REFERENCES

Balagaru, P. N.; Shah, S. P. Fiber-Reinforced Cement Composites. Singapore: McGraw-Hill. 1992.

Berrong, J. M.; Weed, R. M.; and Young J. M. "Fracture resistance of Kevlar reinforced PMMA resins: A Preliminary study" The international J. Prosthodentics. 1990; 34: 391-395.

Billmeyer, F. W. Textbook of Polymer Science. New York: John Wiley & Sons, 1984.

Braden M., Davy KWM, Parker S, Ladizesky NH, Ward IM. "Denture base poly(methyl methacrylate) reinforced with ultra-high modulus polyethylene fibers" British Dental Journal. 1988;164:109-13.

Brydson J. A. Plastics Materials 5 th Ed. Polytechnic of North London. London, 1988: 122-124.

Carroll CE.; Von Fraunhofer JA. "Wire reinforcement of acrylic resin prostheses". Journal of Prosthet Dent..1984: 52:639-41.

Chapman, D. R.; Uvarov, B. Dictionary of Science. London: Cox & Wyman, 1971.

Chen. S. Y. Improvement of denture base resin reinforced by incorporating various fibers school of dentistry China Medical College Taiwan, ROC, 1991.

Chen. X.; Guo. Q.; and Mi Y. "Bamboo Fiber-Reinforced Polypropylene Composites: A Study of the Mechanical Properties" , Journal of Applied Polymer Science. 1997; 69: 1891-1899.

Chow T. W.; Cheng YY.; Ladizesky N. H. "Polyethylene fiber reinforced poly(methyl methacrylate) –water absorption and dimensional changes during immersion".Journal of Dentistry. 1993; 21: 367-72.

Collier; J. R., et al. "Process for obtaining cellulosic fiber bundles from plant stalk rind." Available from: www.lsu.edu/intellectual property/htmldocs/tex2.html.. [2002. April 3].

Donovan, T. E.; Hurst, R. G.; and Campagni. W. V." Physical properties of acrylic resin polymerized by four different techniques" J Prosthet Dent.. 1985; 54: 522-528.

Ekstrand K and Ruyter IE "Carbon/graphite fiber reinforced poly(methyl methacrylate):properties under dry and wet conditions".J Biomed Mater Res.. 1987;21:1065-80.

Geerts, G. A. V. M.; and Jooste, C. H." A comparison of the bond strengths of Microwave and water bath cured denture materials" J Prosthet Dent. 1993; 70:406-409.

Glyn R. "Sorting the names of bamboos" Available form http://www.//gmr.landfood.unimelb.edu.au/Plantnames/Sorting/Bamboos/ Thai_index.html. The University of Melbourne, 1995.

Gutteridge D.L. "The effect of including ultra-high-modulus polyethylene fiber on the impact strength of acrylic resin" British Dentistry Journal. 1988:164:177-80.

Gutterridge D.L. "Reinforcement of poly(methyl methacrylate) with ultra-high-modulus polyethylene fibre" J Dent.. 1992: 20: 50-4.

J.Burdette, L. Conway, W.E. Ella Lanier, and J. Sharpe. "The Manufacture of Pulp and Paper: Science and Engineering Concepts." U.S.A., 1988.

Jain, S.; Kumar, R.: Jindal, U. C. "Physical properties of bamboo" Journal of Material Science. 1992; 27: 4598-4604.

Jeanne M. Anglin. "Engineered materials handbook composite Volume 1" USA: ASM International. 1988.

Kamnueng Kum-udom, Pai Dton 5 th Ed. Asia Pacific Printing, 1999, 7-8.

Kanie, T.; Fujii, K.; Arikawa, H.; and Inoue, K. "Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers" Dental Materials. 2000; 16: 150-158.

Kongsak Dokbua. On Enhancement of Interfacial Adhesion Induced by Coupling Reaction of S-triazine in Polyester Composite Master's Thesis, Department of Science, Graduate School, Chulalongkorn, 1993.

Larson, W. R.; Dixon, D. L.; Aquilino, S. A.; and Clancy, J.M. "The effect of carbon graphite fiber reinforcement on the strength of provisional crown and fixed partial denture resin" J Prosthet Dent. 1991; 66: 816-820.

Lewis, R. J. Hawley's Condensed Chemical Dictionary. U.S.A.: Nortrand Reinhold. 1993.

Li, S.; Fu, S.; and Zhou, F. "Experimental investigation of biomimetic double-helical reinforcing elements" Journal of Materials Science Letters, 1995: 14: 769-772.

Liu. Q., et al. "Filler-coupling agent-matrix interactions in silica/polymethylmethacrylate composites" J Biomed Mater Res., 2001; 57: 384-393.

Manley, T. R.; Bowman, A. J.; and M.Cook. "Denture bases reinforced with carbon fiber" British Dent.J. 1979; 2: 25-26.

Matias, M. C., et al. "Comparative Spectroscopic Study of the Modification of Cellulosic Materials with Different Coupling Agents" Journal of Applied Polymer Science: 1999; 75: 256-266.

Matthews, F. L.; Rawlings, R. D. Composite Materials: Engineering and Science. 1st edition, Chapman & Hill, London. 1994.

McCrum, N. G,; Buckley, C. P.,and Bucknall C .B. Principles of Polymer Engineering. New York : University Press. 1988.

