

REFERENCES

- [1] Bussaraporn Patarachao. Conversion of Zinc Hydrometallurgical Waste to Glass-Ceramic Materials. Master's Thesis, Ceramic Technology, Faculty of Science, Chulalongkorn University, 2004.
- [2] Laksana Kreethawate. Development of Tiles and Ceramic Glaze from Hydrometallurgical Zinc Waste. Master's Thesis, Ceramic Technology, Faculty of Science, Chulalongkorn University, 2005.
- [3] Kingery, W. D. Introduction to Ceramics. 2nd ed. New York: Wiley-Interscience Publication, 1976.
- [4] Rawlings, R. D.; Wu, J. P.; and Boccaccini, A. R. Glass-ceramics: Their production from wastes-A review. Journal of Materials Science 41 (2006): 733-716.
- [5] Barsoum, M. W. Fundamentals of Ceramics. Singapore: McGraw-Hill, 1997.
- [6] Pelino, M. Recycling of zinc-hydrometallurgy wastes in glass and glass ceramic materials. Waste Management 20 (2000): 561-568.
- [7] Montanaro, L.; Bianchini, N.; Rincon, J. M.; and Romero, M. Sintering behaviour of pressed red mud wastes from zinc hydrometallurgy. Ceramics International 27 (2001): 29-37.
- [8] Boccaccini, A. R.; Schawohl, J.; Kern, H.; Schunck, B.; Rincon, J. M.; and Romero, M. Sintered glass ceramics from municipal incinerator fly ash. Glass Technology 41, 3 (June 2000): 99-105.
- [9] Romero, M.; Rincon, J., Ma.; Rawlings, R. D.; and Boccaccini, A. R. Use of vitrified urban incinerator waste as raw material for production of sintered glass-ceramics. Materials Research Bulletin 36 (2001): 383-395.

- [10] Barbieri, L.; Corradi, A.; and Lancellotti, I. Thermal and chemical behaviour of different glasses containing steel fly ash and their transformation into glass-ceramics. Journal of the European Ceramic Society 22 (2002): 1759-1765.
- [11] Cheng, T. W.; and Chen, Y. S. Characterisation of glass ceramics made from incinerator fly ash. Ceramics International 30 (2004): 343-349.
- [12] Folgueras, M. V.; De Oliveira, P. N.; and Alarcon, O. E. Glass-ceramics obtained from processed slag and fly ash. American Ceramic Society Bulletin (November 2005): 9201-9205.
- [13] Tang, S.; Liang, Z.; and Chen, G. Crystallisation heat treatment of an antimony containing slag glass ceramic. Glass Technology 36, No. 2 (1995): 61-64.
- [14] Gomes, V.; De Borba, C., D. G.; and Riella, H. G. Production and characterization of glass ceramics from steelwork slag. Journal of Materials Science 37 (2002): 2581-2585.
- [15] Wu, J. W.; Rawlings, R. D.; and Boccaccini, A. R. Waste not, want not-an inexpensive glass-ceramic from waste. American Ceramic Society Bulletin 85, 5 (May 2006): 29-34.
- [16] Francis, A. A.; Rawlings, R. D.; and Boccaccini, A. R. Glass-ceramics from mixtures of coal ash and soda-lime glass by the petruergic method. Journal of Materials Science Letters 21 (2002): 975-980.
- [17] Francis, A. A.; Rawlings, R. D.; Sweeney, R.; and Boccaccini, A. R. Crystallization kinetic of glass particles prepared from a mixture of coal ash and soda-lime cullet glass. Journal of Non-Crystalline Solids 333 (2004): 187-193.
- [18] Yoon, S. O.; and Yun, Y. H. An advanced technique for recycling fly ash and waste glass. Journal of Materials Processing Technology 168 (2005): 56-61.
- [19] Yoon, S. O.; and Yun, Y. H. Waste glass and fly ash derived glass-ceramics. Journal of Materials Science 41 (2006): 4315-4319.

- [20] Mangutova, M.; Angjuševa, B.; Miloševski, D.; Fidancevska, E.; Bossert, J.; and Miloševski, M. Utilisation of fly ash and waste glass in production of glass-ceramics composites. Bulletin of the Chemists and Technologists of Macedonia 23 (2004): 157-162.
- [21] ASTM C 373-88. Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products. ASTM International. 1999.
- [22] ASTM C1161-02C. Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature. ASTM International. (n.d.).
- [23] ASTM C1327-99. Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics. ASTM International. (n.d.).
- [24] Toxic characteristic leaching procedure Method 1311 [online]. Available from: http://ehso.com/cssepa/TCLP_from%20EHSOcom_Method_1311.pdf, 1 September, 2006.
- [25] Donald, S. B.; Swink, A. M.; and Schreiber, H. D. High-Iron Ferric Glass. Journal of Non-Crystalline Solids 352 (2006): 539-543.
- [26] Rahaman, M. N. Ceramic Processing and Sintering. New York: Marcel Dekker, Inc, 2003.
- [27] Pascoal, H. B.; Pontuschka, W. M.; and Rechenberg, H. Investigation of Fe⁺³ and Fe⁺² properties in calciumaluminoborate glasses. Applied Physics A Materials Science & Processing 70 (2000): 211-214.
- [28] ASTM E 1356 – 03. Standard Practices for Measurement of Liquidus Temperature of Glass by the Gradient Furnace. ASTM International. 2000.
- [29] Perkin Elmer, Inc. Thermal Analysis: Pyris Software Version 7.0.0.0110. [Computer software]. USA: Perkin Elmer, 2004.

