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จุฬาลงกรณ์มหาวิทยาลัย



APPENDICES

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย



APPENDIX A

Compositions from XRF of Raw Materials.

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC
Application:	CERAMIC
Sample:	XR-0013/47 ASH
Sum (%):	98.621
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
Na2O	0.150	%	
SiO2	95.727	%	
Al2O3	0.126	%	
CaO	0.666	%	
K2O	1.252	%	
MgO	0.594	%	
P2O5	0.019	%	
PbO	0.004	%	
TiO2	0.010	%	
Fe2O3	0.073	%	
BaO	0.008	%	
WO3	0.001	%	
ZnO	0.000	%	
ZrO2	-0.007	%	
B2O3	0.000	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Quantification of sample XR-0013/47 AL(OH)3

R.M.S.:	0.111
Sum:	64.6%
Sample type:	Pressed powder
Initial sample weight (g):	5.000
Weight after pressing (g):	6.000
Correction applied for medium:	No
Correction applied for film:	None
Used Compound list:	OXIDES
Results database:	iq+
Results database in:	c:\program files\philips\superq\userdata

Analyte	Calibration status	Compound formula	Concentration (%)	Calculation method
Na	Calibrated	Na2O	0.420	Calculate
Mg	Calibrated	MgO	0.201	Calculate
Al	Calibrated	Al(OH)3	63.444	Calculate
Si	Calibrated	SiO2	0.429	Calculate
Ca	Calibrated	CaO	0.042	Calculate
Fe	Calibrated	Fe2O3	0.057	Calculate
Sn	Calibrated	SnO2	0.023	Calculate



APPENDIX B

Thermal Analysis of Raw Materials.

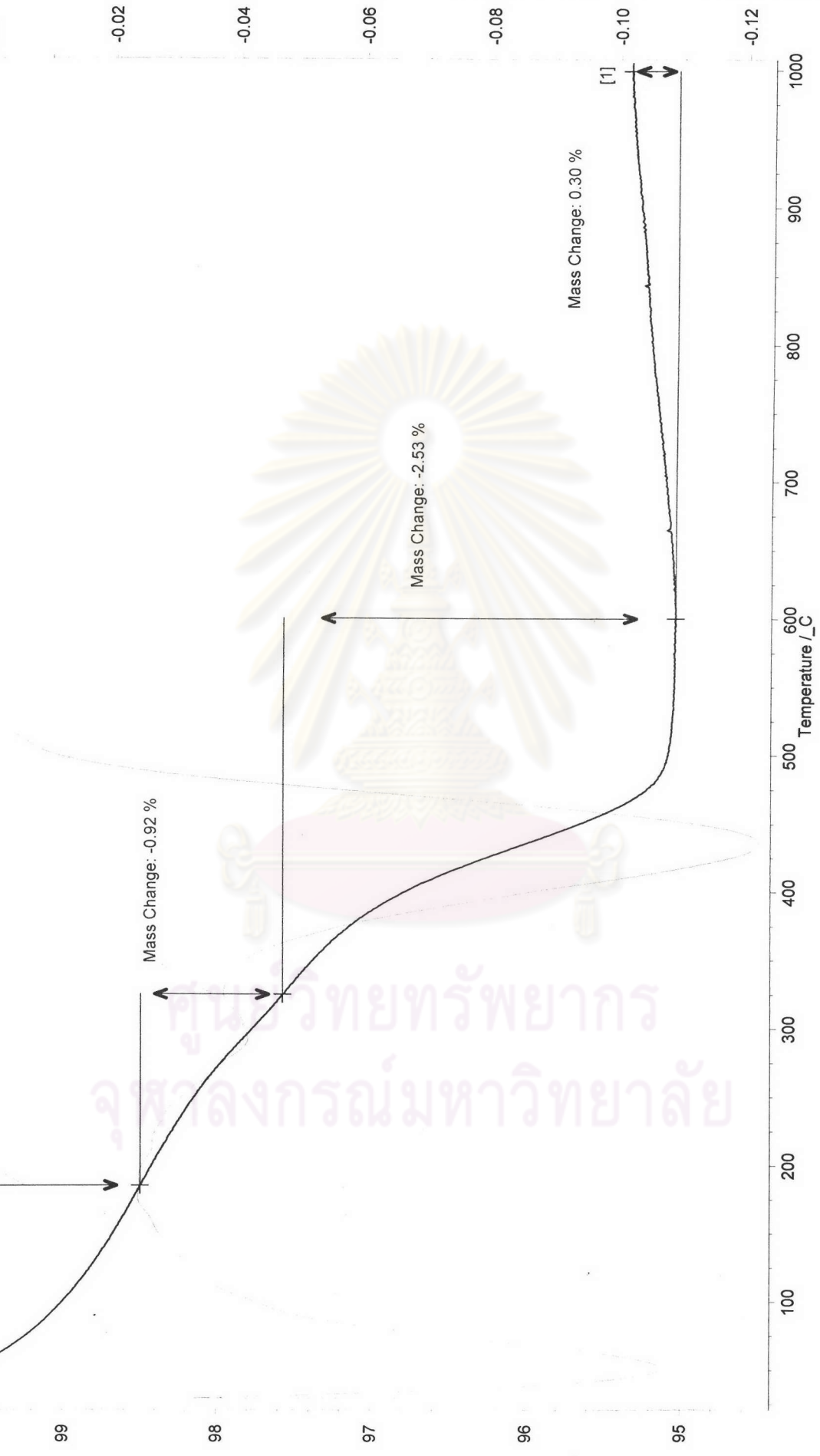
ศูนย์วิจัยทรัพยากร
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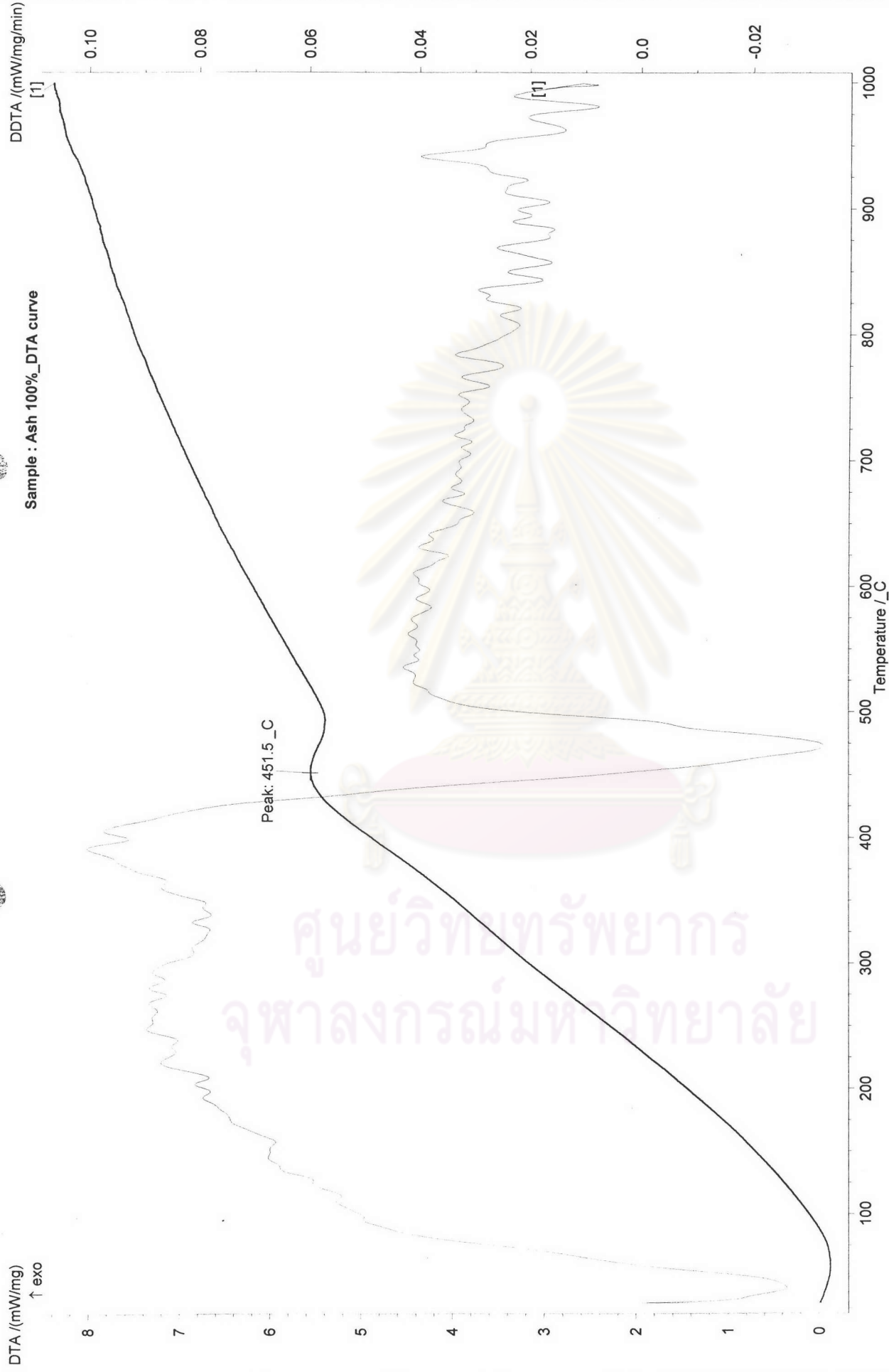
DTG (%/min)
[1]