Mohmod , A. L., and others Variability in Specific Gravity, Fiber Dimesion, and Chemical Compostions of Six Malasian Bamboos. Paper Prepared for Presentation at the Intermation Conference on Forest Products, Bangkok, Thailand, December 16-22,1996, 1-12.

Niranchana Kasemsook. The Use of Silane Coupling Agents in Natural Fiber-Unsaturated Polyester Composites. Master's Thesis, The Petroleum and Petrochemical College, Graduate School, Chulalongkorn University, 1999.

Ordain, G. Principle of Polymerization. 3rd Edition John Wiley&Sons, 1991.

Pattamage, S. Biodegradable Plastic Processing from Tapioca Starch Master's thesis, Department of Science. King Mongkut's Institute of Technology Ladkrabang (KMITL), 1996.

Pinyo Panitchapun "Basic knowledge about carbohydrate" document prepared in the conference, Department of Science,Srinakharinwirot University, 8 May 1996: 7-110.

Piyawan Tangkawanwanit. Studies of Natural Fiber/Polymer Composites from Bamboo. Master's Thesis, Department of Science, Graduate School, King Mongkut's Institute of Technology Ladkrabang (KMITL), 1998.

Ramos, V.; Runyan D. A.; and Christensen, L. C. "The effect of plasma treated PE fiber on the fracture strength of PMMA" J Prosthet Dent. 1996; 76: 94-96.

Ray N. Dental Material Science [Online]. 1998. Available from: http://www.ucc.ie/ucc/depts/restorative/dentext/dchap4.pdf [2002. Mar 23].

Richardson, T. Composite: A design Guide. New York: Industrial Press, New York, 1987.

Rozman, H. D., et al. "The effect of lignin as a compatibilizer on the physical properties of coconut fiber-polypropylene composites" European Polymer Journal. 2000; 36: 1483-1494.

Ruffino AR. Effect of steel strengtheners on fracture resistance of the acrylic resin complete denture base. J Prosthet Dent. 1985; 54: 75-8.

Ryu S.R. and Lee D.J. Effect of Fiber Aspect Ratio, Fiber Content, and Bonding Agent on Tensile and Tear Properties of Short-Fiber Reinforced Rubber. KSME International Journal. 2001; 15: 35-43.

Salamone, C. C. Polymer materials encyclopedia. vol. 1 / A - B , By CRC Press,1996.

Samadzadeh A, Kugel G, hurley E, Aboushala A. "Fracture Strengths of provisional restorations reinforced with plasma-treated woven polyethylene fiber."J.Prosthet Dent.. 1997; 78: 447-50.

Samapuddhi, K.; Mem., I. A. W. A A Prelimary Study in the structure and some properties of some thai bamboos. Thailand: Royal Forest Department Ministry of Agriculture.1959.]

Schwartz, M. M. Composite Material. Volume I: Properties Nondestructive, Testing and Repair. U.S.A.: Prentice Hall PTR Prentice-Hall. Inc. 1997.

Shane, B., et al. "Effects of coupling agent on the physical properties of wood-polymer composites" Journal of Materials Processing Technology; 1995, 48: 365-372.

Sharma, Y. M. L. "Asia Pacific Forest Industries Development Group Regional Resources of Bamboo and Its Utilization in Asia Pacific Region". FO:RAS/78/100, Working Paper No.21 July 1983.

Shihong Li, Ronghui Zhang, Shaoyun Fu, Xin Chen and Benlian Zhou. J. Material Science Technology. 1994; 10:34-38.

Shriner, R. L.; Fuson, R. C.; and Curtin, D. Y. The Systematic Identification of Organic Compounds.5 th Ed. New York: John Willy & Sons, 1964].

Soderstrom, T. R. "Genera of Bamboos Native to the New World (Gramineae: Bambusoideas)" U.S.A.: F.A. McClure, Smithsonian Institution Press City. 1973.

Solnit, G. S. "The effect of PMMA reinforced with silane treated and untreated glass fiber" J Prosthet Dent., 1991; 66: 310-314.

Stipho Hd. "Effect of glass fiber reinforcement on some mechanical properties of autopolymerizing poly(methyl methacrylate)". J Prosthet Dent., 1998; 79: 580-4.

T. Kanie, K. Fujii, H. Arikawa, K. Inoue "Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers" Dental Materials: 16 (2000): 150-158.

Uzun G. Hersek N. Tincer T. "Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resins". J Prosthet Dent., 1999; 81: 616-20.

V.Verma. Dictionary of Biology. New Delhi: Mehtasons.1984.

Vallittu, P.K., Narva K. "Impact strength of a modified continuous glass fiber-poly(methyl methacrylate)". Int. J. prosthodont, 1997; 10:24:124-30.

Vallittu, P. K. "Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers". J Prosthet Dent., 1999; 81: 318-26.

Vallittu, P. K." Curing of a silane coupling agent and its effects on the transverse strength of autopolymerizing PMMA-glass fiber composite" J Oral Rehabilit., 1997; 24:124-130.

Wang, Q.; Kaliaguine, S.; and Ait-Kadi, A.,"A review of recent composite material" Journal of Applied Polymer Science. 1983; 48: 126-136.

Yazdanie N, Mahood M. "Carbon fiber acrylic resin composite: an investigation of transverse strength. J P.osthet Dent.. 1985; 54: 543-7.