- [30] Bruker Axs GmbH. Diffraclus EVA (version 7). [Computer software]. Germany: Bruker Axs, 2002.
- [31] Fabries, J.; Ferguson, A. K.; Ginzburg, I. V.; Ross, M.; and Seifert, F. A. Nomenclature of pyroxenes. American Mineralogist 73 (1988): 1123-1133.
- [32] Michael, A. C.; and Donald, R. P. Chemistry and structure of esseneite ($\text{CaFe}^{3+}\text{AlSiO}_6$), a new pyroxene produced by pyrometamorphism. American Mineralogist 72 (1987): 148-156.
- [33] Alizadeh, P.; and Marghussian, V. K. Study of bulk crystallization in $\text{MgO-CaO-SiO}_2\text{-Na}_2\text{O}$ glasses in the presence of CaF_2 and MoO_3 nucleant. Journal of Materials Science 38 (2003): 1529-1534.
- [34] Tomohiro, T.; Yoshikazu, K.; Atsuo, Y.; and Kiyoshi O. Preparation and properties of glass-ceramics from wastes (Kira) of silica sand and kaolin clay refining. Journal of the European Ceramic Society 24 (2004): 2367-2372.
- [35] Apirat Theerapapvisetpong. Comparison of Liquidus Temperature of E-glass by Uniform Temperature Method and Heating Stage Microscope. Master's Thesis, Ceramic Technology, Faculty of Science, Chulalongkorn University, 2005.
- [35] Appendino, P.; Ferraris, M.; Matekovits, I.; and Salvo, M. Production of glass-ceramic bodies from the bottom ashes of municipal solid waste incinerators. Journal of the European Ceramic Society 24 (2004): 803-810.
- [37] Calculator for Conversion between Vickers Hardness Number and SI Units MPa and GPa [online]. Available from:
<http://gordonengland.co.uk/hardness/hvconv.htm>, 1 October 2006.
- [38] Mohs-Vickers hardness conversion [online]. Available from:
<http://www.grantadesign.com/resources/materials/hardnesscharts.htm>,
1 October 2006.

- [39] ASTM C 650-97. Standard Test Method for Resistance of Ceramic Tile to Chemical Substances. ASTM International. (n.d.).
- [40] Hazardous Waste Fact Sheet: TCLP: Toxicity Characteristic Leaching Procedure and Characteristic Hazardous Wastes [online]. Available from: <http://ehso.com/cssepa/TCLP%20fact%20sheet%20from%20EHSO.pdf>, 1 September, 2006.
- [41] Bernardo, E.; Castellan, R.; and Hreglich, S. Sintered glass-ceramics from mixtures of wastes. Ceramics International (2005): in press.
- [42] Hong, K. J.; Kim, J. M.; and Kim, H. S. Microstructure and properties of CaO-ZrO₂-SiO₂ glass-ceramics prepared by sintering. Journal of the European Ceramic Society 23 (2003): 2193-2202.
- [43] Cheng, T. W. Effect of additional materials on the properties of glass-ceramics produced from incinerator fly ashes. Chemosphere 56 (2004): 127-131.
- [44] Tanaka, M.; Suzuki, S.; Imai, T.; and Kaneko, T. Glass-ceramics for construction materials synthesized from municipal incinerator residue. Journal of Ceramic Society of Japan 113, 9 (2005): 573-578.

APPENDICES

APPENDIX A

Table A-1 Apparent porosity of glass-ceramics made from coarse powders

Zn-waste (wt%)	Apparent porosity (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	1.14	0.09	1.06	0.12	0.85	0.08
20	8.42	3.53	7.65	0.90	3.95	0.37
30	37.22	0.24	32.53	0.93	3.55	1.08
40	39.11	4.02	36.16	0.30	9.23	0.74
50	39.41	0.20	39.36	0.59	3.07	1.28
60	42.44	1.36	40.45	0.64	3.18	0.22
70	41.65	1.05	38.52	0.37	3.68	0.26
80	39.96	0.64	23.29	0.68	3.66	0.28
90	36.26	0.39	18.77	1.31	4.72	0.36

Table A-2 Water absorption of glass-ceramics made from coarse powders

Zn-waste (wt%)	Water absorption (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	0.51	0.04	0.47	0.05	0.38	0.04
20	4.30	1.83	4.09	0.48	2.07	0.20
30	22.21	0.21	18.28	0.70	1.70	0.52
40	24.10	3.08	21.03	0.26	4.23	0.35
50	23.64	0.17	23.70	0.59	1.34	0.55
60	26.20	1.11	24.21	0.65	1.41	0.10
70	25.08	1.08	22.12	0.35	1.64	0.12
80	22.70	0.58	10.43	0.37	1.72	0.13
90	19.04	0.30	7.90	0.61	2.22	0.17

