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APPENDICES

APPENDIX A

Results of Mechanical and Thermal Properties from the Experiments

Appendix A-1: The flexural properties of carbon fiber-reinforced epoxy composites.

Condition	Temperature (^oC)	Humidity	UV	Flexural Strength (MPa)	Flexural Modulus (GPa)
1	40	Wet	Yes	95.811	2.099
2	40	Wet	None	106.315	2.342
3	40	Dry	Yes	103.401	2.189
4*	40	Dry	None	103.466	2.245
5**	40	Dry	None	111.919	2.547
6	60	Wet	Yes	91.874	2.106
7	60	Wet	None	92.997	2.148
8	60	Dry	Yes	107.078	2.342
9*	60	Dry	None	100.376	2.181
10**	60	Dry	None	95.984	2.388

*test in air circulating oven
**test in vacuum oven

Appendix A-2: The flexural properties of aramid fiber-reinforced epoxy composites.

Condition	Temperature (^oC)	Humidity	UV	Flexural Strength (MPa)	Flexural Modulus (GPa)
1	40	Wet	Yes	107.22	2.471
2	40	Wet	None	107.661	2.315
3	40	Dry	Yes	112.503	2.592
4*	40	Dry	None	104.049	2.486
5**	40	Dry	None	106.651	2.532
6	60	Wet	Yes	102.27	2.663
7	60	Wet	None	98.676	2.607
8	60	Dry	Yes	114.991	2.315
9*	60	Dry	None	112.577	2.552
10**	60	Dry	None	119.747	2.642

*test in air circulating oven
**test in vacuum oven

Appendix A-3: The compressive properties of carbon fiber-reinforced epoxy composites.

Direction "1"

Condition	Temperature (°C)	Humidity	UV	Compressive Strength (MPa)	Compressive Modulus (GPa)
1	40	Wet	Yes	87.374	4.445
2	40	Wet	None	80.453	3.121
3	40	Dry	Yes	85.733	4.638
4*	40	Dry	None	85.719	3.9
5**	40	Dry	None	83.68	3.929
6	60	Wet	Yes	83.915	3.646
7	60	Wet	None	75.396	3.184
8	60	Dry	Yes	86.122	3.08
9*	60	Dry	None	86.043	3.724
10**	60	Dry	None	88.223	4.731

Direction "2"

Condition	Temperature (°C)	Humidity	UV	Compressive Strength (MPa)	Compressive Modulus (GPa)
1	40	Wet	Yes	72.677	2.039
2	40	Wet	None	71.696	2.26
3	40	Dry	Yes	76.403	2.12
4*	40	Dry	None	73.324	2.126
5**	40	Dry	None	73.657	2.081
6	60	Wet	Yes	71.068	1.925
7	60	Wet	None	72.186	2.15
8	60	Dry	Yes	76.727	2.066
9*	60	Dry	None	71.343	2.007
10**	60	Dry	None	74.599	2.153

*test in air circulating oven
**test in vacuum oven

Appendix A-4: The compressive properties of aramid fiber-reinforced epoxy composites.

Direction "1"

Condition	Temperature (°C)	Humidity	UV	Compressive Strength (MPa)	Compressive Modulus (GPa)
1	40	Wet	Yes	73.687	2.162
2	40	Wet	None	74.007	2.492
3	40	Dry	Yes	75.351	2.39
4*	40	Dry	None	76.573	2.591
5**	40	Dry	None	82.836	2.762
6	60	Wet	Yes	76.508	2.59
7	60	Wet	None	73.242	2.714
8	60	Dry	Yes	77.855	2.313
9*	60	Dry	None	74.945	2.694
10**	60	Dry	None	82.415	2.61

Normal to the principal axis of anisotropy

Condition	Temperature (°C)	Humidity	UV	Compressive Strength (MPa)	Compressive Modulus (GPa)
1	40	Wet	Yes	64.478	1.537
2	40	Wet	None	67.008	1.778
3	40	Dry	Yes	69.862	1.661
4*	40	Dry	None	63.39	1.836
5**	40	Dry	None	70.902	2.12
6	60	Wet	Yes	63.557	2.055
7	60	Wet	None	61.334	1.664
8	60	Dry	Yes	69.284	1.93
9*	60	Dry	None	63.763	2.017
10**	60	Dry	None	74.687	2.219

*test in air circulating oven
**test in vacuum oven

Appendix A-5: The double torsion properties of carbon fiber-reinforced epoxy composites.