Appendices

Appendix A

Error analyses

Most experimental data in this thesis are reported with the error bar of 90 % confidence. It should be noted that the 90% confidence interval or 0.90 confidence coefficient in fact means if it is assumed that the distribution is the normal probability distribution, 90% of data fall within this region. The value can be defined as;

$$t_{.050}\left(\frac{\sigma}{\sqrt{n}}\right) \qquad (A\text{-}1)$$

where $t_{.050}$ is the standard normal value of t.050 at the degree of freedom of (n-1), as can be seen in figure A-1.

σ is standard deviation

n is number of data

<u>For example</u>

From flexural strength test, it appears that the standard deviation of flexural strength of PMMA is 72.8 and the number of specimen is five. At the column of t_{05}, the degree of freedom of 4 in figure A-1, it gives 2.132. Therefore, the value of 90% confidence of flexural strength of PMMA is 2.86. It means that 90 % of flexural strength of PMMA is in the range 72.8 ± 2.9.

Table A-1   Standard Normal Value at various degree of freedom of n-1
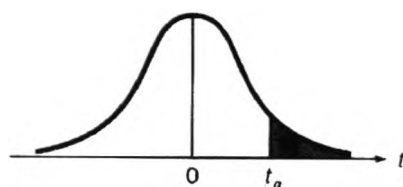
ν	$t_{.100}$	$t_{.050}$	$t_{.025}$	$t_{.010}$	$t_{.005}$	$t_{.001}$	$t_{.0005}$
1	3.078	6.314	12.706	31.821	63.657	318.31	636.62
2	1.886	2.920	4.303	6.965	9.925	22.326	31.598
3	1.638	2.353	3.182	4.541	5.841	10.213	12.924
4	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	1.319	1.714	2.069	2.500	2.807	3.485	3.767
24	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	1.296	1.671	2.000	2.390	2.660	3.232	3.460
120	1.289	1.658	1.980	2.358	2.617	3.160	3.373
∞	1.282	1.645	1.960	2.326	2.576	3.090	3.291

From Mendenhall, W. and Sincich, T., " A Second Course in Statistics: Regression Analysis", 5th edition, Prentice-Hall International, New Jersey, 1996.

Appendix B

Raw Data to find Average Aspect Ratio of Each Size-Group

Table B-1 Raw data of 50 raw data to calculate average aspect ratio of L-size fiber.

Aspect Ratio of Fiber (Size L)				
Group 1	Group 2	Group 3	Group 4	Group 5
17.9	17.0	13.5	14.3	12.8
10.3	15.5	12.2	13.2	17.7
10.8	17.0	11.5	19.0	22.1
10.8	16.5	7.1	12.2	12.5
6.5	15.9	17.9	15.7	20.3
18.0	7.8	22.1	15.2	17.6
13.9	13.6	23.4	20.4	21.6
16.7	10.4	18.4	13.5	13.9
8.3	11.0	18.9	15.4	21.2
12.6	13.2	5.9	11.5	24.3
Average 12.6	13.8	15.1	15.0	18.4
S.D. 4.0	3.2	6.0	2.8	4.2

Average of Fiber (Size L) = 15.0

S.D. of Fiber (Size L) =   4.5

Table B-2 Raw data of 50 raw data to calculate average aspect ratio of M-size fiber.

Aspect Ratio of Fiber (Size M)				
Group 1	Group 2	Group 3	Group 4	Group 5
64.2	46.2	37.9	48.7	36.6
46.9	34.6	65.2	30.3	54.1
57.0	39.0	54.9	45.0	55.9
57.0	40.9	37.6	54.4	41.0
32.2	40.0	36.2	50.9	52.0
53.8	39.7	50.1	27.2	39.3
46.8	34.4	56.8	31.3	41.8
47.9	45.2	41.9	52.6	47.7
42.9	47.3	49.6	46.3	42.5
31.1	50.2	50.3	46.9	44.9
Average	48.0	41.8	48.1	43.4	45.6
S.D.	10.6	5.3	9.5	10.0	6.6

Average of Fiber (Size M)   =   45.3

S.D. of Fiber (Size M) =   8.7

Table B-3 Raw data of 50 raw data to calculate average aspect ratio of S-size fiber.

Aspect Ratio of Fiber (Size S)				
Group 1	Group 2	Group 3	Group 4	Group 5
78.0	84.4	73.8	70.8	88.5
74.4	73.3	92.1	80.0	103.1
80.0	80.0	100.0	75.0	75.0
96.0	80.0	93.3	77.0	76.0
80.0	84.2	75.9	81.8	80.0
82.1	76.8	70.9	80.0	68.8
86.7	70.4	64.8	75.0	80.0
84.4	88.0	85.0	73.5	61.3
73.1	78.0	70.0	86.7	72.3
72.5	75.0	80.0	88.5	86.7
Average	80.7	79.0	80.6	78.8	79.2
S.D.	7.1	5.5	11.6	5.7	11.7

Average of Fiber (Size S) =   79.7

S.D. of Fiber (Size S) =   8.4

Table B-4 Raw data of 50 raw data to calculate average aspect ratio of

S-fiber treated with NaOH for 6 hours

Aspect Ratio of Fiber (Lignin Removal) (6 hours of NaOH treatment, Size S)				
Group 1	Group 2	Group 3	Group 4	Group 5
69.1	78.3	81.3	74.3	83.3
87.5	80.0	76.9	93.3	94.5
80.0	105.0	83.3	72.7	90.0
105.6	80.0	84.0	77.8	100.0
85.0	100.0	100.0	74.3	94.1
115.0	75.0	75.9	96.0	85.0
122.0	77.5	75.0	82.5	88.0
78.3	83.3	94.3	83.3	88.0
71.2	60.0	87.1	84.0	90.9
70.0	91.7	75.0	109.1	89.1
Average				
88.4	83.1	83.3	84.7	90.3
S.D.				
19.2	13.0	8.5	11.6	4.9