Sample : Ash 100%_TGA curve

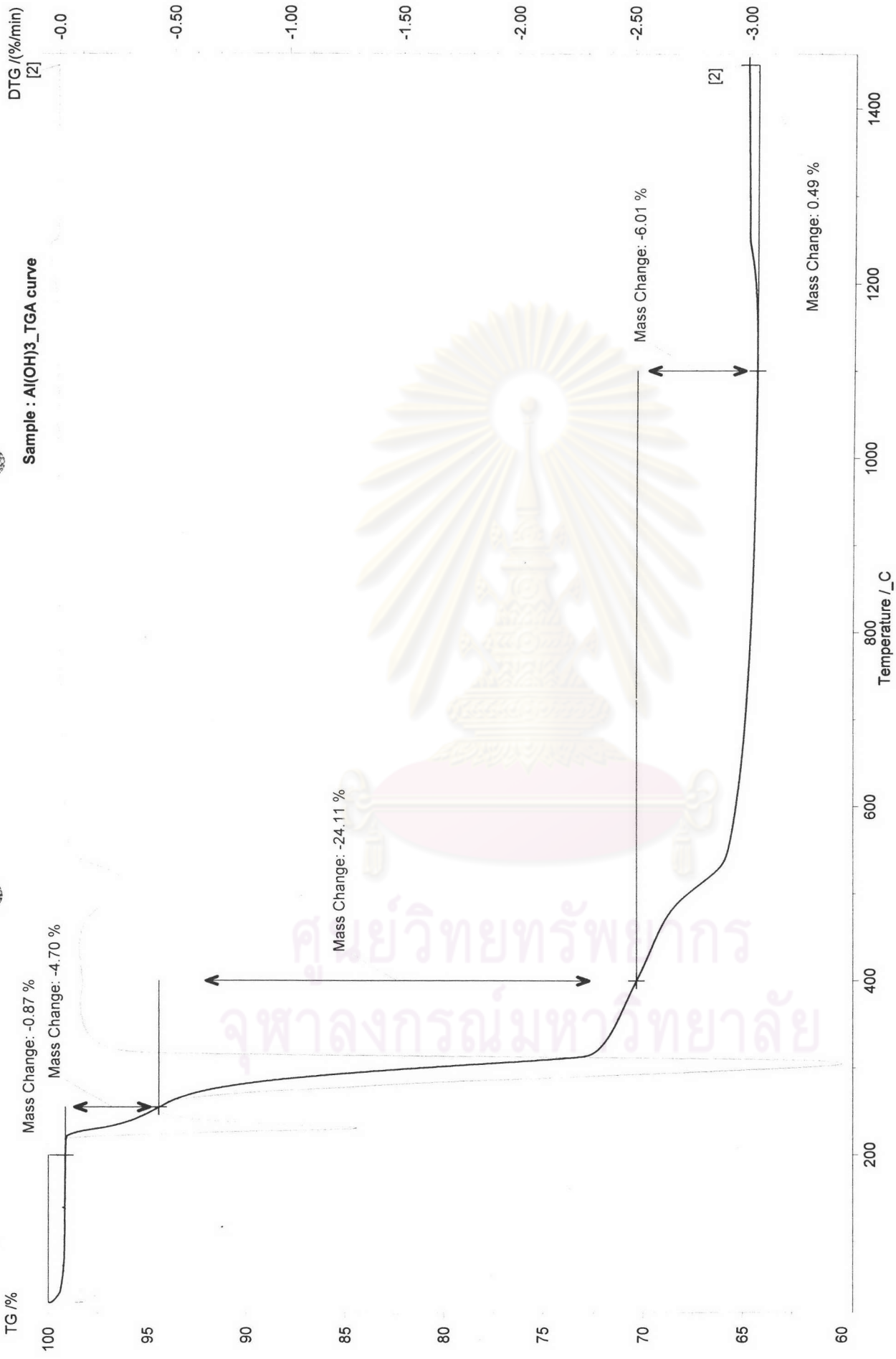
TG %



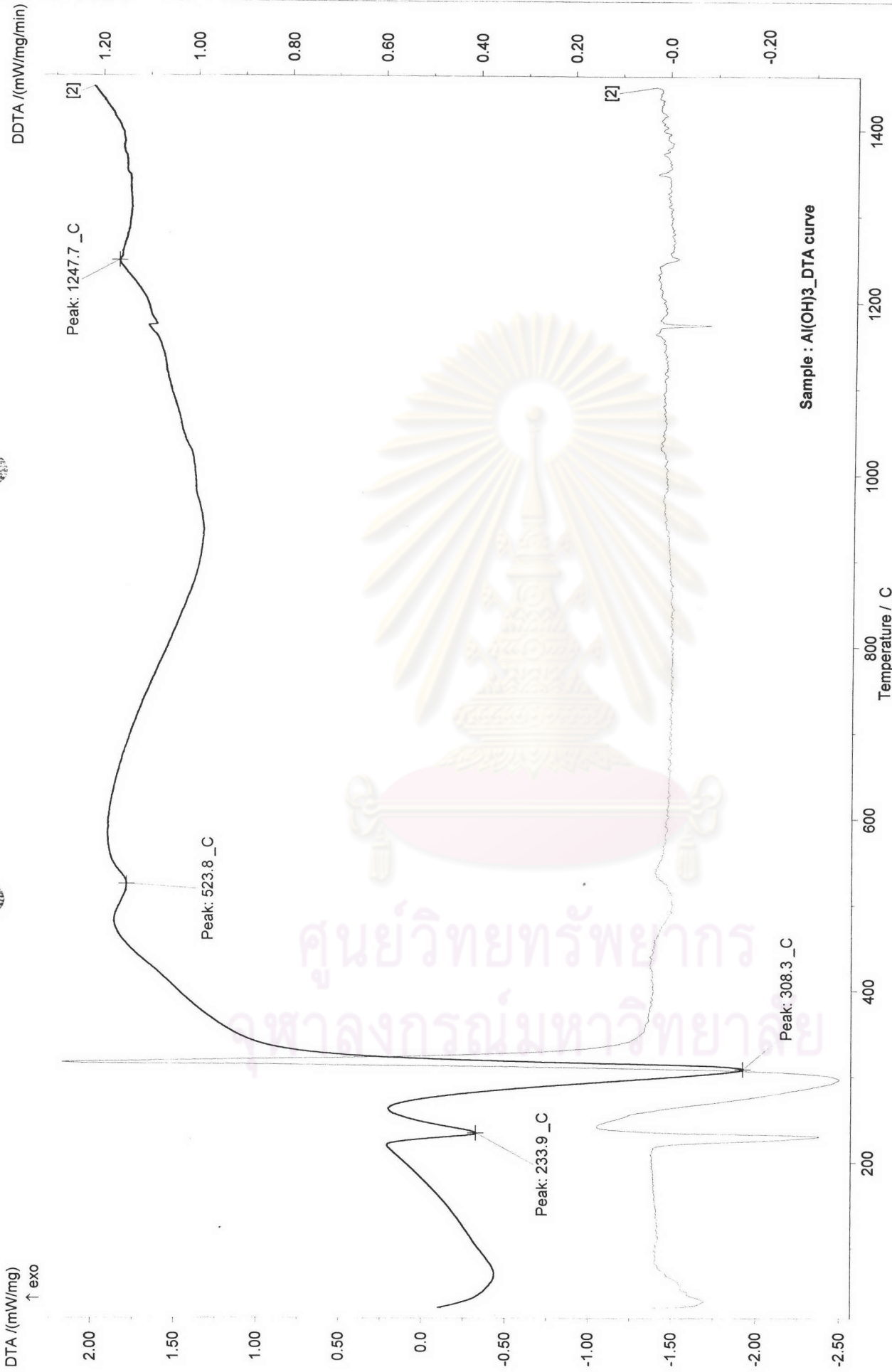
Instrument:	NETZSCH STA 449C	Mode/Type of Meas.:	DTA-TG / Sample + Correction
File:	Ash100%_2.dsu	Segments:	1/1
Project:	TA 063/47	Crucible:	DTA/TG crucible Al2O3
Identity:	Ash 100%	Atmosphere:	Air/20.00 / -/
Date/Time:	7/19/04 9:21:54 AM	TG Corr./M.Range:	220/5000 mg
Laboratory:	TA MTEC	DSC Corr./M.Range:	020/5000 uV
Operator:	siriporn	Remark:	



Instrument:	NETZSCH STA 449C	Mode/Type of Meas.:	DTA-TG / Sample + Correction
File:	Ash100%_2.dsu	Segments:	1/1
Project:	TA 063/47	Crucible:	DTA/TG crucible Al2O3
Identity:	Ash 100%	Atmosphere:	Air/20.00 / +/-
Date/Time:	7/19/04 9:21:54 AM	TG Corr./M.Range:	220/5000 mg
Laboratory:	TA MTEC	DSC Corr./M.Range:	020/5000 uV
Operator:	siriborn	Remark:	
Sample:	Ash 100%_2, 26.955 mg		
Reference:	alumina,0.000 mg		
Material:	Ash		
Correction File:	cor_30-1000-R5-Air_040422.bsu		
Temp.Cal./Sens. Files:	040211_tcal.tsu / 040211_sencal.esu		
Range:	30_C/5.0(K/min)/1000_C		
Sample Car./TC:	DTA(TG) HIGH RG 4 / S		



Instrument:	NETZSCH STA 449C	Sample:	Al(OH) ₃ , 49.000 mg	Mode/Type of Meas.:	DTA-TG / Sample + Correction
File:	Al(OH) ₃ .dsu	Reference:	alumina, 0.000 mg	Segments:	1/1
Project:	TA 063/47	Material:	Al(OH) ₃	Crucible:	DTA/TG crucible Al2O3