Table A-3 Bulk density of glass-ceramics made from coarse powders

Zn-waste (wt%)	Bulk density (g/cm ³)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	2.23	0.01	2.24	0.01	2.24	0.01
20	1.97	0.04	1.90	0.01	1.91	0.01
30	1.68	0.01	1.78	0.02	2.08	0.01
40	1.63	0.04	1.72	0.01	2.18	0.01
50	1.67	0.01	1.66	0.02	2.28	0.01
60	1.62	0.02	1.67	0.02	2.25	0.01
70	1.66	0.03	1.74	0.01	2.24	0.01
80	1.76	0.02	2.23	0.02	2.13	0.01
90	1.90	0.01	2.38	0.02	2.13	0.01

Table A-4 Volume shrinkage of glass-ceramics made from coarse powders

Zn-waste (wt%)	Volume shrinkage (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	14.83	1.00	19.80	2.36	3.15	2.38
20	7.65	0.83	6.45	0.94	-8.86	1.81
30	6.47	1.23	10.81	1.47	19.24	1.63
40	5.18	1.29	7.49	0.41	19.29	1.19
50	4.72	0.97	8.16	1.74	25.80	1.05
60	3.81	0.04	10.34	1.27	29.66	1.18
70	4.49	0.86	10.54	2.06	28.76	0.53
80	7.52	1.01	24.61	1.01	21.87	0.98
90	11.64	1.17	29.84	1.14	19.77	0.80

Table A-5 Bending strength of glass-ceramics made from coarse powders sintered at 1100°C 2 h

Zn-waste (wt %)	Bending strength (MPa)	
	Mean	STDEV
10	17.93	1.70
20	9.29	1.39
30	18.27	1.90
40	17.92	2.12
50	29.71	2.48
60	28.34	0.92
70	26.42	1.67
80	19.11	1.68
90	16.10	0.99

APPENDIX B

Table B-1 Apparent porosity of glass-ceramics made from fine powders

Zn-waste (wt%)	Apparent porosity (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	2.36	0.84	2.17	1.78	0.53	0.48
20	0.67	0.13	0.60	0.11	1.10	0.13
30	11.30	0.88	5.92	1.27	2.85	0.23
40	29.28	0.34	20.27	1.81	18.75	0.52
50	23.03	0.17	22.27	0.36	23.88	3.86
60	26.58	1.06	23.78	0.39	20.16	0.24
70	29.27	0.48	24.89	0.44	17.80	1.10
80	29.35	0.38	21.75	0.26	11.63	0.22
90	33.02	0.19	19.62	0.73	3.78	0.17

Table B-2 Water absorption of glass-ceramics made from fine powders

Zn-waste (wt%)	Water absorption (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	1.14	0.41	1.10	0.10	0.27	0.24
20	0.30	0.06	0.29	0.05	0.57	0.07
30	5.11	0.42	2.73	0.57	1.50	0.13
40	15.29	0.24	10.00	0.92	9.82	0.30
50	11.09	0.09	10.98	0.21	12.52	2.75
60	13.22	0.70	11.70	0.25	9.65	0.13
70	14.90	0.33	12.11	0.27	8.53	0.63
80	14.62	0.12	9.86	0.14	5.32	0.12
90	16.54	0.13	8.31	0.38	1.61	0.08

Table B-3 Bulk density of glass-ceramics made from fine powders

Zn-waste (wt%)	Bulk density (g/cm ³)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	2.07	0.03	2.00	0.03	2.01	0.01
20	2.24	0.01	2.10	0.01	1.94	0.01
30	2.21	0.01	2.17	0.01	1.90	0.02
40	1.92	0.01	2.03	0.03	1.91	0.01
50	2.08	0.01	2.03	0.01	1.92	0.10
60	2.01	0.02	2.03	0.01	2.09	0.01
70	1.97	0.01	2.05	0.01	2.09	0.02
80	2.01	0.02	2.21	0.01	2.19	0.01
90	2.00	0.01	2.36	0.02	2.35	0.01

Table B-4 Volume shrinkage of glass-ceramics made from fine powders

Zn-waste (wt%)	Volume shrinkage (%)					
	1000°C 2 h		1050°C 2 h		1100°C 2 h	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
10	9.13	1.13	3.53	2.34	4.51	3.51
20	21.76	0.78	13.95	1.11	-3.70	3.61
30	23.60	1.64	25.49	1.89	10.40	2.54
40	13.87	0.87	22.06	1.43	14.24	0.82
50	20.16	0.68	23.12	0.77	12.40	7.76
60	15.22	0.49	17.77	0.88	24.85	2.31
70	9.97	1.35	13.70	1.02	17.59	1.25
80	10.79	1.01	17.59	1.47	22.26	0.00
90	9.51	0.78	20.96	2.07	20.63	1.52