Condition	**Temperature (^oC)**	**Humidity**	**UV**	**K_{Ic} ($MPa*m^{1/2}$)**	**G_{Ic} (kJ/m^2)**
1	40	Wet	Yes	2.754	1.706
2	40	Wet	None	3.039	2.959
3	40	Dry	Yes	2.673	1.541
4*	40	Dry	None	3.319	2.825
5**	40	Dry	None	2.925	2.178
6	60	Wet	Yes	4.117	4.649
7	60	Wet	None	2.243	1.58
8	60	Dry	Yes	4.242	5.842
9*	60	Dry	None	2.625	1.85
10**	60	Dry	None	2.553	1.378

*test in air circulating oven
**test in vacuum oven

Appendix A-6: The double torsion properties of aramid fiber-reinforced epoxy composites.

Condition	**Temperature (^{o}C)**	**Humidity**	**UV**	**K_{Ic} ($MPa*m^{1/2}$)**	**G_{Ic} (kJ/m^2)**
1	40	Wet	Yes	3.833	6.796
2	40	Wet	None	3.47	4.832
3	40	Dry	Yes	4.321	7.812
4*	40	Dry	None	4.79	8.855
5**	40	Dry	None	4.893	8.668
6	60	Wet	Yes	6.725	17.462
7	60	Wet	None	6.955	17.822
8	60	Dry	Yes	7.43	23.867
9*	60	Dry	None	6.756	16.943
10**	60	Dry	None	7.247	20.122

*test in air circulating oven
**test in vacuum oven

Appendix A-7: T_g from DMA test of carbon fiber-reinforced epoxy composites.

Condition	Temperature (°C)	Humidity	UV	T_g (°C)
1	40	Wet	Yes	78.9
2	40	Wet	None	78
3	40	Dry	Yes	82.1
4*	40	Dry	None	77
5**	40	Dry	None	78.5
6	60	Wet	Yes	81.5
7	60	Wet	None	79.3
8	60	Dry	Yes	83.3
9*	60	Dry	None	84.2
10**	60	Dry	None	84

*test in air circulating oven
**test in vacuum oven

Appendix A-8: T_g from DMA test of aramid fiber-reinforced epoxy composites.

Condition	Temperature (°C)	Humidity	UV	T_g (°C)
1	40	Wet	Yes	80.6
2	40	Wet	None	78
3	40	Dry	Yes	83.9
4*	40	Dry	None	78.6
5**	40	Dry	None	79.7
6	60	Wet	Yes	83.3
7	60	Wet	None	80.2
8	60	Dry	Yes	84.4
9*	60	Dry	None	85
10**	60	Dry	None	85.5

*test in air circulating oven
**test in vacuum oven

APPENDIX B

Calculation method for statistical analysis

Statistical analysis for the flexural strength of carbon fiber-reinforced epoxy composites is exemplified in this part. Other mechanical properties can be analyzed by the same method as well.

1. Yates' Algorithm for the 2^k factorial design.

There is a very simple technique invented by Yates (1937) for estimating the effects and the sums of squares in a 2^k factorial design. The procedure is occasionally useful for manual calculations.

Firstly, consider the data for the flexural strength of carbon fiber-reinforced epoxy composites in Appendix A-1. Condition 4 and 10 that are tested in air circulating oven will be set aside because one factor, humidity, is not in the range of 2^3 factorial design. The data have been entered in Table B-1. The treatment combinations are always written down in standard order. The first half of column (1) is gained by adding the responses in adjacent pairs. The second half of column (1) is obtained by changing the sign of the first entry in each of the pairs in the response column and adding the adjacent pairs.

Column (2) is acquired from column (1) just as column (1) is obtained from the response column. Similarly, column (3) is attained from column (2). Generally, it is necessary to construct k columns of this type for a 2^k design. To receive the estimate of the effect, column (3) will be divided by $n2^{k-1}$ (in this example, $n2^{k-1} = 4$). Finally, the sums of squares for the effects are obtained by squaring column (3) and dividing by $n2^k$ (in our example, $n2^k = 8$).

