Appendix

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Analysis of Variance (ANOVA)*

Explanation: one way Calculation/Computation

What is it?

An **ANOVA**, sometimes called an F test, is closely related to the t test. The major difference is that, where the t test measures the difference between the means of two groups, an ANOVA tests the difference between the means of two or more groups.

A **one-way ANOVA**, or single factor ANOVA, tests differences between groups that are only classified on one independent variable. It can also use multiple independent variables and test for interactions using factorial ANOVA. The advantage of using ANOVA rather than multiple t-tests is that it reduces the probability of a type-I error. Making multiple comparisons increases the likelihood of finding something by chance - making a type-I error. One potential drawback to an ANOVA is that you lose specificity: all an *F* tells are that there is a significant difference between groups, not which groups are significantly different from each other. To test for this, use a post-hoc comparison to find out where the differences are - which groups are significantly different from each other and which are not. Some commonly used post-hoc comparisons are Scheffe's and Tukey's.

Analysis of Variance: Testing for the equality of *k* population means

In general, analysis of variance can be used to test for the equality of k population means. The general form of the hypotheses tested is

$$H_o: \mu_1 = \mu_2 = \ldots \mu_k$$

H_a: Not all the means are equal

Where

μ_j = mean of the jth population

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*Anderson D.R., Sweeney D.J., Williams T.A. *Introduction to statistics concepts and applications*. 3rd ed. West Publishing Co. Minneapolis, pp. 441-445, 1994.

We assume that a simple random sample of size n_j has been selected from each of the k populations. Let

X_{ij} = the ith observation in the jth sample

n_j = the number of observations in the jth sample

$\bar{x}_j$ = the mean of the jth sample

S_j^2 = the variance of the jth sample

S_j = the standard deviation of the jth sample

The formulas for the jth sample mean and variance are as follows:

$$\bar{x}_j = \frac{\sum_{i=1}^{nj} x_{ij}}{n_j} \qquad \text{.....(1)}$$

$$s_j^2 = \frac{\sum_{i=1}^{nj} (x_{ij} - \bar{x}_j)^2}{n_j - 1} \qquad \text{.....(2)}$$

The overall sample mean, denoted $\bar{\bar{x}}$, is the sum of all the observations divided by the total number of observations. That is,

$$\bar{\bar{x}} = \frac{\sum_{j=1}^{k} \sum_{i=1}^{nj} x_{ij}}{n_T} \qquad \text{.....(3)}$$

Where

$$n_T = n_1 + n_2 + \ldots + n_k \qquad \text{.....(4)}$$

If the size of each sample is n, $n_T = kn$; in this case, expression (3) reduces to

$$\bar{\bar{x}} = \frac{\sum_{i=1}^{k} \sum_{i=1}^{nj} x_{ij}}{kn} = \frac{\sum_{j=1}^{k} \sum_{i=1}^{nj} x_{ij} / n}{k} = \frac{\sum_{j=1}^{k} \bar{x}_j}{k} \qquad \text{.....(5)}$$

In other words, whenever the sample sizes are the same, the overall sample mean is just the average of the k sample means.

Between-samples estimate of population variance

The estimate of σ^2 is called the *mean square between* and is denoted MSB. The general formula for computing MSB is as follows:

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$$MSB = \frac{\sum_{j=1}^{k} n_j (\bar{x}_j - \bar{\bar{x}})^2}{k-1} \qquad \text{……..(6)}$$

The numerator in equation (6) is called the *sum of squares between* and is denoted SSB. The denominator, k - 1, represents the degrees of freedom associated with SSB. Thus, the mean square between can be computed as follows:

$$MSB = \frac{SSB}{k-1} \qquad \text{……..(7)}$$

Where

$$SSB = \sum_{j=1}^{k} n_j (\bar{x}_j - \bar{\bar{x}})^2 \qquad \text{……..(8)}$$

If H_o is true, MSB provides an unbiased estimate of σ^2. However, if the means of the k populations are not equal, MSB is not an unbiased of σ^2; in fact, in this case, MSB should overestimated σ^2.

Within-samples estimate of population variance

The second estimate of σ^2 is based on the variance of the sample observations within each sample. This estimate of σ^2 is called the *mean square within* and is denoted MSW. The general formula for computing MSW is as follows:

$$MSW = \frac{\sum_{j=1}^{k} (n_j - 1) s_j^2}{n_T - k} \qquad \text{……..(9)}$$

The numerator in equation (9) is called the *sum of squares within* and is denoted SSW. The denominator of MSW is referred to as the degrees of freedom associated with SSW. Thus, the formula for MSW can also be stated as follows:

$$MSW = \frac{SSW}{n_T - k} \qquad \text{……..(10)}$$

Where

$$SSW = \sum_{j=1}^{k} (n_j - 1) s_j^2 \qquad \text{……..(11)}$$

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Note that MSW is based on the variation within each of the samples; it is not influenced by whether or not the null hypothesis is true. Thus, MSW always provides an unbiased estimate of σ^2.

Comparing the variance estimates: The F test

Let us assume for the moment that the null hypothesis is true. In this case, MSB and MSW provide two independent, unbiased estimates of σ^2. For normal populations, the sampling distribution of the ratio of two independent estimates of σ^2 follows an F distribution. Thus, if the null hypothesis is true and the ANOVA assumptions are valid, the sampling distribution of MSB/MSW is an F distribution with numerator degrees of freedom equal to k -1 and denominator degrees of freedom equal to n_T - k.

If the means of the k populations are not equal, the value of MSB/MSW will be inflated because MSB overestimates σ^2. Hence, we will reject H_o if the resulting value of MSB/MSW appears to be too large to have been selected at random from an F distribution with degrees of freedom k - 1 in the numerator and nT - k in the denominator. The value of MSB/MSW that will cause us to reject H_o depends on α, the level of significance. Once α is selected, a critical value can be determined.

