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APPENDICES

Appendix A Determination of Thermal Conductivity of Metal Oxide-filled Epoxy Composite

Filler type	Filler content (vol%)	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
CuO < 5 micron	0	0.216	0.217	0.215	0.216
	0.5	0.219	0.221	0.218	0.219
	1.0	0.225	0.224	0.222	0.224
	2.0	0.234	0.233	0.235	0.234
CuO nanoparticle	0	0.216	0.217	0.215	0.216
	0.5	0.224	0.225	0.223	0.224
	1.0	0.229	0.230	0.228	0.229
	2.0	0.239	0.237	0.24	0.239
ZnO < 1 micron	0	0.216	0.217	0.215	0.216
	0.5	0.227	0.226	0.226	0.226
	1.0	0.231	0.233	0.232	0.232
	2.0	0.246	0.245	0.244	0.245
ZnO nanoparticle	0	0.216	0.217	0.215	0.216
	0.5	0.231	0.233	0.227	0.230
	1.0	0.237	0.236	0.233	0.235
	2.0	0.251	0.250	0.247	0.249

Appendix B Determination of Thermal Conductivity of BN-filled Epoxy Composite

Table B1 Thermal conductivity at various filler content for 30 min at 30°C

Mixing speed (rpm)	Filler content (vol%)	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
80	0	0.216	0.217	0.215	0.216
	9.09	0.356	0.357	0.352	0.354
	16.67	0.487	0.483	0.485	0.485
	23.08	0.650	0.649	0.645	0.648
	28.57	0.863	0.862	0.858	0.861
	33.33	1.064	1.063	1.060	1.062
	37.50	1.255	1.253	1.251	1.253
300	0	0.216	0.217	0.215	0.216
	9.09	0.423	0.424	0.427	0.425
	16.67	0.668	0.670	0.672	0.670
	23.08	0.925	0.922	0.923	0.923
	28.57	1.253	1.251	1.248	1.250
	33.33	1.499	1.493	1.496	1.496
	37.50	1.688	1.686	1.690	1.688

Table B2 Thermal conductivity at various mixing conditions with 28.57 vol% BN-filled epoxy composite

Type of condition	Mixing conditions	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
Mixing speed (rpm)	80	0.863	0.862	0.858	0.861
	150	0.998	0.102	0.994	0.998
	220	1.149	1.152	1.151	1.150
	300	1.249	1.253	1.248	1.250
Mixing time (sec)	5	0.216	0.217	0.215	0.770
	15	0.813	0.815	0.817	0.815
	30	0.863	0.862	0.858	0.861
	60	0.976	0.970	0.973	0.973
Mixing temperature (°C)	30	0.863	0.862	0.858	0.861
	50	1.158	1.165	1.162	1.162
	70	1.450	1.447	1.443	1.447

Table B3 Thermal conductivity of admicellar treated BN-filled epoxy composite

Type of monomer	Surfactant:monomer ratio	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
PMMA	0	1.484	1.488	1.486	1.486
	1:2.5	2.016	2.015	2.017	2.016
	1:5	2.366	2.365	2.364	2.365
	1:7.5	2.541	2.542	2.540	2.541
	1:10	2.683	2.685	2.684	2.684
	1:12.5	2.679	2.680	2.678	2.679
	1:15	2.096	2.098	2.100	2.098
PS	0	1.488	1.485	1.484	1.486
	1:2.5	1.957	1.956	1.958	1.957
	1:5	2.253	2.256	2.252	2.254
	1:7.5	2.433	2.432	2.434	2.433
	1:10	2.569	2.570	2.568	2.569
	1:12.5	2.207	2.211	2.209	2.209
	1:15	1.723	1.725	1.727	1.725