Treatment combination	Response	(1)	(2)	(3)	Estimate of effect	Sum of squares
(1)	111.919	207.903	407.215	805.829	-	-
a	95.984	199.312	398.164	-29.513	-7.3783	108.8771
b	106.315	210.479	-29.253	-31.385	-7.8463	123.1273
ab	92.997	187.685	-0.26	-4.997	-1.2493	3.1213
c	103.401	-15.935	-8.591	-9.051	-2.2628	10.2401
ac	107.078	-13.318	-22.794	28.993	7.2483	105.0743
bc	95.811	3.677	2.617	-14.203	-3.5508	25.2157
abc	91.874	-3.937	-7.614	-10.231	-2.5578	13.0842

Table B-1: Yates' algorithm for the flexural strength of carbon fiber-reinforced epoxy composites.

2. A single replicate of the 2^k design.

If the single replicate of the design is run, the experimenter will consider this technique. The assumption of this strategy is that the random error or noise in the process that is studied is moderately small.

A single replicate of a 2^k design is occasionally called an unreplicated factorial. With only one replicate, there is no internal estimate of error (or pure error). One method to analyze an unreplicated factorial is to assume that some high order interactions are negligible and include their mean squares to estimate the error. This is an appeal to the sparsity of effect principle; that is, most systems are dominated by some of the main effects and low order interactions and most high order interactions are negligible.

When data from unreplicated factorial designs are analyzed, sometimes real high order interactions happen. Therefore, the use of an error mean square acquired by pooling high order interactions is not fit for these cases. An approach of analysis attributed to Daniel (1959) provides an easy way to overcome this puzzle. He proposes examining a normal probability plot of the estimates of the effects. The effects that are negligible are normally distributed with mean zero and variance σ^2 and will tend to lie along a straight line on this plot while significant effects will have nonzero means and will not fall along the straight line. Thus, the preliminary model will be specified to contain those effects that are nonzero based on the normal probability plot. The negligible effects are viewed as an estimate of error.

For flexural strength of carbon fiber reinforced epoxy composites, the estimates of effects in Table B-1 are employed to draw the normal probability plot. The normal probability plot of these effects is illustrated in Figure B-1.