Identity:	Al(OH) ₃	Correction File:	cor_30-1450-R5-Air_040419.bsu	Atmosphere:	Air/20.00 / -/ -
Date/Time:	6/11/04 9:34:27 AM	Temp.Cal./Sens. Files:	040211_ical.tsu / 040211_sencal.esu	TG Corr./M.Range:	020/5000 mg
Laboratory:	TA MTEC	Range:	30_C/5.0(K/min)/1450_C	DSC Corr./M.Range:	020/5000 uV
Operator:	siriborn	Sample Car./TC:	DTA/TG) HIGH RG 4 / S	Remark:	



Instrument:	NETZSCH STA 449C	Mode/Type of Meas.:	DTA-TG / Sample + Correction
File:	Al(OH)3.dsu	Segments:	1/1
Project:	TA 063/47	Crucible:	DTA/TG crucible Al2O3
Identity:	Al(OH)3	Atmosphere:	Air/20.00 / -/-
Date/Time:	6/11/04 9:34:27 AM	TG Corr./M.Range:	020/5000 mg
Laboratory:	TA MTEC	DSC Corr./M.Range:	020/5000 uV
Operator:	sirinorn	Remark:	
Sample:	Al(OH)3, 49.000 mg		
Reference:	alumina, 0.000 mg		
Material:	Al(OH)3		
Correction File:	cor_30-1450-R5-Air_040419.bsu		
Temp. Cal./Sens. Files:	040211_tcal.itsu / 040211_sencal.esu		
Range:	30_C/5.0(K/min)/1450_C		
	Sample Car /TC:		
	DTA/TG: HIGH RG 4 / S		

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APPENDIX C

Estimate of Compositions of RHA/SRM30 and RHA/WS Samples Before and After Mullitization

Molecular weight of Al_2O_3 , SiO_2 and mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) = 102, 60 and 426, respectively.