APPENDIX C

Table C-1 Pore inside of glass-ceramics made from coarse powders

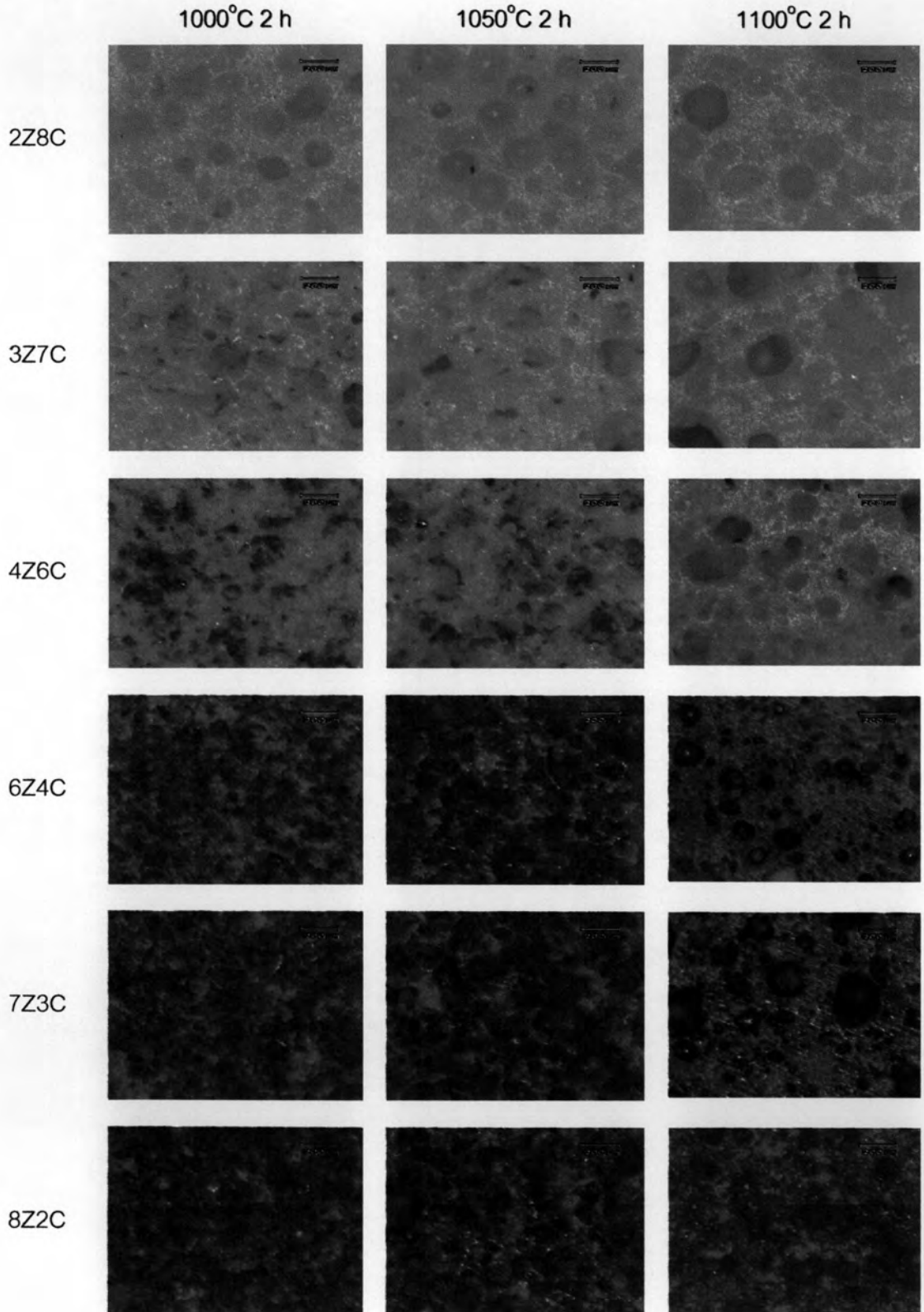
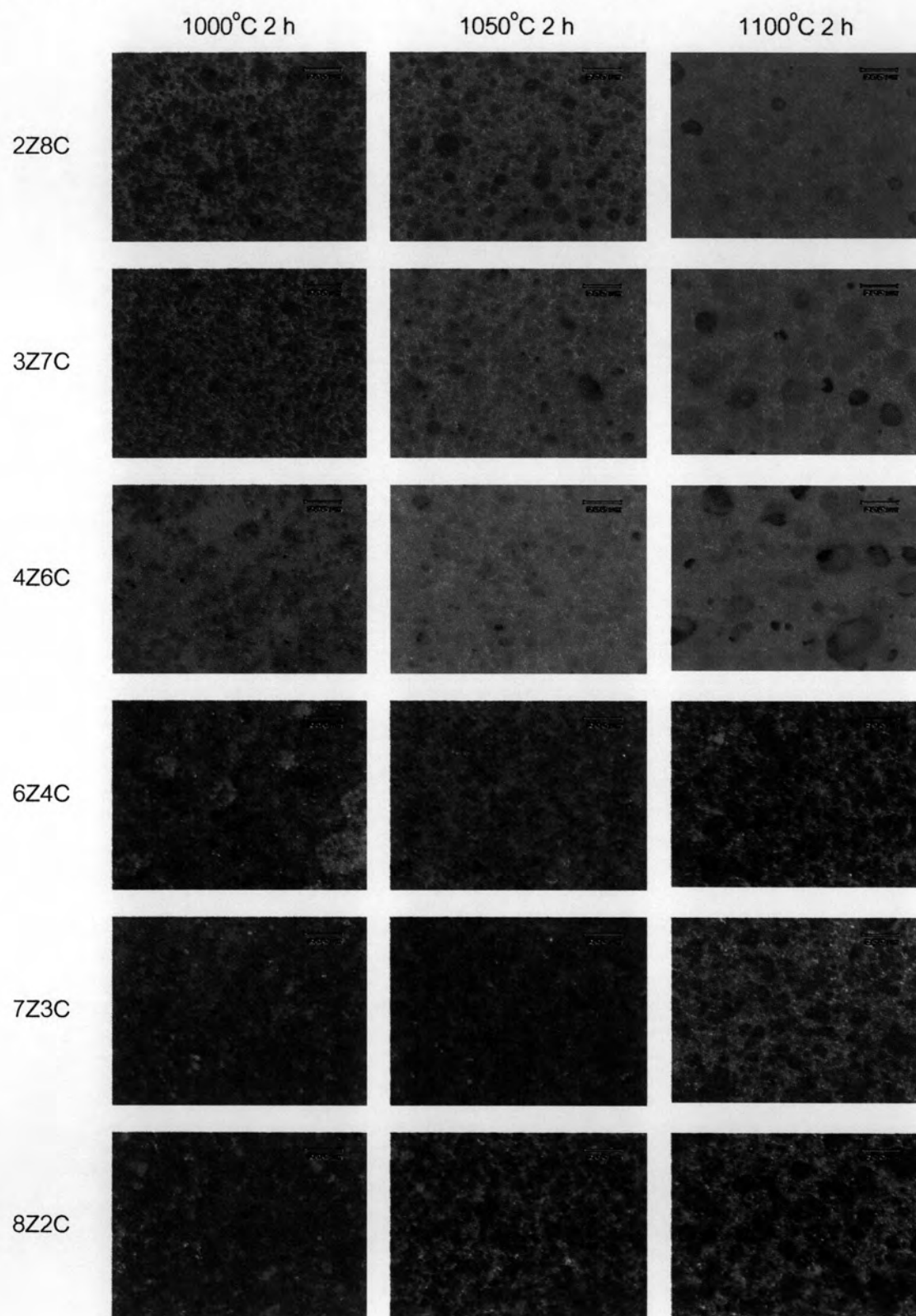