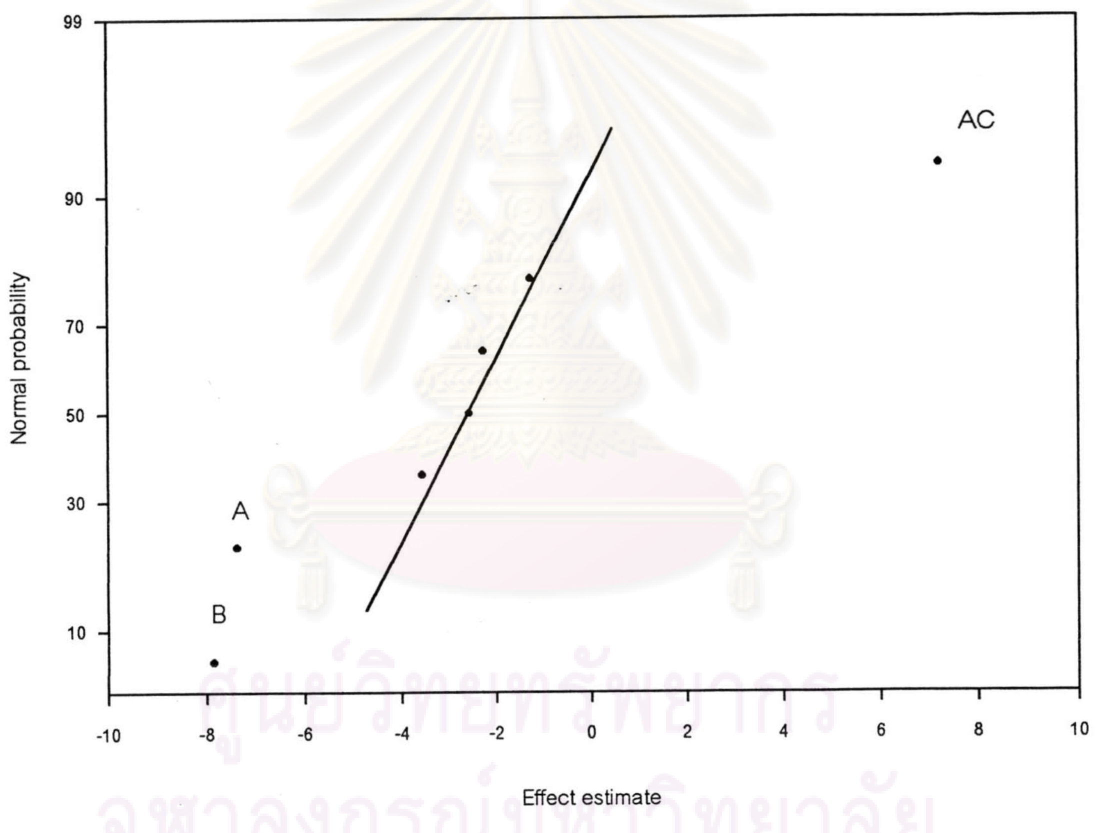

Figure B-1: Normal probability plot of effects for flexural strength of carbon fiber reinforced epoxy composites.

All of the effects that fall along the straight line are negligible, whereas the large effects are far from the line. The important effects that emerge from this analysis are the main effects of A, B and AC.

3. Analysis of variance (ANOVA)

The analysis of variance for the flexural strength of carbon fiber reinforced epoxy composites is summarized in Table B-2. Sum of squares from Table B-1 is used.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	108.8771	1	108.8771	8.4301
B	123.1273	1	123.1273	9.5334
AC	105.0743	1	105.0743	8.1356
Error	51.661	4	12.9153	
Total	388.7398	7	R^2 = 0.8671	

Table B-2: Analysis of variance for the flexural strength of carbon fiber reinforced epoxy composites.

In this case, error sum of square is calculated from summation of sum of square C, AB, BC and ABC that is not the main effect. Mean square of effect can be computed by dividing individual sum of square by degree of freedom. Statistical value F_0 of the regression analysis is calculated by dividing mean square of effects by mean square of error. Finally, coefficient of determination of regression analysis (R^2) is calculated from equation B-1.

$$R^2 = 1 - \frac{SS_E}{SS_T} \qquad \text{B-1}$$

4. The regression model

In a 2^k factorial design, it is simple to express the results of the experiment in terms of a regression model. A fitted regression model will show only significant effect for the experiment. Therefore, the estimated flexural strengths of carbon fiber reinforced epoxy composites are given by equation B-2 in which x_1, x_2 and x_3 represent the effects of A, B and C, respectively. AC interaction are represented by x_1x_3.

$$\hat{y} = 100.6724 - \left(\frac{7.3783}{2}\right)x_1 - \left(\frac{7.8463}{2}\right)x_2 + \left(\frac{7.2483}{2}\right)x_1x_3 \qquad \text{B-2}$$

where the intercept is the grand average of all 8 observations and the regression coefficients are one half of the corresponding factor effect estimates. The reason that the regression coefficient is one-half the effect estimate is that a regression coefficient measures the effect of unit change in x on the mean of y and the effect estimate depend on a two-unit change (from −1 to +1).

5. Residual analysis

The residuals are the differences between the observed and fitted values of y. The values of observed values, predicted values and residuals for the flexural strength of carbon fiber reinforced epoxy composites are shown in Table B-3.

Effects	Observed values	Predicted values	Residuals
(1)	111.919	111.9089	0.0102
A	95.984	97.2823	-1.2983
B	106.315	104.0626	2.2525
AB	92.997	89.436	3.5611
C	103.401	104.6606	-1.2596
AC	107.078	104.5306	2.5475
BC	95.811	96.8143	-1.0033
ABC	91.874	96.6843	-4.8103

Table B-3: Observed and predicted values and calculated residuals for flexural strength of carbon fiber reinforced epoxy composites.

A normal probability plot of the residuals is exhibited in Figure B-2. The points on this plot lie reasonably close to a straight line, supporting to our conclusion that *A*, *B* and *AC* are the only significant effects and that the assumptions of the analysis are satisfied.