For RHA/SRM30 samples

Before mullitization

$$\text{Al}_2\text{O}_3 = \text{SRM30}$$

$$\text{SiO}_2 = 0.9708 \cdot \text{RHA} \quad (\% \text{ SiO}_2 \text{ from XRF data} = 97.08\%)$$

After mullitization (Excess SiO_2)

$$\text{Mullite} = 426 \cdot \text{Al}_2\text{O}_3 / 306$$

$$\text{Used SiO}_2 = 120 \cdot \text{Mullite} / 426$$

$$\text{Remain SiO}_2 = \text{SiO}_2 - \text{Used SiO}_2$$

$$\text{Used Al}_2\text{O}_3 = \text{Al}_2\text{O}_3$$

$$\text{Remain Al}_2\text{O}_3 = 0$$

After mullitization (Excess Al_2O_3)

$$\text{Mullite} = 426 \cdot \text{SiO}_2 / 120$$

$$\text{Used SiO}_2 = \text{SiO}_2$$

$$\text{Remain SiO}_2 = 0$$

$$\text{Used Al}_2\text{O}_3 = 306 \cdot \text{Mullite} / 426$$

$$\text{Remain Al}_2\text{O}_3 = \text{Al}_2\text{O}_3 - \text{Used Al}_2\text{O}_3$$

For RHA/WS samples

Before mullitization

$$\text{Al}_2\text{O}_3 = 0.6431 \cdot \text{WS}$$

$$(\% \text{ Total weight loss of WS from thermal analysis} = 35.69\%)$$

$$\text{SiO}_2 = 0.9708 \cdot \text{RHA} \quad (\% \text{ SiO}_2 \text{ from XRF data} = 97.08\%)$$

After mullitization

Calculation is the same of RHA/SRM30 samples

APPENDIX D

Sample Compositions in Specimens from Calculation

For RHAWS_H samples

$$\text{Al}_2\text{O}_3 = 0.1330 \cdot \text{WS}$$

(From thermal analysis

$$\% \text{ Total weight loss of WS (25-1000 } ^\circ\text{C)} = 35.69\%$$

$$\% \text{ Weight loss after heat treatment} = 22.39\%$$

$$\% \text{ Weight loss remain} = 35.69 - 22.39 = 13.30\%$$

$$\text{SiO}_2 = 0.9708 \cdot \text{RHA} \quad (\% \text{ SiO}_2 \text{ from XRF data} = 97.08\%)$$



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APPENDIX D(Cont.)

Compositions from XRF of Specimens after Fired 1700 °C.

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 2D
Sum (%):	99.399
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO2	21.410	%	
Al2O3	75.626	%	
NiO	0.006	%	
Co3O4	0.022	%	
Fe2O3	0.077	%	
P2O5	0.117	%	
K2O	0.498	%	
TiO2	0.012	%	
MgO	0.483	%	
CaO	0.228	%	
Na2O	0.430	%	
WO3	0.463	%	
PbO	-0.003	%	
BaO	-0.004	%	
ZnO	0.001	%	
ZrO2	-0.002	%	
Cr2O3	0.002	%	
Mn3O4	0.031	%	

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View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 3D
Sum (%):	99.328
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO2	31.567	%	
Al2O3	64.977	%	
NiO	0.005	%	
Co3O4	0.011	%	
Fe2O3	0.066	%	
P2O5	0.204	%	
K2O	0.757	%	
TiO2	0.007	%	
MgO	0.506	%	
CaO	0.488	%	
Na2O	0.393	%	
WO3	0.309	%	
PbO	-0.002	%	
BaO	-0.006	%	
ZnO	0.003	%	
ZrO2	0.000	%	
Cr2O3	0.003	%	
Mn3O4	0.042	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 4D
Sum (%):	100.649
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO ₂	41.669	%	
Al ₂ O ₃	55.797	%	
NiO	0.004	%	
Co ₃ O ₄	0.014	%	
Fe ₂ O ₃	0.055	%	
P ₂ O ₅	0.278	%	
K ₂ O	1.109	%	
TiO ₂	0.049	%	
MgO	0.509	%	
CaO	0.345	%	
Na ₂ O	0.450	%	
WO ₃	0.317	%	
PbO	0.000	%	
BaO	-0.004	%	
ZnO	0.006	%	
ZrO ₂	-0.002	%	
Cr ₂ O ₃	0.002	%	
Mn ₃ O ₄	0.051	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 2H
Sum (%):	100.386
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO2	21.535	%	
Al2O3	76.677	%	
NiO	0.007	%	
Co3O4	0.012	%	
Fe2O3	0.069	%	
P2O5	0.102	%	
K2O	0.512	%	
TiO2	0.012	%	
MgO	0.491	%	
CaO	0.229	%	
Na2O	0.435	%	
WO3	0.274	%	
PbO	-0.002	%	
BaO	-0.003	%	
ZnO	0.005	%	
ZrO2	-0.002	%	
Cr2O3	0.002	%	
Mn3O4	0.032	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 3H
Sum (%):	100.530
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO ₂	31.756	%	
Al ₂ O ₃	65.950	%	
NiO	0.005	%	
Co ₃ O ₄	0.018	%	
Fe ₂ O ₃	0.067	%	
P ₂ O ₅	0.193	%	
K ₂ O	0.790	%	
TiO ₂	0.007	%	
MgO	0.492	%	
CaO	0.276	%	
Na ₂ O	0.387	%	
WO ₃	0.550	%	
PbO	-0.003	%	
BaO	-0.006	%	
ZnO	0.006	%	
ZrO ₂	-0.002	%	
Cr ₂ O ₃	0.003	%	
Mn ₃ O ₄	0.042	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

View result

Type:	Routine
Archive:	CERAMIC-17025
Application:	CERAMIC-17025
Sample:	UMAPORN 4H
Sum (%):	99.643
Init weight:	1.1 g
Flux weight:	5.5 g
Final weight:	6.6 g

Compound	Value	Unit	Status
SiO ₂	41.496	%	
Al ₂ O ₃	54.843	%	
NiO	0.005	%	
Co ₃ O ₄	0.019	%	
Fe ₂ O ₃	0.058	%	
P ₂ O ₅	0.278	%	
K ₂ O	1.123	%	
TiO ₂	0.003	%	
MgO	0.511	%	
CaO	0.346	%	
Na ₂ O	0.435	%	
WO ₃	0.475	%	
PbO	-0.003	%	
BaO	-0.006	%	
ZnO	0.006	%	
ZrO ₂	0.001	%	
Cr ₂ O ₃	0.002	%	
Mn ₃ O ₄	0.053	%	

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX E

Physical Properties of 4L Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	3.3061	4.1342	2.1458	1.6627	2.8493	41.6465	25.0476
2	3.2454	4.0567	2.1105	1.6676	2.8596	41.6864	24.9985
3	2.9479	3.6712	1.9154	1.6789	2.8551	41.1949	24.5361
4	4.0661	5.0855	2.6124	1.6441	2.7971	41.2195	25.0707
5	4.5920	5.7415	2.9908	1.6694	2.8678	41.7894	25.0327
6	3.9895	4.9830	2.5941	1.6700	2.8590	41.5882	24.9029
7	4.1635	5.2135	2.7102	1.6632	2.8649	41.9446	25.2192
8	3.2574	4.0692	2.1197	1.6709	2.8631	41.6414	24.9217
9	4.5649	5.7196	2.9764	1.6641	2.8737	42.0932	25.2952
10	3.3061	4.1342	2.1458	1.6627	2.8493	41.6465	25.0476
			Avr.	1.6654	2.8539	41.6451	25.0072
			S.D.	0.0090	0.0214	0.2789	0.2044

APPENDIX E (Cont.)