The ANOVA table

The results of the preceding calculations can be conveniently displayed in a table referred to as the *analysis of variance table*. The sum of squares associated with the source of variance referred to as "Total" is called the total sum of squares (SST).

Analysis of variance table

Source of variation	**Sum of Square**	**Degrees of Freedom**	**Mean Square**	**F**
Between	SSB	K - 1	MSB	$\frac{MSB}{MSW}$
Within	SSW	N - K	MSW	
Total	SST	N - 1		

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Recommendations for performing multiple comparisons

Tukey's procedure is an *unprotected* or *unrestrictive* testing approach. That is, it is not necessary to find a significant difference when using analysis of variance before applying Tukey's procedure. Thus, Tukey's procedure provides an alternative to analysis of variance for testing if the means of k populations are equal. However, to use Tukey's procedure we still have to estimate the population variance using MSW.

Computation steps: SPSS Program

1. Enter data into data table. (see SPSS tutorial for help)
2. Go to **ANALYZE > COMPARE MEANS > ONE WAY ANOVA**
3. Enter dependent variable in Dependent List
4. Enter independent variable in Factor
5. Ignore Contrasts and Post-Hoc buttons
6. Options:
   - Statistics: Descriptive (yes); Homogeneity of variance (no)
   - Means Plot (yes)
7. Continue - OK
8. Output:
   - (a) Descriptives (N, Mean, Std. Dev, etc)
     This will give you a chart that has the between groups and within groups sum of squares, the degrees of freedom, the mean squares, the *F*, and the significance.
9. If the significance is less than .05, you may reject the null hypothesis

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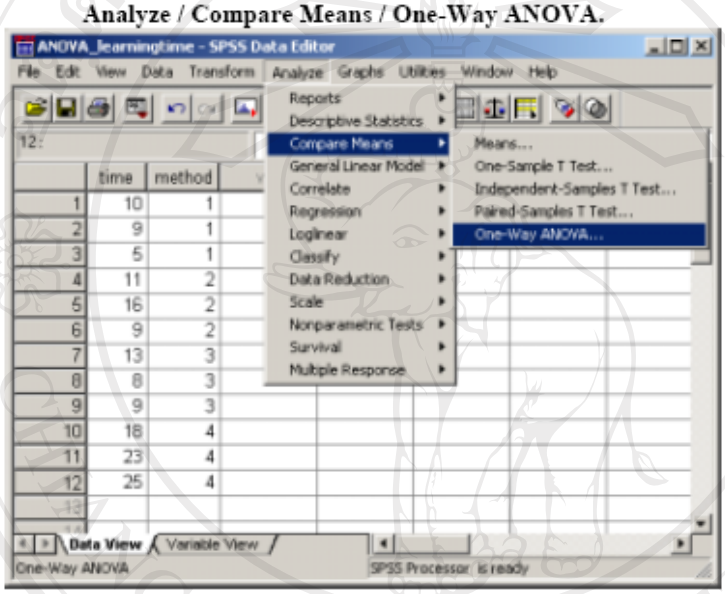
SPSS for One-Way ANOVA

Example: Evaluation of training programs.
Goal: To see if there is significant difference in learning time using different training methods.

To perform one-way ANOVA, for the data listed in the data table which contain 4 independent random samples:

1. Enter the dependent variable values and the independent variable (factor variable) values in the Date Editor. In the SPSS Data Editor sheet, it contains a data sheet for a one-way layout design with four treatment groups. The data in the following picture were scores from four treatment groups. **Method** is the factor variable and learning **time** is the dependent variable.

2. Click through the following menu selection:
   Analyze / Compare Means / One-Way ANOVA.

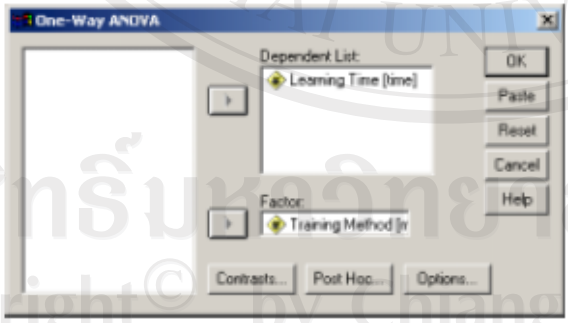


Data table: 3 observations in each sample.

Method 1	Method 2	Method 3	Method 4
10	11	13	18
9	16	8	23
5	9	9	25

Method is a treatment, group or independent variable. Learning time is the dependent variable.

3. Select the dependent or response variable and put into the **Dependent List** box, and put the method or treatment variable into **Factor** box.



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4. Click **Options** button, check **Descriptive** and **Homogeneity-of-Variance box**, and click **Continue** and click **OK**.

SPSS Output:

Descriptives

Learning Time

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
M1	3	8.00	2.65	1.53	1.43	14.57	5	10
M2	3	12.00	3.61	2.08	3.04	20.96	9	16
M3	3	10.00	2.65	1.53	3.43	16.57	8	13
M4	3	22.00	3.61	2.08	13.04	30.96	18	25
Total	12	13.00	6.24	1.80	9.04	16.96	5	25