Table B4 Thermal conductivity of silane treated BN-filled epoxy composite

Type of silane	Concentration of Silane solution (wt%)	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
GPS	0	1.484	1.488	1.486	1.486
	0.025	1.633	1.630	1.631	1.631
	0.05	1.786	1.788	1.787	1.787
	0.075	1.866	1.865	1.864	1.864
	0.1	1.933	1.934	1.935	1.934
	0.15	1.953	1.955	1.954	1.954
APS	0	1.488	1.485	1.484	1.486
	0.025	1.568	1.566	1.567	1.567
	0.05	1.664	1.662	1.663	1.663
	0.075	1.762	1.763	1.764	1.763
	0.1	1.855	1.856	1.857	1.855
	0.15	1.886	1.887	1.885	1.886

Table B5 Thermal conductivity of surfactant treated BN-filled epoxy composite

Type of surfactant	pH	Thermal conductivity (W/mK)			
		I.	II.	III.	Average
DTAB	5.5	2.35	2.36	2.37	2.36
	6.0	2.43	2.42	2.44	2.43
	7.0	2.56	2.58	2.60	2.58
	8.0	2.73	2.74	2.72	2.73
TTAB	5.5	2.58	2.57	2.56	2.57
	6.0	2.63	2.65	2.64	2.64
	7.0	2.77	2.81	2.79	2.79
	8.0	2.94	2.95	2.93	2.94
HTAB	5.5	2.75	2.74	2.76	2.76
	6.0	2.85	2.84	2.86	2.84
	7.0	2.97	3.01	2.98	2.99
	8.0	3.12	3.16	3.14	3.14
OTAB	5.5	3.05	3.06	3.08	3.07
	6.0	3.15	3.13	3.14	3.14
	7.0	3.27	3.28	3.31	3.29
	8.0	3.44	3.43	3.40	3.42

Appendix C Determination of Viscosity of BN-filled Epoxy Suspension

Table C1 The viscosity of BN-filled epoxy suspension with various filler content

Filler content (vol%)	Viscosity (Pa.s)
0	2.10
9.09	2.70
16.67	3.70
23.08	5.65
28.57	9.50
33.33	15.32
37.50	36.50

Table C2 The viscosity of BN-filled epoxy suspension with various mixing conditions

Type of condition	Mixing conditions	Viscosity (Pa.s)			
		I.	II.	III.	Average
Mixing speed (rpm)	80	9.53	9.48	9.51	9.50
	150	10.08	10.00	10.03	10.04
	220	10.97	10.95	10.93	10.95
	300	14.02	14.38	14.00	14.00
Mixing time (sec)	5	7.55	7.49	7.48	7.51
	15	8.45	8.42	8.40	8.42
	30	9.53	9.48	9.51	9.50
	60	11.04	10.98	10.99	11.00
Mixing temperature (^{o}C)	30	9.53	9.48	9.51	9.50
	50	12.02	12.00	11.58	12.00
	70	15.03	15.01	14.97	15.00

Appendix D Determination of Zeta Potential of BN Particles

pH	Zeta potential (mV)
2	3.8
3	1.9
4	0.9
5	-1.5
6	-2.6
7	-5.2
8	-6.1
9	-6.4
10	-6.8

Appendix E Determination of Surfactant Adsorption on BN Surface

Table E1 The amount of adsorbed surfactant (μmol/g BN)

Type of surfactant	pH	The amount of adsorbed surfactant (μmol/g BN)			
		I.	II.	III.	Average
DTAB	5.5	1.46	1.49	1.47	1.48
	6.0	1.65	1.61	1.63	1.63
	7.0	1.81	1.80	1.77	1.79
	8.0	1.85	1.91	1.88	1.88
TTAB	5.5	1.62	1.65	1.61	1.63
	6.0	1.71	1.72	1.73	1.72
	7.0	1.87	1.89	1.88	1.89
	8.0	1.99	1.98	1.98	1.98
HTAB	5.5	1.76	1.74	1.75	1.75
	6.0	1.88	1.84	1.86	1.86
	7.0	2.00	1.96	1.97	1.98
	8.0	2.08	2.12	2.10	2.10
OTAB	5.5	1.98	1.96	1.94	1.96
	6.0	2.01	2.05	2.05	2.04
	7.0	2.13	2.12	2.17	2.15
	8.0	2.24	2.29	2.26	2.27