Physical Properties of 3L Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	4.3004	5.6700	2.8839	1.5435	3.0359	49.1583	31.8482
2	3.6242	4.7956	2.4394	1.5382	3.0589	49.7156	32.3216
3	5.0633	6.7285	3.3873	1.5154	3.0211	49.8384	32.8876
4	3.6303	4.8283	2.4360	1.5175	3.0397	50.0773	33.0000
5	3.8812	5.1363	2.6081	1.5352	3.0486	49.6440	32.3379
6	3.7424	4.9774	2.5091	1.5162	3.0345	50.0344	33.0002
7	3.7261	4.8972	2.3785	1.4794	2.7650	46.4962	31.4296
8	4.1259	5.4651	2.7633	1.5271	3.0280	49.5670	32.4584
9	2.5840	3.4224	1.7298	1.5266	3.0251	49.5333	32.4458
10	4.5337	6.0204	3.0355	1.5189	3.0261	49.8074	32.7922
			Avr.	1.5218	3.0083	49.3872	32.4522
			S.D	0.0179	0.0863	1.0495	0.5106

APPENDIX E (Cont.)

Physical Properties of 2L Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	3.0646	4.3398	2.1306	1.3872	3.2812	57.7223	41.6107
2	3.4319	4.9494	2.4904	1.3956	3.6451	61.7121	44.2175
3	3.5288	5.0459	2.4462	1.3574	3.2596	58.3567	42.9920
4	3.4500	4.9390	2.3916	1.3543	3.2596	58.4518	43.1594
5	3.5839	5.1224	2.4879	1.3604	3.2700	58.3982	42.9281
6	3.5745	5.1061	2.5004	1.3718	3.3279	58.7788	42.8480
7	3.3860	4.7966	2.3428	1.3799	3.2458	57.4863	41.6598
8	2.9230	4.1359	2.0282	1.3868	3.2667	57.5461	41.4950
9	2.9780	4.2602	2.0619	1.3547	3.2507	58.3269	43.0557
10	3.4491	4.9365	2.3869	1.3528	3.2471	58.3386	43.1243
			Avr.	1.3701	3.3054	58.5118	42.7090
			S.D.	0.0162	0.1217	1.2030	0.8628

APPENDIX E (Cont.)

Physical Properties of 4S Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	5.0748	5.8311	3.2352	1.9549	2.7586	29.1344	14.9031
2	4.3966	5.0808	2.8144	1.9399	2.7788	30.1888	15.5620
3	4.9566	5.7102	3.1773	1.9569	2.7857	29.7525	15.2040
4	4.5312	5.2142	2.8997	1.9577	2.7773	29.5096	15.0733
5	4.4105	5.1068	2.8334	1.9400	2.7966	30.6281	15.7873
6	4.5839	5.2670	2.9259	1.9580	2.7647	29.1786	14.9022
7	4.3936	5.1065	2.8272	1.9276	2.8049	31.2771	16.2259
8	4.4626	5.1266	2.8519	1.9618	2.7706	29.1907	14.8792
9	3.4537	3.9833	2.2126	1.9505	2.7828	29.9091	15.3343
10	3.8693	4.4710	2.4881	1.9513	2.8014	30.3444	15.5506
			Avr.	1.9499	2.7821	29.9113	15.3422
			S.D.	0.0108	0.0154	0.7063	0.4426

APPENDIX E (Cont.)

Physical Properties of 3S Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	3.7267	4.6347	2.4874	1.7355	3.0071	42.2857	24.3647
2	3.7065	4.6197	2.4650	1.7202	2.9855	42.3818	24.6378
3	4.3125	5.3530	2.8650	1.7333	2.9793	41.8207	24.1275
4	3.9543	4.9087	2.6268	1.7329	2.9788	41.8248	24.1358
5	4.1933	5.2029	2.7856	1.7347	2.9788	41.7656	24.0765
6	4.5712	5.6865	3.0406	1.7277	2.9865	42.1520	24.3984
7	4.2821	5.3313	2.8609	1.7334	3.0130	42.4709	24.5020
8	4.5298	5.6297	3.0141	1.7318	2.9886	42.0515	24.2814
9	3.3817	4.1918	2.2465	1.7384	2.9789	41.6440	23.9554
10	3.9118	4.8707	2.5985	1.7216	2.9786	42.2014	24.5130
			Avr.	1.7309	2.9875	42.0598	24.2993
			S.D.	0.0060	0.0125	0.2836	0.2211

APPENDIX E (Cont.)

Physical Properties of 2S Samples after Fired at 1400 °C for 2 hours.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	3.1465	4.2334	2.1693	1.5244	3.2199	52.6573	34.5431
2	3.2142	4.3218	2.2133	1.5244	3.2113	52.5302	34.4596
3	3.2954	4.4350	2.2572	1.5132	3.1741	52.3280	34.5815
4	3.0413	4.0845	2.0903	1.5251	3.1980	52.3117	34.3011
5	3.1764	4.2493	2.1837	1.5378	3.1998	51.9413	33.7772
6	3.4653	4.6639	2.3882	1.5227	3.2173	52.6695	34.5886
7	4.2448	5.7107	2.9193	1.5207	3.2024	52.5149	34.5340
8	3.0522	4.0820	2.0938	1.5352	3.1847	51.7956	33.7396
9	3.6523	4.8908	2.5070	1.5321	3.1889	51.9549	33.9101
10	2.9313	3.9300	2.0110	1.5275	3.1852	52.0427	34.0702
			Avr.	1.5263	3.1982	52.2746	34.2505
			S.D.	0.0072	0.0151	0.3208	0.3447

APPENDIX F

Physical properties of 4L samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	2.7626	2.7667	1.7174	2.6328	2.6431	0.3907	0.1484
2	2.1265	2.13	1.3209	2.6282	2.6396	0.4326	0.1646
3	2.1507	2.1525	1.3363	2.6350	2.6408	0.2205	0.0837
4	3.416	3.42	2.1191	2.6259	2.6340	0.3075	0.1171
5	3.6869	3.689	2.2878	2.6312	2.6352	0.1499	0.0570
6	3.0684	3.0729	1.9057	2.6289	2.6390	0.3855	0.1467
7	3.5304	3.5353	2.1992	2.6423	2.6520	0.3667	0.1388
8	2.7148	2.7191	1.6869	2.6301	2.6411	0.4166	0.1584
9	3.3558	3.3585	2.0837	2.6324	2.6380	0.2118	0.0805
10	2.7626	2.7667	1.7174	2.6328	2.6431	0.3907	0.1484
			Avr.	2.6320	2.6406	0.3273	0.1243
			S.D.	0.0045	0.0050	0.0993	0.0377

APPENDIX F (Cont.)

