°	6	2	1	2	120.124	1	3	1	4
68.144°	7	2	0	3	121.853	<1	1	0	6
68.318°	5	3	0	1	122.605	<1	4	1	2
73.468°	2	1	0	4	127.251	<1	3	0	5
75.660°	3	3	0	2	131.203	<1	1	1	6
77.675°	1	2	2	0	132.756	<1	5	0	1
79.884°	2	2	1	3	134.293	<1	4	0	4
80.047°	<1	2	2	1	136.424	1	2	0	6
81.173°	2	1	1	4	137.895	2	4	1	3
81.491°	2	3	1	0	140.318	<1	3	3	0
83.840°	1	3	1	1	143.251	3	5	0	2
84.957°	<1	2	0	4	144.119	<1	3	3	1
87.439°	<1	3	0	3					
90.831°	2	3	1	2					
92.788°	<1	4	0	0					
94.651°	1	1	0	5					

Muscovite 07-0032

07-0032 Wavelength= 1.54056

KAl2Si3AlO10(OH)2

Potassium Aluminum Silicate Hydroxide

Muscovite 2M1, syn

Rad.: Cu λ: 1.5405 Filter: d-sp:

Cut off: Int.: I/Icor.:

Ref:

Sys.: Monoclinic S.G.: C2/m (12)

a: 5.189 b: 8.995 c: 20.097 A: 0.5769 C: 2.2342

α: β: 95.18 γ: Z: 4 mp:

Ref: Ibid.

Dx: 2.832 Dm: SS/FOM$_{32}$=7(.063, 66)

CAS #: 1318-94-1. C.D. Cell: a=20.097, b=8.995, c=5.189, β=95.18, a/b=2.2342, c/b=0.5769, S.G.=A2/m(12). PSC: mCS4. Deleted by minerals in 1980. Mwt: 398.31. Volume[CD]: 934.20.

2θ	Int	h	k	l	2θ	Int	h	k	l
8.836	<100	0	0	2	40.301	6	0	4	1
17.653	55	0	0	4	40.971	6	2	2	1
19.801	55	1	1	0	41.304	8	0	2	8
19.891	65	1	1	1	42.008	10	2	2	2
20.211	14	0	2	1	42.359	25	1	3	5
20.639	20	1	1	1	44.118	6	0	4	4
21.604	14	0	2	2	45.067	75	2	0	7
22.358	12	1	1	2	45.911	14	1	3	7
22.848	35	1	1	3	52.682	6	2	2	8
23.803	30	0	2	3	53.921	6	1	5	0
25.427	45	1	1	4	54.935	12	0	0	12
26.571	<100	0	2	4	55.549	18	1	3	9
27.786	45	1	1	4	57.478	8	1	1	12
29.766	45	0	2	5	61.843	40	0	6	0
31.126	35	1	1	5					
31.901	20	1	1	6					
34.617	50	1	3	1					
34.742	45	1	1	6					
34.994	90	2	0	2					
35.684	20	0	0	8					
36.526	20	1	3	3					
36.711	12	2	0	2					
37.506	10	2	0	4					
37.767	25	1	3	3					
40.096	12	2	2	1					

Muscovite 07-0025

07-0025 Wavelength= 1.5418

KAl2Si3AlO10(OH)2

Potassium Aluminum Silicate Hydroxide

Muscovite-1M, syn

Rad.: CuKa λ: 1.5418 Filter: Ni Beta M d-sp:

Cut off: Int.: Diffract. I/Icor.:

Ref: Yoder, H., Eugster, H., Geochim. Cosmochim. Acta, 8, 225 (1955)

Sys.: Monoclinic S.G.: C2/m (12)

a: 5.208 b: 8.995 c: 10.275 A: 0.5790 C: 1.1423

α: β: 101.6 γ: Z: 2 mp:

Ref: Ibid.

Dx: 2.805 Dm: 2.825 SS/FOM$_{25}$=9(.037, 84)

εα: 1.563(11) ωβ: 1.596(14) γ: 1.602(15) Sign: - 2V:30-47

Ref: Ibid.

Color: Colorless, light green, pink, light brown
CAS #: 1318-94-1. Synthesized from K Al Si O4 + kaolinite + water at 200 C and 15,000 p.s.i. for 4120 hours. Mica group, dioctahedral subgroup. C.D. Cell: a=10.275, b=8.995, c=5.208, β=101.60, a/b=1.1423, c/b=0.5790, S.G.=A2/m(12). PSC: mC42. To replace 2-56. Mwt: 398.31. Volume[CD]: 471.51.

2θ	Int	h	k	l
8.755	100	0	0	1
17.597	35	0	0	2
19.773	90	0	2	0
20.416	25	1	1	1
21.622	16	0	2	1
24.318	60	1	1	2
26.521	<100	0	0	3
29.086	50	1	1	2
30.520	6	1	1	3
33.319	16	0	2	3
34.743	50	1	3	0
34.981	90	1	3	1
35.193	20	2	0	0
36.680	12	1	3	1
37.391	4	1	3	2
37.799	12	1	1	4
40.148	8	0	4	0
40.658	8	2	2	0
41.201	4	0	4	1
41.901	20	1	3	3
42.880	6	2	0	2
45.034	30	0	0	5
46.397	8	1	3	3
47.875	4	1	3	4
55.054	18	2	4	2
55.597	12	1	5	1
56.263	12	2	0	4
61.219	4	1	3	5
61.898	35	0	6	0

Gibbsite 33-0018

33-0018 Wavelength= 1.54060

Al(OH)3

Aluminum Hydroxide

Gibbsite, syn

Rad.: CuKa1λ: 1.5406 Filter: d-sp: Diffractometer

Cut off: Int.: Diffract. I/Icor.: 1.0

Ref: Clear, A., Poulsen, K., Dow Chemical Company, Freeport, TX, USA, ICDD Grant-in-Aid, (1979)

Sys.: Monoclinic S.G.: $P2_1/n$ (14)

a: 8.6552 b: 5.0722 c: 9.7161 A: 1.7064 C: 1.9156

α: β: 94.607 ° γ: Z: 8 mp:

Ref: Ibid.

Dx: 2.437 Dm: 2.400 SS/FOM$_3$(ζ=10(.025,113)

εα: 1.577 ηωβ: 1.577 εγ: 1.595 Sign: 2V:0°

Ref: Dana's System of Mineralogy, 7th Ed., I, 663 (1944)

Color: White

Sample of reagent grade chemical from Matheson, Coleman, and Bell. Optical data on artificial material; measured density on crystals. C.D. Cell: a=9.716, b=5.072, c=8.655, β=94.61, a/b=1.9156, c/b=1.7064, S.G.=P21/n(14). Silicon used as an internal stand. PSC: mP56. To replace 1-263, 1-264, 1-265, 1-266, 7-324 and 12-460 and validated by calculated pattern 29-41. Mwt: 78.00. Volume[CD]: 425.17.

2θ	Int	h	k	l	2θ	Int	h	k	l
18.283	100	0	0	2	59.494*	3	2	0	$\bar{6}$
20.300*	70	1	1	0	62.512*	4	2	1	$\bar{6}$
20.549*	50	2	0	0	62.512*	4	2	3	2
26.515*	17	2	0	$\bar{2}$	63.800*	30	3	2	4
26.896*	30	1	1	$\bar{2}$	63.800*	30	3	3	0
28.011*	25	1	1	2	64.653*	18	4	1	$\bar{5}$
28.725*	13	1	0	$\bar{3}$	66.149*	19	3	3	$\bar{5}$
36.407*	25	3	1	$\bar{1}$	66.650*	13	3	1	$\bar{6}$
36.616*	40	0	2	1	67.817*	6	3	3	$\bar{2}$
37.083*	15	0	0	4	68.883*	10	0	2	$\bar{8}$
37.684*	55	3	1	1	70.718*	7	1	2	6
38.318*	4	1	2	$\bar{1}$	71.111*	4	2	2	$\bar{6}$
39.314*	15	3	1	$\bar{2}$	72.681*	3	4	1	$\bar{6}$
40.108*	20	0	2	$\bar{2}$	77.430*	3	6	2	$\bar{2}$
41.140*	2	1	2	$\bar{2}$	77.797*	2	3	3	4
41.691*	27	3	1	2	78.613*	6	4	2	5
43.374*	4	1	1	4	78.613*	6	2	4	0
44.167*	40	3	1	$\bar{3}$	78.954*	7	1	4	2
44.754*	3	2	2	$\bar{2}$	81.581*	4	1	1	$\bar{8}$
45.440*	28	0	2	$\bar{3}$	84.541*	4	6	2	$\bar{4}$
46.192*	6	1	2	$\bar{3}$	89.589*	3	4	4	0
46.192*	6	2	2	2	90.719*	4	6	3	$\bar{2}$
47.306*	15	1	2	$\bar{3}$					
50.548*	30	3	2	$\bar{2}$					
52.175*	30	0	2	$\bar{4}$					
52.667*	4	1	2	4					
53.977*	4	1	2	4					
54.424*	30	3	1	4					
55.383*	9	1	3	0					
55.383*	9	2	2	$\bar{4}$					
57.851*	7	4	1	$\bar{4}$					
58.095*	7	3	1	$\bar{5}$					
58.605*	8	5	0	$\bar{5}$					
58.605*	8	2	3	0					

Gibbsite 07-0324

07-0324 Wavelength= 1.5418

Al(OH)3

Aluminum Hydroxide

Gibbsite

Rad.: CuKa λ: 1.5418 Filter: Ni Beta M d-sp:

Cut off: Int.: Diffract. I/Icor.:

Ref: Gillery, Min. Ind., Penn State University, University Park, Pennsylvania, USA, Private Communication

Sys.: Monoclinic S.G.: $P2_1/n$ (14)

a: 8.659 b: 5.077 c: 9.703 A: 1.7055 C: 1.9112

α: β: 94.2 γ: Z: 8 mp:

Ref: Ibid.

Dx: 2.436 Dm: 2.400 SS/FOM$_3$(ζ=7(.031,146)

εα: 1.568 ηωβ: 1.568 εγ: 1.587 Sign:+ 2V:0°

Ref: Dana's System of Mineralogy, 7th Ed.

Color: Colorless

Specimen from Cheener mine, Richmond, Massachusettes, USA. C.D. Cell: a=9.703, b=5.077, c=8.659, β=94.20, a/b=1.9112, c/b=1.7055, S.G.=P21/n(14). PSC: mP56. To replace 1-263, 1-264, 1-265 and 1-266. Deleted by 33-18, lower FN, MTG 5/92. Mwt: 78.00. Volume[CD]: 425.42.

d Å	Int	h	k	l	d Å	Int	h	k	l
4.85000	100	0	0	2	1.39800	2	$\bar{3}$	1	6
4.37000	16	1	1	0	1.38000	1	$\bar{1}$	0	7
4.32000	8	$\bar{2}$	0	0	1.36100	1	0	2	6
3.30600	5	$\bar{1}$	1	2	1.34000	1	$\bar{4}$	0	6
3.18700	4	1	1	$\bar{2}$	1.33000	1	$\bar{4}$	3	0
3.11200	3	$\bar{2}$	0	2	1.32000	1	$\bar{3}$	1	6
2.45400	8	0	2	1	1.24600	1	$\bar{1}$	4	1
2.42000	6	0	0	4	1.21400	1	0	2	7
2.38800	8	$\bar{3}$	1	1					
2.28500	2	$\bar{3}$	1	2					
2.24400	3	2	1	3					
2.16800	3	3	1	2					
2.08500	1	1	1	4					
2.04300	6	$\bar{3}$	1	3					
1.99300	4	0	2	3					
1.96000	1	$\bar{1}$	2	3					
1.92100	4	4	1	1					
1.79900	4	$\bar{3}$	1	4					
1.75000	5	0	2	4					
1.68900	4	3	1	4					
1.65400	1	$\bar{2}$	2	4					
1.63800	1	$\bar{4}$	2	1					
1.59300	1	2	2	4					
1.58400	1	$\bar{4}$	2	2					
1.57300	1	$\bar{5}$	0	3					
1.55500	1	4	0	4					
1.55100	1	2	3	1					
1.48600	1	3	1	5					
1.47700	1	$\bar{2}$	2	5					
1.45700	3	3	3	0					
1.44100	2	6	0	0					
1.40900	2	$\bar{6}$	0	2					

Montmorillonite 13-0135

13-0135 Wavelength= 1.5418

Ca0.2(Al,Mg)2Si4O10(OH)2·4H2O

Calcium Magnesium Aluminum Silicate Hydroxide Hydrate

Montmorillonite-15A

Rad.: λ: Filter: d-sp: Diffractometer

Cut off: Int.: Diffract. I/Icor.:

Ref: Rosenquist, Nor. Geol. Tidsskr., 39, 350 (1959)

Sys.: Hexagonal S.G.: P

a: 5.169(7) b: c: 15.02(3) A: C: 2.9058

α: β: γ: Z: 1 mp:

Ref: Bayliss, P., Powder Diffraction, 4, 19 (1989)

Dx: Dm: 2.300 SS/FOM$_{12}$=2(.127, 66)

ωα: 1.545(6) ηωβ: 1.57(7) εγ: 1.57(7) Sign: 2V: 0(15)

Ref: Ibid.

Color: White, yellow, green
Specimen from Skyrvedalen, Hemsedal, Norway. CAS #: 1318-93-0. Analysis (wt.%): Si O2 59.58, Al2 O3 22.96, Fe2 O3 0.47, MgO 3.67, CaO 3.38, Na2 O 0.06, loss 1° 9.61. Smectite group, dioctahedral subgroup.
° 15.0 expands to 18.0 with glycerol treatment.
PSC: hP32.20. Volume[CD]: 347.55.

2θ	Int	h	k	l
5.892°	100	0	0	1
17.703°	60	0	0	3
19.728°	80	1	0	0
23.598°	20	0	0	4
25.448°	10			
27.019°	10	1	0	3
29.579°	60	0	0	5
34.771°	40	1	1	0
35.921°	40	0	0	6
39.889°	10	2	0	0
42.023°	10	0	0	7
48.416°	10	0	0	8
53.933°	30	2	1	0
61.852°	50	0	0	10
62.175°	50	3	0	0
73.729°	20	2	2	1
76.660°	20	3	1	0

Halloysite 09-0451

09-0451 Wavelength= 1.78897

Al2Si2O5(OH)4·2H2O

Aluminum Silicate Hydroxide Hydrate

Halloysite-10A

Rad.: λ: Filter: d-sp:

Cut off: Int.: Estimation I/Icor.:

Ref: MacEwan, Amoros, Anales Edafol. Fisiol. Vegetal (Madrid), 9, 363 (1950)

Sys.: Hexagonal S.G.: P

a: 5.122(4) b: c: 10.03(11) A: C: 1.9582

α: β: γ: Z: 1 mp:

Ref: Bayliss, P., Powder Diffraction, 4, 19 (1989)

Dx: 2.144 Dm: 2.140 SS/FOM$_{12}$=1(.112,116)

ωα: ηωβ: 1.490 εγ: Sign: 2V:

Ref: Alexander, L. et al., Am. Mineral., 28, 1 (1943)

Color: Colorless
Kaolinite-serpentine group, dioctahedral subgroup.mAlso called: endellite.PSC: hP23. Mwt: 294.19. Volume[CD]: 227.88.

2θ	Int	h	k	l
10.162°	90	0	0	1
23.351	100	1	0	0
31.068°	90	0	0	3
40.902°	80	1	1	0
44.546°	60			
47.296°	20	2	0	0
51.471°	10			
64.426°	80	2	1	0
74.310°	90	3	0	0
88.403°	70	2	2	0
93.111°	70	3	1	0
108.092	40	3	1	4
122.348	20	1	1	9
136.513	20	4	1	1
*	40	3	3	0
*	20	4	2	0

Mullite 15-0776

15-0776 — Wavelength= 1.54056

Al6Si2O13

Aluminum Silicate

Mullite, syn

Rad.: CuKa1λ: 1.5405 Filter: Ni Beta M d-sp:

Cut off: Int.: Diffract. I/Icor.:

Ref: Natl. Bur. Stand. (U.S.) Monogr. 25, 3, 3 (1964)

Sys.: Orthorhombic S.G.: Pbam (55)

a: 7.5456 b: 7.6898 c: 2.8842 A: 0.9812 C: 0.3751

α: β: γ: Z: .75 mp:

Ref: Ibid.

Dx: 3.171 Dm: 3.000 SS/FOM$_{32}$=60(.0135, 37)

εα: 1.637 ηωβ: 1.641 : nγ: 1.652 Sign:+ 2V:45-50

Ref: Winchell, Elements of Optical Mineralogy, 2, 401

Color: Colorless

Pattern taken at 25 C. Sample was prepared from stoichiometric mixture of Al2 O3 and Si O2 !x H2 O. Sample was repeatedly ground and heated up to temperature of 1725 C. Spectrographic analysis: 0.01 to 0.1% Fe, and 0.001 to 0.01% each of Ca, Cr, Mg, Mn, Ni, Ti and Zr. Chemical analysis showed Al2 O3 61.6, Si O2 38 (mole%). Tungsten used as an internal stand. PSC: oP15.75. Mwt: 426.05. Volume[CD]: 167.35.