Average of Fiber (6-hour treatment) =   86.0

S.D. of Fiber (6-hour treatment) =   12.2

Table B-5 Raw data of 50 raw data to calculate average aspect ratio of
S-fiber treated with NaOH for 12 hours

Aspect Ratio of Fiber (Lignin Removal) (12 hours of NaOH treatment, Size S)					
	Group 1	Group 2	Group 3	Group 4	Group 5
	110.0	89.1	100.0	83.3	81.1
	95.2	102.6	113.3	94.5	100.0
	82.3	100.0	71.4	105.0	90.0
	97.5	88.0	82.0	103.1	122.0
	91.7	89.1	120.0	75.6	105.0
	88.1	86.7	90.9	90.9	106.7
	105.9	113.6	94.4	97.3	90.7
	96.0	95.0	101.3	98.0	96.3
	88.0	114.3	100.0	87.7	105.0
	109.1	85.3	94.1	90.0	95.8
Average	96.4	96.4	96.7	92.6	99.3
S.D.	9.4	10.9	14.0	9.0	11.3

Average of Fiber (12-hour treatment) =   96.3

S.D. of Fiber (12-hour treatment) =   10.8

Table B-6 Raw data of 50 raw data to calculate average aspect ratio of

S-fiber treated with NaOH for 18 hours

Aspect Ratio of Fiber (Lignin Removal) (18 hours of NaOH treatment, Size S)				
Group 1	Group 2	Group 3	Group 4	Group 5
91.5	100.0	114.3	108.8	112.0
110.0	108.0	104.5	106.4	95.5
100.0	95.7	120.0	128.9	100.0
108.9	100.1	96.2	106.3	114.7
106.7	100.0	100.7	97.8	100.0
125.7	112.5	103.6	106.7	120.0
120.5	93.3	100.0	95.7	96.6
94.0	116.7	119.0	105.4	96.7
90.0	108.3	115.4	98.0	120.9
113.3	122.7	118.8	112.0	96.7
Average	106.1	105.7	109.2	106.6	105.3
S.D.	12.1	9.5	9.1	9.5	10.4

Average of Fiber (18-hour treatment) =   106.6

S.D. of Fiber (18-hour treatment) =   9.9

Table B-7 Raw data of 50 raw data to calculate average aspect ratio of
S-fiber treated with NaOH for 24 hours

Aspect Ratio of Fiber (Lignin Removal) (24 hours of NaOH treatment, Size S)				
Group 1	Group 2	Group 3	Group 4	Group 5
146.7	133.2	133.2	120.0	117.5
120.8	125.0	125.0	121.7	121.8
145.0	135.0	135.0	120.0	130.3
126.6	125.0	125.0	128.6	119.2
132.7	125.0	125.0	128.3	126.7
142.2	128.6	128.6	125.7	117.0
116.7	128.4	128.4	124.8	121.7
123.3	119.4	119.4	130.5	128.3
119.0	120.8	120.8	132.8	125.0
120.0	126.7	126.7	133.2	125.9
Average	126.6	123.3	126.7	126.6	123.3
S.D.	11.5	4.6	4.9	4.9	4.9

Average of Fiber (24-hour treatment) =   126.5

S.D. of Fiber (24-hour treatment) =   6.7

APPENDIX C

AVERAGE AND STANDARD DIVIATION OF TESTING DATA

FLEXURAL STRENGTH

TABLE C-1 Flexural Strength of Bamboo/PMMA composite with and without coupling agent

	Effect of Using Silane Coupling Agent and Fiber Content on Flexural Strength					
	Flexural Strength (MPa) , (Standard Deviation)					
	small-fiber composite		medium-fiber composite		large-fiber composite	
% fiber content	SN	SC	MN	MC	LN	LC
0	72.8 (3.0)	72.8 (3.0)	72.8 (3.0)	72.8 (3.0)	72.8 (3.0)	72.8 (3.0)
5	66.7 (2.9)	61.7 (2.6)	56.4 (2.9)	54.1 (6.2)	50.4 (2.9)	50.6 (7.0)
10	64.9 (2.9)	58.1 (4.2)	57.2 (5.3)	51.7 (1.9)	48.7 (6.4)	48.0 (4.1)
20	59.0 (6.8)	55.6 (3.8)	47.9 (3.0)	50.9 (1.1)	45.1 (4.5)	48.0 (3.1)

N = 5

SN = small-fiber composite (no coupling agent used)

SC = small-fiber composite (with coupling agent)

MN = medium-fiber composite (no coupling agent used)

MC = medium-fiber composite (with coupling agent)

LN = large-fiber composite (no coupling agent used)

LC = large-fiber composite (with coupling agent)