Physical properties of 3L samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	2.1744	2.2695	1.4221	2.5660	2.8903	11.2226	4.3736
2	2.5939	2.7252	1.7045	2.5413	2.9165	12.8637	5.0619
3	2.5342	2.6553	1.6633	2.5546	2.9099	12.2077	4.7786
4	2.5562	2.702	1.6857	2.5152	2.9365	14.3462	5.7038
5	2.0669	2.1853	1.363	2.5136	2.9364	14.3986	5.7284
6	2.3246	2.4647	1.5431	2.5224	2.9745	15.2018	6.0268
7	2.7671	2.926	1.8263	2.5162	2.9412	14.4494	5.7425
8	2.3477	2.4751	1.545	2.5241	2.9248	13.6975	5.4266
9	1.644	1.7392	1.0872	2.5215	2.9526	14.6012	5.7908
10	3.4328	3.618	2.2631	2.5336	2.9348	13.6689	5.3950
			Avr.	2.5308	2.9317	13.6658	5.4028
			S.D	0.0179	0.0233	1.2287	0.5183

APPENDIX F (Cont.)

Physical properties of 2L samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	1.3113	1.462	0.902	2.3416	3.2038	26.9107	11.4924
2	1.7726	2.0033	1.224	2.2746	3.2311	29.6035	13.0148
3	1.919	2.1774	1.3223	2.2442	3.2160	30.2187	13.4653
4	1.7449	1.9922	1.2031	2.2113	3.2206	31.3395	14.1727
5	1.4928	1.7013	1.0285	2.2188	3.2152	30.9899	13.9670
6	1.6658	1.8965	1.1479	2.2252	3.2165	30.8175	13.8492
7	1.2393	1.4172	0.857	2.2122	3.2417	31.7565	14.3549
8	1.2808	1.4546	0.8823	2.2380	3.2141	30.3687	13.5696
9	1.035	1.1857	0.716	2.2035	3.2445	32.0843	14.5604
10	1.6863	1.9254	1.1640	2.2147	3.2286	31.4027	14.1790
			Avr.	2.2384	3.2232	30.5492	13.6625
			S.D.	0.0418	0.0130	1.4798	0.8892

APPENDIX F (Cont.)

Physical properties of 4S samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	2.2598	2.2617	1.3837	2.5738	2.5794	0.2164	0.0841
2	1.8008	1.8028	1.107	2.5881	2.5956	0.2874	0.1111
3	2.5109	2.5128	1.5528	2.6155	2.6207	0.1979	0.0757
4	1.5288	1.5305	0.9348	2.5664	2.5737	0.2854	0.1112
5	3.6069	3.6119	2.209	2.5710	2.5802	0.3564	0.1386
6	2.2507	2.254	1.3945	2.6186	2.6287	0.3839	0.1466
7	3.2464	3.2498	2.0214	2.6428	2.6501	0.2768	0.1047
8	3.162	3.1668	1.9711	2.6445	2.6551	0.4014	0.1518
9	2.5412	2.544	1.5847	2.6490	2.6568	0.2919	0.1102
10	2.4042	2.4083	1.4940	2.6296	2.6414	0.4484	0.1705
			Avr.	2.6099	2.6182	0.3146	0.1205
			S.D.	0.0325	0.0333	0.0808	0.0305

APPENDIX F (Cont.)

Physical properties of 3S samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	3.025	3.0272	1.9535	2.8174	2.8231	0.2049	0.0727
2	3.1796	3.1819	2.0505	2.8103	2.8160	0.2033	0.0723
3	3.7281	3.7299	2.4064	2.8168	2.8207	0.1360	0.0483
4	2.9486	2.9489	1.9022	2.8170	2.8179	0.0287	0.0102
5	4.0268	4.0299	2.597	2.8102	2.8163	0.2163	0.0770
6	3.4739	3.4793	2.2432	2.8104	2.8227	0.4369	0.1554
7	2.9838	2.9891	1.9252	2.8046	2.8186	0.4982	0.1776
8	3.6466	3.651	2.3548	2.8133	2.8229	0.3395	0.1207
9	2.4062	2.4082	1.553	2.8136	2.8202	0.2339	0.0831
10	2.962	2.9641	1.9148	2.8228	2.8285	0.2001	0.0709
			Avr.	2.8137	2.8207	0.2498	0.0888
			S.D.	0.0051	0.0038	0.1393	0.0497

APPENDIX F (Cont.)

Physical properties of 2S samples after fired at 1700 °C for 1 hour.

sample	dry weight (g)	saturated weight (g)	suspended weight (g)	bulk density (g/cm ³)	apparent density (g/cm ³)	% apparent porosity	% water absorption
1	1.8628	1.8661	1.2225	2.8943	2.9093	0.5127	0.1772
2	2.3229	2.3244	1.5179	2.8802	2.8856	0.1860	0.0646
3	2.4971	2.499	1.6311	2.8772	2.8835	0.2189	0.0761
4	2.4422	2.4446	1.5945	2.8728	2.8810	0.2823	0.0983
5	2.3146	2.3164	1.5117	2.8764	2.8828	0.2237	0.0778
6	2.4614	2.4642	1.6056	2.8668	2.8761	0.3261	0.1138
7	3.4692	3.4725	2.2645	2.8719	2.8797	0.2732	0.0951
8	2.0741	2.0769	1.3515	2.8593	2.8703	0.3860	0.1350
9	2.4986	2.5006	1.6332	2.8806	2.8872	0.2306	0.0800
10	1.9126	1.9155	1.2520	2.8826	2.8952	0.4371	0.1516
			Avr.	2.8762	2.8851	0.3077	0.1069
			S.D.	0.0095	0.0108	0.1069	0.0370

APPENDIX G

Young's Modulus and Flexural Strength at Room Temperature of 4L Samples Fired 1700 °C for 1 hour.

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	1.203	3.65	38.28	3.27	0.3522	135.48	15.20	121.53
2	1.2746	4.04	38.09	3.20	0.3405	123.10	15.30	123.07
3	1.3844	4.10	39.05	3.29	0.3611	122.20	14.90	124.69
4	1.3388	4.36	38.51	3.08	0.4029	145.91	14.50	124.37
5	1.218	4.04	37.94	3.08	0.2958	115.77	14.80	122.09
6	1.2939	4.01	38.42	3.26	0.3561	124.98	15.30	122.34
7	1.2983	4.18	38.17	3.14	0.3316	120.53	15.00	124.03
8	1.2832	4.08	38.89	3.09	0.3311	127.39	14.00	121.24
9	1.2539	4.35	37.62	2.94	0.3025	120.68	14.30	121.74
10	1.0684	4.10	35.75	2.92	0.2617	112.04	15.50	113.29
					Avr.	124.81		121.84
					S.D.	9.75		3.24

APPENDIX G (Cont.)

Young's Modulus and Flexural Strength at Room Temperature of 3L Samples Fired 1700 °C for 1 hour.

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	1.135	3.91	37.21	3.25	0.2889	104.93	15.00	97.58
2	0.9175	3.87	39.13	2.78	0.2009	101.09	11.10	80.10
3	0.7726	3.78	34.51	2.71	0.1899	102.70	14.10	82.82
4	0.7715	3.81	38.40	2.40	0.1604	109.24	10.20	83.43
5	1.1942	4.14	38.67	2.94	0.327	136.96	12.00	92.90
6	0.932	4.31	38.16	2.54	0.1917	103.60	11.10	88.40
7	0.8667	3.75	38.55	2.78	0.1945	101.00	11.20	76.11
8	1.1807	4.08	34.42	3.51	0.3481	103.88	18.90	98.76
9	1.4312	4.24	42.58	3.27	0.2941	97.38	12.00	105.78
10	1.2785	4.25	39.76	3.16	0.2598	91.90	13.00	100.09
					Avr.	105.27		90.60
					S.D.	12.06		9.88

APPENDIX G (Cont.)