2θ	Int	h	k	l	2θ	Int	h	k	l
16.432°	50	1	1	0	66.514*	8	5	2	0
23.554*	8	2	0	0	67.130°	<2	1	1	2
25.971°	95	1	2	0	69.616*	6	2	0	2
26.267	100	2	1	0	69.806*	6	4	4	0
30.960°	20	0	0	1	70.442°	12	1	5	1
33.228°	40	2	2	0	70.844*	5	1	2	2
35.278°	50	1	1	1	70.991*	5	2	1	2
36.993°	14	1	3	0	71.576*	4	5	1	1
37.554°	<2	3	1	0	71.904*	3	3	5	0
38.992*	4	0	2	1	72.647*	4	5	3	0
39.276°	20	2	0	1	73.901*	7	0	6	0
40.874°	60	1	2	1	74.191°	13	2	5	1
42.590°	25	2	3	0	74.580*	6	2	2	2
42.908*	8	3	2	0	75.162°	12	5	2	1
46.059*	2	2	2	1	75.555°	<2	6	0	0
47.227*	2	0	4	0	76.836*	6	1	3	2
48.184*	8	4	0	0	77.182*	2	3	1	2
48.845°	<2	1	4	0	78.311*	2	4	4	1
49.468*	10	3	1	1	78.835°	<2	2	6	0
50.812°	<2	3	3	0	80.480*	4	2	3	2
53.462*	6	2	4	0	81.046*	3	5	3	1
53.883°	14	3	2	1	84.493°	<2	4	0	2
54.093°	10	4	2	0	87.002*	1	2	6	1
57.561°	20	0	4	1	88.569*	4	2	4	2
58.412°	12	4	0	1	89.090*	5	4	2	2
58.994*	2	1	4	1	93.817°	<2	2	7	0
59.763*	2	4	1	1	98.446*	4	1	7	1
60.711°	35	3	3	1	98.958*	4	2	5	2
61.492°	<2	1	5	0	99.868*	8	3	7	0
62.674°	<2	5	1	0					
63.054°	<2	2	4	1					
63.661*	8	4	2	1					
64.571°	18	0	0	2					
65.494*	4	2	5	0					

Sillimanite 38-0471

38-0471 Wavelength= 1.54178

Al2SiO5

Aluminum Silicate

Sillimanite

Rad.: CuKa λ: 1.5417 Filter: Graph Mono d-sp: Diffractometer

Cut off: 17.7 Int.: Diffract. I/Icor.:

Ref: Keller, L., Rask, J., Buseck, P., Arizona State Univ., Tempe, AZ, USA, ICDD Grant-in-Aid, (1987)

Sys.: Orthorhombic S.G.: Pbnm (62)

a: 7.486(1) b: 7.675(1) c: 5.7729(6) A: 0.9754 C: 0.7522

α: β: γ: Z: 4 mp:

Ref: Ibid.

Dx: 3.245 Dm: 3.250 SS/FOM30=50(.0159, 38)

ωα: 1.6575 nωβ: 1.66 εγ: 1.678 Sign:+ 2V:29

Ref: Deer, W., Howie, R., Zussmann, J., Rock Forming Minerals, 1, 121 (1962)

Color: Colorless

Specimen from Norwich, CT, USA. Chemical analysis, average of seven (wt.%): Si O2 36.15, Al2 O3 62.17, Fe2 O3 0.90. Silicon used as an internal stand. PSC: oP32. To replace 10-369 and 22-18. Mwt: 162.05. Volume[CD]: 331.68.

2θ	Int	h	k	l	2θ	Int	h	k	l
16.520*	12	1	1	0	49.060*	1	1	3	2
19.401*	2	1	0	1	49.740*	2	3	1	2
23.168*	14	0	2	0	50.135*	1	0	4	1
23.771*	3	2	0	0	50.135*	1	4	1	0
26.092	100	1	2	0	51.133*	2	3	3	0
26.479*	35	2	1	0	51.660*	1	1	4	1
27.915*	1	0	2	1	53.693*	7	2	4	0
30.413*	1	1	2	1	53.693*	7	3	3	1
30.756*	1	2	1	1	54.146*	2	3	2	2
30.985*	7	0	0	2	54.554*	3	4	2	0
33.434*	16	2	2	0	54.751*	1	1	2	3
35.307*	20	1	1	2	54.968*	1	2	1	3
36.992*	3	2	2	1	57.678*	12	0	4	2
37.135*	20	1	3	0	58.802*	1	4	0	2
37.914*	1	3	1	0	59.108*	3	2	2	3
39.042*	2	0	2	2	59.108*	3	1	4	2
39.362*	5	3	0	1	60.782*	1	3	0	3
39.362*	5	2	0	2	60.950*	14	3	4	0
40.391*	1	1	3	1	60.950*	14	3	3	2
40.946*	30	1	2	2	61.375*	1	4	3	0
41.161*	2	3	1	1	61.683*	1	1	5	0
41.161*	2	2	1	2	62.095*	1	3	1	3
42.816*	12	2	3	0	63.277*	1	2	4	2
43.246*	1	3	2	0	63.277*	1	5	1	0
45.739*	1	2	3	1	63.678*	1	4	3	1
46.189*	1	3	2	1	64.021*	1	1	5	1
46.189*	1	2	2	2	64.021*	1	4	2	2
48.650*	2	4	0	0	64.269*	1	5	0	1
48.867*	1	1	0	3	64.563*	5	0	0	4
49.060*	1	1	4	0	65.588*	1	5	1	1

2θ	Int	h	k	l	2θ	Int	h	k	l
65.588*	1	2	3	3	83.882*	1	0	4	4
65.744*	4	2	5	0	84.612*	1	6	0	2
65.954*	1	3	2	3	84.840*	1	4	0	4
67.136*	2	5	2	0	84.840*	1	2	5	3
67.136*	2	1	1	4	85.107*	2	1	4	4
67.971*	1	2	5	1	87.322*	1	3	6	1
69.591*	1	0	2	4	87.322*	1	2	6	2
70.306*	2	4	4	0	88.759*	1	2	4	4
70.306*	2	4	3	2	89.035*	1	4	4	3
70.427*	2	1	4	3	89.230*	3	4	5	2
70.633*	8	1	5	2	89.230*	3	6	2	2
70.884*	5	1	2	4	89.468*	1	4	2	4
71.075*	3	2	1	4	89.780*	1	5	4	2
72.135*	1	5	1	2	89.780*	1	2	1	5
72.135*	1	3	3	3					
72.256*	1	3	5	0					
72.410*	1	4	4	1					
74.118*	30	0	6	0					
74.417*	8	3	5	1					
74.417*	8	2	5	2					
74.704*	2	2	2	4					
74.988*	1	4	2	3					
75.372*	2	5	3	1					
75.372*	2	1	6	0					
75.732*	2	5	2	2					
76.275*	1	0	6	1					
76.275*	1	6	0	0					
76.908*	1	1	3	4					
77.389*	1	3	1	4					
77.493*	1	1	6	1					
77.493*	1	6	1	0					
78.747*	1	4	4	2					
79.113*	1	2	6	0					
80.647*	1	2	3	4					
80.647*	1	3	5	2					
80.917*	1	4	3	3					
80.917*	1	3	2	4					
81.181*	1	1	5	3					
81.181*	1	2	6	1					
81.590*	1	5	4	0					
81.590*	1	5	3	2					
82.472*	1	0	6	2					

Table 1B Diffraction data of Hypure Vector®

JEOL — Peak search — T:VECTOR.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	8.640	10.22585	221	28	21	50.040	1.82126	116	15					
2	12.180	7.26060	708	90	22	55.200	1.66261	137	17					
3	17.700	5.00676	111	14	23	56.720	1.62161	106	13					
4	19.740	4.49371	300	38	24	59.900	1.54289	120	15					
5	20.280	4.37525	211	27	25	62.220	1.49082	153	19					
6	20.740	4.27924	305	39	26	68.200	1.37393	100	13					
7	24.800	3.58712	513	65										
8	26.520	3.35824	788	100										
9	27.860	3.19969	144	18										
10	29.680	3.00749	115	15										
11	34.900	2.56869	249	32										
12	35.940	2.49671	161	20										
13	36.400	2.46620	137	17										
14	37.800	2.37802	151	19										
15	38.380	2.34340	195	25										
16	39.160	2.29850	140	18										
17	40.140	2.24462	104	13										
18	42.440	2.12814	117	15										
19	45.280	2.00104	129	16										
20	45.480	1.99271	126	16										

Table 2B Diffraction data of BCW

JEOL — Peak search — T:BCW.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	5.720	15.43783	187	29	21	55.220	1.66206	127	20					
2	8.780	10.06311	245	38	22	59.360	1.54383	111	17					
3	12.220	7.23692	445	69	23	62.140	1.49255	133	21					
4	17.660	5.01801	156	24	24	68.260	1.37287	94	15					
5	19.860	4.46682	285	44										
6	20.820	4.26298	344	54										
7	21.900	4.05613	233	36										
8	24.820	3.58427	386	60										
9	26.620	3.34585	641	100										
10	27.400	3.25235	281	44										
11	27.820	3.20420	311	49										
12	34.940	2.56584	216	34										
13	35.860	2.50209	172	27										
14	36.460	2.46228	158	25										
15	37.660	2.38653	159	25										
16	38.360	2.34458	169	26										
17	42.380	2.13102	117	18										
18	45.400	1.99603	134	21										
19	50.120	1.81856	126	20										
20	54.840	1.67267	128	20										

Table 3B Diffraction data of B85

JEOL — Peak search — TJB85.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	8.780	10.06311	681	50	21	55.060	1.66651	139	10					
2	12.200	7.24874	1353	100	22	60.040	1.53963	73	5					
3	17.700	5.00676	165	12	23	62.220	1.49082	185	14					
4	18.180	4.87564	85	6										
5	19.800	4.48023	364	27										
6	20.260	4.37963	324	24										
7	20.740	4.27924	275	20										
8	20.780	4.27109	272	20										
9	21.160	4.19524	260	19										
10	24.760	3.59282	910	67										
11	26.620	3.34585	454	33										
12	34.920	2.56726	219	16										
13	35.400	2.53354	164	12										
14	35.900	2.49940	253	19										
15	36.520	2.45837	106	8										
16	37.580	2.39143	175	13										
17	38.300	2.34811	280	21										
18	39.200	2.29625	172	13										
19	45.360	1.99770	234	17										
20	50.900	1.79250	83	6										

Table 4B Diffraction data of K325

JEOL — Peak search — TJK325.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	8.760	10.08604	650	41	21	51.040	1.78792	88	6					
2	8.760	10.08604	650	41	22	56.240	1.63150	150	10					
3	12.260	7.21340	1570	100	23	56.820	1.61899	102	6					
4	17.820	4.97331	213	14	24	59.960	1.54149	100	6					
5	18.360	4.82824	103	7	25	62.280	1.48953	181	12					
6	19.860	4.46682	310	20										
7	20.360	4.35824	280	18										
8	20.360	4.35824	280	18										
9	20.820	4.26298	312	20										
10	23.000	3.86362	170	11										
11	24.900	3.57294	1095	70										
12	26.780	3.32623	824	52										
13	29.900	2.98586	109	7										
14	34.980	2.56300	237	15										
15	35.380	2.53493	160	10										
16	36.020	2.49134	266	17										
17	37.660	2.38653	190	12										
18	38.380	2.34340	257	16										
19	39.260	2.29288	181	12										
20	45.420	1.99520	312	20										

Table 5B Diffraction data of RC9 1200°C

JEOL — Peak search — comRC9-1.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	16.350	5.41700	305	64	21	57.549	1.60021	110	23					
2	20.750	4.27720	213	45	22	60.650	1.52560	188	40					
3	23.550	3.77461	170	36	23	63.600	1.46176	93	20					
4	26.050	3.41776	474	100	24	64.450	1.44451	145	31					
5	26.500	3.36073	373	79	25	66.200	1.41061	93	20					
6	30.950	2.88692	190	40	26	69.450	1.35223	77	16					
7	32.099	2.78615	110	23	27	70.349	1.33713	98	21					
8	33.200	2.69623	210	44	28	70.700	1.33135	116	24					
9	34.200	2.61964	108	23	29	74.000	1.27993	98	21					
10	35.150	2.55099	283	60	30	74.349	1.27478	99	21					
11	36.799	2.44037	123	26	31	75.050	1.26461	105	22					
12	37.549	2.39333	96	20										
13	39.250	2.29344	152	32										
14	40.200	2.24141	99	21										
15	40.799	2.20987	298	63										
16	42.450	2.12766	139	29										
17	45.900	1.97545	83	18										
18	48.250	1.88458	93	20										
19	49.299	1.84690	108	23										
20	53.850	1.70106	123	26										

Table 6B Diffraction data of RC9 1245°C

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	16.350	5.41700	337	81	21	75.050	1.26461	93	22					
2	20.750	4.27720	203	49										
3	21.650	4.10139	239	57										
4	25.900	3.43721	416	100										
5	29.800	2.99565	134	32										
6	30.900	2.89147	218	52										
7	33.100	2.70415	237	57										
8	35.200	2.54748	319	77										
9	37.049	2.42448	128	31										
10	39.250	2.29344	159	38										
11	40.800	2.20982	332	80										
12	42.500	2.12528	167	40										
13	49.450	1.84162	104	25										
14	53.400	1.71433	99	24										
15	57.600	1.59891	113	27										
16	60.600	1.52674	217	52										
17	63.549	1.46281	97	23										
18	64.450	1.44451	163	39										
19	70.450	1.33546	122	29										
20	74.450	1.27330	102	25										

Table 7B Diffraction data of RC11 1200°C

JEOL — Peak search — pom\RC11.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	12.100	7.30842	148	33	21	49.350	1.8451	106	24					
2	16.399	5.40092	279	62	22	50.049	1.82097	103	23					
3	18.399	4.81809	171	38	23	53.150	1.72180	96	21					
4	19.950	4.44688	185	41	24	53.799	1.70255	125	28					
5	20.649	4.29789	216	48	25	57.450	1.60273	125	28					
6	23.200	3.83076	188	42	26	59.549	1.55115	97	22					
7	23.649	3.75903	180	40	27	60.500	1.52902	196	44					
8	24.750	3.59425	167	37	28	64.400	1.44552	147	33					
9	26.100	3.41132	445	99	29	70.450	1.33546	106	24					
10	26.500	3.36073	450	100	30	74.050	1.27919	105	23					
11	30.850	2.89605	197	44	31	75.000	1.26532	108	24					
12	31.550	2.83337	128	28	32	76.599	1.24285	86	19					
13	33.049	2.70820	227	50										
14	35.150	2.55099	296	66										
15	36.600	2.45318	125	28										
16	37.000	2.42758	129	29										
17	38.000	2.36696	98	22										
18	39.200	2.29625	158	35										
19	40.799	2.20967	279	62										
20	42.500	2.12528	153	34										

Table 8B Diffraction data of Hypure Vector® 1200°C

JEOL — Peak search — pom\EVECTOR.std < smoothing data >

No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io	No.	2-theta	d-value	INT.	I/Io
1	16.399	5.40092	268	51	21	58.299	1.58139	91	17					
2	20.700	4.28742	216	41	22	60.600	1.52674	195	37					
3	25.200	3.53106	182	35	23	63.650	1.46073	108	21					
4	26.200	3.39853	526	100	24	64.450	1.44451	137	26					
5	26.550	3.35452	434	83	25	68.000	1.37749	94	18					
6	30.950	2.88692	194	37	26	70.250	1.33878	101	19					
7	33.200	2.69623	217	41	27	70.800	1.32972	111	21					
8	34.450	2.60120	114	22	28	74.200	1.27697	106	20					
9	35.350	2.53699	277	53	29	75.050	1.26461	104	20					
10	36.100	2.48601	114	22	30	78.050	1.22333	82	16					
11	36.500	2.45967	128	24	31	80.700	1.18971	85	16					
12	36.900	2.43392	123	23	32	89.200	1.09703	81	15					
13	39.150	2.29907	161	31										
14	40.750	2.22241	298	57										
15	42.549	2.12294	144	27										
16	43.150	2.09476	93	18										
17	48.150	1.88826	96	18										
18	49.350	1.8451	110	21										
19	53.900	1.69960	110	21										
20	57.600	1.59891	124	24										

APPENDIX C

True density (specific gravity) and particle size distribution data

Table 1C True density of raw materials

True density* (g/cm^3)		RC6	RC9	RC10	RC11	RC12
BCW	2.5174	40%	40%	60%	60%	60%
B85	2.6109	-	60%	-	20%	40%
K325	2.6164	60%	-	40%	20%	-
Calculated true density (g/cm^3)		2.5735	2.5735	2.5570	2.5559	2.5548

* True density of Hypure Vector® = 2.5715 g/cm^3

Table 2C Particle size distribution of raw materials compared with Hypure Vector®. (refer to Fig. 5.6)

Equivalent spherical diameter (μm)	Weight percent finer			
	VECTOR	BCW	K325	B85
40.0	100.0	100.0	100.0	100.0
30.0	100.0	100.0	97.0	93.6
20.0	100.0	100.0	93.4	85.9
10.0	94.7	88.4	67.6	59.8
8.0	94.7	83.5	59.2	52.4
6.0	91.2	77.9	49.9	44.1
5.0	88.3	74.2	44.0	40.1
4.0	84.4	69.5	37.5	34.8
3.0	77.0	64.0	31.6	29.2
2.0	65.6	57.0	24.2	22.5
1.0	42.6	44.6	13.8	13.8
0.8	35.2	40.3	11.1	11.2
0.6	26.2	34.3	8.1	8.3
0.5	21.1	30.2		6.6
0.4	15.7	24.7		
0.3		17.3		

Table 3C Particle size distribution of selected RC formula (refer to Fig. 5.12)

Equivalent spherical diameter (μm)	Weight percent finer					
	VECTOR	RC6	RC9	RC10	RC11	RC12
40.0	100.0	100.0	100.0	100.0	100.0	100.0
30.0	100.0	85.3	100.0	100.0	83.5	100.0
20.0	100.0	73.0	92.0	86.4	81.3	92.5
10.0	94.7	58.9	71.3	73.4	64.8	74.8
8.0	94.7	52.9	64.2	69.1	56.6	68.0
6.0	91.2	46.3	56.7	62.2	50.0	60.5
5.0	88.3	43.1	53.0	58.1	45.9	56.1
4.0	84.4	37.5	45.6	51.8	43.1	49.8
3.0	77.0	31.4	40.1	45.1	37.1	42.6
2.0	65.6	25.4	33.5	38.0	31.2	35.6
1.0	42.6	16.4	23.5	26.7	21.9	25.7
0.8	35.2	14.0	20.4	23.2	19.3	22.5
0.6	26.2	10.9	16.3	18.8	15.9	18.5
0.5	21.1	9.2		16.0	13.8	15.8
0.4	15.7	7.0		12.4	11.1	12.3
0.3				8.2	8.0	8.1