Appendix F Determination of Mechanical Properties of BN-filled Epoxy Composite

Table F1 Determination of flexural property with various filler content

Mechanical Property	Filler content (vol%)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	0	24.8	26.7	25.6	25.7
	9.09	33.6	32.4	31.4	32.5
	16.67	37.9	36.4	36.9	37.1
	23.08	41.5	39.7	40.7	40.6
	28.57	46.2	42.5	44.3	44.1
	33.33	47.6	44.9	45.2	46.0
	37.50	49.2	46.3	47.3	47.6
Flexural modulus (MPa)	0	2462	2482	2455	2466
	9.09	2509	2532	2520	2520
	16.67	2598	2574	2585	2586
	23.08	2670	2645	2660	2658
	28.57	2718	2738	2752	2736
	33.33	2878	2920	2888	2895
	37.50	3110	3072	3063	3082

Table F2 Determination of flexural property at various mixing speed

Mechanical Property	Mixing speed (rpm)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	80	46.2	42.5	44.3	44.1
	150	42.1	44.7	43.6	43.5
	220	46.5	50.7	48.6	48.6
	300	49.5	51.7	53.5	51.5
Flexural modulus (MPa)	80	2718	2738	2752	2736
	150	2879	2860	2950	2896
	220	3278	3312	3334	3305
	300	3575	3589	3482	3549

Table F3 Determination of flexural property at various mixing time

Mechanical Property	Mixing time (sec)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	5	41.8	43.9	42.6	42.8
	30	46.2	42.5	44.3	44.1
	60	47.9	43.8	44.9	45.6
Flexural modulus (MPa)	5	2616	2625	2652	2631
	30	2718	2738	2752	2736
	60	2832	2812	2786	2810

Table F4 Determination of flexural property at various mixing temperature

Mechanical Property	Mixing temperature (°C)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	30	46.2	42.5	44.3	44.1
	50	47.6	46.4	47.8	47.2
	70	49.8	51.4	50.1	50.6
Flexural modulus (MPa)	30	2718	2738	2752	2736
	50	2948	2951	2963	2956
	70	3089	3126	3101	3105

Table F5 Determination of impact strength with various filler content

Filler content (vol%)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
0	10.8	11.6	12.4	11.8
9.09	15.6	16.4	18.4	16.9
16.67	19.9	21.4	22.9	21.8
23.08	24.5	28.7	23.7	26.4
28.57	32.2	30.5	31.3	31.6
33.33	38.6	34.9	35.2	36.4
37.50	29.2	28.6	32.3	30.1

Table F6 Determination of impact strength at various mixing speed

Mixing speed (rpm)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
80	32.2	30.5	31.3	31.6
150	34.1	35.7	38.6	36.2
220	38.5	39.7	42.6	40.1
300	41.5	44.7	43.5	43.4

Table F7 Determination of impact strength at various mixing time

Mixing time (sec)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
5	26.8	27.9	29.6	28.6
30	30.2	29.8	32.7	31.6
60	31.9	32.6	34.9	33.2

Table F8 Determination of impact strength at various mixing temperature

Mixing temperature (°C)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
30	32.2	30.5	31.3	31.6
50	31.9	32.4	34.7	33.8
70	34.8	35.8	37.9	36.3

Table F9 Determination of flexural strength of admicellar treated BN-filled epoxy composite

Type of monomer	Surfactant:monomer ratio	Flexural strength (MPa)			
		I.	II.	III.	Average
PMMA	0	45.63	45.22	45.45	45.58
	1:2.5	48.72	48.65	48.97	48.82
	1:5	49.78	49.57	49.63	49.68
	1:7.5	50.55	50.34	50.41	50.43
	1:10	51.08	50.76	50.86	50.97
	1:12.5	50.96	50.72	50.62	50.85
	1:15	50.51	50.32	50.28	50.40
PS	0	45.63	45.22	45.45	45.58
	1:2.5	48.12	47.75	47.83	47.95
	1:5	48.74	48.46	48.59	48.62
	1:7.5	49.22	49.01	48.92	49.14
	1:10	49.76	49.47	49.53	49.65
	1:12.5	49.38	49.12	49.21	49.23
	1:15	47.89	47.57	47.71	47.75