Young's Modulus and Flexural Strength at Room Temperature of 2L Samples Fired 1700 °C for 1 hour.

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	0.9402	4.21	31.83	3.20	0.2412	83.86	20.50	93.39
2	0.9216	4.01	34.47	3.04	0.1696	68.55	15.50	80.04
3	1.0347	4.12	35.46	3.22	0.1865	65.35	15.40	79.30
4	1.0283	4.36	34.31	3.12	0.1794	63.27	16.50	85.11
5	1.0376	4.05	35.39	3.26	0.1763	61.37	15.80	81.73
6	0.9964	4.18	35.75	3.04	0.1538	59.77	15.20	89.03
7	1.0926	4.37	34.65	3.28	0.2038	65.11	16.00	75.92
8	0.7687	3.74	33.96	2.80	0.1748	89.34	16.90	103.64
9	0.8360	3.76	33.14	3.06	0.1554	66.15	17.80	89.54
10	0.8664	3.38	36.89	3.37	0.2019	78.66	14.50	70.46
					Avr.	70.14		84.82
					S.D.	10.15		9.52

APPENDIX G (Cont.)

Young's Modulus and Flexural Strength at Room Temperature of 4S Samples Fired 1700 °C for 1 hour.

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	1.2481	4.20	37.69	3.05	0.4156	159.34	15.00	124.50
2	1.1134	3.95	36.26	3.05	0.2852	116.68	15.90	119.19
3	1.2343	3.83	36.92	3.47	0.4504	146.50	17.40	117.96
4	1.1915	3.81	35.66	3.48	0.3467	112.83	18.50	116.26
5	0.9839	3.49	34.84	3.17	0.2653	113.60	17.90	120.19
6	1.4302	4.71	38.22	3.10	0.4787	158.87	14.75	122.72
7	1.2014	4.37	37.48	2.91	0.2473	100.24	14.30	118.38
8	1.2179	4.10	36.31	3.17	0.3615	132.00	16.70	124.48
9	1.1600	4.13	35.95	3.10	0.2992	112.99	16.90	124.33
10	1.2558	4.11	37.21	3.16	0.3432	125.33	15.50	118.96
					Avr.	127.84		120.70
					S.D.	20.71		3.06

APPENDIX G (Cont.)

Young's Modulus and Flexural Strength at Room Temperature of 3S Samples Fired 1700 °C for 1 hour.

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	1.5578	4.33	36.37	3.61	0.5218	138.96	21.10	165.82
2	1.4476	4.44	35.96	3.31	0.4986	153.32	19.50	158.57
3	1.4595	4.22	36.66	3.42	0.4886	148.48	19.90	169.09
4	1.3433	4.18	36.86	3.34	0.4672	150.47	18.90	154.54
5	1.4126	4.17	34.76	3.35	0.5387	173.01	20.35	158.21
6	1.46	4.34	37.87	3.22	0.4758	158.81	17.45	165.88
7	1.5057	4.49	37.55	3.13	0.4231	144.38	17.10	167.94
8	1.066	3.81	35.79	2.82	0.3293	163.27	16.40	152.18
9	1.3674	4.29	36.91	3.12	0.4105	147.33	17.10	153.02
10	1.2906	4.19	36.79	3.07	0.3815	144.71	16.40	141.07
Avr.					152.28		158.63	
S.D.					10.18		8.81	

APPENDIX G (Cont.)

Young's Modulus and Flexural Strength at Room Temperature of 2S Samples Fired 1700 °C for 1 hour

Sample	weight (g) m	Dimension (mm)			Load (kN)	Flexural strength (MPa)	Frequency (kHz)	Young's modulus (GPa)
		Width b	Length L	Thickness t				
1	1.3550	4.12	35.53	3.30	0.3778	126.56	19.80	161.74
2	1.5164	4.15	36.63	3.39	0.4982	156.26	19.80	180.38
3	1.2928	3.62	35.58	3.54	0.4509	148.95	21.00	161.30
4	1.3284	3.60	36.31	3.58	0.3754	121.93	19.20	143.00
5	1.1785	3.75	31.80	3.40	0.3876	134.12	25.80	174.57
6	1.2571	3.98	33.18	3.27	0.4689	165.61	22.70	172.12
7	1.5397	3.99	37.12	3.71	0.4238	115.85	21.80	185.78
8	1.5585	4.11	35.99	3.59	0.4228	119.41	21.40	176.25
9	1.5184	3.86	36.77	3.79	0.5015	135.32	20.00	145.36
10	1.4058	4.13	34.12	3.38	0.3897	123.89	21.40	161.95
					Avr.	134.79		166.24
					S.D.	16.86		14.24

APPENDIX H

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 4L samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})	
	2a ₁	2a ₂	2a	c ₁	c ₂	c				
1	51.63	52.64	52.14	63.82	63.80	63.82	6.69	682.25	1.56	
2	52.41	53.03	52.72	69.08	69.07	69.07	6.55	667.19	1.24	
3	51.64	51.97	51.81	62.01	60.93	61.47	6.78	690.97	1.73	
4	51.63	50.84	51.24	63.73	64.23	63.98	6.93	706.43	1.52	
5	52.30	51.99	52.15	65.13	64.30	64.72	6.69	681.99	1.49	
							Avr.	6.73	685.77	1.51
							S.D.	0.14	14.37	0.18

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 4S samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})	
	2a ₁	2a ₂	2a	c ₁	c ₂	c				
1	51.39	51.03	51.21	62.75	62.25	62.50	6.94	707.12	1.61	
2	51.64	51.32	51.48	63.60	63.75	63.75	6.86	699.72	1.53	
3	52.30	53.31	52.81	64.31	63.41	64.31	6.52	665.05	1.53	
4	52.72	51.70	52.21	60.57	60.78	60.68	6.67	680.29	1.80	
5	51.30	50.99	51.15	60.77	60.23	60.77	6.95	708.92	1.75	
							Avr.	6.79	692.22	1.65
							S.D.	0.19	18.96	0.13

APPENDIX H (Cont.)

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 3L samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})
	2a ₁	2a ₂	2a	c ₁	c ₂	c			
1	67.76	65.89	66.825	-	-	-	4.07	415.27	-
2	70.07	64.57	67.32	-	-	-	4.01	409.18	-
3	69.08	67.88	68.48	-	-	-	3.88	395.44	-
4	64.47	64.57	64.52	-	-	-	4.37	445.47	-
5	64.47	62.58	63.525	-	-	-	4.51	459.53	-
Avr.							4.17	424.98	
S.D.							0.26	26.60	

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 3S samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})
	2a ₁	2a ₂	2a	c ₁	c ₂	c			
1	45.07	43.38	44.23	53.79	55.80	54.79	9.30	948.13	2.72
2	49.67	50.00	49.84	68.42	45.70	57.06	7.32	746.68	2.71
3	47.04	46.69	46.87	62.83	51.49	57.16	8.28	844.32	2.54
4	48.36	47.68	48.02	67.11	45.03	56.07	7.89	804.19	2.76
5	45.07	46.69	45.88	53.29	58.12	55.70	8.64	880.96	2.69
Avr.							8.29	844.86	2.68
S.D.							0.75	76.26	0.08

APPENDIX H (Cont.)