Table 4C Particle size distribution of slip before spray drying (refer to Fig. 5.26)

Equivalent spherical diameter (μm)	Weight percent finer					
	VECTOR	40RC11 +1B	50RC11 +1B	50RC9 +1B	60RC9	60RC9 +1B
40.0	100.0	100.0	100.0	100.0	100.0	100.0
30.0	100.0	97.7	88.8	100.0	100.0	100.0
20.0	100.0	89.5	73.6	79.3	83.1	92.9
10.0	94.7	66.6	56.4	57.2	64.9	70.2
8.0	94.7	62.3	51.2	51.2	58.8	64.3
6.0	91.2	56.6	45.0	43.8	53.7	55.1
5.0	88.3	52.6	41.0	39.7	49.8	49.5
4.0	84.4	47.9	37.0	37.3	44.7	43.2
3.0	77.0	43.2	32.8	32.8	39.8	39.2
2.0	65.6	37.6	27.3	28.2	36.3	33.8
1.0	42.6	28.5	20.2	21.9	28.9	25.9
0.8	35.2	26.0	18.0	20.3	26.6	23.9
0.6	26.2	23.2	15.0	18.3	23.9	21.5
0.5	21.1	21.7	13.1	17.3	22.1	20.1
0.4	15.7	20.2	10.7	16.1	20.2	18.8
0.3		18.8	7.8		18.1	

APPENDIX D

Deflocculant demand and shear response data

Table 1D Effect of deflocculant content on viscosity of slips at 50 wt% solid compared with Hypure Vector®. (refer to Fig. 5.11)

$\%Na_2SiO_3$ by dry wt.	Viscosity(cP) of slip at 50% solid after adding Na_2SiO_3					
	50RC6	50RC9	50RC10	50RC11	50RC12	Vector
0.02						87.0
0.03		165.0				84.8
0.04		143.8				82.5
0.05	217.5	122.5				77.5
0.06	147.5	101.3				71.5
0.07	117.5	80.0			462.5	65.0
0.08	97.5	72.5	492.5	352.5	392.5	59.5
0.09	85.0	65.0	408.8	301.3	322.5	54.0
0.10	80.0	57.5	325.0	250.0	283.8	53.0
0.11	75.0	56.9	301.7	233.3	245.0	52.0
0.12	70.0	56.3	278.3	216.7	229.2	51.0
0.13	62.5	55.6	255.0	200.0	213.3	46.0
0.14	62.5	55.0	228.8	186.3	197.5	41.0
0.15	55.0	52.5	202.5	172.5	182.5	43.0
0.16	55.0	50.0	190.0	161.3	167.5	45.0
0.17		47.5	177.5	147.0	157.5	42.8
0.18		46.3	171.7	145.0	147.5	40.7
0.19		45.0	165.8	140.0	141.7	38.5
0.20		43.8	160.0	135.0	135.8	
0.21		42.5	151.3	130.0	130.0	
0.22		41.7	142.5	125.0	125.0	
0.23		40.8	136.3	120.0	120.0	
0.24		40.0	130.0	115.0	110.0	
0.25		39.4	123.8	110.8	110.0	
0.26		38.8	117.5	106.7	105.0	
0.27		38.1	114.2	102.5	100.0	
0.28		37.5	110.8	98.8	96.7	
0.29		36.7	107.5	95.0	93.3	
0.30		35.8	102.5		90.0	
0.31		35.0	97.5		87.5	
0.32		35.8	95.0		85.0	
0.33		36.7	92.5			
0.35		37.5				

Table 2D Effect of deflocculant content on viscosity of RC11 slip at 40 and 50 wt% solid with and without addition of binder (1 wt%). (refer to Fig. 5.16)

$\%Na_2SiO_3$ by dry wt.	Viscosity (cP) of RC11 slips after adding Na_2SiO_3			
	40RC11	40RC11+1B	50RC11	50RC11+1B
0.00	67.5			
0.02	52.5			
0.03	40.0			
0.04	36.3	262.5		
0.05	32.5	183.8	352.5	
0.06	35.0	105.0	301.3	
0.07	32.5	85.0	250.0	
0.08	30.0	65.0	200.0	
0.09	27.5	60.0	186.3	332.5
0.10	30.0	55.0	172.5	278.8
0.11	32.5	55.0	161.3	225.0
0.12		55.0	150.0	145.0
0.13			135.0	133.8
0.14			130.0	122.5
0.15			125.0	100.0
0.16			115.0	92.5
0.17			108.8	85.0
0.18			102.5	82.5
0.19			95.0	80.0
0.20				75.0
0.22				70.0
0.24				70.0

Table 3D Effect of deflocculant content on viscosity of RC9 slip at 50 and 60 wt% solid with and without addition of binder (1 wt%). (refer to Fig. 5.17, Fig 5.18)

%Na_2SiO_3	Viscosity(cP) after adding Na_2SiO_3		%Na_2SiO_3	Viscosity(cP) after adding Na_2SiO_3	
By dry wt.	50RC9	50RC9+1B	By dry wt.	60RC9	60RC9+1B
0.00			0.23	480.0	
0.03	165.0	450.0	0.25	377.5	
0.05	136.7	310.0	0.28	317.5	
0.06	108.3	170.0	0.30	280.0	490.0
0.07	80.0	135.0	0.33	250.0	443.8
0.08	72.5	100.0	0.35	225.0	397.5
0.09	65.0	85.0	0.40	197.5	340.0
0.10	57.5	70.0	0.45	172.5	305.0
0.11	56.7	66.7	0.50	157.5	280.0
0.12	55.8	63.3	0.55	142.5	265.0
0.13	55.0	60.0	0.60	140.0	247.5
0.15	51.3	52.5	0.65	132.5	235.0
0.17	47.5	47.5	0.70	127.5	222.5
0.19	45.0	45.0	0.75	125.0	217.5
0.20	42.5	43.8	0.78	125.0	212.5
0.22	41.3	42.5	0.80	125.0	208.8
0.23	40.0	42.5	0.85	122.5	205.0
0.24	39.2	42.5	0.90	120.0	200.0
0.26	38.3	40.0	0.93		195.0
0.27	37.5		1.00		190.0
0.30	35.0		1.08		185.0
0.33	37.5		1.15		180.0
			1.23		177.5

Table 4D Variation of shear stress with shear rate

(refer to Fig. 5.19, Fig 5.21)

rpm	Small sample DV II+ Spindle No.18							
	40% RC11 + 1 wt% Binder + 0.08 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	0.15	0.396	0.06	0.29	-0.40	-1.23	-0.54	-0.83
0.6	0.18	0.792	0.15	0.38	-0.10	-0.84	-0.42	-0.73
1.5	0.16	1.980	0.32	0.53	0.30	-0.50	-0.28	-0.80
3	0.13	3.960	0.52	0.68	0.60	-0.28	-0.17	-0.88
6	0.10	7.920	0.78	0.86	0.90	-0.11	-0.07	-1.00
12	0.07	15.800	1.13	1.13	1.20	0.05	0.05	-1.15
30	0.04	39.600	1.77	1.73	1.60	0.25	0.24	-1.35
60	0.03	79.200	2.09	2.09	1.90	0.32	0.32	-1.58
Stop 5 min								
0.3	3.89	0.396	1.54	1.54	-0.40	0.19	0.19	0.59
rpm	Small sample DV II+ Spindle No.31							
	50% RC11 + 1 wt% Binder + 0.14 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	0.40	0.102	0.04	3.40	-0.99	-1.39	0.53	-0.40
0.6	6.02	0.204	1.23	3.43	-0.69	0.09	0.54	0.78
1.5	5.29	0.510	2.70	3.77	-0.29	0.43	0.58	0.72
3.0	3.36	1.020	3.43	3.92	0.01	0.54	0.59	0.53
6.0	1.96	2.040	4.00	4.12	0.31	0.60	0.61	0.29
12.0	1.17	4.080	4.78	4.62	0.61	0.68	0.66	0.07
30.0	0.56	10.200	5.76	5.60	1.01	0.76	0.75	-0.25
60.0	0.33	20.400	6.76	6.76	1.31	0.83	0.83	-0.48
Stop 5 min								
0.3	15.10	0.102	1.54	1.54	-0.99	0.19	0.19	1.18
rpm	Small sample DV II+ Spindle No.31							
	50% RC9 + 0.10 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	0.20	0.102	0.02	0.06	-0.99	-1.70	-1.21	-0.71
0.6	0.15	0.204	0.03	0.07	-0.69	-1.51	-1.15	-0.82
1.5	0.16	0.510	0.08	0.13	-0.29	-1.09	-0.88	-0.79
3	0.14	1.020	0.14	0.20	0.01	-0.84	-0.69	-0.85
6	0.12	2.040	0.25	0.29	0.31	-0.61	-0.54	-0.92
12	0.10	4.080	0.40	0.43	0.61	-0.40	-0.37	-1.01
30	0.07	10.200	0.73	0.76	1.01	-0.13	-0.12	-1.14
60	0.06	20.400	1.15	1.15	1.31	0.06	0.06	-1.25
Stop 5 min								
0.3	15.10	0.102	1.54	1.54	-0.99	0.19	0.19	1.18

Table 5D Variation of shear stress with shear rate

(refer to Fig. 5.22, Fig 5.24)

rpm	Small sample DV II+ Spindle No.31							
	50% RC9 + 1 wt% Binder + 0.06 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	3.20	0.102	0.33	2.14	-0.99	-0.49	0.33	0.50
0.6	3.60	0.204	0.73	2.14	-0.69	-0.13	0.33	0.56
1.5	3.14	0.510	1.60	2.21	-0.29	0.20	0.34	0.50
3	2.01	1.020	2.05	2.26	0.01	0.31	0.35	0.30
6	1.22	2.040	2.48	2.50	0.31	0.39	0.40	0.08
12	0.73	4.080	2.97	2.87	0.61	0.47	0.46	-0.14
30	0.36	10.200	3.68	3.50	1.01	0.57	0.54	-0.44
60	0.22	20.400	4.41	4.41	1.31	0.64	0.64	-0.67
Stop 5 min								
0.3	15.10	0.102	1.54	1.54	-0.99	0.19	0.19	1.18

rpm	Small sample DV II+ Spindle No.31							
	60% RC9 + 0.55 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	1.10	0.102	0.11	0.16	-0.99	-0.95	-0.79	0.04
0.6	0.80	0.204	0.16	0.20	-0.69	-0.79	-0.69	-0.10
1.5	0.56	0.510	0.29	0.31	-0.29	-0.54	-0.51	-0.25
3.0	0.44	1.020	0.45	0.47	0.01	-0.35	-0.33	-0.36
6.0	0.33	2.040	0.67	0.68	0.31	-0.17	-0.17	-0.48
12.0	0.27	4.080	1.09	1.08	0.61	0.04	0.03	-0.57
30.0	0.20	10.200	2.08	2.06	1.01	0.32	0.31	-0.69
60.0	0.17	20.400	3.42	3.42	1.31	0.53	0.53	-0.78
Stop 5 min								
0.3	15.10	0.102	1.54	1.54	-0.99	0.19	0.19	1.18

rpm	Small sample DV II+ Spindle No.31							
	60% RC9 + 1 wt% Binder + 0.80 wt% Na_2SiO_3							
	η-up (Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ -up (Pa)	τ -down (Pa)	log ($\dot{\gamma}$)	log (τ) up	log (τ) down	log (η)
0.3	1.70	0.102	0.17	0.21	-0.99	-0.76	-0.67	0.23
0.6	1.35	0.204	0.28	0.29	-0.69	-0.56	-0.54	0.13
1.5	0.84	0.510	0.43	0.51	-0.29	-0.37	-0.29	-0.08
3	0.64	1.020	0.65	0.76	0.01	-0.19	-0.12	-0.19
6	0.51	2.040	1.04	1.14	0.31	0.02	0.06	-0.29
12	0.42	4.080	1.72	1.81	0.61	0.24	0.26	-0.38
30	0.33	10.200	3.36	3.38	1.01	0.53	0.53	-0.48
60	0.27	20.400	5.45	5.45	1.31	0.74	0.74	-0.57
Stop 5 min								
0.3	15.10	0.102	1.54	1.54	-0.99	0.19	0.19	1.18

Table 6D Variation of shear stress with shear rate of 40%RC11 and 50%RC11 with 1 wt% binder (refer to Fig. 1D)

rpm	Small sample DV II+ Spindle No.18					
	40% RC11 + 1 wt% Binder + 0.08 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	0.09	0.396	0.04	-0.40	-1.44	-1.04
0.6	0.09	0.792	0.07	-0.10	-1.15	-1.05
1.5	0.10	1.980	0.20	0.30	-0.69	-0.99
3.0	0.09	3.960	0.36	0.60	-0.45	-1.05
6.0	0.07	7.920	0.59	0.90	-0.23	-1.13
12.0	0.06	15.800	0.90	1.20	-0.05	-1.24
30.0	0.04	39.600	1.51	1.60	0.18	-1.42
60.0	0.03	79.200	2.20	1.90	0.34	-1.56
0.3	0.19	0.396	0.08	-0.40	-1.12	-0.72
Stop 5 min						
0.3	0.37	0.396	0.15	-0.40	-0.84	-0.43
rpm	Small sample DV II+ Spindle No.31					
	50% RC11 + 1 wt% Binder + 0.14 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	3.50	0.102	0.36	-0.99	-0.45	0.54
0.6	4.30	0.204	0.88	-0.69	-0.06	0.63
1.5	2.90	0.510	1.48	-0.29	0.17	0.46
3.0	1.96	1.020	2.00	0.01	0.30	0.29
6.0	1.24	2.040	2.52	0.31	0.40	0.09
12.0	0.76	4.080	3.11	0.61	0.49	-0.12
30.0	0.39	10.200	3.95	1.01	0.60	-0.41
60.0	0.23	20.400	4.78	1.31	0.68	-0.63
0.3	7.10	0.102	0.72	-0.99	-0.14	0.85
Stop 5 min						
0.3	14.90	0.102	1.52	-0.99	0.18	1.17

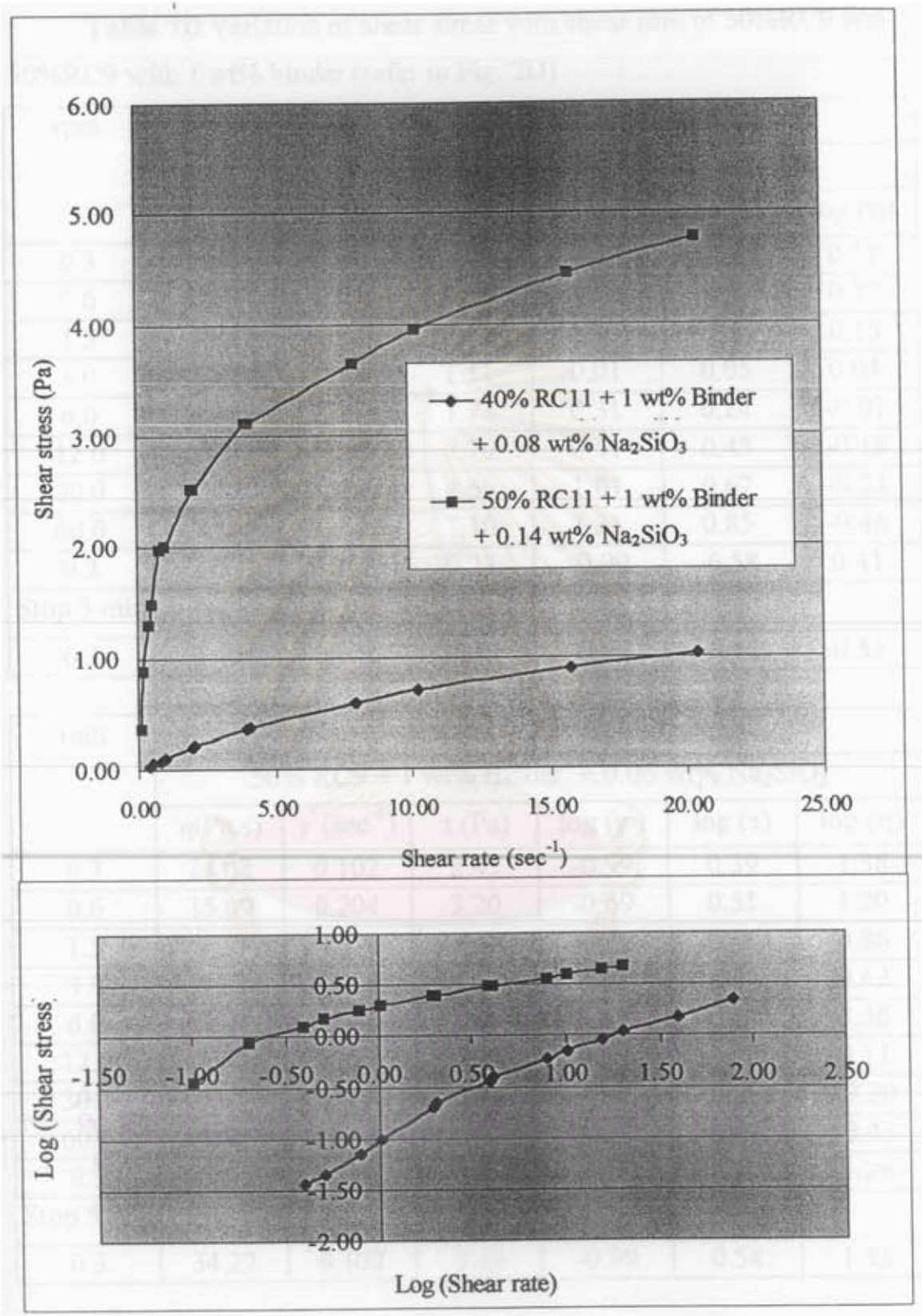


Fig. 1D Variation of shear stress with shear rate of 40%RC11 with 1 wt% binder and 50%RC11 with 1 wt% binder (Rechecking before spray drying and relating to Table 6D)

