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Statistical assessment of physicomechanical properties of refractory ceramics based on petroleum waste sludge -bauxite compositions

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Abstract: The aim of this work is to apply the analysis of variance (ANOVA) statistical program to the experimental data of high-quality refractory ceramics prepared from various compositions of petroleum waste sludge (PWS) and raw bauxite mineral to reach a precise and conclusive decision on a statistical basis to the optimum mix that is thought to be more suitable for use in refractory applications. Seven ceramic mixes were prepared from various proportions of PWS and bauxite varying between 0 and 100 wt. % via solid state technique with heat treatment at different degrees of firing reached 1600 ^{o}C. The physicomechanical properties namely, linear change, mechanical strength, bulk density, as well as apparent porosity were tested according to the international standards. The One-way ANOVA proves that there is statistically difference regarding linear shrinkage ($p = 0.01$) and mechanical strength ($p < 0.001$) for six groups of firing temperature [$F (5, 24) = 15.87$, $p < 0.001$]. There was also a statistically significant difference in both bulk density of the ceramic bodies for the six groups [$F (5, 24) = 12.5$, $p = 000$] and the apparent porosity in mean apparent porosity [$F (5, 24) = 21.538$, $p = 0.000$]. Thus, the One-way ANOVA results are compatible with the results shown in our previous published data. Moreover, the test added a good value by showing CM4 almost like CM3 and economically it is much better to utilize it instead of CM3 in industrial applications.

Keywords: ANOVA, bauxite, petroleum waste sludge, mechanical, density, porosity, shrinkage.

1. Introduction

Refractories are defined as materials that can stand heat at high temperature and mainly contained alumina oxide (Al_2O_3) and silica oxide (SiO_2) to form a group of aluminosilicate fireclay bricks, this chemical composition serves as a basic for classification of refractories [1]. Refractories are classified as non-metallic, heterogeneous, porous and inorganic materials composed of additives, thermally stable mineral combinations and a binder phase [2-4]. The physical characteristic of refractory is one of the major and essential properties that must be considered in material assortment to produce refractories [5]. Consequently, refractories with particular set of properties are prudently chosen for a precise purpose to meet the exact service conditions and other special requirements. The cost effectiveness of refractories considerably influences cost of refractory product. Therefore, proper selection of refractory materials is extremely essential to ensure low production costs and durability of refractory product. The combination of these properties was to maintain reliability and standards of refractories in the thermal industry. The physical properties include apparent porosity, bulk density, firing shrinkage, water absorption [6].

Recently, many researchers and industrialist paid attention to waste management to overcome the associated ecological and healthy problems resulting from their steady accumulation as by-products during various industries. [7-14]. Several attempts scientifically and economically were made to develop different methods to make use of these wastes [16,17]. Avoiding the serious environmental risk arises from gases and solid seep to environment without any treatments that can reflected in climatic change [18-20]. Saudi Arabia is one of the largest producing oil countries in the world, the oil industries accompanied with huge industrial wastes during the extraction, manufacture processes. The petroleum sludge (solid wastes) that resulting from oil well drilling, collection, transportation as well as refining processes in the form of complex emulsion

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containing different hydrocarbon compounds, heavy metals, water, and solid materials. Using chemical process could remove the hydrocarbons, while the heavy metals and solid particles are still problematic after the industrial manufacturing. The huge accumulation of such remnants (petroleum sludge) causing severe damage to the environment through air pollution, soil and water. Many studies were done to make use of these wastes in different ways, majority of these studies were concentrated on extracting and recovering the hydrocarbons materials [15].

On the other hand, huge reservoir of bauxite is available in Saudi Arabia, especially in Al-Zubaira region, east of KSA however its use is still limited to the field of aluminium metal industries [21]. In our previous research work [22] we have studied the suitability of using PWS and bauxite to produce high-quality ceramics. From the preliminary reading of the physicomechanical and refractory properties results, ceramic mix composition prepared from 40 wt. % PWS and 60 wt.% bauxite was considered as the optimum ceramic mix. These data were published in Ceramics International Journal [22]. However, a credible decision for accurate selection of the most suitable batch composition could not be concluded due to the relative variance in the obtained data. So, some statistical calculations are needed urgently for reaching a more suitable decision from economical point of view. Analysis of variance (ANOVA), a statistical tool applied to the data analysis that have a great utility and flexibility for the experimental data that can be applied in order to determine what experiments should be carried out to help in designing decisions effectively based on the differences between several different groups of treatments and multiple comparisons between the group means using t-tests [23].