Table C-2 Pore inside of glass-ceramics made from fine powders



APPENDIX D

Table D-1 Apparent porosity of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Apparent porosity (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	0.20	0.08	0.14	0.07
2Z8C	0.52	0.03	0.36	0.09
4Z6C	0.23	0.04	0.42	0.04
6Z4C	0.20	0.03	0.24	0.03
100A	0.18	0.04	0.29	0.01
2Z4A	0.31	0.05	0.40	0.07
4Z6A	0.17	0.02	0.24	0.04
6Z4A	0.21	0.04	0.23	0.15

Table D-2 Water absorption of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Water absorption (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	0.08	0.03	0.06	0.03
2Z8C	0.21	0.01	0.14	0.03
4Z6C	0.09	0.02	0.16	0.01
6Z4C	0.07	0.01	0.08	0.01
100A	0.07	0.02	0.12	0.01
2Z4A	0.12	0.02	0.16	0.03
4Z6A	0.07	0.01	0.09	0.02
6Z4A	0.08	0.01	0.09	0.05

Table D-3 Bulk density of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Bulk density (g/cm ³)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	2.49	0.001	2.45	0.002
2Z8C	2.52	0.003	2.55	0.002
4Z6C	2.60	0.001	2.67	0.002
6Z4C	2.70	0.004	2.83	0.010
100A	2.49	0.010	2.41	0.001
2Z4A	2.52	0.001	2.48	0.001
4Z6A	2.59	0.010	2.60	0.002
6Z4A	2.67	0.002	2.72	0.010

Table D-4 Linear shrinkage of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Linear shrinkage (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	11.30	0.07	10.63	0.07
2Z8C	11.90	0.19	11.27	0.09
4Z6C	11.93	0.09	11.83	0.17
6Z4C	11.60	0.09	12.30	0.27
100A	11.17	0.12	10.47	0.07
2Z4A	12.10	0.09	11.60	0.15
4Z6A	11.90	0.19	11.60	0.15
6Z4A	11.90	0.19	12.30	0.18

Table D-5 Volume shrinkage of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Volume shrinkage (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	24.71	0.95	16.11	0.44
2Z8C	28.71	0.63	22.36	0.54
4Z6C	29.84	0.47	30.76	1.75
6Z4C	29.12	0.96	30.92	1.52
100A	24.18	0.17	19.59	1.39
2Z4A	28.67	0.92	24.95	0.96
4Z6A	29.62	0.11	26.09	0.54
6Z4A	21.59	0.17	31.48	0.87