Table 7D Variation of shear stress with shear rate of 50%RC9 and 50%RC9 with 1 wt% binder (refer to Fig. 2D)

rpm	Small sample DV II+ Spindle No.31					
	50% RC9 + 0.10 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	1.50	0.102	0.15	-0.99	-0.82	0.18
0.6	1.65	0.204	0.34	-0.69	-0.47	0.22
1.5	1.40	0.510	0.71	-0.29	-0.15	0.15
3.0	1.09	1.020	1.11	0.01	0.05	0.04
6.0	0.85	2.040	1.73	0.31	0.24	-0.07
12.0	0.66	4.080	2.70	0.61	0.43	-0.18
30.0	0.46	10.200	4.66	1.01	0.67	-0.34
60.0	0.35	20.400	7.10	1.31	0.85	-0.46
0.3	2.60	0.102	0.27	-0.99	-0.58	0.41
Stop 5 min						
0.3	3.40	0.102	0.35	-0.99	-0.46	0.53

rpm	Small sample DV II+ Spindle No.31					
	50% RC9 + 1 wt% Binder + 0.06 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	24.02	0.102	2.45	-0.99	0.39	1.38
0.6	15.69	0.204	3.20	-0.69	0.51	1.20
1.5	7.20	0.510	3.67	-0.29	0.56	0.86
3.0	4.13	1.020	4.21	0.01	0.62	0.62
6.0	2.29	2.040	4.68	0.31	0.67	0.36
12.0	1.30	4.080	5.30	0.61	0.72	0.11
30.0	0.63	10.200	6.46	1.01	0.81	-0.20
60.0	0.38	20.400	7.66	1.31	0.88	-0.43
0.3	19.61	0.102	2.00	-0.99	0.30	1.29
Stop 5 min						
0.3	34.22	0.102	3.49	-0.99	0.54	1.53

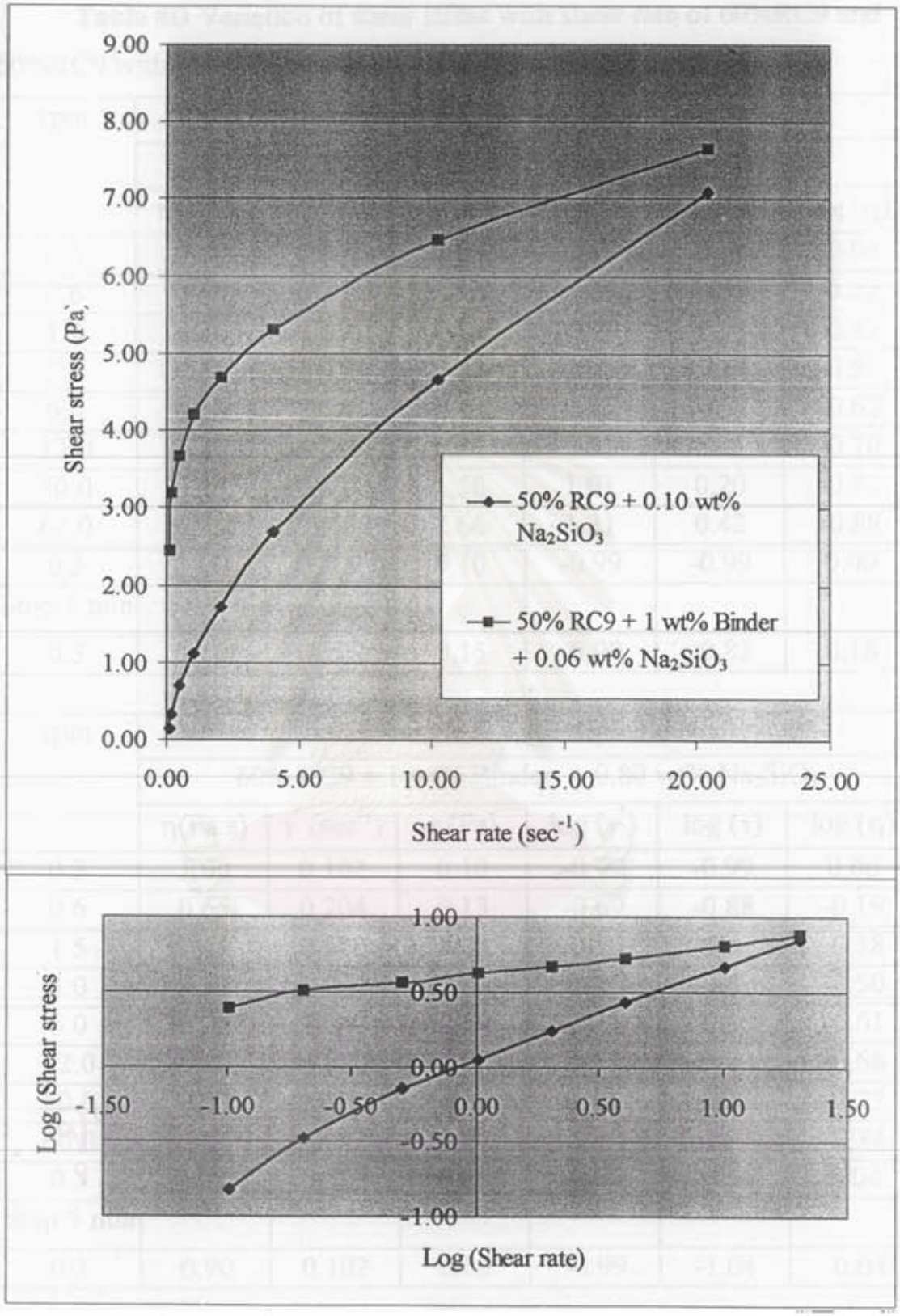


Fig. 2D Variation of shear stress with shear rate of 50%RC9 with and without 1wt%binder

(Rechecking before spray drying and relating to Table 7D)

Table 8D Variation of shear stress with shear rate of 60%RC9 and 60%RC9 with 1 wt% binder (refer to Fig. 3D)

rpm	Small sample DV II+ Spindle No.31					
	60% RC9 + 0.55 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	0.90	0.102	0.09	-0.99	-1.04	-0.04
0.6	0.60	0.204	0.12	-0.69	-0.91	-0.22
1.5	0.38	0.510	0.19	-0.29	-0.71	-0.42
3.0	0.31	1.020	0.32	0.01	-0.50	-0.51
6.0	0.24	2.040	0.49	0.31	-0.31	-0.62
12.0	0.20	4.080	0.81	0.61	-0.09	-0.70
30.0	0.15	10.200	1.58	1.01	0.20	-0.81
60.0	0.13	20.400	2.66	1.31	0.42	-0.88
0.3	1.00	0.102	0.10	-0.99	-0.99	0.00
Stop 5 min						
0.3	1.50	0.102	0.15	-0.99	-0.82	0.18
rpm	Small sample DV II+ Spindle No.31					
	60% RC9 + 1 wt% Binder + 0.80 wt% Na_2SiO_3					
	η(Pa.s)	$\dot{\gamma}$ (sec^{-1})	τ (Pa)	log ($\dot{\gamma}$)	log (τ)	log (η)
0.3	1.00	0.102	0.10	-0.99	-0.99	0.00
0.6	0.65	0.204	0.13	-0.69	-0.88	-0.19
1.5	0.42	0.510	0.21	-0.29	-0.67	-0.38
3.0	0.32	1.020	0.33	0.01	-0.49	-0.50
6.0	0.25	2.040	0.50	0.31	-0.30	-0.61
12.0	0.21	4.080	0.85	0.61	-0.07	-0.68
30.0	0.17	10.200	1.72	1.01	0.24	-0.77
60.0	0.15	20.400	2.98	1.31	0.47	-0.84
0.3	1.10	0.102	0.11	-0.99	-0.95	0.04
Stop 5 min						
0.3	0.90	0.102	0.09	-0.99	-1.04	-0.04

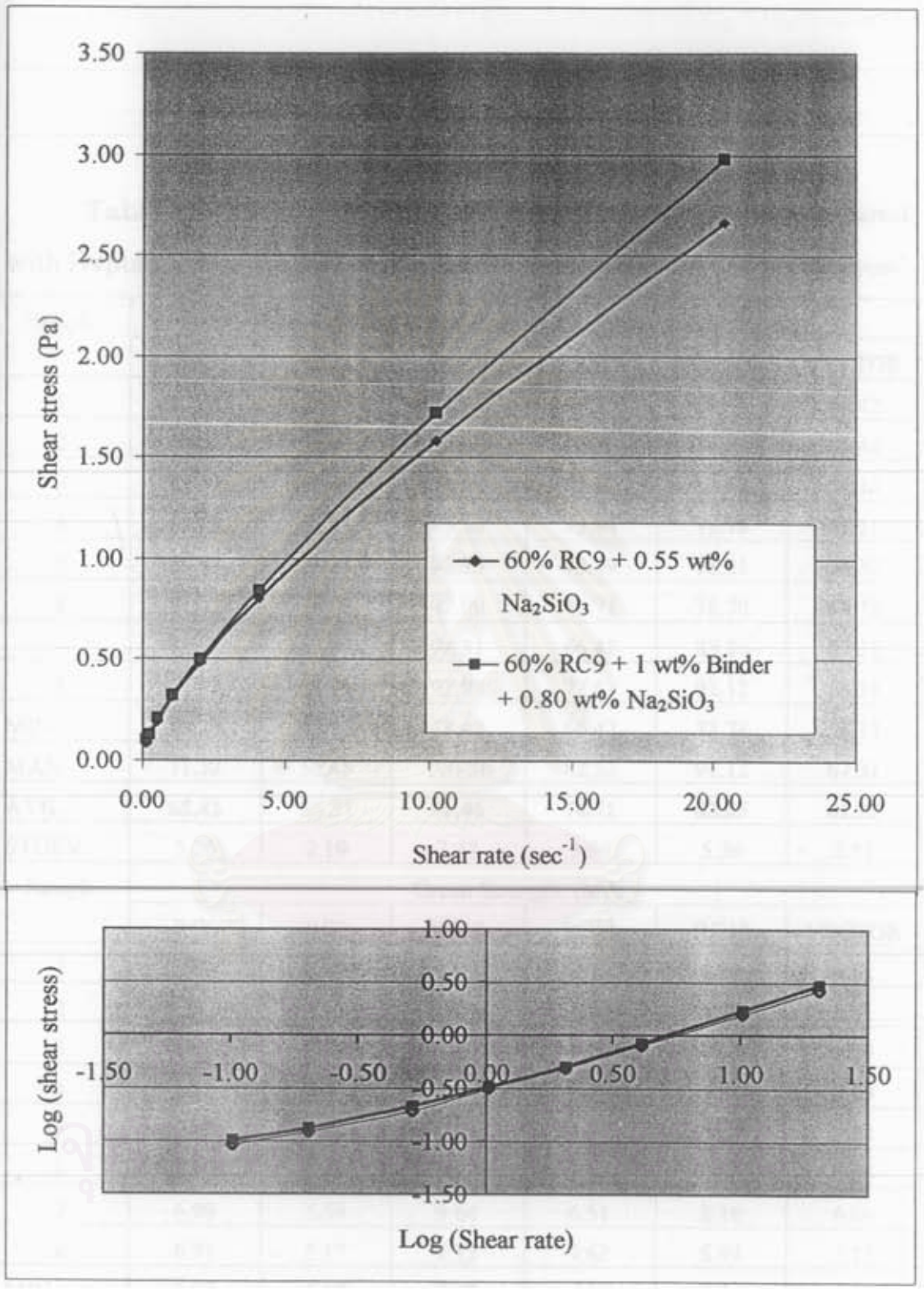


Fig. 3D Variation of shear stress with shear rate of 60%RC9 with and without 1wt%binder

(Rechecking before spray drying and relating to Table 8D)

APPENDIX E

Modulus of rupture data (Green strength)

Table 1E Green strength of RC slips at 50 wt% solid compared with Hypure Vector®.(refer to Fig. 5.13) **1MPa = 1MN/m² = 10.019716 kg/cm²**

Sample	Green strength (kg/cm²)					
	RC6	RC9	RC10	RC11	RC12	VECTOR
1	60.08	55.15	82.34	78.70	81.16	66.42
2	59.31	54.37	100.36	66.76	86.52	66.42
3	67.82	58.45	78.42	82.52	83.62	62.13
4	65.03	54.11	93.54	73.44	73.78	61.11
5	60.08	53.14	92.73	72.49	78.21	54.37
6	71.32	58.03	92.99	79.71	78.70	64.72
7	71.32	56.95	98.31	66.42	83.26	67.31
8	68.43	52.75	92.99	77.67	91.12	53.14
MIN	59.31	52.75	78.42	66.42	73.78	53.14
MAX	71.32	58.45	100.36	82.52	91.12	67.31
AVG.	**65.42**	**55.37**	**91.46**	**74.71**	**82.05**	**61.95**
STDEV.	5.06	2.19	7.47	5.96	5.36	5.51
Sample	Green Strength (MPa)					
	RC6	RC9	RC10	RC11	RC12	VECTOR
1	5.89	5.41	8.07	7.72	7.96	6.51
2	5.82	5.33	9.84	6.55	8.49	6.51
3	6.65	5.73	7.69	8.09	8.20	6.09
4	6.38	5.31	9.17	7.20	7.24	5.99
5	5.89	5.21	9.09	7.11	7.67	5.33
6	6.99	5.69	9.12	7.82	7.72	6.35
7	6.99	5.59	9.64	6.51	8.16	6.60
8	6.71	5.17	9.12	7.62	8.94	5.21
MIN	5.82	5.17	7.69	6.51	7.24	5.21
MAX	6.99	5.73	9.84	8.09	8.94	6.60
AVG.	**6.42**	**5.43**	**8.97**	**7.33**	**8.05**	**6.08**
STDEV.	0.50	0.21	0.73	0.58	0.53	0.54

Table 2E Modulus of rupture (green strength) of RC9 slips before and after spray drying compared with Hypure Vector®.

(refer to Fig. 5.25) **1MPa = 1MN/m² = 10.019716 kg/cm²**

Sample	Green strength before spray drying (MPa)			
	50RC9	50RC9+1B	60RC9	60RC9+1B
1	5.06	5.97	6.82	6.95
2	5.46	5.97	6.04	7.37
3	5.59	6.12	5.97	8.15
4	5.41	5.97	6.74	7.90
5	5.59	5.88	6.65	7.16
6	6.03	5.74	6.55	6.90
7	5.24	5.41	6.77	7.51
8		6.12	6.42	7.71
MIN	5.06	5.41	5.97	6.90
MAX	6.03	6.12	6.82	8.15
AVG.	5.48	5.89	6.49	7.46
STDEV.	0.31	0.23	0.33	0.45
Sample	Green strength after spray drying (MPa)			
	50RC9	50RC9+B	60RC9	VECTOR
1	4.70	4.95	6.68	6.51
2	4.45	6.24	6.25	6.51
3	4.36	4.67	6.19	6.09
4	5.44	4.95	5.84	5.99
5	5.37	6.29	6.27	5.33
6	4.95	5.94	5.44	6.35
7	5.14	5.40	5.33	6.60
8	4.70	5.55	6.27	5.21
MIN	4.36	4.67	5.33	5.21
MAX	5.44	6.29	6.68	6.60
AVG.	4.89	5.50	6.03	6.08
STDEV.	0.40	0.62	0.46	0.54

APPENDIX F

Granule properties

Table 1F Granule size distribution of samples by sieve analysis. (refer to Fig. 5.27)

Samples (fixed condition)	Weight percent over than (%)						
	VECTOR	40RC11 +0.08Na +1B	50RC11 +0.14Na +1B	50RC9 +0.1Na	50RC9 +0.06Na +1B	60RC9 +0.55Na	60RC9 +0.08Na +1B
+180 μm	77.80	0.36	0.60	0.56	0.56	1.84	4.24
+125 μm	90.40	0.56	1.12	1.04	0.92	3.16	6.16
+106 μm	93.20	0.72	1.92	1.96	1.24	3.96	7.16
+75 μm	98.00	3.40	8.56	13.76	3.12	7.84	9.04
+45 μm	99.60	69.40	76.56	80.38	78.36	82.80	76.62
-45 μm	99.76	99.56	99.68	99.28	99.56	99.44	99.85

Samples (varied Condition)	Weight percent over than (%)				
	50RC11 +0.28Na	46RC11	46RC11 +0.1Na +1B	50RC11 +0.3Na +1B	50RC11 +0.3Na +2B
+180 μm	1.04	1.16	0.89	0.72	0.96
+125 μm	1.56	1.56	1.56	1.12	1.56
+106 μm	1.84	1.84	1.91	1.44	2.12
+75 μm	3.48	15.40	17.38	3.16	4.84
+45 μm	81.08	92.28	79.96	75.56	75.92
-45 μm	99.80	99.88	99.87	99.56	99.52

Table 2F Granule size distribution of samples, measured by stereomicroscope. (refer to Fig. 5.28-5.29)