In the present work, we extend our evaluation to the prepared ceramic bodies through statistical studies for the experimental data physicomechanical properties to aid the understanding of chemical processes and contribute to make reliable decisions. To perform this analysis, One-way analysis of variance (ANOVA), is applied. This procedure allows to test the possible differences in physicomechanical properties according to the treatments used, considering that the data are functions.

2. Materials and Methods

2.1. Material

PWS was provided by petroleum company, while bauxite mineral was collected from Al-Zuberia region east KSA. Detailed chemical and mineralogical studies were presented in our previous study [22].

2.2. Experimental

2.2.1. Compositions of the prepared ceramic mixes:

The compositions of the prepared ceramic mixes are given in table (1).

Table 1: Compositions of the ceramic mixes [22]

Ceramic mix no.	**Bauxite, wt.%**	**PWS, wt. %**
CM1	100.0	00.0
CM2	80.0	20.0
CM3	60.0	40.0
CM4	50.0	50.0
CM5	40.0	60.0
CM6	20.0	80.0
CM7	00.0	100.0

2.2.2. Physicomechanical properties:

Linear shrinkage (LS, %), bulk density (BD, g/cm^3), apparent porosity (AP, %) as well as cold crushing strength (CCS., kg/cm^2) were tested according to the international standard specifications of refractories [24, 25].

2.2.3. Statistical calculations

A One-way Analysis of variance is a method to test the difference of three or more means at the time. There are many assumptions, among them, the true populations must be normally or approximately, the samples must be independent, and the variance of the populations must be equal. The null hypothesis is the all population means are equal the alternative hypothesis is that at least one mean is different. The test model is

$$Y_{ij} = \mu_i + \varepsilon_{ij} \qquad i = 1, \dots, I; j = 1, \dots, J, \qquad \varepsilon_{ij} \text{ i.i.} d\ N(0, \sigma^2),$$

Table 2: ANOVA table

Source of variance	**SS**	**df**	**MS**	**F**
Between	*SSB*	*k-1*	*SSB/k-1*	*MSB/MSW*
Within	*SSW*	*N-K*	*SSW/N-K*	
Total	*SST*	*N-1*		

Where SSB, is the difference between groups, SSW, is the difference within groups, SST, the total of difference, df is the degree of freedom [26,27].

3. Results

3.1. Obtained results

3.1.1. Descriptive statistics for linear shrinkage (%):

The values of linear shrinkage obtained from the experimental data [22] are given in the table 3.

Table 3: LS of ceramic bodies fired at different firing temperatures [22]

Temperature (oC)	**Linear shrinkage (%)**				
	CM1	**CM2**	**CM3**	**CM4**	**CM5**
800	2.250	2.900	3.150	3.300	3.750
1000	2.700	3.100	3.500	3.800	3.950
1200	2.650	2.900	3.100	3.400	3.810
1400	2.980	3.220	3.450	3.760	3.930
1500	3.100	3.200	3.600	3.750	3.980
1600	2.900	3.000	3.200	3.350	3.400

*N.B. Ceramic bodies prepared from CM6 and CM7 batches failed to withstand more than 1300 ^{o}C so they were excluded from further study.

Table 4, provides some very useful descriptive statistics for the samples, including; mean, standard deviation and 95% confidence intervals for the dependent variable linear shrinkage (%) for each separate group (CM1, CM2, CM3, CM4, and CM5), as well as for all combined groups (Total). The experiment repeated 30 times, we conducted it with equal replications, six times for each batch. CM5 has the highest mean of linear shrinkage (%), (M = 3.8, SD = 0.22), followed by CM4 (M = 3.56, SD = 0.23), CM1 has the smallest mean of (M = 2.7, SD = 0.3), the overall mean is (M=3.3, SD= 0.4).