APPENDIX E

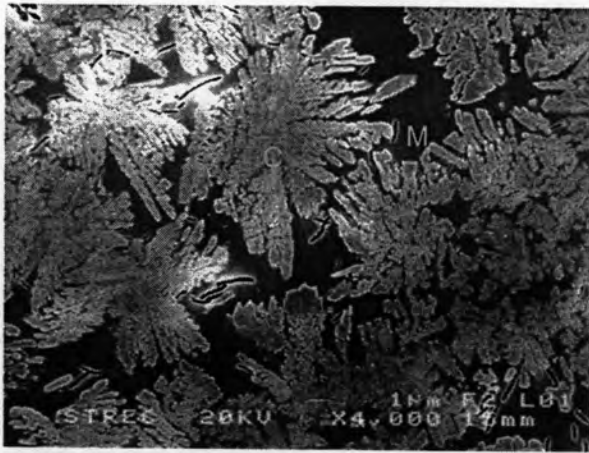
Table E-1 Chemical compositions of glass-ceramics obtained by melting and sintering process

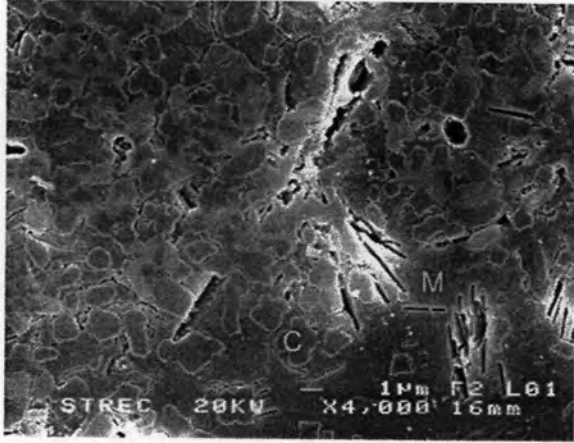
Oxides	2Z8C	4Z6C	6Z4C	2Z8A	4Z6A	6Z4A
SiO ₂	61.78	52.92	44.07	61.07	52.39	43.72
Na ₂ O	12.18	9.14	6.09	9.98	7.48	4.99
K ₂ O	0.39	0.50	0.60	0.24	0.38	0.53
CaO	7.53	8.09	8.66	10.57	10.38	10.18
MgO	3.62	2.93	2.23	2.61	2.17	1.72
ZnO	1.57	3.13	4.70	1.57	3.14	4.70
Al ₂ O ₃	2.14	2.66	3.18	2.48	2.91	3.35
Fe ₂ O ₃	1.39	2.70	4.00	1.58	2.84	4.10
P ₂ O ₅	0.04	0.06	0.07	0.05	0.06	0.08
SO ₃	5.35	10.60	15.86	5.27	10.55	15.82
TiO ₂	0.09	0.11	0.13	0.14	0.15	0.15
MnO	0.13	0.24	0.34	0.11	0.22	0.34
CuO	0.04	0.07	0.11	0.04	0.07	0.11
As ₂ O ₃	0.01	0.02	0.04	0.01	0.02	0.04
CdO	0.01	0.02	0.04	0.01	0.02	0.04
PbO	0.17	0.35	0.52	0.17	0.35	0.52
SnO ₂	0.52	0.39	0.26	0	0	0