Samples (fixed condition)	Percent finer than (%)						
	VECTOR	40RC11 +0.08Na +1B	50RC11 +0.14Na +1B	50RC9 +0.1Na	50RC9 +0.06Na +1B	60RC9 +0.55Na	60RC9 +0.08Na +1B
-10 μm	0.00	7.25	10.10	5.10	17.72	10.13	5.26
-20 μm	0.00	34.78	54.55	48.98	46.84	46.84	41.05
-30 μm	0.00	73.91	78.79	77.55	64.56	64.56	72.63
-40 μm	0.00	88.41	91.92	94.90	70.89	78.48	88.42
-50 μm	0.00	94.20	95.96	97.96	93.67	94.94	98.95
-56 μm	3.23	94.20	95.96	97.96	93.67	94.94	98.95
-60 μm	3.23	95.65	98.99	100.00	97.47	97.47	100.00
-70 μm	3.23	97.10	100.00	100.00	100.00	97.47	100.00
-80 μm	3.23	98.55	100.00	100.00	100.00	98.73	100.00
-90 μm	3.23	100.00	100.00	100.00	100.00	98.73	100.00
-100 μm	3.23	100.00	100.00	100.00	100.00	98.73	100.00
-110 μm	3.23	100.00	100.00	100.00	100.00	98.73	100.00
-111 μm	12.90	100.00	100.00	100.00	100.00	98.73	100.00
-120 μm	12.90	100.00	100.00	100.00	100.00	100.00	100.00
-168 μm	22.58	100.00	100.00	100.00	100.00	100.00	100.00
-222 μm	41.94	100.00	100.00	100.00	100.00	100.00	100.00
-278 μm	70.97	100.00	100.00	100.00	100.00	100.00	100.00
-333 μm	80.65	100.00	100.00	100.00	100.00	100.00	100.00
-389 μm	90.32	100.00	100.00	100.00	100.00	100.00	100.00
-444 μm	96.77	100.00	100.00	100.00	100.00	100.00	100.00
-667 μm	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Samples (varied Condition)	Percent finer than (%)				
	50RC11 +0.28Na	46RC11	46RC11 +0.1Na +1B	50RC11 +0.3Na +1B	50RC11 +0.3Na +2B
-10 μm	0.00	0.00	10.96	8.06	11.11
-20 μm	15.00	10.81	47.95	38.71	26.39
-30 μm	51.67	29.73	82.19	70.97	69.44
-40 μm	75.00	48.65	93.15	85.48	86.11
-50 μm	91.67	86.49	97.26	90.32	94.44
-56 μm	91.67	86.49	97.26	90.32	94.44
-60 μm	100.00	94.59	100.00	96.77	95.83
-70 μm	100.00	97.30	100.00	96.77	97.22
-80 μm	100.00	97.30	100.00	96.77	98.61
-90 μm	100.00	97.30	100.00	98.39	98.61
-100 μm	100.00	100.00	100.00	100.00	100.00

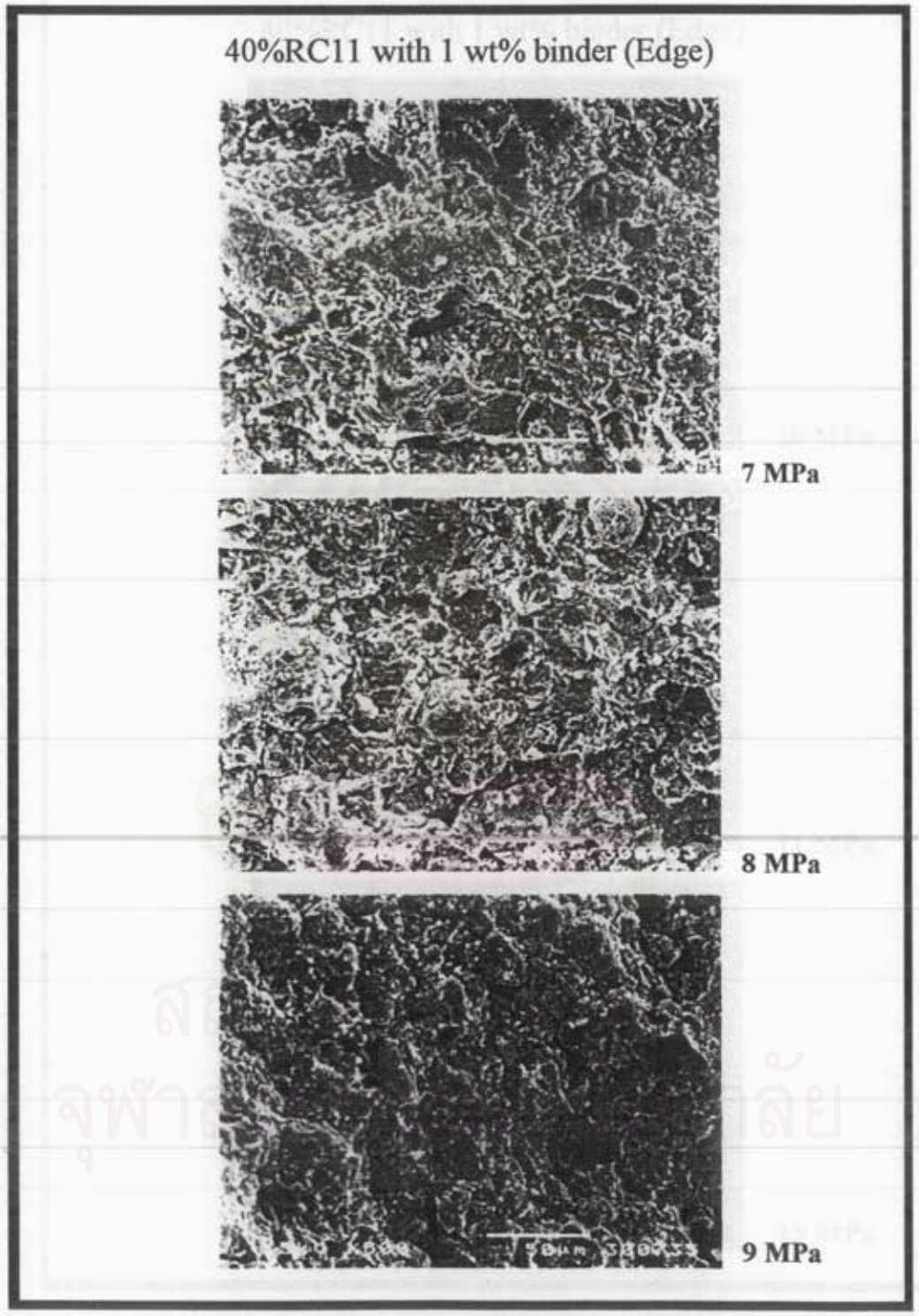


Fig. 1F Granule deformation of 40%RC11 with 1 wt% binder at various pressures – 7 to 9 MPa. (Fracture surface by SEM x 500)

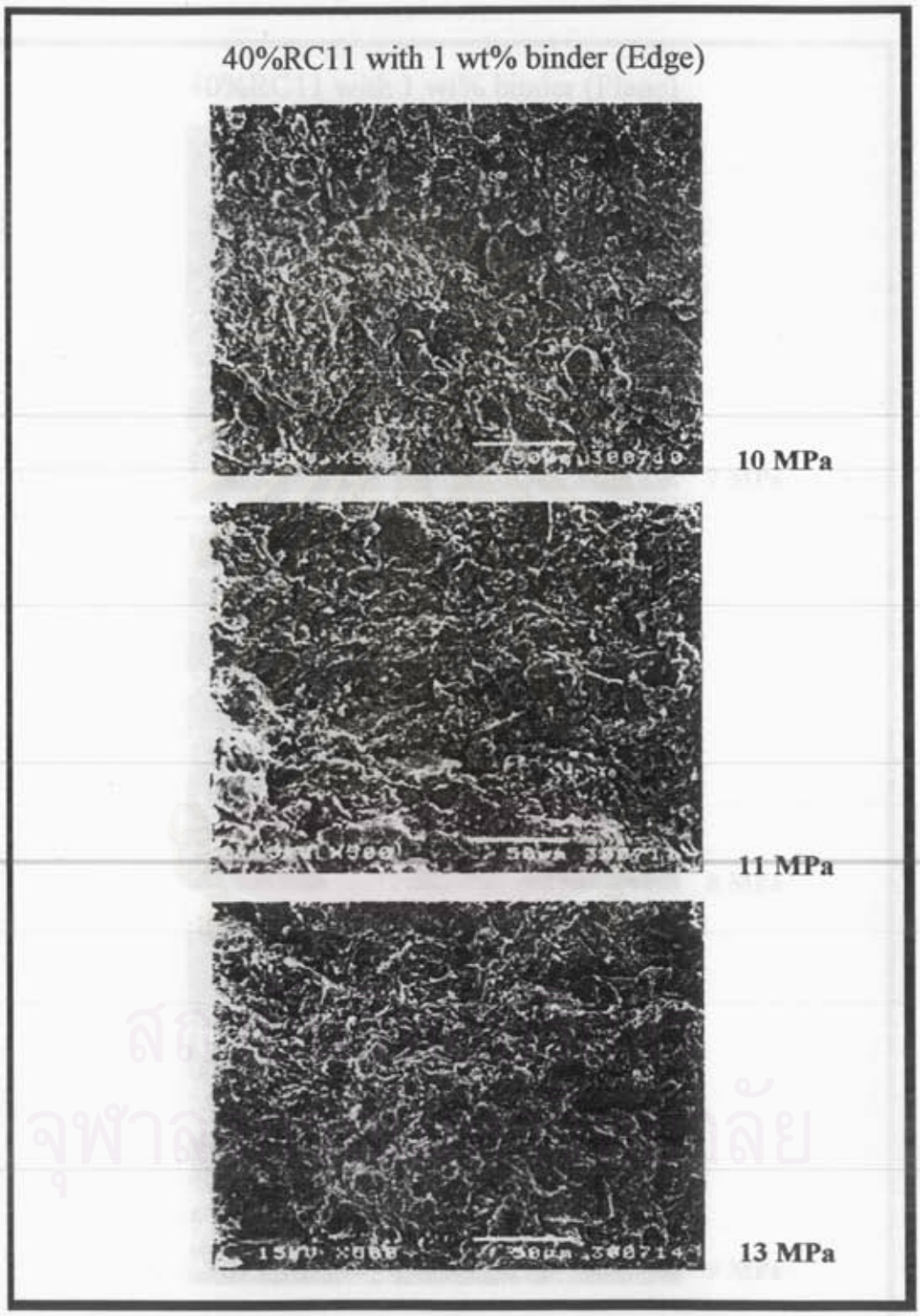


Fig. 2F Granule deformation of 40%RC11 with 1 wt% binder at various pressures – 10 to 13 MPa. (Fracture surface by SEM x 500)

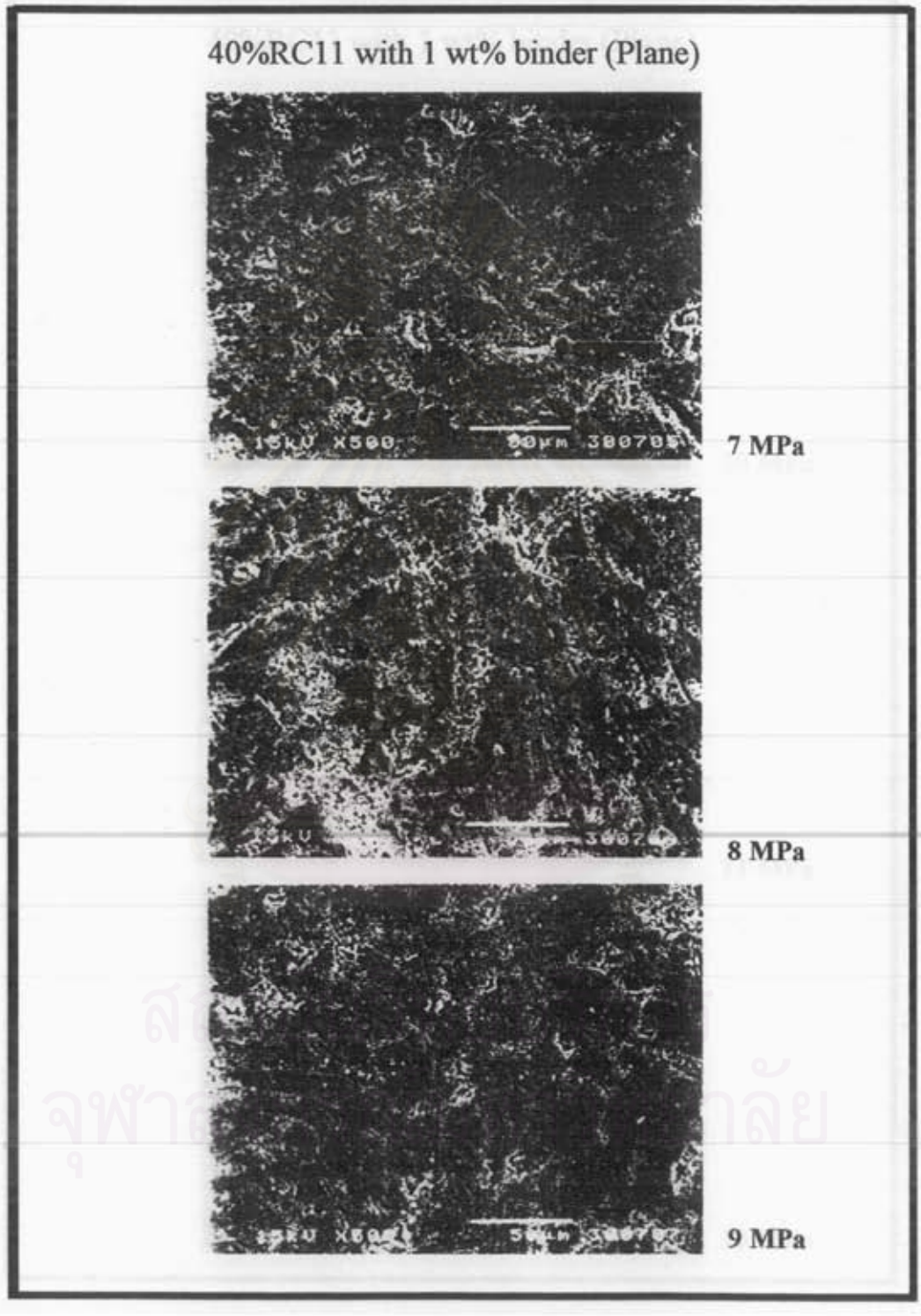


Fig. 3F Surface of 40%RC11 with 1wt% binder
at various pressures – 7 to 9 MPa. (Fracture surface by SEM x 500)

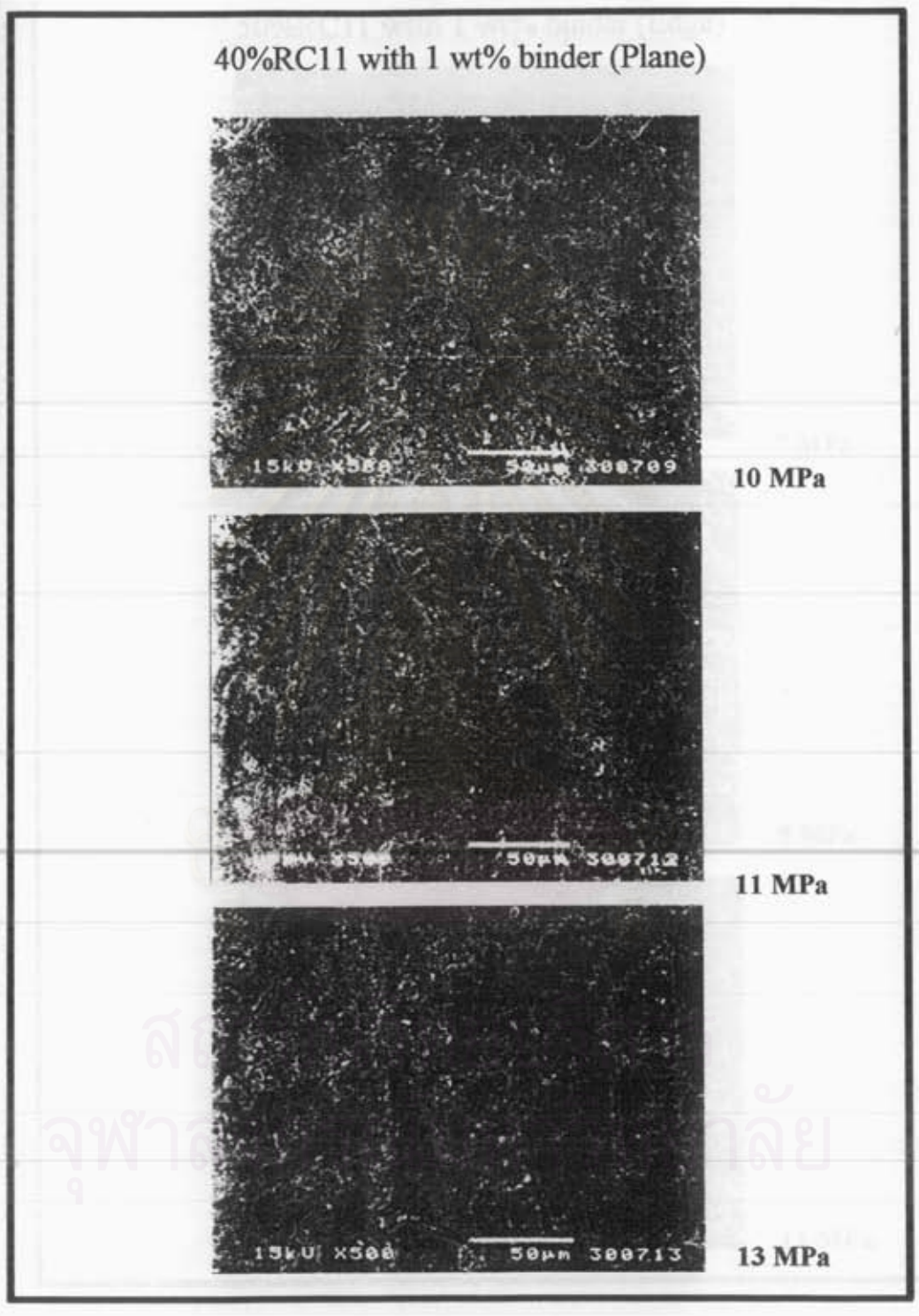


Fig. 4F Surface of 40%RC11 with 1wt% binder at various pressures – 10 to 13 MPa. (Fracture surface by SEM x 500)