Table F10 Determination of flexural modulus of admicellar treated BN-filled epoxy composite

Type of monomer	Surfactant:monomer ratio	Flexural modulus (GPa)			
		I.	II.	III.	Average
PMMA	0	2.75	2.63	2.98	2.86
	1:2.5	3.14	3.21	3.43	3.24
	1:5	3.22	3.30	3.54	3.36
	1:7.5	3.26	3.38	3.62	3.44
	1:10	3.39	3.45	3.74	3.51
	1:12.5	3.35	3.71	3.42	3.50
	1:15	3.28	3.62	3.38	3.4
PS	0	2.75	2.63	2.98	2.86
	1:2.5	2.97	3.08	3.32	3.16
	1:5	3.11	3.23	3.41	3.28
	1:7.5	3.32	3.24	3.55	3.35
	1:10	3.29	3.36	3.64	3.40
	1:12.5	3.18	3.31	3.57	3.38
	1:15	3.11	3.53	3.19	3.20

Table F11 Determination of flexural strength of silane treated BN-filled epoxy composite

Type of silane	Concentration of Silane solution (wt%)	Flexural strength (MPa)			
		I.	II.	III.	Average
GPS	0	45.63	45.22	45.45	45.58
	0.025	46.66	46.74	46.98	46.82
	0.05	47.52	47.63	47.82	47.68
	0.075	48.33	48.40	48.63	48.43
	0.1	48.76	48.85	49.10	48.97
APS	0	45.63	45.22	45.45	45.58
	0.025	45.78	45.84	46.12	45.95
	0.05	46.31	46.39	46.60	46.42
	0.075	47.02	47.11	47.34	47.14
	0.1	47.48	47.59	47.85	47.65

Table F12 Determination of flexural modulus of silane treated BN-filled epoxy composite

Type of silane	Concentration of Silane solution (wt%)	Flexural strength (MPa)			
		I.	II.	III.	Average
GPS	0	2.75	2.63	2.98	2.86
	0.025	2.76	2.98	2.85	2.90
	0.05	2.87	2.94	3.04	2.97
	0.075	3.01	3.28	3.11	3.15
	0.1	3.19	3.46	3.25	3.30
APS	0	2.75	2.63	2.98	2.86
	0.025	2.74	2.83	2.97	2.88
	0.05	2.98	2.85	2.73	2.90
	0.075	2.88	3.16	3.08	3.05
	0.1	2.88	2.97	3.12	2.93

Table F13 Determination of impact strength of admicellar treated BN-filled epoxy composite

Type of monomer	Surfactant:monomer ratio	Impact strength (kJ/m^2)			
		I.	II.	III.	Average
PMMA	0	31.2	34.7	32.2	32.5
	1:2.5	37.5	38.0	39.1	38.1
	1:5	40.1	41.2	42.8	41.5
	1:7.5	45.9	44.0	42.8	44.1
	1:10	45.2	46.3	48.5	46.8
	1:12.5	44.9	45.6	48.4	46.0
	1:15	43.1	47.0	46.2	45.5
PS	0	31.2	34.7	32.2	32.5
	1:2.5	35.6	38.7	36.8	37.2
	1:5	37.0	38.6	41.7	39.8
	1:7.5	42.1	41.0	44.5	42.3
	1:10	43.9	44.8	47.2	45.2
	1:12.5	43.3	44.0	46.2	44.5
	1:15	42.1	43.5	45.4	43.8

Table F14 Determination of impact strength of silane treated BN-filled epoxy composite