Test of Homogeneity of Variances

Learning Time

Levene Statistic	df1	df2	Sig.
.267	3	8	.848

p-value indicating equal variances

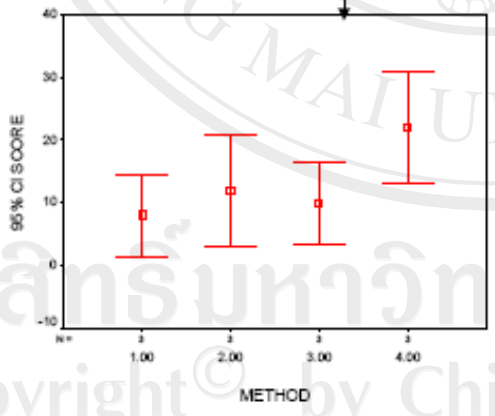
ANOVA

Learning Time

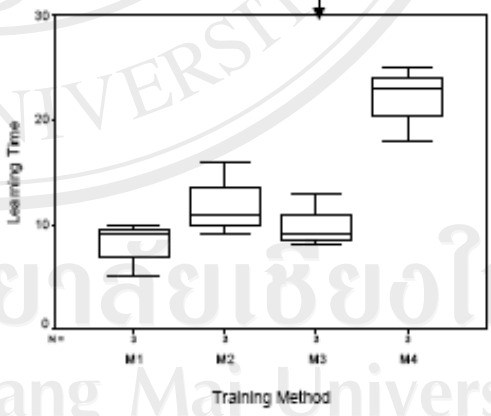
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	348.000	3	116.000	11.600	.003
Within Groups	80.000	8	10.000		
Total	428.000	11			

p-value indicating significant difference between treatment groups.

Error bar chart using SPSS graph



Side-by-side boxplot using SPSS Explore



Both error bar chart and side-by-side box plot above seem to suggest that the treatment group "four" may be significantly different from treatments 1, 2 and 3.

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5. To perform multiple comparisons, in the ANOVA dialog box, click the **Post Hoc…** button and check Tukey or any other method and click **Continue** and **OK**.

SPSS produces two tables. The multiple comparisons table containing confidence intervals can help us to understand the difference between each pairs of means. If interval doesn't cover zero, it implies that the difference between the pair of means are statistically significant.

Multiple Comparisons

Dependent Variable: Learning Time

Tukey HSD

(I) Training Method	(J) Training Method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M1	M2	-4.00	2.58	.455	-12.27	4.27
	M3	-2.00	2.58	.864	-10.27	6.27
	M4	-14.00*	2.58	.003	-22.27	-5.73
M2	M1	4.00	2.58	.455	-4.27	12.27
	M3	2.00	2.58	.864	-6.27	10.27
	M4	-10.00*	2.58	.020	-18.27	-1.73
M3	M1	2.00	2.58	.864	-6.27	10.27
	M2	-2.00	2.58	.864	-10.27	6.27
	M4	-12.00*	2.58	.007	-20.27	-3.73
M4	M1	14.00*	2.58	.003	5.73	22.27
	M2	10.00*	2.58	.020	1.73	18.27
	M3	12.00*	2.58	.007	3.73	20.27

*. The mean difference is significant at the .05 level.

The homogenous subsets table can help us to divide the four groups into homogenous subgroups. Within each subgroup the difference in means is statistically insignificant. The difference between average learning time of Methods 1, 2 and 3 are statistically insignificant and their means are significantly different from the mean from Method 4.

Learning Time

Tukey HSD[a]

Training Method	N	Subset for alpha = .05	
		1	2
M1	3	8.00	
M3	3	10.00	
M2	3	12.00	
M4	3		22.00
Sig.		.455	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

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Statistical Analysis for Uniaxial flexural strength (One-Way ANOVA)

1. Al_2O_3-reinforced system

1.1 Al_2O_3-reinforced ceramics

1.1.1 Descriptives

Materials	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Dental ceramic	20	83.4745	8.30799	1.85772	79.5862	87.3628	65.71	95.56
D-40%Al	20	133.3810	11.86379	2.65282	127.8286	138.9334	111.90	150.94
D-50%Al	20	124.0810	14.28516	3.19426	117.3953	130.7667	102.04	151.20
D-30%An	20	119.6080	20.07598	4.48913	110.2122	129.0038	93.09	167.13
D-40%An	20	119.1170	22.65199	5.06514	108.5155	129.7185	88.71	154.53
D-50%An	20	148.7560	13.58798	3.03836	142.3966	155.1154	132.20	172.73
D-30%Am	20	135.4400	17.74821	3.96862	127.1336	143.7464	93.95	159.44
D-40%Am	20	132.7200	19.13668	4.27909	123.7638	141.6762	93.09	155.37
D-30%Af	20	165.0570	18.07852	4.04248	156.5960	173.5180	139.88	187.40
D-40%Af	20	143.2590	17.52380	3.91844	135.0576	151.4604	116.92	165.72
Total	200	130.4894	26.36613	1.86437	126.8129	134.1658	65.71	187.40

1.1.2 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
4.067	9	190	.000

1.1.3 ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		84574.009	9	9397.112	33.208	.000
	Linear Term	Contrast	6174.077	1	6174.077	21.818	.000
		Deviation	78399.933	8	9799.992	34.632	.000
Within Groups			53765.381	190	282.976		
Total			138339.390	199			