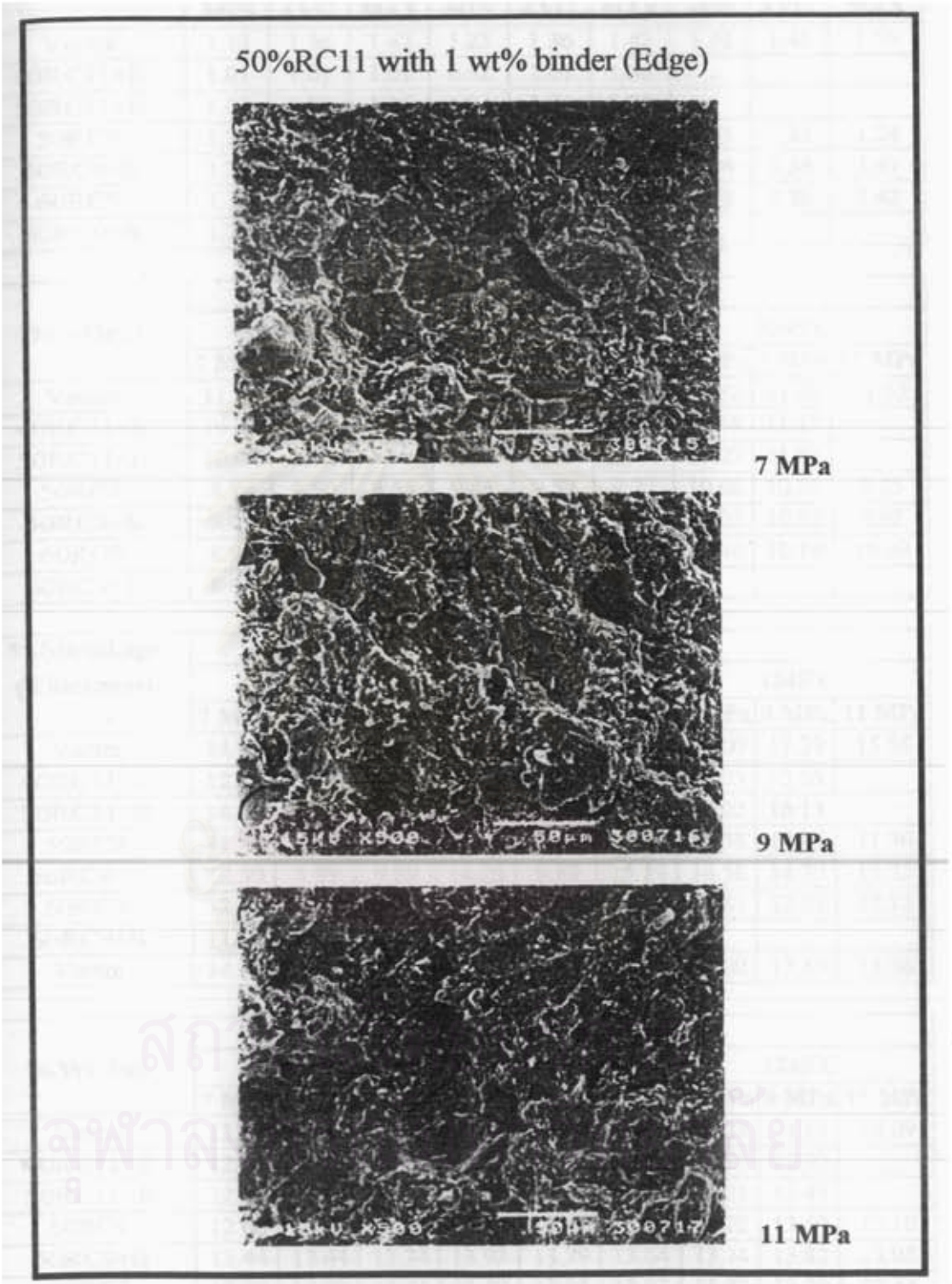


Fig. 5F Granule deformation of 50%RC11 with 1 wt% binder at various pressures. (Fracture surface by SEM x 500)

Table 3F %Shrinkage and %wt. loss of pressed samples (related to Fig. 5.43 to 5.44)

Mould-dry	%Shrinkage								
	7 MPa (70 Bar)			9 MPa (90 Bar)			11 MPa (110 Bar)		
	MIN	AVG.	MAX	MIN	AVG.	MAX	MIN	AVG.	MAX
Vector	1.13	1.36	1.47	1.23	1.36	1.42	1.32	1.48	1.56
40RC11+B	1.01	1.01	1.01	0.92	1.01	1.06			
50RC11+B	1.01	1.08	1.15	1.24	1.26	1.28			
50RC9	1.23	1.25	1.28	1.24	1.24	1.24	1.15	1.21	1.24
50RC9+B	1.24	1.32	1.47	1.15	1.24	1.33	1.24	1.36	1.47
60RC9	1.15	1.27	1.33	1.38	1.44	1.47	1.33	1.36	1.42
60RC9+B	1.38	1.47	1.56	1.22	1.28	1.33			

Dry-Fired	%Shrinkage								
	1150°C			1200°C			1245°C		
	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa
Vector	11.04	10.72	10.26	11.51	11.14	10.68	11.82	11.21	11.62
40RC11+B	10.43	10.11		10.97	10.76		11.58	11.17	
50RC11+B	10.04	9.85		10.51	10.44		11.29	11.01	
50RC9	8.74	8.50	8.55	9.85	9.57	9.27	10.68	10.36	9.25
50RC9+B	9.01	8.83	8.74	10.08	9.90	9.95	11.05	10.63	9.92
60RC9	8.94	8.79	8.69	9.72	9.40	9.23	10.46	10.19	10.09
60RC9+B	8.66	8.67		9.41	9.23				

%Shrinkage (Thickness)	%Shrinkage								
	1150°C			1200°C			1245°C		
	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa
Vector	14.89	15.22	13.33	14.89	15.22	15.22	20.00	17.39	15.56
40RC11+B	12.77	12.09		15.63	13.98		15.05	13.55	
50RC11+B	14.58	13.04		15.72	14.02		17.02	16.13	
50RC9	11.46	11.11	13.04	12.50	11.11	13.04	14.58	14.13	11.36
50RC9+B	12.50	8.89	9.89	14.29	9.89	15.79	14.58	14.29	13.33
60RC9	12.50	7.87	11.11	13.54	11.11	11.11	13.83	12.22	12.22
60RC9+B	11.11	10.34		12.22	11.93				
Vector	14.89	15.22	13.33	14.89	15.22	15.22	20.00	17.39	15.56

%Wt. loss	%Wt. loss								
	1150°C			1200°C			1245°C		
	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa	7 MPa	9 MPa	11 MPa
Vector	13.74	13.46	13.64	14.37	14.22	14.26	14.37	14.17	14.09
40RC11+B	12.46	12.66		13.52	13.77		13.51	13.30	
50RC11+B	12.51	12.75		13.07	13.15		13.21	13.45	
50RC9	12.66	12.79	12.89	13.32	13.43	13.68	13.22	13.49	13.10
50RC9+B	13.44	13.44	13.34	13.93	13.79	13.64	13.74	13.82	13.95
60RC9	12.79	12.73	12.74	13.39	13.25	13.33	13.27	13.29	13.33
60RC9+B	13.30	13.25		13.82	13.89				

Table 4F Green density of pressed samples **(related to Fig. 5.42)**

Green density	Green density (g/cm^3)								
	70 Bar (7 MPa)			90 Bar (9 MPa)			110 Bar (11 MPa)		
	MIN	AVG.	MAX	MIN	AVG.	MAX	MIN	AVG.	MAX
Vector	1.73	1.77	1.80	1.79	1.82	1.84	1.86	1.88	1.89
40RC11+B	1.76	1.76	1.77	1.79	1.80	1.81			
50RC11+B	1.70	1.73	1.75	1.75	1.78	1.81			
50RC9	1.71	1.75	1.77	1.78	1.83	1.87	1.84	1.88	1.94
50RC9+B	1.73	1.74	1.76	1.82	1.85	1.87	1.76	1.84	1.90
60RC9	1.73	1.76	1.78	1.86	1.88	1.90	1.76	1.84	1.90
60RC9+B	1.85	1.86	1.86	1.91	1.91	1.91			

Table 5F Bulk density, %water absorption, %apparent porosity and specific gravity of pressed samples **(related to Fig. 5.45 and Fig. 6F)**

B=D/(M-S)	Bulk density (g/cm^3)								
	1150°C			1200°C			1245°C		
	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa
Vector	2.40	2.45	2.43	2.43	2.49	2.48	2.47	2.48	2.47
40RC11+B	2.28	2.34	2.32	2.36	2.31	2.41	2.38	2.42	2.42
50RC9	2.17	2.22	2.33	2.29	2.29	2.34	2.29	2.39	2.44
50RC9+B	2.19	2.21	2.23	2.24	2.32	2.32	2.30	2.35	2.46
60RC9	2.18	2.23	2.29	2.25	2.34	2.39	2.37	2.44	2.48

A=(M-D)/D x 100	%Water absorption								
	1150°C			1200°C			1245°C		
	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa
Vector	0.14	0.04	0.34	0.12	0.07	0.05	0.06	0.05	0.07
40RC11+B	4.84	4.11	3.84	2.9	3.58	2.05	2.36	1.36	1.64
50RC9	8.39	7.04	4.91	5.25	5.58	4.34	5.01	3.43	2.33
50RC9+B	7.84	7.59	6.58	6.37	4.34	4.85	4.98	3.81	2.58
60RC9	8.24	7.08	5.39	6.21	4.14	3.38	3.82	2.21	1.57

P=(M-D)/(M-S) x 100	%Apparent porosity								
	1150°C			1200°C			1245°C		
	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa
Vector	0.32	0.10	0.81	0.29	0.17	0.13	0.16	0.13	0.18
40RC11+B	11.02	9.61	8.88	6.83	8.38	4.93	5.62	3.29	3.97
50RC9	18.24	15.63	11.44	12.02	12.78	10.13	11.47	8.78	5.68
50RC9+B	17.15	16.69	14.69	14.25	10.04	11.24	11.45	8.94	6.30
60RC9	17.91	15.72	12.33	13.96	9.70	8.06	8.96	5.40	3.89

T=D/(D-S)	Apparent specific gravity (g/cm^3)								
	1150°C			1200°C			1245°C		
	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa	7 MPa	9MPa	11 MPa
Vector	2.41	2.45	2.45	2.44	2.49	2.48	2.48	2.48	2.47
40RC11+B	2.56	2.59	2.55	2.53	2.55	2.53	2.52	2.50	2.51
50RC9	2.66	2.63	2.63	2.60	2.63	2.60	2.59	2.60	2.59
50RC9+B	2.64	2.65	2.62	2.61	2.58	2.61	2.60	2.58	2.62
60RC9	2.66	2.64	2.62	2.61	2.59	2.60	2.60	2.58	2.58

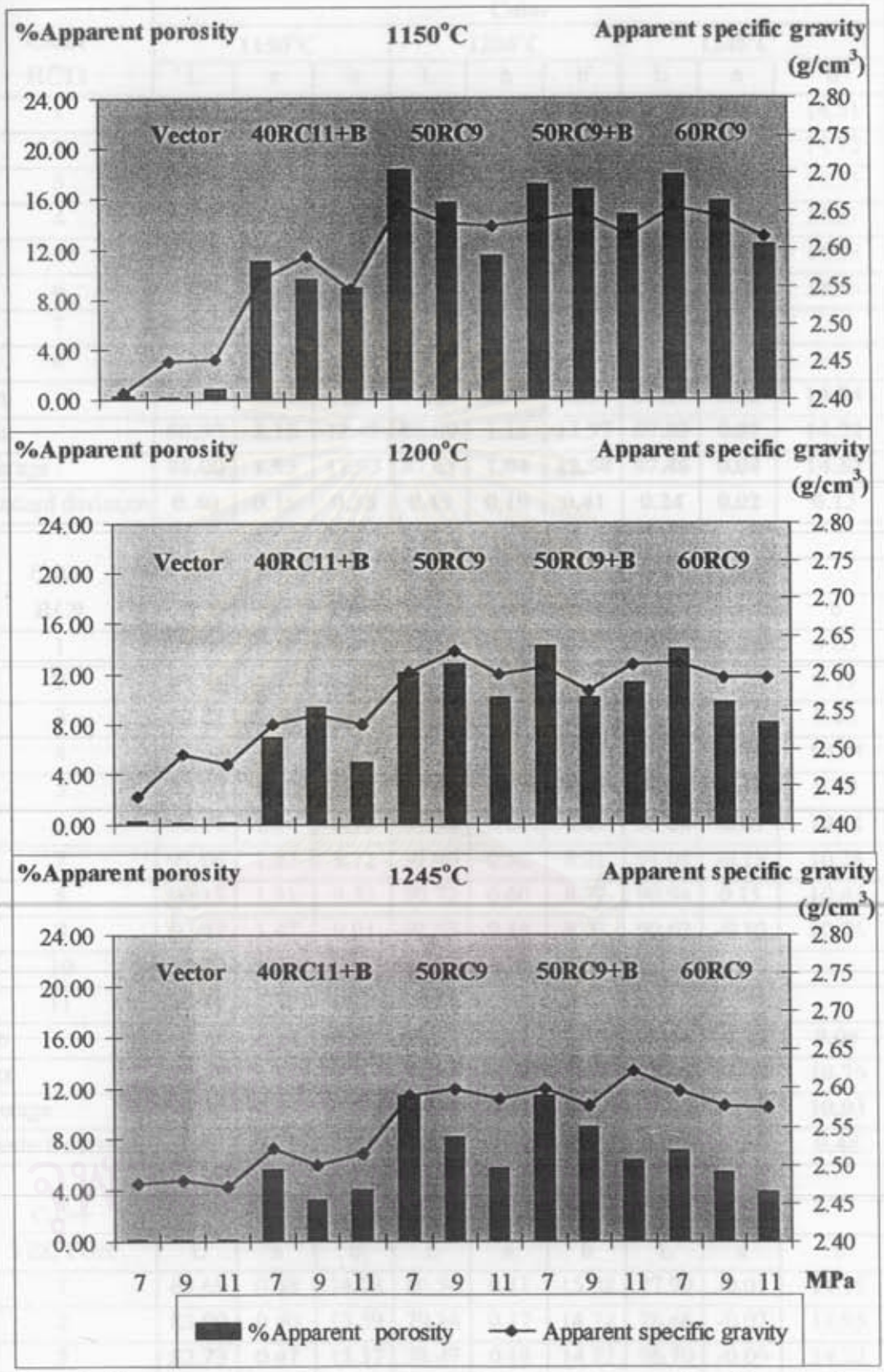


Fig. 6F Apparent specific gravity and apparent porosity of pressed samples at 1150°C-1245°C. (Table 5F)

Table 6F Color after firing of pressed samples

Color RC11	Color								
	1150°C			1200°C			1245°C		
	L	a	b	L	a	b	L	a	b
1	88.57	1.80	11.33	88.09	0.90	12.29	87.83	0.05	14.51
2	87.81	2.05	12.15	87.86	1.12	12.17	87.29	0.07	14.72
3	87.88	2.07	12.04	87.24	1.03	12.97	87.70	0.03	14.55
4	88.35	1.83	11.64	87.24	1.11	12.89	87.39	0.05	14.57
5	88.24	1.96	11.86				87.30	0.01	14.34
6	87.53	2.15	12.11				87.27	0.04	14.45
7	88.19	1.67	11.79						
8	87.45	1.89	12.48						
Min	**87.45**	**1.67**	**11.33**	**87.24**	**0.90**	**12.17**	**87.27**	**0.01**	**14.34**
Max	**88.57**	**2.15**	**12.48**	**88.09**	**1.12**	**12.97**	**87.83**	**0.07**	**14.72**
Average	**88.00**	**1.93**	**11.93**	**87.61**	**1.04**	**12.58**	**87.46**	**0.04**	**14.52**
Standard deviation	**0.40**	**0.16**	**0.35**	**0.43**	**0.10**	**0.41**	**0.24**	**0.02**	**0.13**
Color RC9	**Color**								
	1150°C			1200°C			1245°C		
	L	a	b	L	a	b	L	a	b
1	91.68	1.17	8.18	91.63	0.32	8.30	92.40	-0.29	9.05
2	91.41	1.27	8.33	90.65	0.48	8.77	91.51	-0.23	9.99
3	90.87	1.38	8.88	90.98	0.48	8.67	90.46	0.06	9.83
4	91.44	1.25	8.54	92.24	0.38	7.65	91.33	-0.16	10.04
5	90.90	1.40	8.90	91.68	0.38	8.30	91.67	-0.19	9.79
6	90.71	1.44	8.99	91.70	0.27	8.49	90.84	-0.07	10.11
7	91.06	1.22	8.72	91.40	0.52	8.21	91.05	-0.13	10.28
8	90.15	1.51	9.35	90.72	0.60	8.77	90.94	0.15	10.45
9	90.42	1.47	9.01	91.55	0.44	8.23	90.62	-0.10	10.76
10	90.82	1.38	8.90	91.93	0.36	8.04			
11	90.36	1.38	9.16	90.31	0.58	9.00			
Min	**90.15**	**1.17**	**8.18**	**90.31**	**0.27**	**7.65**	**90.46**	**-0.29**	**9.05**
Max	**91.68**	**1.51**	**9.35**	**92.24**	**0.60**	**9.00**	**92.40**	**0.15**	**10.76**
Average	**90.89**	**1.35**	**8.81**	**91.34**	**0.44**	**8.40**	**91.20**	**-0.11**	**10.03**
Standard deviation	**0.48**	**0.11**	**0.35**	**0.60**	**0.11**	**0.39**	**0.60**	**0.14**	**0.48**
Color VECTOR	**Color**								
	1150°C			1200°C			1245°C		
	L	a	b	L	a	b	L	a	b
1	85.69	0.58	14.28	80.50	0.11	15.02	77.99	-0.01	14.19
2	83.99	0.40	13.59	79.14	0.17	14.72	78.66	-0.07	13.95
3	82.73	0.47	13.37	78.47	0.18	14.77	76.70	-0.09	14.22
Min	**82.73**	**0.40**	**13.37**	**78.47**	**0.11**	**14.72**	**76.70**	**-0.09**	**13.95**
Max	**85.69**	**0.58**	**14.28**	**80.50**	**0.18**	**15.02**	**78.66**	**-0.01**	**14.22**
Average	**84.14**	**0.48**	**13.75**	**79.37**	**0.15**	**14.84**	**77.78**	**-0.06**	**14.12**
Standard deviation	**1.49**	**0.09**	**0.47**	**1.03**	**0.04**	**0.16**	**1.00**	**0.04**	**0.15**