TABLE C-2 Flexural Strength of Bamboo/PMMA composite with NaOH-treatment fiber

S-Fiber (10-wt %)	Effect of Aspect Ratio on Flexural Strength	
	Average Aspect Ratio (S.D)	Flexural Strength (MPa), (SD.)
0 hour of NaOH treatment	79.7 (8.4)	64.9 (2.9)
6 hour of NaOH treatment	86.0 (12.2)	66.0 (5.5)
12 hour of NaOH treatment	96.3 (10.8)	68.1 (3.9)
18 hour of NaOH treatment	106.6 (9.9)	73.4 (2.3)
24 hour of NaOH treatment	126.5 (6.7)	74.7 (2.5)

N = 5

Flexural strength of PMMA = 72.8 MPa, S.D. = 3.0

FLEXURAL MODULUS

TABLE C-3 Flexural Modulus of Bamboo/PMMA composite with and without coupling agent

	Effect of Using Silane Coupling Agent and Fiber Content on Flexural Modulus					
	Flexural Modulus (MPa) , (Standard Deviation)					
	small-fiber composite		medium-fiber composite		large-fiber composite	
% fiber content	SN	SC	MN	MC	LN	LC
0	2558 (101)	2558 (101)	2558 (101)	2558 (101)	2558 (101)	2558 (101)
5	3156 (99)	3060 (457)	3029 (185)	3008 (91)	3173 (363)	3191 (279)
10	3120 (115)	3193 (146)	3191 (69)	3043 (367)	3078 (198)	2981 (292)
20	3363 (374)	3399 (186)	3082 (181)	3471 (191)	3312 (379)	3493 (364)

N = 5

SN = small-fiber composite (no coupling agent used)

SC = small-fiber composite (with coupling agent)

MN = medium-fiber composite (no coupling agent used)

MC = medium-fiber composite (with coupling agent)

LN = large-fiber composite (no coupling agent used)

LC = large-fiber composite (with coupling agent)

TABLE C-4 Flexural Modulus of Bamboo/PMMA composite with NaOH-treatment fiber

S-Fiber (10-wt %)	Effect of Aspect Ratio on Flexural Modulus	
	Average Aspect Ratio (S.D)	Flexural Modulus (MPa), (SD.)
0 hour of NaOH treatment	79.7 (8.4)	3120 (115)
6 hour of NaOH treatment	86.0 (12.2)	3379 (103)
12 hour of NaOH treatment	96.3 (10.8)	3224 (219)
18 hour of NaOH treatment	106.6 (9.9)	3629 (199)
24 hour of NaOH treatment	126.5 (6.7)	3779 (186)

N = 5

Flexural Modulus of PMMA = 2558 MPa, S.D. = 101.3

IMPACT STRENGTH

TABLE C-5 Impact Strength of Bamboo/PMMA composite with and without coupling agent

	Effect of Using Silane Coupling Agent and Fiber Content on Impact Strength					
	Impact Strength (kJ/m^2) , (Standard Deviation)					
	small-fiber composite		medium-fiber composite		large-fiber composite	
% fiber content	SN	SC	MN	MC	LN	LC
0	1.61 (0.21)	1.61 (0.21)	1.61 (0.21)	1.61 (0.21)	1.61 (0.21)	1.61 (0.21)
5	2.27 (0.38)	6.03 (1.08)	1.36 (0.24)	4.43 (1.57)	1.30 (1.17)	3.31 (3.69)
10	3.03 (0.66)	6.99 (1.52)	1.32 (0.28)	6.18 (1.58)	1.25 (0.26)	7.00 (0.16)
20	3.36 (0.60)	7.60 (0.35)	1.38 (0.05)	5.13 (1.27)	1.57 (1.00)	4.97 (1.63)

Izod, notched

N = 5

SN = small-fiber composite (no coupling agent used)

SC = small-fiber composite (with coupling agent)

MN = medium-fiber composite (no coupling agent used)

MC = medium-fiber composite (with coupling agent)

LN = large-fiber composite (no coupling agent used)

LC = large-fiber composite (with coupling agent)

TABLE C-6 Impact Strength of Bamboo/PMMA composite with NaOH treatment fiber

S-Fiber (10-wt %)	Effect of Aspect Ratio on Impact Strength	
	Average Aspect Ratio,(S.D)	Impact Strength (kJ/m^2), (S.D.)
0 hour of NaOH treatment	79.7 (8.4)	3.03 (0.41)
6 hour of NaOH treatment	86.0 (12.2)	3.22 (0.44)
12 hour of NaOH treatment	96.3 (10.8)	3.31 (0.44)
18 hour of NaOH treatment	106.6 (9.9)	3.45 (0.75)
24 hour of NaOH treatment	126.5 (6.7)	5.13 (0.83)

$N = 5$

Impact strength of PMMA = 1.61 kJ/m^2, S.D. = 0.21

COMPRESSIVE STRENGTH

TABLE C-7 Compressive Strength of Bamboo/PMMA composite with and without coupling agent

	Effect of Using Silane Coupling Agent and Fiber Content on Compressive Strength					
	Compressive Strength (MPa), (Standard Deviation)					
	small-fiber composite		medium-fiber composite		large-fiber composite	
% fiber content	SN	SC	MN	MC	LN	LC
0	75.8 (1.7)	75.8 (1.7)	75.8 (1.7)	75.8 (1.7)	75.8 (1.7)	75.8 (1.7)
5	82.9 (7.5)	94.9 (3.3)	89.9 (4.0)	98.7 (5.9)	77.2 (2.7)	89.7 (7.0)
10	95.2 (5.7)	105.2 (3.8)	94.3 (4.3)	99.8 (4.1)	80.8 (10.1)	100.6 (2.1)
20	101.9 (2.5)	113.2 (7.3)	97.2 (1.3)	112.9 (6.2)	92.8 (3.0)	110.2 (10.2)