Table 4: Descriptive statistics for linear shrinkage (%)

Batches	**N**	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
					Lower Bound	**Upper Bound**		
CM1	6	2.7633	.30310	.12374	2.4453	3.0814	2.25	3.10
CM2	6	3.0533	.14236	.05812	2.9039	3.2027	2.90	3.22
CM3	6	3.3333	.20897	.08531	3.1140	3.5526	3.10	3.60
CM4	6	3.5600	.23281	.09504	3.3157	3.8043	3.30	3.80
CM5	6	3.8033	.21649	.08838	3.5761	4.0305	3.40	3.98
Total	30	3.3027	.42789	.07812	3.1429	3.4624	2.25	3.98

Table 5, shows the descriptive statistics, including the mean, standard deviation and 95% confidence interval for the linear shrinkage (%) in different levels of firing temperatures (800 ^{o}C to 1600 ^{o}C), we measured the linear shrinkage 30 time, five for each temperature, the overall sample mean (M = 3.3, SD = 0.43), the 1500 ^{o}C shows the highest mean (M = 3.53, SD = 0.37) while 800 ^{o}C has the lowest mean (M = 3.1, SD = 0.55), it is clear that the mean increases with increasing temperature until 1500 oC then it decreases at 1600 ^{o}C.

Table 5: Descriptive statistics for linear shrinkage (%)

Temp.	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
800ºC	5	3.0700	.55295	.24729	2.3834	3.7566	2.25	3.75
1000 ºC	5	3.4100	.51284	.22935	2.7732	4.0468	2.70	3.95
1200 ºC	5	3.1720	.45019	.20133	2.6130	3.7310	2.65	3.81
1400 ºC	5	3.4680	.38687	.17301	2.9876	3.9484	2.98	3.93
1500 ºC	5	3.5260	.37065	.16576	3.0658	3.9862	3.10	3.98
1600 ºC	5	3.1700	.21679	.09695	2.9008	3.4392	2.90	3.40
Total	30	3.3027	.42789	.07812	3.1429	3.4624	2.25	3.98

3.1.2. Descriptive statistics for mechanical strength (Kg/cm^2):

The mechanical strength (CCS kg/cm^2) values obtained from the experimental data [22] are given in the table 6.

Table 6: CCS of ceramic bodies at different firing temperatures [22]

Temperature (ºC)	CCS (Kg/cm^2)				
	CM1	CM2	CM3	CM4	CM5
800	140	190	210	195	178
1000	190	210	300	290	255
1200	310	420	600	560	510
1400	400	480	720	660	590
1500	510	600	910	710	640
1600	460	520	830	650	590

Table 7, shows the descriptive statistics for the effect of different batches of compositions on the mechanical strength of the ceramic bodies (CCS (Kg/cm^2)), including the mean, standard deviation and 95% confidence intervals for separate group (CM1, CM2, CM3, CM4, and CM5), CM3 composition shows the largest mean of CCS (kg/cm^2), (M=595, S= 285), while CM1 shows the lowest one, (M= 335, S= 148), and the total mean is (M = 460, S = 213).

Table 7: Descriptive statistics for CCS (Kg/cm^2)

Batches	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CM1	6	335.0000	148.42507	60.59428	179.2374	490.7626	140.00	510.00
CM2	6	403.3333	168.12694	68.63753	226.8949	579.7717	190.00	600.00
CM3	6	595.0000	284.72794	116.23969	296.1964	893.8036	210.00	910.00
CM4	6	510.8333	215.50909	87.98122	284.6704	736.9963	195.00	710.00
CM5	6	460.5000	195.06281	79.63406	255.7941	665.2059	178.00	640.00
Total	30	460.9333	213.11709	38.90968	381.3541	540.5126	140.00	910.00

Table 8, contains descriptive statistics of cold crushing strength (CCS, kg/cm^2) of the ceramic bodies at different firing temperatures, these are mean, standard deviation and 95% confidence intervals, (800 ºC to 1600 ºC), the experiment done 30 times, repeated equally for all firing temperatures, among them 1500 ºC has the largest mean of CCS (kg/cm^2), (M = 674, S= 150), 800 ºC shows the lowest mean (M = 182, S = 26), as we can see from the table the mean of CCS (kg/cm^2) increases with increasing the firing temperature until 1500 ºC, then it decreases at 1600 ºC. The total mean of CCS (kg/cm^2) at all firing temperatures is (M = 461, S = 213).