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1.1.4 Post Hoc Tests

Multiple Comparisons: Dependent Variable: Scheffe

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dental ceramic	D-40%Al	-49.90650(*)	5.31955	.000	-72.0736	-27.7394
	D-50%Al	-40.60650(*)	5.31955	.000	-62.7736	-18.4394
	D-30%An	-36.13350(*)	5.31955	.000	-58.3006	-13.9664
	D-40%An	-35.64250(*)	5.31955	.000	-57.8096	-13.4754
	D-50%An	-65.28150(*)	5.31955	.000	-87.4486	-43.1144
	D-30%Am	-51.96550(*)	5.31955	.000	-74.1326	-29.7984
	D-40%Am	-49.24550(*)	5.31955	.000	-71.4126	-27.0784
	D-30%Af	-81.58250(*)	5.31955	.000	-103.7496	-59.4154
	D-40%Af	-59.78450(*)	5.31955	.000	-81.9516	-37.6174
D-40%Al	Dental ceramic	49.90650(*)	5.31955	.000	27.7394	72.0736
	D-50%Al	9.30000	5.31955	.961	-12.8671	31.4671
	D-30%An	13.77300	5.31955	.667	-8.3941	35.9401
	D-40%An	14.26400	5.31955	.618	-7.9031	36.4311
	D-50%An	-15.37500	5.31955	.502	-37.5421	6.7921
	D-30%Am	-2.05900	5.31955	1.000	-24.2261	20.1081
	D-40%Am	.66100	5.31955	1.000	-21.5061	22.8281
	D-30%Af	-31.67600(*)	5.31955	.000	-53.8431	-9.5089
	D-40%Af	-9.87800	5.31955	.942	-32.0451	12.2891
D-50%Al	Dental ceramic	40.60650(*)	5.31955	.000	18.4394	62.7736
	D-40%Al	-9.30000	5.31955	.961	-31.4671	12.8671
	D-30%An	4.47300	5.31955	1.000	-17.6941	26.6401
	D-40%An	4.96400	5.31955	1.000	-17.2031	27.1311
	D-50%An	-24.67500(*)	5.31955	.014	-46.8421	-2.5079
	D-30%Am	-11.35900	5.31955	.869	-33.5261	10.8081
	D-40%Am	-8.63900	5.31955	.976	-30.8061	13.5281
	D-30%Af	-40.97600(*)	5.31955	.000	-63.1431	-18.8089
	D-40%Af	-19.17800	5.31955	.172	-41.3451	2.9891
D-30%An	Dental ceramic	36.13350(*)	5.31955	.000	13.9664	58.3006
	D-40%Al	-13.77300	5.31955	.667	-35.9401	8.3941
	D-50%Al	-4.47300	5.31955	1.000	-26.6401	17.6941
	D-40%An	.49100	5.31955	1.000	-21.6761	22.6581
	D-50%An	-29.14800(*)	5.31955	.001	-51.3151	-6.9809
	D-30%Am	-15.83200	5.31955	.454	-37.9991	6.3351
	D-40%Am	-13.11200	5.31955	.731	-35.2791	9.0551
	D-30%Af	-45.44900(*)	5.31955	.000	-67.6161	-23.2819
	D-40%Af	-23.65100(*)	5.31955	.024	-45.8181	-1.4839

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1.1.4 Post Hoc Tests (cont.)

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
D-40%An	Dental ceramic	35.64250(*)	5.31955	.000	13.4754	57.8096
	D-40%Al	-14.26400	5.31955	.618	-36.4311	7.9031
	D-50%Al	-4.96400	5.31955	1.000	-27.1311	17.2031
	D-30%An	-.49100	5.31955	1.000	-22.6581	21.6761
	D-50%An	-29.63900(*)	5.31955	.001	-51.8061	-7.4719
	D-30%Am	-16.32300	5.31955	.405	-38.4901	5.8441
	D-40%Am	-13.60300	5.31955	.684	-35.7701	8.5641
	D-30%Af	-45.94000(*)	5.31955	.000	-68.1071	-23.7729
	D-40%Af	-24.14200(*)	5.31955	.018	-46.3091	-1.9749
D-50%An	Dental ceramic	65.28150(*)	5.31955	.000	43.1144	87.4486
	D-40%Al	15.37500	5.31955	.502	-6.7921	37.5421
	D-50%Al	24.67500(*)	5.31955	.014	2.5079	46.8421
	D-30%An	29.14800(*)	5.31955	.001	6.9809	51.3151
	D-40%An	29.63900(*)	5.31955	.001	7.4719	51.8061
	D-30%Am	13.31600	5.31955	.712	-8.8511	35.4831
	D-40%Am	16.03600	5.31955	.434	-6.1311	38.2031
	D-30%Af	-16.30100	5.31955	.407	-38.4681	5.8661
	D-40%Af	5.49700	5.31955	.999	-16.6701	27.6641
D-30%Am	Dental ceramic	51.96550(*)	5.31955	.000	29.7984	74.1326
	D-40%Al	2.05900	5.31955	1.000	-20.1081	24.2261
	D-50%Al	11.35900	5.31955	.869	-10.8081	33.5261
	D-30%An	15.83200	5.31955	.454	-6.3351	37.9991
	D-40%An	16.32300	5.31955	.405	-5.8441	38.4901
	D-50%An	-13.31600	5.31955	.712	-35.4831	8.8511
	D-40%Am	2.72000	5.31955	1.000	-19.4471	24.8871
	D-30%Af	-29.61700(*)	5.31955	.001	-51.7841	-7.4499
	D-40%Af	-7.81900	5.31955	.988	-29.9861	14.3481
D-40%Am	Dental ceramic	49.24550(*)	5.31955	.000	27.0784	71.4126
	D-40%Al	-.66100	5.31955	1.000	-22.8281	21.5061
	D-50%Al	8.63900	5.31955	.976	-13.5281	30.8061
	D-30%An	13.11200	5.31955	.731	-9.0551	35.2791
	D-40%An	13.60300	5.31955	.684	-8.5641	35.7701
	D-50%An	-16.03600	5.31955	.434	-38.2031	6.1311
	D-30%Am	-2.72000	5.31955	1.000	-24.8871	19.4471
	D-40%Am	-32.33700(*)	5.31955	.000	-54.5041	-10.1699
	D-30%Af	-10.53900	5.31955	.914	-32.7061	11.6281

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1.1.4 Post Hoc Tests (cont.)