N = 5

SN = small-fiber composite (no coupling agent used)

SC = small-fiber composite (with coupling agent)

MN = medium-fiber composite (no coupling agent used)

MC = medium-fiber composite (with coupling agent)

LN = large-fiber composite (no coupling agent used)

LC = large-fiber composite (with coupling agent)

TABLE C-8 Compressive Strength of Bamboo/PMMA composite with NaOH treatment fiber

S-Fiber (10-wt %)	Effect of Aspect Ratio on Compressive Strength	
	Average Aspect Ratio, (S.D)	Compressive Strength (MPa), (SD.)
0 hour of NaOH treatment	79.7 (8.4)	98.5 (5.7)
6 hour of NaOH treatment	86.0 (12.2)	102.5 (2.5)
12 hour of NaOH treatment	96.3 (10.8)	103.7 (2.3)
18 hour of NaOH treatment	106.6 (9.9)	104.7 (4.3)
24 hour of NaOH treatment	126.5 (6.7)	105.4 (2.5)

N = 5

Compressive strength of PMMA = 75.8 MPa, S.D. = 1.7

APPENDIX D

SAMPLE AND FIBER CODES

Sample Identification:

Sample code = W-X-Y (Z)-T

Where

X = Percent by weight of fiber content

Y = Size of fiber

Z = Condition of fiber

T = type of testing

Meaning of Sample Codes:

Sample Code			
X	Y	Z	T
Blank = 0 %	S = Small (150-250 μm.)	N = no treatment	F =
		C = with Coupling Agent	Flexural Test
5 = 5 %		6H = 6-hour NaOH treatment	
	M = Medium (450-650 μm.)		I =
10 = 10 %		12H = 12-hour NaOH treatment	Impact Test
20 = 20%	L = Large (1- 2 mm.)	18H = 18-hour NaOH treatment	C =
			Compressive
		24H = 24-hour NaOH treatment	Test

Such as,

5SCF

It means that 5%-bamboo fiber, small size (150-250 micron), with coupling agent was used in the composites for flexural test.

Fiber Codes

Meaning of Fiber Codes:

Fiber Code	Meaning
L	Large fiber
M	Medium fiber
S	Small fiber
SC	Small fiber with coupling agent
S6H	Small fiber with 6 hour NaOH treatment
S12H	Small fiber with 12 hour NaOH treatment
S18H	Small fiber with 18 hour NaOH treatment
S24H	Small fiber with 24 hour NaOH treatment

APPENDIX E

RAW DATA OF EXPERIMENTAL RESULT

Table E-1 Flexural Strength and Flexural Modulus at break of PMMA

	Blank	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	70.5	2518
2	77.9	2482
3	71.2	2736
4	72.0	2523
5	72.2	2530
AVERAGE	72.8	2558
S.D.	3.0	101

Table E-2 Flexural Strength and Flexural Modulus at break of 20SN composite

	20SNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	50.8	3840
2	54.6	3326
3	59.6	2887
4	68.5	3608
5	61.3	3155
AVERAGE	59.0	3363
S.D.	6.8	374

Table E-3 Flexural Strength and Flexural Modulus at break of 20MN composite

	20MNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	49.1	3309
2	46.3	3064
3	51.9	3214
4	48.0	2959
5	44.0	2866
AVERAGE	47.9	3082
S.D.	3.0	181

Table E-4 Flexural Strength and Flexural Modulus at break of 20LN composite

	20LNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	46.8	2841
2	41.8	3030
3	47.2	3770
4	50.4	3041
5	39.3	2877
AVERAGE	45.1	3112
S.D.	4.5	379

Table E-5 Flexural Strength and Flexural Modulus at break of 10SN composite

	10SNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	65.8	3002
2	67.1	3114
3	60.6	3024
4	65.6	3300
5	66.3	3161
AVERAGE	64.9	3120
S.D.	2.9	115

Table E-6 Flexural Strength and Flexural Modulus at break of 10MN composite

	10MNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	55.6	3282
2	54.1	3169
3	63.0	3153
4	50.9	3240
5	62.3	3112
AVERAGE	57.2	3191
S.D.	5.3	69

Table E-7 Flexural Strength and Flexural Modulus at break of 10LN composite

	10LNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	49.5	3127
2	56.9	3140
3	52.0	2950
4	44.6	2826
5	40.6	3345
AVERAGE	48.7	3078
S.D.	6.4	198

Table E-8 Flexural Strength and Flexural Modulus at break of 5SN composite

	5SNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	70.6	3254
2	62.8	3170
3	67.6	3245
4	67.0	3034
5	65.5	3077
AVERAGE	66.7	3156
S.D.	2.9	99

Table E-9 Flexural Strength and Flexural Modulus at break of 5MN composite

	5MNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	57.8	3183
2	51.6	2869
3	57.8	3270
4	56.1	2939
5	58.9	2883
AVERAGE	56.4	3029
S.D.	2.9	185

Table E-10 Flexural Strength and Flexural Modulus at break of 5LN composite

	5LNF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	47.2	2653
2	54.2	3654
3	52.4	3293
4	48.4	3197
5	49.8	3069
AVERAGE	50.4	3173
S.D.	2.9	363