Table 8: Descriptive statistics for CCS (Kg/cm²)

Temp.	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
800°C	5	182.6000	26.43483	11.82201	149.7768	215.4232	140.00	210.00
1000 °C	5	249.0000	48.27007	21.58703	189.0648	308.9352	190.00	300.00
1200 °C	5	480.0000	116.40447	52.05766	335.4648	624.5352	310.00	600.00
1400 °C	5	570.0000	130.38405	58.30952	408.1068	731.8932	400.00	720.00
1500 °C	5	674.0000	150.43271	67.27555	487.2131	860.7869	510.00	910.00
1600 °C	5	610.0000	142.30249	63.63961	433.3081	786.6919	460.00	830.00
Total	30	460.9333	213.11709	38.90968	381.3541	540.5126	140.00	910.00

3.1.3. Descriptive statistics for bulk density (g/cm3):

Table 9 shows the bulk densities (BD) values from experimental data [22] for prepared ceramic bodies fired at different temperatures.

Table 9: BD of the ceramic bodies at different firing temperature [22]

Temperature (°C)	Bulk density (g/cm³)				
	CM1	CM2	CM3	CM4	CM5
800	2.40	2.55	2.75	2.70	2.65
1000	2.70	3.00	3.10	2.80	2.76
1200	2.95	3.10	3.20	2.90	2.81
1400	3.15	3.22	3.27	3.15	2.93
1500	3.20	3.29	3.38	3.27	3.08
1600	2.97	3.10	3.25	3.18	2.91

Table 10, shows the descriptive statistics for the effect of different batches composition on the bulk density (g/cm³) of the ceramic bodies prepared including the mean, standard deviation and 95% confidence intervals for separate batches (CM1, CM2, CM3, CM4, and CM5), the number of trails is 30, six trails for each batch, the results show that CM3 composition has the largest mean of bulk density (g/cm³), (M =3.15, S = 0.22), while CM5 have the lowest mean of bulk density (g/cm³), (M = 2.85, S = 0.14), and the total mean is (M = 2.99, S = 0.24).

Table 10: Descriptive statistics for Bulk density (g/cm³)

Batches	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CM1	6	2.8950	.29992	.12244	2.5803	3.2097	2.40	3.20
CM2	6	3.0433	.26220	.10704	2.7682	3.3185	2.55	3.29
CM3	6	3.1583	.21995	.08979	2.9275	3.3892	2.75	3.38
CM4	6	3.0000	.23143	.09448	2.7571	3.2429	2.70	3.27
CM5	6	2.8567	.14989	.06119	2.6994	3.0140	2.65	3.08
Total	30	2.9907	.24663	.04503	2.8986	3.0828	2.40	3.38

Table 11, gives the descriptive statistics of bulk density (g/cm³) of the ceramic bodies at different firing temperatures, these are, the mean, standard deviation and 95% confidence intervals, for each separate temperature (800 °C to 1600 °C), the total number of trails is 30, repeated equally for all firing temperatures, among them 1500 °C has the largest mean of bulk density (M = 3.24, S = 0.11) whereas 800 °C shows the lowest mean (M = 2.6, S = 0.13), as we can see from the table (11) the mean increases with increasing the firing temperatures until 1500 °C, then it decreases at 1600 °C (M = 3, S =0.14). The total mean of bulk density at different firing temperatures is (M = 2.99, S = 0.25).

Table 11: Descriptive statistics for bulk density (g/cm3)

Temp.	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
800 ºC	5	2.6100	.13874	.06205	2.4377	2.7823	2.40	2.75
1000 ºC	5	2.8720	.17006	.07605	2.6608	3.0832	2.70	3.10
1200 ºC	5	2.9920	.15675	.07010	2.7974	3.1866	2.81	3.20
1400 ºC	5	3.1440	.12992	.05810	2.9827	3.3053	2.93	3.27
1500 ºC	5	3.2440	.11194	.05006	3.1050	3.3830	3.08	3.38
1600 ºC	5	3.0820	.14167	.06336	2.9061	3.2579	2.91	3.25
Total	30	2.9907	.24663	.04503	2.8986	3.0828	2.40	3.38

3.1.4. Descriptive statistics for apparent porosity (%):

Table 12, shows the apparent porosity (AP) percentages from experimental data [22] for ceramic bodies at different firing temperature.

Table 12: AP of the ceramic bodies at different firing temperature [22]

Temperature (ºC)	Apparent porosity (%)				
	CM1	CM2	CM3	CM4	CM5
800	17.03	15.66	13.01	14.66	16.08
1000	12.93	11.43	10.22	11.96	13.11
1200	11.86	10.35	08.93	10.77	12.07
1400	09.04	07.93	06.31	08.50	10.21
1500	07.33	06.18	04.02	07.03	08.96
1600	08.91	07.96	05.16	08.19	09.86

The sample characteristics of the effect of different batches on the apparent porosity of the ceramic bodies are shown in table 13, the descriptive statistics are, the mean, standard deviation and 95% confidence intervals for different batches (CM1, CM2, CM3, CM4, and CM5), as we can see, the highest mean of apparent porosity was in CM5 (M = 11.5, S = 2.62), while CM3 has the smallest one (M = 7.9, S = 3.39), the total mean is (M = 10.188, S = 3.22).