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
D-30%Af	Dental ceramic	81.58250(*)	5.31955	.000	59.4154	103.7496
	D-40%Al	31.67600(*)	5.31955	.000	9.5089	53.8431
	D-50%Al	40.97600(*)	5.31955	.000	18.8089	63.1431
	D-30%An	45.44900(*)	5.31955	.000	23.2819	67.6161
	D-40%An	45.94000(*)	5.31955	.000	23.7729	68.1071
	D-50%An	16.30100	5.31955	.407	-5.8661	38.4681
	D-30%Am	29.61700(*)	5.31955	.001	7.4499	51.7841
	D-40%Am	32.33700(*)	5.31955	.000	10.1699	54.5041
	D-40%Af	21.79800	5.31955	.059	-.3691	43.9651
D-40%Af	Dental ceramic	59.78450(*)	5.31955	.000	37.6174	81.9516
	D-40%Al	9.87800	5.31955	.942	-12.2891	32.0451
	D-50%Al	19.17800	5.31955	.172	-2.9891	41.3451
	D-30%An	23.65100(*)	5.31955	.024	1.4839	45.8181
	D-40%An	24.14200(*)	5.31955	.018	1.9749	46.3091
	D-50%An	-5.49700	5.31955	.999	-27.6641	16.6701
	D-30%Am	7.81900	5.31955	.988	-14.3481	29.9861
	D-40%Am	10.53900	5.31955	.914	-11.6281	32.7061
	D-30%Af	-21.79800	5.31955	.059	-43.9651	.3691

* The mean difference is significant at the .05 level.

1.1.5 Homogeneous Subsets

Scheffe

Experimental conditions	N	Subset for alpha = .05				
		a	b	c	d	e
Dental ceramic	20	83.4745				
D-40%An	20		119.1170			
D-30%An	20		119.6080			
D-50%Al	20		124.0810	124.0810		
D-40%Am	20		132.7200	132.7200	132.7200	
D-40%Al	20		133.3810	133.3810	133.3810	
D-30%Am	20		135.4400	135.4400	135.4400	
D-40%Af	20			143.2590	143.2590	143.2590
D-50%An	20				148.7560	148.7560
D-30%Af	20					165.0570
Sig.		1.000	.405	.172	.434	.059

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 20.000.

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1.2 Al_2O_3-M_xO_y reinforced ceramics

1.2.1 Descriptives

Materials	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Dental ceramic	20	83.4745	8.30799	1.85772	79.5862	87.3628	65.71	95.56
D-38.6%Al-1.4%Ti	20	125.1900	19.95391	4.46183	115.8513	134.5287	84.13	150.07
D-38.6%Af-1.4%Ti	20	201.3370	21.99390	4.91799	191.0435	211.6305	170.33	234.34
D-38.6%Af-1.4%Mg	20	125.7230	19.67702	4.39992	116.5139	134.9321	79.97	152.50
D-37.2%Af-2.8%Zn	20	135.5105	24.79426	5.54416	123.9064	147.1146	96.05	171.07
D-34.6%Af-5.4%Zn	20	146.3020	14.83805	3.31789	139.3576	153.2464	125.12	175.76
D-32.4%Af-7.6%Zn	20	152.4920	19.87638	4.44449	143.1896	161.7944	111.75	181.88
Total	140	138.5756	37.97374	3.20937	132.2301	144.9211	65.71	234.34

1.2.2 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
4.392	6	133	.000

1.2.3 ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		151644.929	6	25274.155	68.891	.000
	Linear Term	Contrast	60956.730	1	60956.730	166.153	.000
		Deviation	90688.199	5	18137.640	49.439	.000
Within Groups			48793.741	133	366.870		
Total			200438.670	139			

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1.2.4 Post Hoc Tests

Multiple Comparisons: Dependent Variable: Scheffe

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dental ceramic	D-38.6%Al-1.4%Ti	-41.71550(*)	6.05698	.000	-63.5581	-19.8729
	D-38.6%Af-1.4%Ti	-117.86250(*)	6.05698	.000	-139.7051	-96.0199
	D-38.6%Af-1.4%Mg	-42.24850(*)	6.05698	.000	-64.0911	-20.4059
	D-37.2%Af-2.8%Zn	-52.03600(*)	6.05698	.000	-73.8786	-30.1934
	D-34.6%Af-5.4%Zn	-62.82750(*)	6.05698	.000	-84.6701	-40.9849
	D-32.4%Af-7.6%Zn	-69.01750(*)	6.05698	.000	-90.8601	-47.1749
D-38.6%Al-1.4%Ti	Dental ceramic	41.71550(*)	6.05698	.000	19.8729	63.5581
	D-38.6%Af-1.4%Ti	-76.14700(*)	6.05698	.000	-97.9896	-54.3044
	D-38.6%Af-1.4%Mg	-.53300	6.05698	1.000	-22.3756	21.3096
	D-37.2%Af-2.8%Zn	-10.32050	6.05698	.819	-32.1631	11.5221
	D-34.6%Af-5.4%Zn	-21.11200	6.05698	.067	-42.9546	.7306
	D-32.4%Af-7.6%Zn	-27.30200(*)	6.05698	.004	-49.1446	-5.4594
D-38.6%Af-1.4%Ti	Dental ceramic	117.86250(*)	6.05698	.000	96.0199	139.7051
	D-38.6%Al-1.4%Ti	76.14700(*)	6.05698	.000	54.3044	97.9896
	D-38.6%Af-1.4%Mg	75.61400(*)	6.05698	.000	53.7714	97.4566
	D-37.2%Af-2.8%Zn	65.82650(*)	6.05698	.000	43.9839	87.6691
	D-34.6%Af-5.4%Zn	55.03500(*)	6.05698	.000	33.1924	76.8776
	D-32.4%Af-7.6%Zn	48.84500(*)	6.05698	.000	27.0024	70.6876
D-38.6%Af-1.4%Mg	Dental ceramic	42.24850(*)	6.05698	.000	20.4059	64.0911
	D-38.6%Al-1.4%Ti	.53300	6.05698	1.000	-21.3096	22.3756
	D-38.6%Af-1.4%Ti	-75.61400(*)	6.05698	.000	-97.4566	-53.7714
	D-37.2%Af-2.8%Zn	-9.78750	6.05698	.854	-31.6301	12.0551
	D-34.6%Af-5.4%Zn	-20.57900	6.05698	.081	-42.4216	1.2636
	D-32.4%Af-7.6%Zn	-26.76900(*)	6.05698	.005	-48.6116	-4.9264
D-37.2%Af-2.8%Zn	Dental ceramic	52.03600(*)	6.05698	.000	30.1934	73.8786
	D-38.6%Al-1.4%Ti	10.32050	6.05698	.819	-11.5221	32.1631
	D-38.6%Af-1.4%Ti	-65.82650(*)	6.05698	.000	-87.6691	-43.9839
	D-38.6%Af-1.4%Mg	9.78750	6.05698	.854	-12.0551	31.6301
	D-34.6%Af-5.4%Zn	-10.79150	6.05698	.785	-32.6341	11.0511
	D-32.4%Af-7.6%Zn	-16.98150	6.05698	.257	-38.8241	4.8611
D-34.6%Af-5.4%Zn	Dental ceramic	62.82750(*)	6.05698	.000	40.9849	84.6701
	D-38.6%Al-1.4%Ti	21.11200	6.05698	.067	-.7306	42.9546
	D-38.6%Af-1.4%Ti	-55.03500(*)	6.05698	.000	-76.8776	-33.1924
	D-38.6%Af-1.4%Mg	20.57900	6.05698	.081	-1.2636	42.4216
	D-37.2%Af-2.8%Zn	10.79150	6.05698	.785	-11.0511	32.6341
	D-32.4%Af-7.6%Zn	-6.19000	6.05698	.983	-28.0326	15.6526
D-32.4%Af-7.6%Zn	Dental ceramic	69.01750(*)	6.05698	.000	47.1749	90.8601
	D-38.6%Al-1.4%Ti	27.30200(*)	6.05698	.004	5.4594	49.1446
	D-38.6%Af-1.4%Ti	-48.84500(*)	6.05698	.000	-70.6876	-27.0024
	D-38.6%Af-1.4%Mg	26.76900(*)	6.05698	.005	4.9264	48.6116
	D-37.2%Af-2.8%Zn	16.98150	6.05698	.257	-4.8611	38.8241
	D-34.6%Af-5.4%Zn	6.19000	6.05698	.983	-15.6526	28.0326