Table E-11 Flexural Strength and Flexural Modulus at break of 20SC composite

	20SCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	52.05	3531
2	49.49	3426
3	50.59	3302
4	51.91	3600
5	50.38	3134
AVERAGE	50.88	3399
S.D.	1.08	186

Table E-12 Flexural Strength and Flexural Modulus at break of 20MC composite

	20MCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	59.02	3372
2	57.37	3403
3	50.45	3291
4	58.29	3501
5	52.69	3786
AVERAGE	55.56	3471
S.D.	3.78	191

Table E-13 Flexural Strength and Flexural Modulus at break of 20LC composite

	20LCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	45.14	2907
2	46.37	3516
3	49.80	3449
4	52.60	3790
5	46.26	3801
AVERAGE	48.03	3493
S.D.	3.09	364

Table E-14 Flexural Strength and Flexural Modulus at break of 10SC composite

	10SCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	52.7	3067
2	56.4	3028
3	59.7	3335
4	57.3	3340
5	64.1	3194
AVERAGE	58.1	3193
S.D.	4.2	146

Table E-15 Flexural Strength and Flexural Modulus at break of 10MC composite

	10MCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	52.3	2866
2	51.2	2493
3	51.1	3176
4	49.5	3419
5	54.5	3260
AVERAGE	51.7	3043
S.D.	1.9	367

Table E-16 Flexural Strength and Flexural Modulus at break of 10LC composite

	10LCF	
SAMPLE CODE	Flexural strength (MPa)	Flexural Modulus (MPa)
1	42.7	2650
2	50.8	2682
3	46.0	3122
4	53.3	3223
5	47.0	3231
AVERAGE	48.0	2981
S.D.	4.1	292

Table E-17 Flexural Strength and Flexural Modulus at break of 5SC composite

SAMPLE CODE	5SCF	
	Flexural strength (MPa)	Flexural Modulus (MPa)
1	64.7	2599
2	60.6	2619
3	63.4	3046
4	61.5	3463
5	58.1	3575
AVERAGE	61.7	3060
S.D.	2.6	457

Table E-18 Flexural Strength and Flexural Modulus at break of 5MC composite

SAMPLE CODE	5MCF	
	Flexural strength (MPa)	Flexural Modulus (MPa)
1	62.2	3086
2	46.3	3054
3	55.6	2880
4	49.6	3076
5	56.7	2945
AVERAGE	54.1	3008
S.D.	6.2	91

Table E-19 Flexural Strength and Flexural Modulus at break of 5LC composite

SAMPLE CODE	5LCF	
	Flexural strength (MPa)	Flexural Modulus (MPa)
1	40.1	3212
2	58.4	3129
3	55.2	2755
4	49.0	3459
5	50.4	3400
AVERAGE	50.6	3191
S.D.	7.0	279

Table E-20 Flexural Strength and Flexural Modulus at break of 10S6H composite

	10S6H	
SAMPLE CODE	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	73.0	3388
2	59.2	3365
3	63.5	3413
4	70.2	3508
5	64.1	3222
AVERAGE	66.0	3379
S.D.	5.5	103

Table E-21 Flexural Strength and Flexural Modulus at break of 10S12H composite

	10S12H	
SAMPLE CODE	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	70.1	3349
2	61.2	3350
3	69.8	3438
4	70.6	2941
5	68.7	3041
AVERAGE	68.1	3224
S.D.	3.9	219

Table E-22 Flexural Strength and Flexural Modulus at break of 10S18H composite

	10S18H	
SAMPLE CODE	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	71.8	3527
2	71.7	3933
3	71.9	3494
4	76.7	3726
5	75.1	3464
AVERAGE	73.4	3629
S.D.	2.3	199

Table E-23 Flexural Strength and Flexural Modulus at break of 10S24H composite

	10S24H	
SAMPLE CODE	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	71.8	3598
2	72.4	3599
3	75.6	3853
4	76.9	3805
5	76.9	4038
AVERAGE	74.7	3779
S.D.	2.5	186

Table E-24 Impact Strength of composite with 20-wt % fiber without coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	20SNI	20MNI	20LNI
1	2.85	1.44	3.14
2	2.94	1.35	1.55
3	3.04	1.39	1.43
4	3.73	1.40	1.33
5	4.24	1.31	0.38
Average	3.36	1.38	1.57
S.D.	0.60	0.05	1.00

Table E-25 Impact Strength of composite with 10-wt % fiber without coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	10SNI	10MNI	10LNI
1	3.73	1.20	0.98
2	3.75	1.12	1.65
3	2.36	1.23	1.31
4	2.67	1.18	1.25
5	2.64	1.73	1.04
Average	3.03	1.32	1.25
S.D.	0.66	0.28	0.26

Table E-26 Impact Strength of composite with 5-wt % fiber without coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	5SNI	5MNI	5LNI
1	2.76	1.38	0.45
2	2.45	1.61	0.32
3	1.76	1.56	0.99
4	2.08	1.07	3.20
5	2.33	1.16	1.55
Average	2.27	1.36	1.30
S.D.	0.38	0.24	1.17