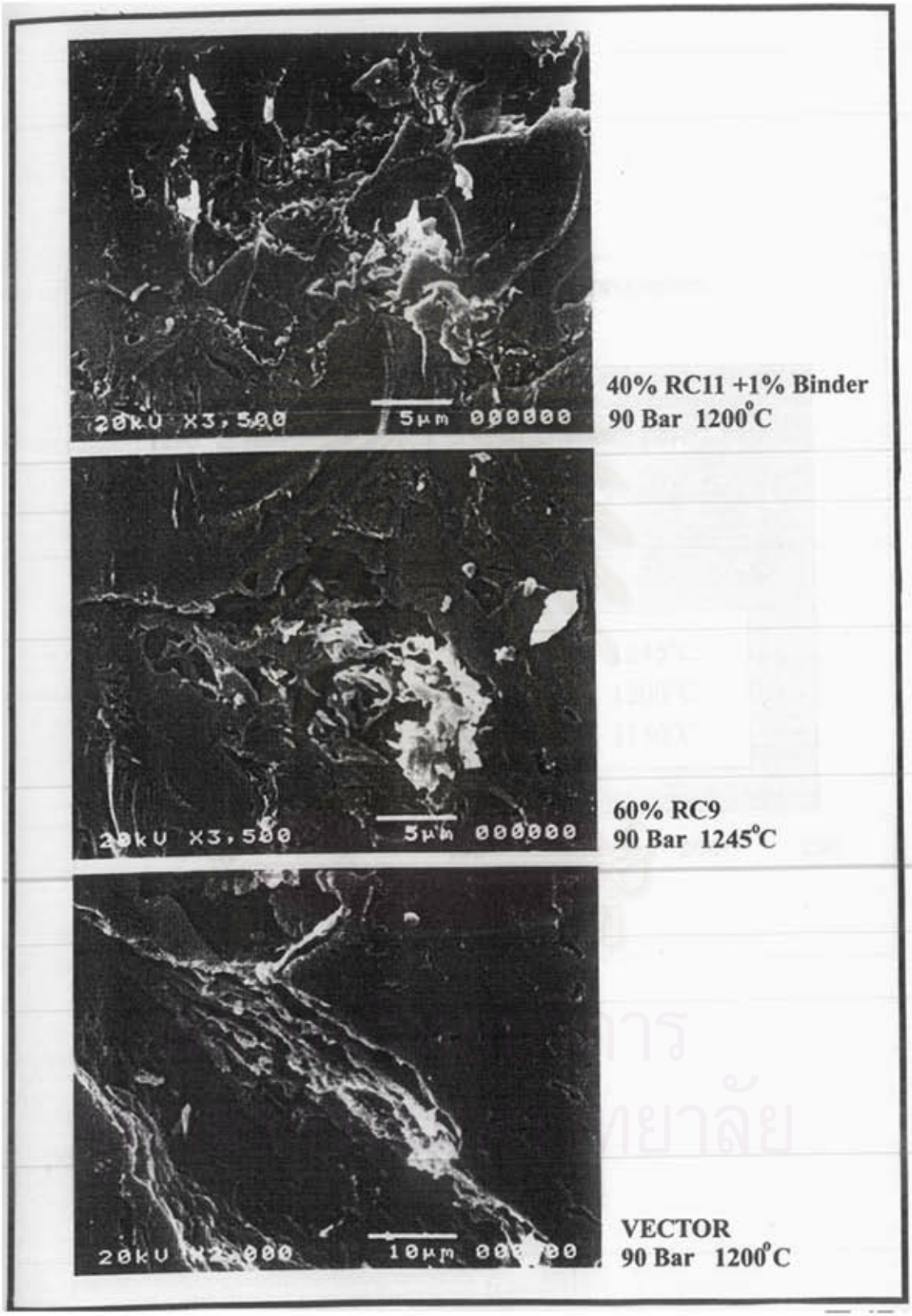
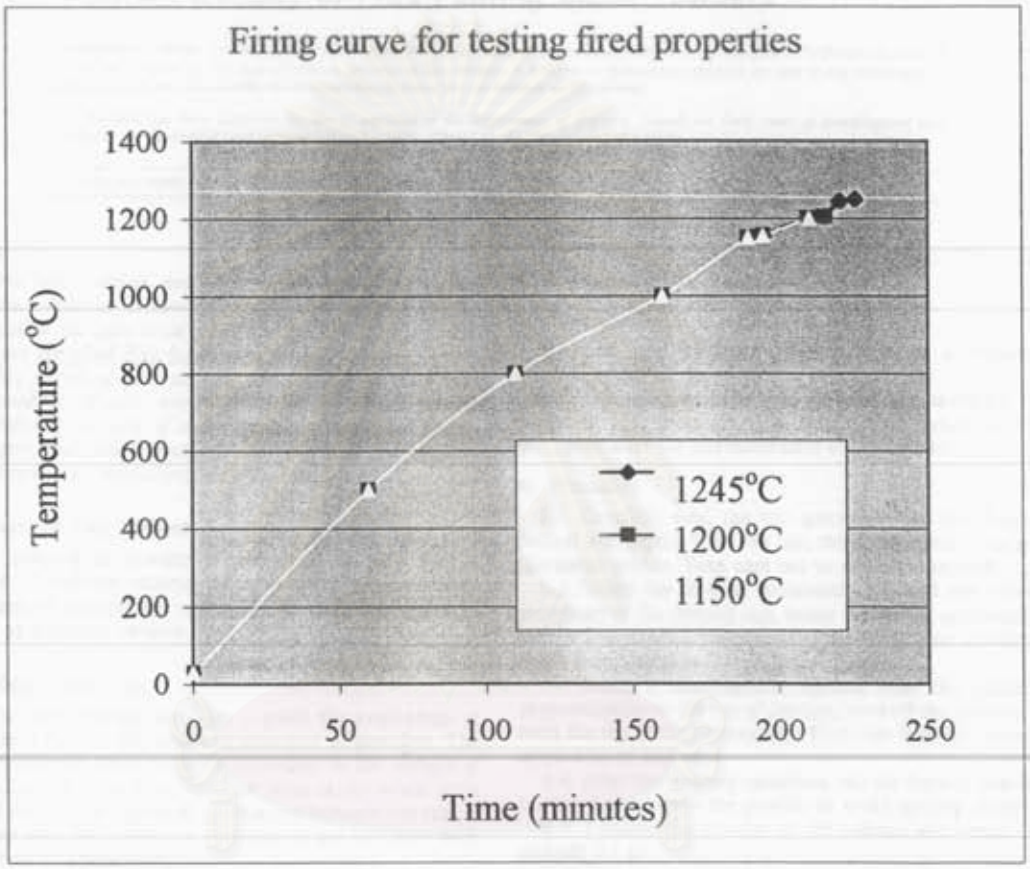


Fig. 8F Micrograph of pressed samples after firing.

APPENDIX G



APPENDIX H

ASTM standard

Designation: B 212 – 89 (Reapproved 1995)[ε1]

Standard Test Method for Apparent Density of Free-Flowing Metal Powders[1]

This standard is issued under the fixed designation B 212; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

[ε1] NOTE—Keywords were added editorially in September 1995.

1. Scope

1.1 This test method describes a procedure for determining the apparent density of free-flowing metal powders and is suitable for only those powders that will flow unaided through the specified Hall flowmeter funnel.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Summary of Test Method

2.1 A volume of powder is permitted to flow into a container of definite volume under controlled conditions. The weight of powder per unit volume is determined and reported as apparent density.

3. Significance and Use

3.1 This test method provides a guide for evaluation of the apparent density physical characteristic of powders. The density measured bears some relationship to the weight of powder that will fill a fixed volume press cavity when parts are being made. The degree of correlation between the results of this test and the quality of powders in use will vary with each particular application.

4. Apparatus

4.1 *Powder Flowmeter Funnel*[2]—A standard Hall flowmeter funnel (Fig. 1) having a calibrated orifice.

4.2 *Density Cup*[2]—A cylindrical cup (Fig. 1) having a capacity of 25 ± 0.05 cm^3.

4.3 *Stand*[2]—A stand (Fig. 1) to support the powder flowmeter concentric with the density cup so that the bottom of the powder flowmeter orifice is 1 in. (25 mm) above the top of the density cup when the apparatus is assembled as shown in Fig. 1.

4.4 *Base*—A level, vibration-free base to support the powder flowmeter.

4.5 *Balance*, having a capacity of at least 200 g and a sensitivity of 0.1 g.

5. Test Specimen

5.1 The test specimen shall consist of a volume of approximately 30 to 40 cm^3 of metal powder.

5.2 The test specimen shall be tested as sampled. Note, however, that moisture, oils, stearic acid, stearates, waxes, etc., may alter the characteristics of the powder.

6. Procedure

6.1 Carefully load the test specimen into the flowmeter funnel and permit it to run into the density cup through the discharge orifice. Take care not to move the density cup.

6.2 When the powder completely fills and overflows the periphery of the density cup, rotate the funnel approximately 90° in a horizontal plane so that the remaining powder falls away from the cup.

6.3 Using a nonmagnetic spatula with the blade held perpendicular to the top of the cup, level off the powder flush with the top of the density cup. Take care to avoid jarring the apparatus at any time.

6.4 After the leveling operation, tap the density cup lightly on the side to settle the powder to avoid spilling in transfer.

6.5 Transfer the powder to the balance and weigh to the nearest 0.1 g.

7. Calculation

7.1 Calculate the apparent density as follows:

$$\text{Apparent density, g/cm}^3 = \text{weight in grams} \times 0.04$$

8. Report

8.1 Results shall be reported as apparent density to the nearest 0.01 g/cm^3.

9. Precision and Bias

9.1 The following criteria should be used to judge acceptability of the results at the 95 % confidence level.

9.1.1 *Repeatability*—Duplicate results by the same operator should be considered suspect if they differ by more than 0.9 %.

9.1.2 *Reproducibility*—The results submitted by each of two laboratories should not be considered suspect unless they differ by more than 6.0 %.

10. Keywords

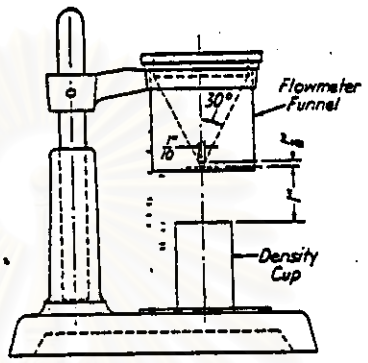
10.1 apparent density; Hall flowmeter funnel; metal powders

---

[1] This test method is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.02 on Base Metal Powders.

Current edition approved Jan. 27, 1989. Published March 1989. Originally published as B 212 – 46 T. Last previous edition B 212 – 82.

[2] The flowmeter funnel, density cup, and stand are available from Alcan Powder and Pigments, Division of Alcan Aluminum Corp., 901 Lehigh Ave., Union, NJ 07083-7632.



Metric Equivalents

in.	mm
1/10	2.5
1/8	3.2
1	25

FIG. 1 Flowmeter Apparatus

Designation: B 213 – 90

Standard Test Method for Flow Rate of Metal Powders[1]

This standard is issued under the fixed designation B 213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval. B 213

1. Scope

1.1 This test method covers the determination of the flow rate of metal powders and is suitable only for those powders which will flow unaided through the specified apparatus.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 The flow rate of a metal powder determines the rate of filling of a die cavity in the pressing of sintered metal parts or bearings. High flow rates (low flow times) are usually desired for high productivity. The test method may be part of the purchase agreement between powder manufacturer and P/M parts producers, or it may be an internal quality control test for powder blended by a parts producer. It is commonly applied to ferrous powders and copper base alloys, but may be used on other powders as well. The test is not applicable to wet or pasty mixtures of metal powders, since they will not flow through the funnel and are not commonly used in P/M processing.

3. Apparatus

3.1 *Powder Flowmeter Funnel*—A standard flowmeter funnel[2] (Fig. 1) having a calibrated orifice of 0.10 in. (2.54 mm) in diameter.

3.2 *Stand*[2]—A stand (Fig. 1) to support the powder flowmeter funnel.

3.3 *Base*—A level, vibration-free base to support the powder flowmeter.

3.4 *Stop Watch.*

3.5 *Balance*—A balance suitable for weighing accurately to 0.01 g.

4. Test Specimen

4.1 The test specimen shall be 50 g, weighed to the nearest 0.1 g.

5. Procedure

5.1 The test specimen shall be tested as sampled. It should be noted, however, that moisture, oils, stearic acid, stearates, waxes, etc., may alter the characteristics of the powder.

5.2 Carefully load the test specimen into the flowmeter funnel while keeping closed the discharge orifice at the bottom of the funnel by placing a dry finger under it. Take care that the short stem of the funnel is filled.

5.3 Start the stop watch simultaneously with removal of the finger from the discharge orifice and stop it at the instant the last of the powder leaves the funnel. Record the elapsed time in seconds.

6. Report

6.1 The elapsed time shall be multiplied by the correction factor (see Note) and the result reported in seconds to the nearest second.

NOTE —The manufacturer supplies the funnel calibrated as follows: Using the procedure described in Section 5, the flow rate of standard 150-mesh Turkish emery is determined. The average of five determinations (the extremes of which shall not differ by more than 0.4 s) is stamped on the bottom of the funnel. The correction factor of the unused funnel is 40.0 divided by this number. It is recommended that the factor be periodically verified by the user by determining, by the above method, the flow rate of the standard 150-mesh Turkish emery.[3] If the flow rate has changed from that stamped on the instrument, the new correction factor will be 40.0 divided by this new flow rate. Before adopting the new correction factor, however, it is recommended that the cause of the change be investigated. If the flow rate has increased, it is probable that repeated use has burnished the orifice and the new correction factor may be used. A decrease in flow rate may indicate a plating of soft powder upon the orifice. This should be carefully removed with the aid of a pipe cleaner and the calibration test rerun, the new correction factor being calculated if required. It is recommended that the use of a funnel be discontinued after the flow rate of the standard sample has increased such that the time of flow is less than 37 s. The manufacturer's experience indicates that, under conditions of almost continuous daily use, a decrease in time of flow of 3 s should be expected after 5 years of service.

7. Precision and Bias

7.1 The precision of this test method is presently being determined by Subcommittee B09.02.

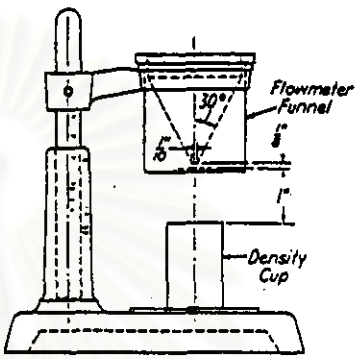
---

[1] This test method is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.02 on Base Metal Powders.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as B 213 – 46 T. Last previous edition B 213 – 83.

[2] The powder flowmeter funnel, density cup, and stand are available from Alcan Powders and Pigments, 901 Lehigh Ave., Union, NJ 07083-7632.

[3] Standardized No. 150 emery grit is no longer being sold. In those instances where the user desires to verify the correction factor and does not possess the No. 150 emery grit, the funnel may be returned to Alcan Powders and Pigments, 901 Lehigh Ave., Union, NJ 07083-7632, for re-calibration and re-certification. It is recommended that verification be done at least annually depending on frequency of use.



Metric Equivalents

in.	mm
1/10	2.54
1/8	3
1	25

FIG. 1 Flowmeter Apparatus

Designation: B 214 – 92

Standard Test Method for Sieve Analysis of Granular Metal Powders[1]

This standard is issued under the fixed designation B 214; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the determination of the dry sieve analysis of granular metal powders.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 212 Test Method for Apparent Density of Free-Flowing Metal Powders[2]

B 215 Practices for Sampling Finished Lots of Metal Powders[2]

B 243 Terminology of Powder Metallurgy[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Terminology

3.1 *Definitions*—Useful definitions of terms for metal powders and powder metallurgy are found in Terminology B 243.

4. Significance and Use

4.1 The particle size distribution of a metal powder affects its behavior in P/M processing and other applications of these materials. The test method may be part of the purchase agreement between powder manufacturer and user, or it may be an internal quality control test for either. This test method is appropriate for materials with size distributions typified by base metal powders used in powder metallurgy.

5. Apparatus

5.1 *Sieves*—A set of standard sieves selected from Table 1 of Specification E 11, or the equivalent Tyler standard sieves. The sieves shall be 8 in. (203.2 mm) in diameter and either 1 or 2 in. (25 or 50 mm) in depth and fitted with bronze, brass, stainless steel, or other suitable wire cloth. The U.S. sieves given in Table 1 of this method shall conform to Specification E 11. If Tyler standard sieves are substituted, they shall conform to the permissible variations given in Table 1 of Specification E 11.

NOTE 1—The new U.S. Series standard sieves, adopted in 1970, are the preferred sieves to use. The old U.S. Series standard sieves and equivalent sieves manufactured by other companies, such as Tyler, may also be used if the new U.S. Series is not available. Care should be taken to make sure that sieve opening sizes are correct when performing standardization work.

5.2 *Sieve Shaker*—A mechanically operated, single eccentric sieve shaker which imparts to the set of sieves a rotary motion and tapping action of uniform speed, shall be used. The number of rotations per minute shall be between 270 and 300. The number of taps per minute shall be between 140 and 160. The sieve shaker shall be fitted with a plug to receive the impact of the tapping device. The entire apparatus shall be rigidly mounted by bolting to a solid foundation, preferably of concrete. A time switch should be provided to ensure accuracy of duration of the test.

NOTE 2—Use of a sound proof enclosure is recommended.

5.3 *Balance*—A balance having a capacity of at least 100 g and a sensitivity of 0.01 g.