Table 13: Descriptive statistics for apparent porosity (%)

Batches	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
M1	6	11.1833	3.52994	1.44109	7.4789	14.8878	7.33	17.03
M2	6	9.9183	3.38236	1.38084	6.3688	13.4679	6.18	15.66
M3	6	7.9417	3.39515	1.38606	4.3787	11.5047	4.02	13.01
M4	6	10.1850	2.83872	1.15890	7.2059	13.1641	7.03	14.66
M5	6	11.7150	2.62379	1.07116	8.9615	14.4685	8.96	16.08
Total	30	10.1887	3.22971	.58966	8.9827	11.3947	4.02	17.03

Table 14, shows the descriptive statistics of apparent porosity at different firing temperature, the total sample size (number of trails) is 30, divided equally for different temperature, the statistics are, the mean, standard deviation and 95% confidence intervals, for each separate temperature (800 ºC , 1000 ºC, 1200 ºC, 1400 ºC, 1500 ºC, 1600 ºC), from the result, 800 ºC group has the largest mean comparing to other groups (M = 15.29, S = 1.5), while 1500 ºC shows the minimum mean (M = 6.7, S = 1.8), the total mean was (M = 10.188, S = 3.2).

Table 14: Descriptive statistics for apparent porosity (%)

Temp.	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
800 ºC	5	15.2880	1.53166	.68498	13.3862	17.1898	13.01	17.03
1000 ºC	5	11.9300	1.17977	.52761	10.4651	13.3949	10.22	13.11
1200 ºC	5	10.7960	1.26853	.56731	9.2209	12.3711	8.93	12.07
1400 ºC	5	8.3980	1.43916	.64361	6.6111	10.1849	6.31	10.21
1500 ºC	5	6.7040	1.80735	.80827	4.4599	8.9481	4.02	8.96
1600 ºC	5	8.0160	1.75995	.78707	5.8307	10.2013	5.16	9.86
Total	30	10.1887	3.22971	.58966	8.9827	11.3947	4.02	17.03

3.2. Discussion

There was statistically significant difference between groups in comparing the effect of different batches on the linear shrinkage (%) of the ceramic bodies at the ($p < 0.01$) as determined by One-way ANOVA [F (4, 25) = 19.588, p = 000], (table 15). A Tukey post hoc test (table 16) revealed that there is statistically difference in linear shrinkage (%) between CM1 and CM3 (P = 0.002) as well as between CM1 and CM4 (P= 000), also between CM1 and CM5 (p = 000). In addition, the test stated that there is statistically difference between CM2 and CM4 (p = 006), as well as between CM2 and CM5 (p = 000), the test also shows that there is statistically difference in linear shrinkage (%) between the CM3 and CM5 (p = 0.01). However, there were no difference between (CM1 & CM2), (CM2 & CM3), (CM3 & CM4), finally (CM4 and CM5) ($p > 0.05$). A One- way between groups, ANOVA was performed to compare the effect of different firing temperature on linear shrinkage (%). There wasn't any significant effect of temperatures on linear shrinkage (%) at the ($P < 0.05$) level, [F (5, 24) = 0.964, p = 0.459], table 17.

A One-way between groups analysis of variance was conducted to explore the impact of the firing temperatures on mechanical strength of the prepared ceramic bodies. There was a statistically significant difference (table 18) at the ($p < 0.001$) level in mechanical strength for five groups of firing temperatures [F (5, 24) = 15.87, $p < 0.001$]. Post-hoc comparison (table 19) using the Tukey HSD test indicated that the mean strength at 800 ºC (M = 182.6, SD = 26.4) was significantly different from 1200 ºC (M= 480, SD = 116.4), 1400 ºC (M = 570, SD = 130.38), 1500 ºC (M = 674, SD =150.4), and 1600 ºC (M = 610, SD =142.3), in addition the test revealed that the mean strength of 1000 ºC (M = 249, SD = 48) was statistically different from 1200 ºC (M = 480, SD = 116.4), 1400 ºC (M =570, SD = 130.38), 1500 ºC (M = 674, SD =150.4), and 1600 ºC (M = 610, SD =142.3). There was no statistically significant difference in mean strength between the firing temperatures (1200 ºC &1400 ºC), (1200 ºC & 1500 ºC) and (1200 ºC & 1600 ºC), (table 20).