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 2L samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})
	2a ₁	2a ₂	2a	c ₁	c ₂	c			
1	106.25	99.01	102.63	-	-	-	1.73	176.06	-
2	108.22	94.04	101.13	-	-	-	1.78	181.32	-
3	101.64	91.06	96.35	-	-	-	1.96	199.76	-
4	110.20	95.03	102.615	-	-	-	1.73	176.11	-
5	102.91	90.73	96.82	-	-	-	1.94	197.82	-
Avr.							1.83	186.21	
S.D.							0.11	11.70	

Vicker hardness (HV) 1 kg load and fracture toughness (K_{Ic}) of 2S samples fired 1700 °C for 1 hour.

Sample	Mean length of diagonal (microns)						HV (GPa)	HV (kg/mm ²)	K_{Ic} (MPa m ^{1/2})
	2a ₁	2a ₂	2a	c ₁	c ₂	c			
1	53.95	49.34	51.645	54.9	54.97	54.97	6.82	695.26	3.30
2	48.03	49.01	48.52	68.32	68.00	68.32	7.73	787.70	1.61
3	50.99	49.67	50.33	67.11	51.32	59.22	7.18	732.06	2.57
4	50.00	50.99	50.495	64.8	45.03	54.92	7.13	727.29	3.23
Avr.							7.22	735.58	2.68
S.D.							0.38	38.40	0.78

APPENDIX H (Cont.)

Vicker hardness (HV) 5 kg loads of 4L samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	114.75	115.57	115.16	6.86	699.15
2	115.28	115.64	115.46	6.82	699.72
3	117.4	118.2	117.8	6.55	665.05
4	118.3	119.64	118.97	6.43	656.81
5	120.3	119.89	120.095	6.31	681.99
			Avr.	6.59	680.54
			S.D.	0.24	19.49

Vicker hardness (HV) 5 kg loads of 4S samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	121.31	118.03	119.67	6.35	647.44
2	123.77	117.21	120.49	6.27	638.66
3	122.13	110.66	116.40	6.71	684.39
4	114.75	113.93	114.34	6.96	709.21
5	118.85	118.03	118.44	6.48	660.96
			Avr.	6.55	668.13
			S.D.	0.28	28.72

APPENDIX H (Cont.)

Vicker hardness (HV) 5 kg loads of 3L samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	151.64	152.46	152.05	3.93	401.05
2	155.74	147.54	151.64	3.96	403.22
3	151.64	155.74	153.69	3.85	392.54
4	162.30	145.90	154.10	3.83	390.45
5	151.64	151.64	151.64	3.96	403.22
			Avr.	3.91	398.10
			S.D.	0.06	6.14

Vicker hardness (HV) 5 kg loads of 3S samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	109.84	106.56	108.2	7.77	791.99
2	109.02	107.38	108.2	7.77	791.99
3	109.02	106.56	107.79	7.83	798.02
4	111.48	106.56	109.02	7.65	780.12
5	109.84	105.74	107.79	7.83	798.02
			Avr.	7.77	792.03
			S.D.	0.07	7.31

APPENDIX H (Cont.)

Vicker hardness (HV) 5 kg loads of 2L samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	263.11	261.48	262.295	1.32	134.77
2	254.92	254.1	254.51	1.40	143.14
3	252.46	247.54	250.00	1.46	148.35
4	258.20	250.00	254.1	1.41	143.60
5	262.3	246.72	254.51	1.40	143.14
			Avr.	1.40	142.60
			S.D.	0.05	4.90

Vicker hardness (HV) 5 kg loads of 2S samples fired 1700 °C for 1 hour.

Number	Mean length of diagonal (microns)			HV (GPa)	HV (kg/mm ²)
	2a ₁	2a ₂	2a		
1	116.39	117.21	116.8	6.67	679.65
2	114.75	115.57	115.16	6.86	699.15
3	115.57	114.75	115.16	6.86	699.15
4	118.85	118.03	118.44	6.48	660.96
5	118.03	122.95	120.49	6.27	638.66
			Avr.	6.63	675.52
			S.D.	0.26	26.00

APPENDIX I

Thermal shock resistance of 4L samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	122.15	172.46	41.07	23.30
2	107.41	153.54	18.98	35.58
3	127.29	147.94	45.51	30.57
4	108.95	188.25	28.36	25.11
5	153.31	134.23	41.05	26.10
Avr.	123.82	159.28	34.99	28.13
S.D.	18.54	21.22	11.01	4.95

Thermal shock resistance of 4S samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	34.18	123.84	35.56	34.18
2	17.77	112.18	36.96	17.77
3	24.17	119.87	61.46	24.17
4	29.10	113.31	52.69	29.10
5	26.66	134.75	44.67	26.66
Avr.	26.38	120.79	46.27	26.38
S.D.	6.07	9.15	10.91	6.07

APPENDIX I (Cont.)

Thermal shock resistance of 3L samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	70.72	98.87	28.98	24.67
2	112.88	72.16	33.28	29.56
3	105.67	96.39	20.11	31.51
4	112.90	61.27	19.41	28.10
5	119.33	84.57	44.78	26.44
Avr.	104.30	82.65	29.31	28.05
S.D.	19.38	15.99	10.46	2.66

Thermal shock resistance of 3S samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	158.47	148.55	49.39	26.21
2	143.13	122.24	60.93	28.91
3	124.17	118.13	71.22	36.74
4	189.40	111.50	47.90	24.66
5	143.51	119.45	41.14	22.14
Avr.	151.74	123.98	54.11	27.73
S.D.	24.32	14.29	11.92	5.60

APPENDIX I (Cont.)

Thermal shock resistance of 2L samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	63.50	42.92	25.41	32.24
2	55.39	72.58	43.02	25.99
3	87.14	62.48	39.59	27.13
4	83.37	43.02	38.04	24.51
5	56.68	-	48.96	30.70
Avr.	69.22	55.25	39.01	28.12
S.D.	15.02	14.77	8.68	3.25

Thermal shock resistance of 2S samples fired 1700 °C for 1 hour.

Samples	Flexural strength (MPa)			
	delta T = 200 °C	delta T = 250 °C	delta T = 300 °C	delta T = 400 °C
1	137.64	49.49	65.96	35.91
2	129.46	45.80	52.15	25.43
3	129.62	64.64	41.23	37.89
4	136.57	57.60	52.69	38.10
5	116.34	67.86	30.91	23.08
Avr.	129.92	57.08	48.59	32.08
S.D.	8.49	9.47	13.21	7.25

BIOGRAPHY

Miss Umaporn Sangwanna was born 8th January 1980 in Suphanburi. She graduated in Bachelor of Engineering (Ceramic Engineering) from Suranaree University of Technology on August 2001. After that, she continued a further study in Master's Degree in the field of Ceramic Technology at Chulalongkorn University and graduated in February 2005.



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