* The mean difference is significant at the .05 level.

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1.2.5 Homogeneous Subsets

Scheffe

Experimental conditions	N	Subset for alpha = .05			
		a	b	c	d
Dental ceramic	20	83.4745			
D-38.6%Al-1.4%Ti	20		125.1900		
D-38.6%Af-1.4%Mg	20		125.7230		
D-37.2%Af-2.8%Zn	20		135.5105	135.5105	
D-34.6%Af-5.4%Zn	20		146.3020	146.3020	
D-32.4%Af-7.6%Zn	20			152.4920	
D-38.6%Af-1.4%Ti	20				201.3370
Sig.		1.000	.067	.257	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 20.000.

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2. TiO_2-reinforced system

2.1 TiO_2-reinforced ceramics

2.1.1 Descriptives

Materials	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Dental ceramic	20	83.4745	8.30799	1.85772	79.5862	87.3628	65.71	95.56
D-10%Ti	20	110.4880	13.51323	3.02165	104.1636	116.8124	85.06	145.83
D-20%Ti	20	118.7080	17.91992	4.00702	110.3212	127.0948	94.09	161.13
D-30%Ti	20	120.6925	11.45048	2.56040	115.3335	126.0515	98.67	138.80
D-10%Tw	20	120.2810	12.83609	2.87024	114.2735	126.2885	99.04	147.20
D-20%Tw	20	124.2790	11.88587	2.65776	118.7162	129.8418	106.92	144.38
D-30%Tw	20	131.2425	11.01666	2.46340	126.0865	136.3985	111.67	148.80
Total	140	115.5951	19.00552	1.60626	112.4192	118.7709	65.71	161.13

2.1.2 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
1.375	6	133	.022

2.1.3 ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		28713.959	6	4785.660	29.612	.000
	Linear Term	Contrast	21244.362	1	21244.362	131.454	.000
		Deviation	7469.597	5	1493.919	9.244	.000
Within Groups			21494.187	133	161.610		
Total			50208.146	139			

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2.1.4 Scheffe Post Hoc Tests