6. Test Specimen

6.1 The size of the test specimen shall be 100 g for any metal powder having an apparent density greater than 1.50 g/cm^3 when determined in accordance with Test Method B 212. A 50-g specimen shall be used when the apparent density of the powder is less than 1.50 g/cm^3. The test specimen should be obtained in accordance with Practices B 215.

7. Procedure

7.1 Assemble the group of sieves selected in consecutive order as to size of openings, with the coarsest sieve at the top, the assembly being completed by a solid collecting pan below the bottom sieve. Place the test specimen on the top sieve and close this sieve with a solid cover. Then fasten the sieve assembly securely in a suitable mechanical sieve shaking device and operate the machine for a period of 15 min.

7.2 Remove the screened fractions from the nest of sieves by removing the coarsest sieve from the nest, gently tapping its contents to one side and pouring them upon a glazed paper. Brush any material adhering to the bottom of the sieve and frame with a soft brush into the next finer sieve. Tap the sieve just removed upside down, on the paper containing the portion that had been retained on it. Weigh this fraction to the nearest 0.1 g and remove it from the balance. Repeat this process for each sieve in the nest and

---

[1] This test method is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products, and is the direct responsibility of Subcommittee B09.02 on Base Metal Powders.

Current edition approved Jan. 15, 1992. Published May 1992. Originally published as B 214 – 46 T. Last previous edition B 214 – 86.

[2] *Annual Book of ASTM Standards*, Vol 02.05

[3] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 U.S. Standard Series Test Sieves and Equivalent Tyler Standard Sieves

Mesh Designation Number	Sieve Opening (μm)		
	New U.S. Series	Old U.S. Series	Tyler Series
20	850	841	833
35	—	—	417
40	425	420	—
60	250	250	295
80	180	177	175
100	150	149	147
140	106	105	—
150	—	—	104
200	75	74	74
230	63	63	—
250	—	—	53
325	45	44	44

remove the fraction collected in the pan and weigh. The sum of the weights of all the fractions shall be not less than 99 % of the weight of the test specimen. Add the difference between this sum and the weight of the test specimen (100 g or 50 g in accordance with Section 6) to the weight of the fraction collected in the pan.

NOTE 3—If the sum is less than 99 %, check the condition of the screens and pan or possible errors in weighing and repeat the test.

8. Report

8.1 Express the weights of the fractions retained on each sieve, and the weight of the fraction collected in the pan, as percentages of the weight of the test specimen to the nearest 0.1 %, and report them in the form shown in Table 2. Report any fraction that is less than 0.1 % of the weight of the test specimen as "trace." If a fraction is absent, report it as "0.0".

8.2 Interpretation of this report should be made with reference to Specification E 11 in which the dimensional tolerances of standard sieves are specified.

TABLE 2 Form for Reporting Test Data

New U.S. Standard Series		
Particle Size (μm)	Mesh Designation No.	% By Weight
> 180	+ 80	...
≤ 180 > 150	− 80 + 100	...
≤ 150 > 106	− 100 + 140	...
≤ 106 > 75	− 140 + 200	...
≤ 75 > 45	− 200 + 325	...
≤ 45	− 325	...
Old U.S. Standard Series		
Particle Size (μm)	Mesh Designation No.	Percentage by Weight
> 177	+ 80	...
≤ 177 > 149	− 80 + 100	...
≤ 149 > 105	− 100 + 140	...
≤ 105 > 74	− 140 + 200	...
≤ 74 > 44	− 200 + 325	...
≤ 44	− 325	...
Tyler Standard Sieve Series		
Particle Size (μm)	Mesh Designation No	Percentage By Weight
> 175	+ 80	...
≤ 175 > 147	− 80 + 100	...
≤ 147 > 104	− 100 + 150	...
≤ 104 > 74	− 150 + 200	...
≤ 74 > 44	− 200 + 325	...
≤ 44	− 325	...

9. Precision and Bias

9.1 The precision and bias that can be expected through use of this test method is currently under review by Subcommittee B09.02 on Base Metal Powders.

APPENDIXES

(Nonmandatory Information)

X1. CERTIFIED SIEVES—MASTER SET

X1.1 Sieves conforming to Specification E 11 can be obtained from the sieve manufacturers, and arrangements can be made through them to have the sieves certified by the National Institute of Standards and Technology (formerly the National Bureau of Standards).[4] If used continually, the sieves will, after a period of time, become less accurate and might no longer be acceptable as certified sieves. The common practice which would be considered acceptable according to this standard, would be to use the certified sieves as a master set for checking other working sets of sieves. By comparing sieve tests on the same sample, run in both the master set and the working set, a factor can be established for correcting results on the working sieves.

[4] Contact the National Institute of Standards and Technology, Gaithersburg, MD 20899.

X2. MATCHED SIEVES

X2.1 The use of a matched set of sieves, established through use of a standard powder, is recommended when closer correlation of tests between supplier and consumer is desired.

X3. SIEVE SERIES GUIDELINES

X3.1 Suggested combinations of sieves are given in Table X3.1 for several nominal mesh size metal powders.

TABLE X3.1 Suggested Sieve Series for Metal Powders

Nominal Powder Mesh Size		20	40	60	100	140	200	325
New U.S. Sieve Series (Mesh Sizes)	20	✓	✓					
	40	✓	✓	✓				
	60	✓	✓	✓				
	80				✓			
	100	✓	✓	✓	✓	✓		
	140			✓	✓	✓	✓	
	200	✓	✓	✓	✓	✓	✓	✓
	230						✓	✓
	325		✓	✓	✓	✓	✓	✓
	Pan	✓	✓	✓	✓	✓	✓	✓

Designation: B 527 – 93

Standard Test Method for Determination of Tap Density of Metallic Powders and Compounds[1]

This standard is issued under the fixed designation B 527; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method specifies a method for the determination of tap density (packed density) of metallic powders and compounds, that is, the density of a powder that has been tapped, to settle contents, in a container under specified conditions.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 212 Test Method for Apparent Density of Free-Flowing Metal Powders[2]

B 215 Practice for Sampling Finished Lots of Metal Powders[2]

B 243 Terminology of Powder Metallurgy[2]

B 329 Test Method for Apparent Density of Powders of Refractory Metals and Compounds by Scott Volumeter[2]

B 417 Test Method for Apparent Density of Non-Free-Flowing Metal Powders[2]

B 703 Test Method for Apparent Density of Metal Powders Using the Arnold Meter[2]

3. Significance and Use

3.1 This test method covers the evaluation of the tapped density physical characteristic of metallic powders and compounds. The degree of correlation between the results of this test method and the quality of powders in use will vary with each particular application and has not been fully determined.

4. Apparatus

4.1 *Balance*, of appropriate capacity an accuracy to satisfy the requirements shown in Table 1.

4.2 *Graduated Glass Cylinder*[3], calibrated to contain 100 cm^3 at 20°C, the height of the graduated portion being approximately 175 mm. The graduations shall be at 1 cm^3 intervals, thus allowing a measuring accuracy of ± 0.5 cm^3. For apparent densities over 4.0 g/cm^3, do not use the 100 cm^3 cylinder.

TABLE 1 Accuracy and Capacity of Balance

Cylinder Capacity, cm^3	Apparent Density, g/cm^3	Mass of Test Portion, g
100	>1	100 ± 0.5
100	<1	50 ± 0.2
25	>7	100 ± 0.5
25	2 to 7	50 ± 0.2
25	<2	20 ± 0.1

4.2.1 Alternatively, the following may be used:

4.2.1.1 *Graduated Glass Cylinder*, calibrated to contain 25 cm^3 at 20°C, the height of the graduated portion being approximately 135 mm. The graduations shall be at 0.2 cm^3 intervals.

4.2.1.2 A 25-cm^3 cylinder shall be used for powders of apparent density higher than 4 g/cm^3, in particular for refractory metal powders, but may also be used for powder of lower apparent density.

4.3 *Tapping Apparatus*,[4] which permits the tapping of the graduated cylinder against a firm base. The tapping shall be such that a densification of the powder can take place without any loosening of its surface layers. The stroke shall be 3 mm (0.118 in.) and the tapping frequency shall be between 100 and 300 taps/min. An example of a tapping apparatus is shown in Fig. 1.

5. Test Specimen

5.1 For the quantities of powder required for each test, see Table 1. Obtain test powder samples according to Practices B 215.

5.2 In general, the powder should be tested in the as-received condition. In certain instances the powder may be dried. However, if the powder is susceptible to oxidation, the drying shall take place in a vacuum or in inert gas. If the powder contains volatile substances, it shall not be dried.

5.3 The test shall be carried out on three test samples.

6. Procedure

6.1 Clean the inside the wall of the graduated cylinder (5.2) with a suitable clean brush or, if necessary, by rinsing with a solvent, such as acetone. If a solvent is used, thoroughly dry the cylinder before reuse.

---

[1] This specification is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.03 on Refractory Metal Powders.

Current edition approved Dec. 15, 1993. Published April 1994. Originally published as B 527 – 70. Last previous edition B 527 – 85 (1991)[ε1].

[2] *Annual Book of ASTM Standards*, Vol 02.05.

[3] Corning No. 3046, Pyrex brand has been found suitable.

[4] The following have been found suitable: Shandon Southern Instruments, Inc., Tap-Pak Volumeter Model JEL-ST2 (Manufactured by J. Engelsmann A.G. or Ludwigshafen 9, Rh., West Germany), 515 Broad Street, Sewickly, PA 15143; Vankel Industries, Vanderkamp Tap Density Tester, 36 Meridian Road, Edison, NJ 08820; Quantachrome Corp., Dual Autotap, 6 Aerial Way, Syosset, NY 11791.

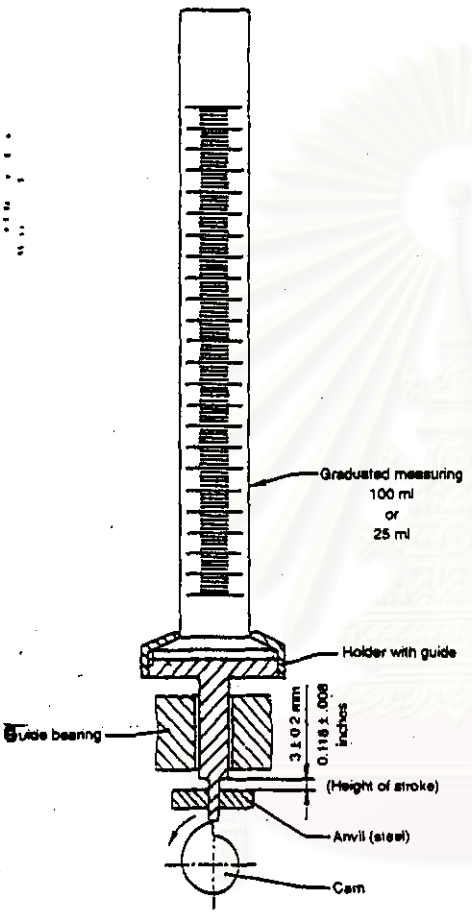


FIG. 1 Example of Tapping Apparatus

6.2 Weigh, to the nearest 0.1 g, the mass of the test portion as indicated in Table 1, using a balance (4.1).

6.3 Pour the test portion into the graduated cylinder. Take care that a level surface of the powder is formed. Place the cylinder in the tapping apparatus (4.3). Tap the cylinder until no further decrease in the volume of the powder takes place (see Note 1).

NOTE 1—In practice, the minimum number of taps, N, such that no further change in volume takes place would be determined. For all further tests on the same type of powder, the cylinder would be subjected to $2N$ taps, except where general experience and acceptance have established a specific number of taps (no less than N taps) as being satisfactory. For fine refractory metal powders, 3000 taps has been found to be satisfactory for all sizes.

6.4 If the tapped surface is level, read the volume directly. If the tapped surface is not level, determine the tape volume by calculating the mean value between the highest and the lowest reading of the tapped surface. Read the final volume to the nearest 0.5 cm^3 when using a 100 cm^3 cylinder and to the nearest 0.2 cm^3 when using a 25 cm^3 cylinder.

7. Calculation

7.1 The tap density is given in the following equation

$$Pt = \frac{M}{V}$$

where:
Pt = tap density, g/cm^3,
M = mass of powder, g, and
V = volume of tapped powder, cm^3.

8. Report

8.1 Report the following information:

8.1.1 Reference to this test method,

8.1.2 All details necessary for identification of the test sample,

8.1.3 The drying procedure, if the powder has been dried,

8.1.4 Cylinder capacity, mass of test portion and method used,

8.1.5 The result obtained,

8.1.6 All operations not specified in this test method or regarded as optional,

8.1.7 Details of any occurrence that may have affected the result.

9. Precision and Bias

9.1 Precision and bias cannot be stated at this time because this test method covers a broad range of powders and associated densities.

10. Keywords

10.1 apparent density; bulk density; density; density ratio; metal powders; packed density; powder metallurgy; tap density

Designation: C 373 – 88 (Reapproved 1994)

Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products[1]

This standard is issued under the fixed designation C 373; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining water absorption, bulk density, apparent porosity, and apparent specific gravity of fired unglazed whiteware products.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Measurement of density, porosity, and specific gravity is a tool for determining the degree of maturation of a ceramic body, or for determining structural properties that may be required for a given application.

3. Apparatus and Materials

3.1 *Balance*, of adequate capacity, suitable to weigh accurately to 0.01 g.

3.2 *Oven*, capable of maintaining a temperature of 150 ± 5°C (302 ± 9°F).

3.3 *Wire Loop, Halter, or Basket*, capable of supporting specimens under water for making suspended mass measurements.

3.4 *Container*—A glass beaker or similar container of such size and shape that the sample, when suspended from the balance by the wire loop, specified in 3.3, is completely immersed in water with the sample and the wire loop being completely free of contact with any part of the container.

3.5 *Pan*, in which the specimens may be boiled.

3.6 *Distilled Water*.

4. Test Specimens

4.1 At least five representative test specimens shall be selected. The specimens shall be unglazed and shall have as much of the surface freshly fractured as is practical. Sharp edges or corners shall be removed. The specimens shall contain no cracks. The individual test specimens shall weigh at least 50 g.

5. Procedure

5.1 Dry the test specimens to constant mass (Note) by heating in an oven at 150°C (302°F), followed by cooling in a desiccator. Determine the dry mass, D, to the nearest 0.01 g.

NOTE—The drying of the specimens to constant mass and the determination of their masses may be done either before or after the specimens have been impregnated with water. Usually the dry mass is determined before impregnation. However, if the specimens are friable or evidence indicates that particles have broken loose during the impregnation, the specimens shall be dried and weighed after the suspended mass and the saturated mass have been determined, in accordance with 5.3 and 5.4 In this case, the second dry mass shall be used in all appropriate calculations.

5.2 Place the specimens in a pan of distilled water and boil for 5 h, taking care that the specimens are covered with water at all times. Use setter pins or some similar device to separate the specimens from the bottom and sides of the pan and from each other. After the 5-h boil, allow the specimens to soak for an additional 24 h.

5.3 After impregnation of the test specimens, determine to the nearest 0.01 g the mass, S, of each specimen while suspended in water. Perform the weighing by placing the specimen in a wire loop, halter, or basket that is suspended from one arm of the balance. Before actually weighing, counterbalance the scale with the loop, halter, or basket in place and immerse in water to the same depth as is used when the specimens are in place. If it is desired to determine only the percentage of water absorption, omit the suspended mass operation.

5.4 After the determination of the suspended mass or after impregnation, if the suspended mass is not determined, blot each specimen lightly with a moistened, lint-free linen or cotton cloth to remove all excess water from the surface, and determine the saturated mass, M, to the nearest 0.01 g. Perform the blotting operation by rolling the specimen lightly on the wet cloth, which shall previously have been saturated with water and then pressed only enough to remove such water as will drip from the cloth. Excessive blotting will introduce error by withdrawing water from the pores of the specimen. Make the weighing immediately after blotting, the whole operation being completed as quickly as possible to minimize errors due to evaporation of water from the specimen.

6. Calculation

6.1 In the following calculations, the assumption is made that 1 cm^3 of water weighs 1 g. This is true within about 3 parts in 1000 for water at room temperature.

6.1.1 Calculate the exterior volume, V, in cubic centimetres, as follows:

$$V = M - S$$

[1] This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.03 on Fundamental Properties.

Current edition approved Sept. 30, 1988. Published November 1988. Originally published as C 373 – 55 T. Last previous edition C 373 – 72 (1982).

6.1.2 Calculate the volumes of open pores V_{OP} and impervious portions V_{IP} in cubic centimetres as follows:

$$V_{OP} = M - D$$

$$V_{IP} = D - S$$

6.1.3 The apparent porosity, P, expresses, as a percent, the relationship of the volume of the open pores of the specimen to its exterior volume. Calculate the apparent porosity as follows:

$$P = [(M - D)/V] \times 100$$

6.1.4 The water absorption, A, expresses as a percent, the relationship of the mass of water absorbed to the mass of the dry specimen. Calculate the water absorption as follows:

$$A = [(M - D)/D] \times 100$$

6.1.5 Calculate the apparent specific gravity, T, of that portion of the test specimen that is impervious to water, as follows:

$$T = D/(D - S)$$

6.1.6 The bulk density, B, in grams per cubic centimetre, of a specimen is the quotient of its dry mass divided by the exterior volume, including pores. Calculate the bulk density as follows:

$$B = D/V$$

7. Report

7.1 For each property, report the average of the values obtained with at least five specimens, and also the individual values. Where there are pronounced differences among the individual values, test another lot of five specimens and, in addition to individual values, report the average of all ten determinations.

8. Precision and Bias

8.1 This test method is accurate to ±0.2 % water absorption in interlaboratory testing when the average value recorded by all laboratories is assumed to be the true water absorption. The precision is approximately ± 0.1 % water absorption on measurements made by a single experienced operator.

BIOGRAPHY

Thanapun Jirasupanun was born on January 6, 1969 in Bangkok. She received a bachelor degree in materials science from Chulalongkorn university in 1991. She has worked at Compound Clay Co.,Ltd. since May 1991. She enrolled for her master study in June 1997 and completed the program in October 1999.