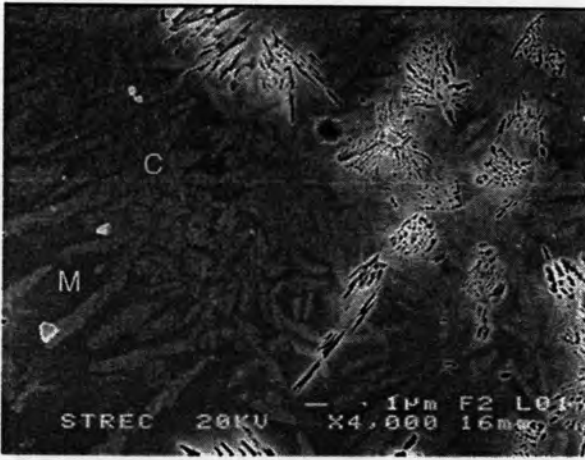
APPENDIX F

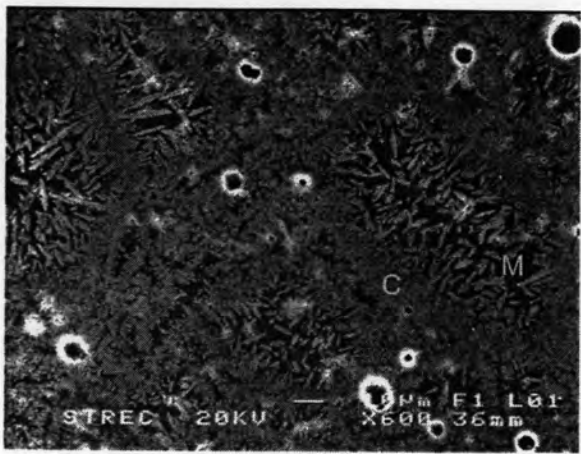
Element analysis from EDS

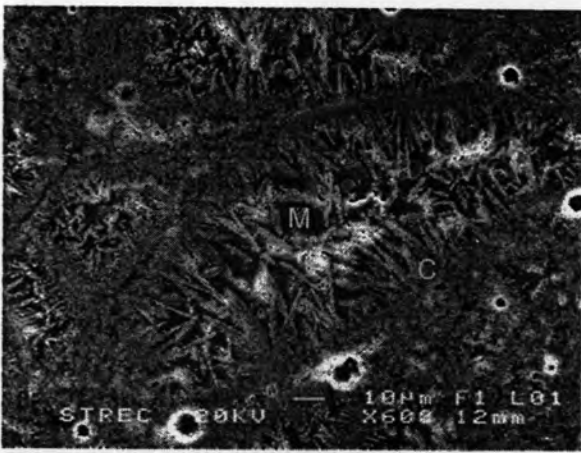
 <p>2Z8C 850°C 2 h</p>	%Oxide	Matrix (M)	Crystal (C)
	C	14.01	12.91
O	33.74	37.35	
Na	7.86	1.62	
Mg	.94	3.81	
Al	1.01	0.74	
Si	33.48	32.43	
K	0.42	0.13	
Ca	4.35	8.22	
Mn	0.1	0.1	
Fe	0.94	1.28	
Zn	3.15	1.42	

 <p>6Z4C 850°C 2 h</p>	%Oxide	Matrix (M)	Crystal (C)
	C	18.36	14.91
O	29.08	31.64	
Na	5.85	3.14	
Mg	0	3.54	
Al	1.48	1.01	
Si	27.86	25.09	
K	0.53	0.18	
Ca	3.62	9.52	
Mn	0.27	0.44	
Fe	2.49	3.79	
Zn	10.45	6.74	

 <p>—1 μm</p> <p>2Z8A 850°C 2 h</p>	%Oxide	Matrix (M)	Crystal (C)
	C	12.62	11.37
O	39.2	42.2	
Na	7.46	2.76	
Mg	1.15	1.85	
Al	0.89	0.97	
Si	30.91	30.57	
K	0.23	0.08	
Ca	2.63	7.26	
Mn	0.22	0.09	
Fe	0.95	1.31	
Zn	3.01	1.55	

 <p>—1 μm</p> <p>6Z4A 850°C 2 h</p>	%Oxide	Matrix (M)	Crystal (C)
	C	16.34	16.96
O	33.64	32.00	
Na	5.21	2.61	
Mg	0	1.75	
Al	1.75	1.54	
Si	29.36	27.79	
K	0.45	0.29	
Ca	2.85	6.86	
Mn	0	0.29	
Fe	3.06	3.61	
Zn	7.34	6.29	

	%Oxide	Matrix (M)	Crystal (C)
		C	16.34
	O	26.59	24.20
	Na	4.34	3.35
	Mg	0.31	2.01
	Al	1.57	1.15
	Si	29.09	27.95
	K	0.58	0.49
	Ca	4.7	7.79
	Mn	0.35	0.65
	Fe	3.88	5.11
	Zn	12.25	13.12

	%Oxide	Matrix (M)	Crystal (C)
		C	17.43
	O	26.71	28.68
	Na	3.59	3.84
	Mg	0.48	0.62
	Al	1.51	1.49
	Si	27.16	26.85
	K	0.49	0.57
	Ca	5.36	4.89
	Mn	0.41	0.36
	Fe	3.54	3.2
	Zn	13.32	12.91

APPENDIX G

Table G-1 Bending strength of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Bending strength (MPa)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	53.09	10.84	65.26	10.84
2Z8C	63.80	6.40	61.20	9.41
4Z6C	55.03	4.83	72.48	6.81
6Z4C	52.50	3.99	86.50	7.54
100A	63.61	6.88	67.09	7.90
2Z4A	57.58	3.77	51.19	10.34
4Z6A	61.15	10.55	66.88	4.69
6Z4A	51.03	5.13	74.91	9.63

Table G-2 Hardness of glass-ceramics sintered at 750°C and 850°C for 2 hours

Samples	Hardness (GPa)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C	5.59	0.31	5.90	0.13
2Z8C	5.86	0.35	5.94	0.42
4Z6C	6.10	0.27	6.42	0.12
6Z4C	5.45	0.43	6.94	0.11
100A	5.74	0.11	5.98	0.20
2Z4A	5.79	0.18	6.03	0.23
4Z6A	5.77	0.39	6.42	0.18
6Z4A	6.14	0.12	6.60	0.13

APPENDIX H

Table H-1 Thermal expansion coefficient of glass and glass-ceramics obtained by melting and sintering process

Samples	Thermal expansion coefficient ($\times 10^{-6}/\text{C}$)		
	Glass	Glass-ceramics	
	1450°C 1 h	750°C 2 h	850°C 2 h
100C	9.9684	10.2506	10.1456
2Z8C	9.3086	9.4422	10.8706
4Z6C	9.2055	8.3056	8.6926
6Z4C	8.1976	8.1925	8.7754
100A	10.7849	10.2131	8.6220
2Z4A	9.2967	9.9695	10.9985
4Z6A	7.6772	8.9156	8.1874
6Z4A	8.3740	8.0719	8.4169

APPENDIX I

Table I-1 Apparent porosity of artificial marble

Samples	Apparent porosity (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C+100A	0.23	0.04	0.36	0.06
100C+2Z8C	0.51	0.28	0.27	0.08
100C+4Z6C	0.33	0.06	0.29	0.03
100C+6Z4C	0.26	0.05	0.29	0.03