Multiple Comparisons: Dependent Variable: Scheffe

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dental ceramic	D-10%Ti	-27.01350(*)	4.02008	.000	-41.5106	-12.5164
	D-20%Ti	-35.23350(*)	4.02008	.000	-49.7306	-20.7364
	D-30%Ti	-37.21800(*)	4.02008	.000	-51.7151	-22.7209
	D-10%Tw	-36.80650(*)	4.02008	.000	-51.3036	-22.3094
	D-20%Tw	-40.80450(*)	4.02008	.000	-55.3016	-26.3074
	D-30%Tw	-47.76800(*)	4.02008	.000	-62.2651	-33.2709
D-10%Ti	Dental ceramic	27.01350(*)	4.02008	.000	12.5164	41.5106
	D-20%Ti	-8.22000	4.02008	.653	-22.7171	6.2771
	D-30%Ti	-10.20450	4.02008	.381	-24.7016	4.2926
	D-10%Tw	-9.79300	4.02008	.435	-24.2901	4.7041
	D-20%Tw	-13.79100	4.02008	.076	-28.2881	.7061
	D-30%Tw	-20.75450(*)	4.02008	.000	-35.2516	-6.2574
D-20%Ti	Dental ceramic	35.23350(*)	4.02008	.000	20.7364	49.7306
	D-10%Ti	8.22000	4.02008	.653	-6.2771	22.7171
	D-30%Ti	-1.98450	4.02008	1.000	-16.4816	12.5126
	D-10%Tw	-1.57300	4.02008	1.000	-16.0701	12.9241
	D-20%Tw	-5.57100	4.02008	.926	-20.0681	8.9261
	D-30%Tw	-12.53450	4.02008	.146	-27.0316	1.9626
D-30%Ti	Dental ceramic	37.21800(*)	4.02008	.000	22.7209	51.7151
	D-10%Ti	10.20450	4.02008	.381	-4.2926	24.7016
	D-20%Ti	1.98450	4.02008	1.000	-12.5126	16.4816
	D-10%Tw	.41150	4.02008	1.000	-14.0856	14.9086
	D-20%Tw	-3.58650	4.02008	.992	-18.0836	10.9106
	D-30%Tw	-10.55000	4.02008	.338	-25.0471	3.9471
D-10%Tw	Dental ceramic	36.80650(*)	4.02008	.000	22.3094	51.3036
	D-105Ti	9.79300	4.02008	.435	-4.7041	24.2901
	D-20%Ti	1.57300	4.02008	1.000	-12.9241	16.0701
	D-30%Ti	-.41150	4.02008	1.000	-14.9086	14.0856
	D-20%Tw	-3.99800	4.02008	.986	-18.4951	10.4991
	D-30%Tw	-10.96150	4.02008	.290	-25.4586	3.5356
D-20Tw	Dental ceramic	40.80450(*)	4.02008	.000	26.3074	55.3016
	D-10%Ti	13.79100	4.02008	.076	-.7061	28.2881
	D-20%Ti	5.57100	4.02008	.926	-8.9261	20.0681
	D-30%Ti	3.58650	4.02008	.992	-10.9106	18.0836
	D-10%Tw	3.99800	4.02008	.986	-10.4991	18.4951
	D-30%Tw	-6.96350	4.02008	.807	-21.4606	7.5336
D-30%Tw	Dental ceramic	47.76800(*)	4.02008	.000	33.2709	62.2651
	D-10%Ti	20.75450(*)	4.02008	.000	6.2574	35.2516
	D-20%Ti	12.53450	4.02008	.146	-1.9626	27.0316
	D-30%Ti	10.55000	4.02008	.338	-3.9471	25.0471
	D-10%Tw	10.96150	4.02008	.290	-3.5356	25.4586
	D-20%Tw	6.96350	4.02008	.807	-7.5336	21.4606

* The mean difference is significant at the .05 level.

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2.1.5 Homogeneous Subsets

Scheffe

Experimental conditions	N	Subset for alpha = .05		
		a	b	c
Dental ceramic	20	83.4745		
D-10%Ti	20		110.4880	
D-20%Ti	20		118.7080	118.7080
D-10%Tw	20		120.2810	120.2810
D-30%Ti	20		120.6925	120.6925
D-20%Tw	20		124.2790	124.2790
D-30%Tw	20			131.2425
Sig.		1.000	.076	.146

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 20.000.

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2.2 TiO_2-Fe_2O_3 reinforced ceramics

2.2.1 Descriptives

Materials	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Dental ceramic	20	83.4745	8.30799	1.85772	79.5862	87.3628	65.71	95.56
D-27.8%Ti-2.2%Fe	20	125.7900	16.59982	3.71183	118.0210	133.5590	93.41	143.63
D-25.6%Ti-4.4%Fe	20	134.4185	16.60876	3.71383	126.6454	142.1916	103.90	166.94
D-23.4%Ti-6.6%Fe	20	135.7810	17.94555	4.01275	127.3822	144.1798	101.90	167.94
D-27.8%Tw-2.2%Fe	20	129.7125	15.54476	3.47591	122.4373	136.9877	92.97	156.80
D-25.6%Tw-4.4%Fe	20	141.8075	15.79390	3.53162	134.4157	149.1993	111.67	172.80
D-23.4%Tw-6.6%Fe	20	149.8060	18.80401	4.20471	141.0055	158.6065	123.20	182.73
Total	140	128.6843	25.31170	2.13923	124.4547	132.9139	65.71	182.73

2.2.2 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
1.800	6	133	.010

2.2.3 ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		55098.979	6	9183.163	35.969	.000
	Linear Term	Contrast	36587.376	1	36587.376	143.307	.000
		Deviation	18511.603	5	3702.321	14.501	.000
Within Groups			33955.822	133	255.307		
Total			89054.802	139			