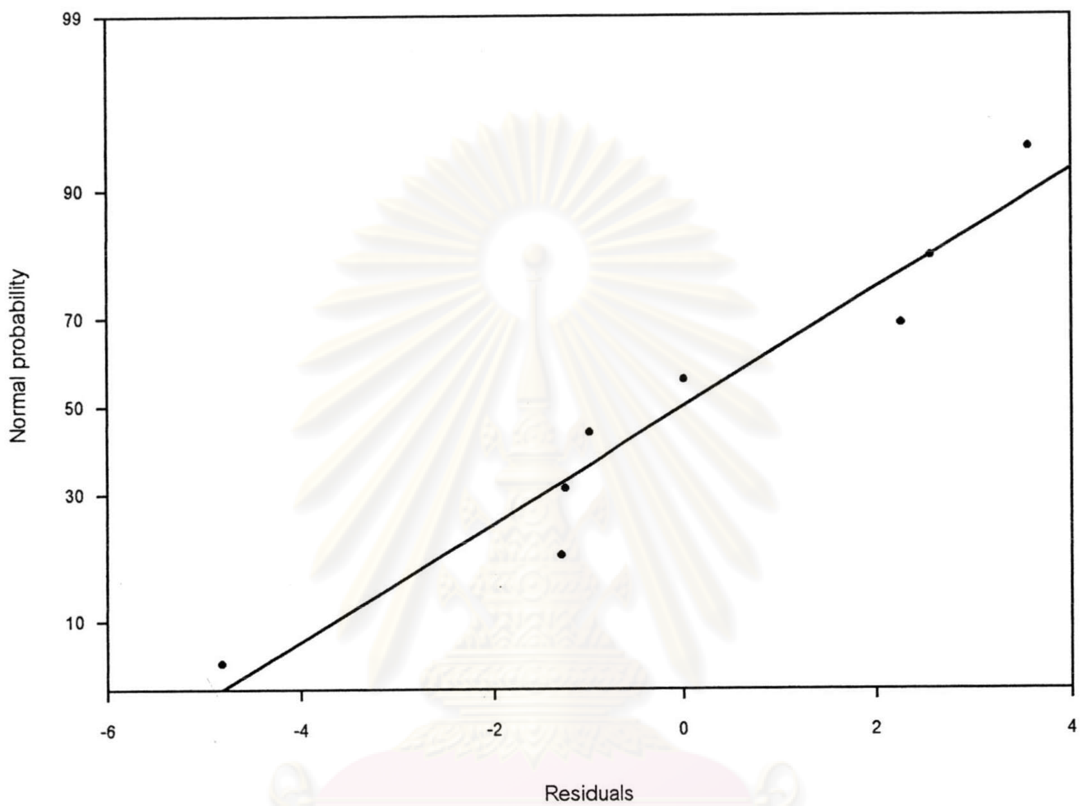

Figure B-2: Normal probability plot of residuals for the flexural strength of carbon fiber reinforced epoxy composites.

Appendix C

Effect estimate and ANOVA table

Appendix C-1: Effect estimate and sum of square for flexural strength of carbon fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	111.919	-	-
A	95.984	-7.3783	108.8771
B	106.315	-7.8463	123.1273
AB	92.997	-1.2493	3.1213
C	103.401	-2.2628	10.2401
AB	107.078	7.2483	105.0743
BC	95.811	-3.5508	25.2157
ABC	91.874	-2.5578	13.0842

Appendix C-2: ANOVA table for regression analysis of the flexural strength of carbon fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	108.8771	1	108.8771	8.4301
B	123.1273	1	123.1273	9.5334
AC	105.0743	1	105.0743	8.1356
Error	51.6611	4	12.9153	
Total	388.7398	7	R^2 = 0.8671	

Appendix C-3: Effect estimate and sum of square for flexural strength of aramid fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	106.651	-	-
A	119.747	0.4123	0.3399
B	107.661	-9.5163	181.118
AB	98.676	-7.3798	108.9214
C	112.503	1.0623	2.2568
AC	114.991	-1.6433	5.4005
BC	107.22	0.5143	0.5289
ABC	102.27	3.6608	26.8022

Appendix C-4: ANOVA table for regression analysis of the flexural strength of aramid fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
B	181.118	1	181.118	25.6334
AB	108.9214	1	108.9214	15.4155
Error	35.3283	5	7.0657	
Total	325.3677	7	R^2 = 0.8914	

Appendix C-5: Effect estimate and sum of square for compressive strength of carbon fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	83.68	-	-
A	88.223	-0.896	1.6056
B	80.453	-4.155	34.5281
AB	75.396	-3.362	22.6061
C	85.733	3.848	29.6142
AC	86.122	-0.639	0.8166
BC	87.374	3.872	29.9848
ABC	83.915	1.438	4.1357