ANOVA

Table 15: LS (%)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.025	4	1.006	19.588	.000
Within Groups	1.284	25	.051		
Total	5.310	29			

ANOVA

Table 17: LS (%)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.888	5	.178	.964	.459
Within Groups	4.422	24	.184		
Total	5.310	29			

ANOVA

Table 18: CCS (Kg/cm^2)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	1011312.667	5	202262.533	15.872	.000
Within Groups	305835.200	24	12743.133		
Total	1317147.867	29			

ANOVA

Table 20: CCS (Kg/cm^2)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	237846.200	4	59461.550	1.377	.270
Within Groups	1079301.667	25	43172.067		
Total	1317147.867	29			

A One-way between groups ANOVA was performed to compare the impact of firing temperature on bulk density of the ceramic bodies. Temperatures divided into five groups (800ºC, 1200 ºC, 1400 ºC, 1500 ºC, 1600 ºC). There was a statistically significant difference in bulk density (table 21) of the prepared ceramic bodies for the six groups [F (5, 24) = 12.5, p = 000]. Post-hoc comparisons using the Tukey HSD test (table 22) indicated that the mean bulk density for 800 ºC (M = 2.6100 SD = 0.13) was significantly different from 1200 ºC (M = 2.99, SD = 0.15), 1400 ºC (M = 3.1, SD = 0.12), 1500 ºC (M = 3.24, SD = 0.11) and 1600 ºC (M = 3.08, SD = 0.14). In addition, the test raveled that the mean bulk density for 1200 ºC (M = 2.99, SD = 0.15) was significantly different from 800 ºC (M = 2.6100 SD = 0.13) only, but it differed from the other firing temperatures. In addition to that the test stated that the mean bulk density for 1500 ºC (M = 3.24 SD = 0.11) was significantly different from 1000 ºC (M = 2.87 SD = 0.17), but the test showed significant difference between other groups. A One-way ANOVA (table 23) was conducted also to compare the effect of different batches on the bulk density of the ceramic bodies, the test shows that there wasn't any significant effect of different batches on the mean bulk density at the P < 0.05 level, [F (4, 25) = 1.54, p = 0.22].

ANOVA

Table 21: BD (g/cm^3)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	1.275	5	.255	12.519	.000
Within Groups	.489	24	.020		
Total	1.764	29			

ANOVA

Table 23: BD (g/cm^3)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.348	4	.087	1.539	.222
Within Groups	1.415	25	.057		
Total	1.764	29			

A one-way between subject's ANOVA was conducted to compare the effect of firing temperatures (800 ºC - 1600 ºC) on apparent porosity of the ceramic bodies. Temperatures divided into five groups (800 ºC, 1200 ºC, 1400 ºC, 1500 ºC, 1600 ºC). There was a statistically significant difference (table 24), in apparent porosity of the prepared ceramic bodies for the six groups [F (5, 24) = 21.5, p = 000]. Tukey HSD test (table 25) indicated that the mean apparent porosity for 800 ºC (M = 15.2 SD = 1.5) was significantly different from 1000 ºC (M= 11.9, SD = 1.17), 1200 ºC (M = 10.78, SD = 1.26), 1400 ºC (M = 8.39, SD = 1.43), 1500 ºC (M = 6.7, SD = 1.8) and 1600 ºC (M = 8.0, SD = 1.8). In addition, the test revealed that the mean apparent porosity for 1000 ºC (M= 11.9, SD = 1.17) was significantly different from 1400 ºC (M = 8.39, SD = 1.43) and 1500 ºC (M = 6.7, SD = 1.8) and 1600 ºC (M = 8.0, SD = 1.8). However, there was no statistically significant difference in mean apparent porosity between 1000 ºC and 1200 ºC. In addition to that the test stated that the mean apparent porosity at 1200 ºC (M = 10.78, SD = 1.26), was significantly different from 1500 ºC (M = 6.7, SD = 1.8), and 1600 ºC (M = 8.0, SD = 1.8), but showed significant difference between mean apparent porosity at 1200 ºC (M = 10.78, SD = 1.26) and 1000 ºC (M= 11.9, SD = 1.17) and 1400 ºC (M = 8.39, SD = 1.43). The test showed the evidence of significance difference in mean apparent porosity between 1400 ºC (M = 8.39, SD = 1.43), 1500 ºC (M = 6.7, SD = 1.8), and 1600 ºC (M = 8.0, SD = 1.8). A One-way ANOVA was conducted also to compare the effect of different batches on the apparent porosity of the ceramic bodies, the test shows that there wasn't significant effect of different batches (table 26) on the mean apparent porosity at the level ($P < 0.05$) level, [$F (4, 25) = 1.25$, $p = 0.313$].