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2.2.4 Post Hoc Tests

Multiple Comparisons: Dependent Variable: Scheffe

(I) Experimental conditions	(J) Experimental conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dental ceramic	D-27.8%Ti-2.2%Fe	-42.31550(*)	5.05279	.000	-60.5368	-24.0942
	D-25.6%Ti-4.4%Fe	-50.94400(*)	5.05279	.000	-69.1653	-32.7227
	D-23.4%Ti-6.6%Fe	-52.30650(*)	5.05279	.000	-70.5278	-34.0852
	D-27.8%Tw-2.2%Fe	-46.23800(*)	5.05279	.000	-64.4593	-28.0167
	D-25.6%Tw-4.4%Fe	-58.33300(*)	5.05279	.000	-76.5543	-40.1117
	D-23.4%Tw-6.6%Fe	-66.33150(*)	5.05279	.000	-84.5528	-48.1102
D-27.8%Ti-2.2%Fe	Dental ceramic	42.31550(*)	5.05279	.000	24.0942	60.5368
	D-25.6%Ti-4.4%Fe	-8.62850	5.05279	.818	-26.8498	9.5928
	D-23.4%Ti-6.6%Fe	-9.99100	5.05279	.689	-28.2123	8.2303
	D-27.8%Tw-2.2%Fe	-3.92250	5.05279	.996	-22.1438	14.2988
	D-25.6%Tw-4.4%Fe	-16.01750	5.05279	.132	-34.2388	2.2038
	D-23.4%Tw-6.6%Fe	-24.01600(*)	5.05279	.002	-42.2373	-5.7947
D-25.6%Ti-4.4%Fe	Dental ceramic	50.94400(*)	5.05279	.000	32.7227	69.1653
	D-27.8%Ti-2.2%Fe	8.62850	5.05279	.818	-9.5928	26.8498
	D-23.4%Ti-6.6%Fe	-1.36250	5.05279	1.000	-19.5838	16.8588
	D-27.8%Tw-2.2%Fe	4.70600	5.05279	.990	-13.5153	22.9273
	D-25.6%Tw-4.4%Fe	-7.38900	5.05279	.905	-25.6103	10.8323
	D-23.4%Tw-6.6%Fe	-15.38750	5.05279	.168	-33.6088	2.8338
D-23.4%Ti-6.6%Fe	Dental ceramic	52.30650(*)	5.05279	.000	34.0852	70.5278
	D-27.8%Ti-2.2%Fe	9.99100	5.05279	.689	-8.2303	28.2123
	D-25.6%Ti-4.4%Fe	1.36250	5.05279	1.000	-16.8588	19.5838
	D-27.8%Tw-2.2%Fe	6.06850	5.05279	.962	-12.1528	24.2898
	D-25.6%Tw-4.4%Fe	-6.02650	5.05279	.964	-24.2478	12.1948
	D-23.4%Tw-6.6%Fe	-14.02500	5.05279	.269	-32.2463	4.1963
D-27.8%Tw-2.2%Fe	Dental ceramic	46.23800(*)	5.05279	.000	28.0167	64.4593
	D-27.8%Ti-2.2%Fe	3.92250	5.05279	.996	-14.2988	22.1438
	D-25.6%Ti-4.4%Fe	-4.70600	5.05279	.990	-22.9273	13.5153
	D-23.4%Ti-6.6%Fe	-6.06850	5.05279	.962	-24.2898	12.1528
	D-25.6%Tw-4.4%Fe	-12.09500	5.05279	.458	-30.3163	6.1263
	D-23.4%Tw-6.6%Fe	-20.09350(*)	5.05279	.019	-38.3148	-1.8722
D-25.6%Tw-4.4%Fe	Dental ceramic	58.33300(*)	5.05279	.000	40.1117	76.5543
	D-27.8%Ti-2.2%Fe	16.01750	5.05279	.132	-2.2038	34.2388
	D-25.6%Ti-4.4%Fe	7.38900	5.05279	.905	-10.8323	25.6103
	D-23.4%Ti-6.6%Fe	6.02650	5.05279	.964	-12.1948	24.2478
	D-27.8%Tw-2.2%Fe	12.09500	5.05279	.458	-6.1263	30.3163
	D-23.4%Tw-6.6%Fe	-7.99850	5.05279	.866	-26.2198	10.2228
D-23.4%Tw-6.6%Fe	Dental ceramic	66.33150(*)	5.05279	.000	48.1102	84.5528
	D-27.8%Ti-2.2%Fe	24.01600(*)	5.05279	.002	5.7947	42.2373
	D-25.6%Ti-4.4%Fe	15.38750	5.05279	.168	-2.8338	33.6088
	D-23.4%Ti-6.6%Fe	14.02500	5.05279	.269	-4.1963	32.2463
	D-27.8%Tw-2.2%Fe	20.09350(*)	5.05279	.019	1.8722	38.3148
	D-25.6%Tw-4.4%Fe	7.99850	5.05279	.866	-10.2228	26.2198

* The mean difference is significant at the .05 level.

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2.2.5 Homogeneous Subsets

Scheffe

Experimental conditions	N	Subset for alpha = .05		
		a	b	c
Dental ceramic	20	83.4745		
D-27.8%Ti-2.2%Fe	20		125.7900	
D-27.8%Tw-2.2%Fe	20		129.7125	
D-25.6%Ti-4.4%Fe	20		134.4185	134.4185
D-23.4%Ti-6.6%Fe	20		135.7810	135.7810
D-25.6%Tw-4.4%Fe	20		141.8075	141.8075
D-23.4%Tw-6.6%Fe	20			149.8060
Sig.		1.000	.132	.168

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 20.000.

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Research Output:

National Conferences:

1. Fabrication and Characterization of Dental Porcelain Nanocomposite from Thailand's Raw Materials "*The 30th Congress on Science and Technology of Thailand, Bangkok (2004)*" **A. Pisitanusorn**, S. Ananta, R. Yimnirun, S. Thiansem

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2. The Influence of Crystalline Phase Additions on the Mechanical Properties of Dental Ceramic Materials "*Ceramic, Glass and Building Material Conference, Germany, (2006)*" **A. Pisitanusorn**, S. Ananta, R. Yimnirun, S. Thiansem

3. Effects of Sintering Condition on Microstructure and Mechanical Properties of Zirconia-reinforced Dental Ceramic Nanocomposites "*The first Thailand Natonal Nanotechnology Conference on Nanomaterials, Pharmaceuticals, Devices and Applications, (2007)*" **A. Pisitanusorn**, R. Yimnirun, S. Ananta

International Conferences:

1. Fabrication and Characterization of High Strength Dental Porcelain Nanocomposite from Thailand's Raw Materials "*The International Conference on Smart Materials (SmartMat-'04) Thailand (2004)*" **A. Pisitanusorn**, S. Ananta, R. Yimnirun, S. Thiansem

2. Titania and Titania-Metal Oxide Based Nanocomposite Materials Reinforced Dental Ceramics "*The 5th International Conference on Materials Processing for Properties and Performance (5th MP^{3}), Singapore (2006)*" **A. Pisitanusorn**, R. Yimnirun, S. Ananta, W. Schulle

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Public Contributions

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