Appendix C-6: ANOVA table for regression analysis of the compressive strength of carbon fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
B	34.5281	1	34.5281	15.7951
C	29.6142	1	29.6142	13.5472
AB	22.6061	1	22.6061	10.3413
BC	29.9848	1	29.9848	13.7167
Error	6.5579	3	2.186	
Total	123.2911	7	R^2 = 0.9468	

Appendix C-7: Effect estimate and sum of square for compressive strength of aramid fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	82.836	-	-
A	82.415	1.0348	2.1414
B	74.007	-5.2533	55.1933
AB	73.242	-0.0068	$9.11*10^{-5}$
C	75.351	-2.2748	10.349
AC	77.855	1.6278	5.2991
BC	73.687	3.7478	28.0913
ABC	76.508	0.1653	0.0546

Appendix C-8: ANOVA table for regression analysis of the compressive strength of aramid fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
B	55.1933	1	55.1933	29.4553
C	10.349	1	10.349	5.523
BC	28.0913	1	28.0913	14.9916
Error	7.4952	4	1.8738	
Total	101.1288	7	R^2 = 0.9259	

Appendix C-9: Effect estimate and sum of square for fracture toughness of carbon fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	2.925	-	-
A	2.553	0.441	0.389
B	3.039	-0.06	0.0072
AB	2.243	-0.1575	0.0496
C	2.673	0.7565	1.1446
AC	4.242	1.025	2.1013
BC	2.754	0.038	0.038
ABC	4.117	0.0545	0.0059

Appendix C-10: ANOVA table for regression analysis of the fracture toughness of carbon fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	0.389	1	0.389	23.7195
C	1.1446	1	1.1446	69.7927
AC	2.1013	1	2.1013	128.128
Error	0.0655	4	0.0164	
Total	3.7004	7	R^2 = 0.9823	

Appendix C-11: Effect estimate and sum of square for fracture toughness of aramid fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	4.893	-	-
A	7.247	2.96	17.5232
B	3.47	-0.727	1.0571
AB	6.955	0.2285	0.1044
C	4.321	-0.064	0.0082
AC	7.43	0.0405	0.0033
BC	3.833	0.1305	0.0341
ABC	6.725	-0.337	0.2271

Appendix C-12: ANOVA table for regression analysis of the fracture toughness of aramid fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	17.5232	1	17.5232	467.2853
B	1.0571	1	1.0571	28.1893
ABC	0.2271	1	0.2271	6.056
Error	0.15	4	0.0375	
Total	18.9574	7	R^2 = 0.9921	

Appendix C-13: Effect estimate and sum of square for fracture energy of carbon fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	2.178	-	-
A	1.378	1.2663	3.2068
B	2.959	-0.0113	0.0003
AB	1.58	-0.4843	0.469
C	1.541	1.4108	3.9804
AC	5.842	2.3558	11.0991
BC	1.706	-0.5028	0.5055
ABC	4.649	-0.1948	0.0759

Appendix C-14: ANOVA table for regression analysis of the fracture energy of carbon fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	3.2068	1	3.2068	12.2071
C	3.9804	1	3.9804	15.1519
AC	11.0991	1	11.0991	42.2501
Error	1.0506	4	0.2627	
Total	19.3369	7	R^2 = 0.9457	

Appendix C-15: Effect estimate and sum of square for fracture energy of aramid fiber reinforced epoxy composites.

Treatment combination	Response	Estimate of effect	Sum of squares
(1)	8.668	-	-
A	20.122	12.7913	327.2322
B	4.832	-3.3893	22.974
AB	17.822	-0.9633	1.8557
C	7.812	1.1233	2.5234
AC	23.867	0.5693	0.6481
BC	6.796	-0.3213	0.2064
ABC	17.462	-1.7313	5.9945

Appendix C-16: ANOVA table for regression analysis of the fracture energy of aramid fiber reinforced epoxy composites.

Source of variation	Sum of squares	Degree of freedom	Mean square	F_0
A	327.2322	1	327.2322	57.4061
Error	34.202	6	5.7003	
Total	361.4342	7	R^2 = 0.9054	

APPENDIX D

Table of statistical F distribution

Appendix D-1: The critical value of F-distribution at the level of significance of 0.1.