Type of silane	Concentration of Silane solution (wt%)	Impact strength (kJ/m^2)			
		I.	II.	III.	Average
GPS	0	31.2	34.7	32.2	32.5
	0.025	34.5	38.0	35.6	36.1
	0.05	38.1	41.2	37.6	39.4
	0.075	40.4	44.1	39.8	42.1
	0.1	42.7	43.6	46.0	44.4
APS	0	31.2	34.7	32.2	32.5
	0.025	34.3	36.8	35.1	35.2
	0.05	35.9	36.4	39.2	37.3
	0.075	37.5	38.9	41.2	39.7
	0.1	40.9	41.6	44.0	42.8

Table F15 Determination of flexural property of HTAB treated BN-filled epoxy composite

Mechanical Property	The amount of adsorbed surfactant (μmol/g BN)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	1.75	57.3	58.6	60.04	59.0
	1.86	59.5	63.0	60.2	61.9
	1.98	66.4	69.1	67.2	67.5
	2.10	75.4	73.9	77.6	75.1
Flexural modulus (GPa)	1.75	3.75	3.96	3.83	3.86
	1.86	4.01	3.79	3.81	3.88
	1.98	3.70	3.86	4.05	3.90
	2.10	3.84	3.90	4.01	3.92

Table F16 Determination of flexural property of surfactant treated BN-filled epoxy composite

Mechanical Property	Chain length (C-atom)	Result			
		I.	II.	III.	Average
Flexural strength (MPa)	12	66.0	68.0	67.0	68.0
	14	69.8	70.4	73.5	71.9
	16	75.4	73.9	77.6	75.1
	18	76.8	78.9	77.1	77.3
Flexural modulus (GPa)	12	3.75	3.66	3.83	3.77
	14	4.01	3.72	3.81	3.83
	16	3.84	3.90	4.01	3.92
	18	3.84	3.90	4.08	3.97

Table F17 Determination of impact strength of HTAB treated BN-filled epoxy composite

The amount of adsorbed surfactant (μmol/g BN)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
1.75	47.6	51.2	48.7	49.5
1.86	49.8	48.2	51.7	50.1
1.98	50.8	49.6	52.7	51.2
2.10	50.7	51.4	53.6	52.0

Table F18 Determination of impact strength of surfactant treated BN-filled epoxy composite

Chain length (C-atom)	Impact strength (kJ/m^2)			
	I.	II.	III.	Average
12	47.2	50.1	48.5	48.6
14	52.5	51.3	49.8	51.2
16	54.4	50.1	51.2	52.0
18	54.8	50.9	51.6	52.5

Appendix G Determination of Contact Angle of Surface-treated BN particles

Table G1 Determination of contact angle of admicellar-treated and silane-treated BN using water droplet

Time (s)	Epoxy	Type of BN particles				
		PMMA	PS	GPS	APS	Untreated
0	96.5	94.0	92.8	90.0	88.3	86.8
5	95.5	93.0	91.5	89.0	87.	86.4
10	94.7	92.2	90.6	88.2	87.2	86.2
15	94.0	91.5	89.6	87.5	86.6	85.5
20	93.4	90.9	89.1	86.9	86.1	85.1
25	92.5	90.0	88.6	86.0	85.2	84.4
30	92.2	89.7	88.2	85.7	84.6	84.0
35	91.6	89.1	87.5	85.1	84.3	83.5
40	91.1	88.6	87.1	84.6	83.9	83.2
45	90.4	87.9	86.5	83.9	83.2	82.5
50	89.6	87.1	85.8	83.1	82.5	81.8
55	89.1	86.6	85.4	82.6	82.2	81.3
60	88.6	86.1	84.5	82.1	81.5	80.7

Table G2 Determination of contact angle of admicellar-treated and silane-treated BN using epoxy droplet