Table I-2 Water absorption of artificial marble

Samples	Water absorption (%)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C+100A	0.08	0.03	0.05	0.03
100C+2Z8C	0.21	0.01	0.14	0.03
100C+4Z6C	0.09	0.01	0.15	0.01
100C+6Z4C	0.07	0.01	0.08	0.01

Table I-3 Bulk density of artificial marble

Samples	Bulk density (g/cm ³)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C+100A	2.49	0.01	2.44	0.01
100C+2Z8C	2.47	0.01	2.41	0.01
100C+4Z6C	2.49	0.01	2.43	0.01
100C+6Z4C	2.52	0.01	2.43	0.01

Table I-4 Bending strength of artificial marble

Samples	Bending strength (MPa)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C+100A	62.72	12.08	46.05	13.10
100C+2Z8C	20.99	9.58	53.56	4.28
100C+4Z6C	15.83	5.67	42.87	8.98
100C+6Z4C	22.93	13.14	16.38	8.95

Table I-5 Hardness of artificial marble

Samples	Hardness (GPa)			
	750°C 2 h		850°C 2 h	
	Mean	STDEV	Mean	STDEV
100C+100A	6.03	0.14	5.61	0.26
100C+2Z8C	5.90	0.16	5.65	0.33
100C+4Z6C	6.19	0.43	5.85	0.24
100C+6Z4C	6.17	0.19	5.90	0.10

APPENDIX J

Examples of conversion Mohs-Vickers Hardness

- The hardness of glass-ceramics (100C) sintered at 750°C for 2 hours was 5.59 GPa.

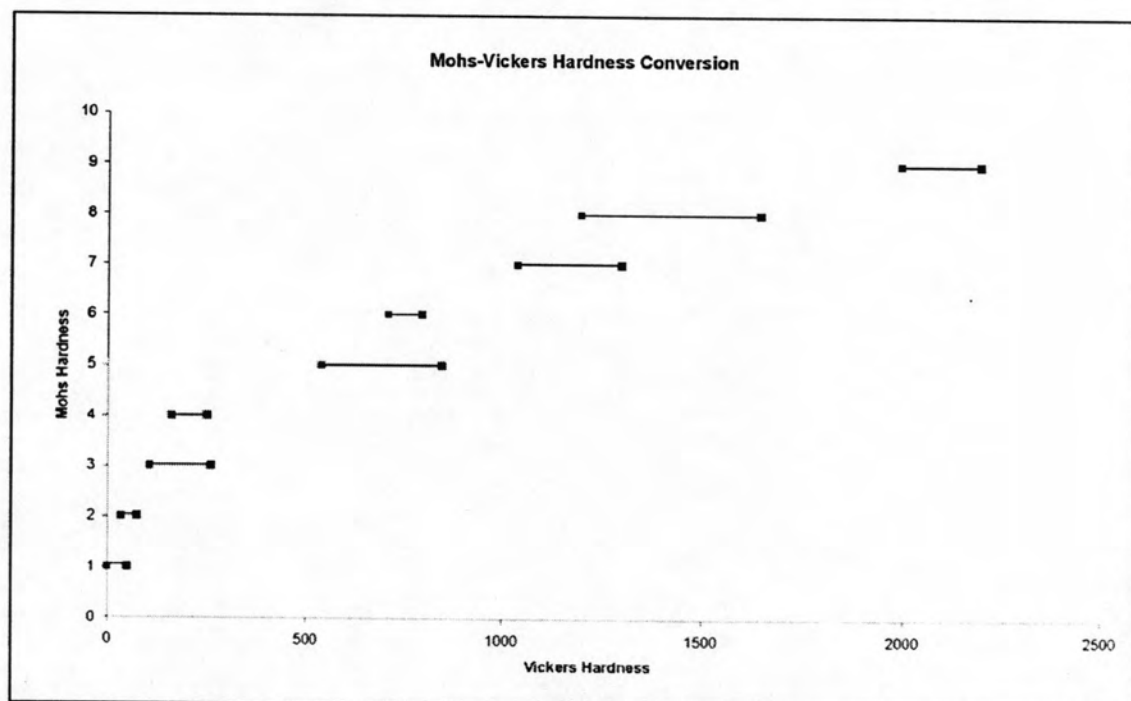
5.59 GPa ~ 570 HV

From Figure 570 HV about 5 Mohs hardness

- The hardness of glass-ceramics (6Z4C) sintered at 850°C for 2 hours was 6.94 GPa.

6.94 GPa ~ 707.7 HV

From Figure 707.7 HV about 5-6 Mohs hardness



BIOGRAPHY

Miss Wilasinee Hanpongpun was born in Lampang on 3rd December 1982. In 2004, after she had earned Bachelor's Degree in Materials Science from Department of Physic, Faculty of Science, Chiang Mai University, she continued to study in Master's program of Ceramic Technology at Chulalongkorn University. In 2005, she had received the research scholarship of Thailand Graduate Institute of Science and Technology (TGIST) and graduated in 2007.