ν_2 \ ν_1	Degrees of Freedom for the Numerator (ν_1) 1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86	60.19	60.71	61.22	61.74	62.00	62.26	62.53	62.79	63.06	63.33
2	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.47	9.48	9.49
3	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.22	5.20	5.18	5.18	5.17	5.16	5.15	5.14	5.13
4	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94	3.92	3.90	3.87	3.84	3.83	3.82	3.80	3.79	3.78	3.76
5	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.30	3.27	3.24	3.21	3.19	3.17	3.16	3.14	3.12	3.10
6	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96	2.94	2.90	2.87	2.84	2.82	2.80	2.78	2.76	2.74	2.72
7	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.67	2.63	2.59	2.58	2.56	2.54	2.51	2.49	2.47
8	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.50	2.46	2.42	2.40	2.38	2.36	2.34	2.32	2.29
9	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.38	2.34	2.30	2.28	2.25	2.23	2.21	2.18	2.16
10	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.28	2.24	2.20	2.18	2.16	2.13	2.11	2.08	2.06
11	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27	2.25	2.21	2.17	2.12	2.10	2.08	2.05	2.03	2.00	1.97
12	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.15	2.10	2.06	2.04	2.01	1.99	1.96	1.93	1.90
13	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16	2.14	2.10	2.05	2.01	1.98	1.96	1.93	1.90	1.88	1.85
14	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12	2.10	2.05	2.01	1.96	1.94	1.91	1.89	1.86	1.83	1.80
15	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	2.02	1.97	1.92	1.90	1.87	1.85	1.82	1.79	1.76
16	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06	2.03	1.99	1.94	1.89	1.87	1.84	1.81	1.78	1.75	1.72
17	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03	2.00	1.96	1.91	1.86	1.84	1.81	1.78	1.75	1.72	1.69
18	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00	1.98	1.93	1.89	1.84	1.81	1.78	1.75	1.72	1.69	1.66
19	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98	1.96	1.91	1.86	1.81	1.79	1.76	1.73	1.70	1.67	1.63
20	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.89	1.84	1.79	1.77	1.74	1.71	1.68	1.64	1.61
21	2.96	2.57	2.36	2.23	2.14	2.08	2.02	1.98	1.95	1.92	1.87	1.83	1.78	1.75	1.72	1.69	1.66	1.62	1.59
22	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93	1.90	1.86	1.81	1.76	1.73	1.70	1.67	1.64	1.60	1.57
23	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.96	1.92	1.89	1.84	1.80	1.74	1.72	1.69	1.66	1.62	1.59	1.55
24	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91	1.88	1.83	1.78	1.73	1.70	1.67	1.64	1.61	1.57	1.53
25	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89	1.87	1.82	1.77	1.72	1.69	1.66	1.63	1.59	1.56	1.52
26	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88	1.86	1.81	1.76	1.71	1.68	1.65	1.61	1.58	1.54	1.50
27	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87	1.85	1.80	1.75	1.70	1.67	1.64	1.60	1.57	1.53	1.49
28	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87	1.84	1.79	1.74	1.69	1.66	1.63	1.59	1.56	1.52	1.48
29	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86	1.83	1.78	1.73	1.68	1.65	1.62	1.58	1.55	1.51	1.47
30	2.88	2.49	2.28	2.14	2.03	1.98	1.93	1.88	1.85	1.82	1.77	1.72	1.67	1.64	1.61	1.57	1.54	1.50	1.46
40	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79	1.76	1.71	1.66	1.61	1.57	1.54	1.51	1.47	1.42	1.38
60	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.66	1.60	1.54	1.51	1.48	1.44	1.40	1.35	1.29
120	2.75	2.35	2.13	1.99	1.90	1.82	1.77	1.72	1.68	1.65	1.60	1.55	1.48	1.45	1.41	1.37	1.32	1.26	1.19
∞	2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63	1.60	1.55	1.49	1.42	1.38	1.34	1.30	1.24	1.17	1.00

Degrees of Freedom for the Denominator (ν_2)

VITA

Mr. Booranin Kamponpan was born in Bangkok, Thailand on May 21, 1978. He graduated at secondary school level in 1993 and high school level in 1995 from Bodindecha (Singh Singhasenee) School. In 1999, he received a Bachelor Degree of Engineering with a major in Chemical Engineering from the Faculty of Engineering, Chulalongkorn University. After graduation, he pursued his graduate study for a Master Degree of Chemical Engineering at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University.