Table E-27 Impact Strength of composite with 20-wt % fiber with coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	20SCI	20MCI	20LCI
1	7.17	3.86	5.26
2	7.54	4.61	6.44
3	8.14	7.19	1.15
4	7.50	1.25	0.59
5	7.67	1.46	3.21
AVERAGE	7.60	3.67	3.33
S.D.	0.35	2.45	2.53

Table E-28 Impact Strength of composite with 10-wt % fiber with coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	10SCI	10MCI	10LCI
1	8.44	7.79	6.93
2	5.81	7.08	6.77
3	8.87	3.88	7.10
4	5.82	6.88	7.19
5	6.03	5.25	7.03
AVERAGE	6.99	6.18	7.00
S.D.	1.52	1.58	0.16

Table E-29 Impact Strength of composite with 5-wt % fiber with coupling agent

SAMPLE CODE	Impact strength (kJ/m^2)		
	5SCI	5MCI	5LCI
1	6.25	4.94	0.37
2	4.11	1.11	1.19
3	6.58	7.28	7.01
4	6.59	0.94	7.65
5	6.62	7.91	0.33
AVERAGE	6.03	4.43	3.31
S.D.	1.08	3.31	3.69

Table E-30 Impact Strength of PMMA ,10SNI ,and composites with NaOH-treatment fiber

SAMPLE CODE	Impact strength (kJ/m^2)					
	Blank	10SNI	10S6HI	10S12HI	10S18HI	10S24HI
1	1.39	3.51	3.18	3.12	4.01	5.65
2	1.50	3.41	3.74	3.14	2.46	3.95
3	1.50	2.62	2.54	3.08	3.90	4.76
4	1.85	2.67	3.45	3.96	4.04	6.12
5	1.83	2.92	3.20	3.23	2.85	5.15
average	1.61	3.03	3.22	3.31	3.45	5.13
S.D.	0.21	0.41	0.44	0.37	0.74	0.83

Table E-31 Compressive Strength of Composite with 20-wt % fiber
without coupling agent

SAMPLE CODE	20SNC	20MNC	20LNC
1	98.9	97.0	93.0
2	103.1	96.2	97.0
3	104.4	97.0	88.5
4	103.5	96.5	92.6
5	99.6	99.5	93.1
A VERAGE	101.9	97.2	92.8
S.D.	2.5	1.3	3.0

Table E-32 Compressive Strength of Composite with 10-wt % fiber
without coupling agent

SAMPLE CODE	10SNC	10MNC	10LNC
1	89.3	101.2	67.3
2	97.9	92.8	84.2
3	105.1	89.3	83.2
4	91.7	94.3	75.4
5	91.8	94.1	94
A VERAGE	95.2	94.3	80.8
S.D.	5.7	4.3	10.1

Table E-33 Compressive Strength of Composite with 5-wt % fiber

without coupling agent

SAMPLE CODE	5SNC	5MNC	5LNC
1	77.5	97.0	77.2
2	87.3	88.2	73.0
3	93.6	88.4	77.0
4	75.4	88.2	78.9
5	80.7	87.9	80.0
A VERAGE	82.9	89.9	77.2
S.D.	7.5	4.0	2.7

Table E-34 Compressive Strength of Composite with 20-wt % fiber

with coupling agent

SAMPLE CODE	20SCC	20MCC	20LCC
1	1ı1.6	1111	125.2
2	107.7	118.9	111.2
3	119.3	118.1	106.3
4	105.3	103.6	111.2
5	122.3	112.9	97
A VERAGE	113.2	112.9	110.2
S.D.	7.3	6.2	10.2

Table E-35 Compressive Strength of Composite with 10-wt % fiber with coupling agent

SAMPLE CODE	10SCC	10MCC	10LCC
1	108.7	103.3	99.6
2	106.1	100.6	97.7
3	105.7	103.6	103
4	98.7	98	101.3
5	106.9	93.7	101.7
A VERAGE	105.2	99.8	100.6
S.D	3.8	4.1	2.1

Table E-36 Compressive Strength of Composite with 5-wt % fiber without coupling agent

SAMPLE CODE	5SCC	5MCC	5LCC
1	92.2	101.4	81.4
2	93.1	103.9	94.3
3	98.6	103.6	84.1
4	98.5	92.7	93.7
5	92.5	91.9	97.2
A VERAGE	94.9	98.7	89.4
S.D.	3.3	5.9	7.0

Table E-37 Compressive Strength of PMMA ,10SNC,and composites with NaOH-treatment fiber

SAMPLE CODE	Blank	10SNC	10S6HC	10S12HC	10S18HC	10S24HC
1	104.8	89.3	101.0	104.7	101.3	100.3
2	102.6	97.9	101.0	102.1	101.2	104.7
3	100.2	105.1	101.9	100.8	105.5	105.3
4	104.6	91.7	106.6	106.8	110.7	107.3
5	101.7	91.8	100.4	103.9	100.4	104.4
AVERAGE	102.8	95.2	102.5	103.7	104.7	105.4
S.D.	2.0	5.7	2.5	2.3	4.3	2.5

CURRICULUM VITAE

Mr. Sunan Tiptipakorn was born in Bangkok, Thailand. He graduated the secondary school from Thiamudomsuksa Pattanakarn School in Bangkok. graduated the Bachelor degree from the department of Engineering, Chulalongkorn University in 1995. Next, he has 4-year working experience in the polymer-engineering field (HMC Polymer, Co., Ltd.). He enrolled the Master Degree of Chemical Engineering Program in 1999.