Time (s)	Type of BN particles				
	Untreated	APS	GPS	PS	PMMA
0	93.1	84.9	79.9	76.4	70.5
5	87.5	76.8	73.8	67.5	59.9
10	82.4	72.4	69.6	63.2	54.1
15	77.4	69.8	66.4	60.1	49.7
20	73.0	67.5	64.6	57.5	45.6
25	70.7	65.6	62.2	55.4	42.1
30	69.2	64.6	61.1	54.2	40.1
35	67.2	63.3	60.4	52.3	38.3
40	65.8	61.5	58.9	50.7	36.8
45	64.2	60.4	56.8	48.6	35.6
50	63.6	59.7	55.5	47.1	34.4
55	62.3	58.6	54.7	46.5	33.5
60	61.1	57.6	53.8	46.2	32.4

Table G3 Determination of contact angle of surfactant- treated BN using water droplet

Time (s)	Type of BN particles				
	OTAB	HTAB	TTAB	DTAB	Untreated
0	96.5	94.0	91.0	89.0	86.6
5	95.5	93.0	90.0	88.0	86.4
10	94.7	92.2	89.2	87.2	86.2
15	94.0	91.5	88.5	86.5	85.5
20	93.4	90.9	87.9	85.9	85.3
25	92.5	90.0	87.0	85.0	84.7
30	92.2	89.7	86.7	84.7	84.0
35	91.6	89.1	86.1	84.1	83.5
40	91.1	88.6	85.6	83.8	83.2
45	90.4	87.9	84.9	83.4	82.5
50	89.6	87.1	84.1	82.9	81.8
55	89.1	86.6	83.6	82.2	81.3
60	88.6	86.1	83.1	81.4	80.7

Appendix H Determination of the Occupied Surface Area of Surfactant-treated BN particles

Table H1 Determination of the occupied surface area of surfactant treated-BN with various the amount of surfactant adsorption at pH 5.5

Experimental data	DTAB	TTAB	HTAB	OTAB
The amount of surfactant adsorption (μmol/g BN)	1.48	1.63	1.79	1.88
The occupied surface area (m^2/g)	2.69	2.93	3.00	3.09

Table H2 Determination of the occupied surface area of surfactant treated-BN with various the amount of surfactant adsorption at pH 6.0

Experimental data	DTAB	TTAB	HTAB	OTAB
The amount of surfactant adsorption (μmol/g BN)	1.63	1.72	1.89	1.98
The occupied surface area (m^2/g)	3.70	3.93	4.03	4.17

Table H3 Determination of the occupied surface area of surfactant treated-BN with various the amount of surfactant adsorption at pH 7.0

Experimental data	DTAB	TTAB	HTAB	OTAB
The amount of surfactant adsorption (μmol/g BN)	1.75	1.86	1.98	2.10
The occupied surface area (m^2/g)	4.77	4.98	5.21	5.44

Table H4 Determination of the occupied surface area of surfactant treated-BN with various the amount of surfactant adsorption at pH 8.0

Experimental data	DTAB	TTAB	HTAB	OTAB
The amount of surfactant adsorption (μmol/g BN)	1.96	2.04	2.15	2.27
The occupied surface area (m^2/g)	5.28	5.52	5.77	5.87

CURRICULUM VITAE

Name: Ms. Karnthidaporn Wattanakul

Date of Birth: July 23, 1979

Nationality: Thai

University Education:

1996–1999 Bachelor Degree of Science (2nd Class Honours), Faculty of Science, King Mongkut's University of Thonburi, Bangkok, Thailand

2000-2003 Master Degree of Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

Work Experience:

2003-2004	Position:	Product Development Engineer
	Company name:	Siam Cement Group, Thailand
2004-2005	Position:	Lecturer
	Company name:	King Mongkut's University of Technology North Bangkok

Publications:

1. Wattanakul, K.; Manuspiya, H.; and Yanumet, N. Effective surface treatments for enhancing the thermal conductivity of BN-filled epoxy composite, accepted.
2. Wattanakul, K.; Manuspiya, H.; and Yanumet, N. The adsorption of cationic surfactants on BN surface: its effects on the thermal conductivity and mechanical properties of BN-epoxy composite, accepted.
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Presentations:

1. Wattanakul, K.; Manuspiya, H.; and Yanumet, N. (2008, February 25-29) Effect of mixing condition on an improvement in thermal conductivity of epoxy

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