These results support our conclusions on the previous work [22] regarding the improvement in physicomechanical properties of the prepared ceramic bodies especially the mixes CM3 and CM4 at 1500 ºC due to the presence of recognized assemblage of minerals namely; mullite ($3Al_2O_3.2SiO_2$), aluminate, barium aluminate ($BaO.Al_2O_3$) and corundum (Al_2O_3) system [22].These formed minerals (proved before with XRD and SEM [22]) are characterized with good mechanical properties,(they interacted together forming a compact rod-like crystals of mullite interacted with patch crystals of barium aluminate while the hexagonal plate-like turned together from one side with the other minerals on the other leading to a well compact microstructure and hence less pores and cavities in the matrix causing on improvement in volume stability (low linear shrinkage), a relatively higher bulk densities, lower apparent porosity and hence good recognized mechanical strength [28-35].

ANOVA

Table 24: AP (%)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	247.371	5	49.474	21.538	.000
Within Groups	55.129	24	2.297		
Total	302.499	29			

ANOVA

Table 26: AP (%)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	50.647	4	12.662	1.257	.313
Within Groups	251.852	25	10.074		
Total	302.499	29			

4. Conclusion:

Based on the detailed statistical studies both CM3 and CM4 mixes show outstanding physicomechanical behavior, however the statistical variance calculation between CM3 and CM4 is not significant, this is also true between temperatures 1500 ºC and 1600 ºC. So, from economical point of view M4 mix (50% bauxite + 50 % PWS) could be selected as the optimum mix regarding the physicomechanical properties.

Multiple Comparisons

Table 16: Linear shrinkage (%) Tukey HSD

(I) Batches		(J) Batches		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
dimension2	CM1	dimension3	CM2	-.29000-	.13086	.207	-.6743-	.0943
			CM3	-.57000-*	.13086	.002	-.9543-	-.1857-
			CM4	-.79667-*	.13086	.000	-1.1810-	-.4123-
			CM5	-1.04000-*	.13086	.000	-1.4243-	-.6557-
	CM2	dimension3	CM1	.29000	.13086	.207	-.0943-	.6743
			CM3	-.28000-	.13086	.235	-.6643-	.1043
			CM4	-.50667-*	.13086	.006	-.8910-	-.1223-
			CM5	-.75000-*	.13086	.000	-1.1343-	-.3657-
	CM3	dimension3	CM1	.57000*	.13086	.002	.1857	.9543
			CM2	.28000	.13086	.235	-.1043-	.6643
			CM4	-.22667-	.13086	.434	-.6110-	.1577
			CM5	-.47000-*	.13086	.011	-.8543-	-.0857-
	CM4	dimension3	CM1	.79667*	.13086	.000	.4123	1.1810
			CM2	.50667*	.13086	.006	.1223	.8910
			CM3	.22667	.13086	.434	-.1577-	.6110
			CM5	-.24333-	.13086	.364	-.6277-	.1410
	CM5	dimension3	CM1	1.04000*	.13086	.000	.6557	1.4243
			CM2	.75000*	.13086	.000	.3657	1.1343
			CM3	.47000*	.13086	.011	.0857	.8543
			CM4	.24333	.13086	.364	-.1410-	.6277

*. The mean difference is significant at the 0.05 level.

Table 19: CCS (Kg/cm^2) Tukey HSD

(I) Tempreture (0C)		(J) Tempreture (0C)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	800C	dimension3	1000C	-66.40000-	71.39505	.935	-287.1486-	154.3486
			1200C	-297.40000-*	71.39505	.004	-518.1486-	-76.6514-
			1400C	-387.40000-*	71.39505	.000	-608.1486-	-166.6514-
			1500C	-491.40000-*	71.39505	.000	-712.1486-	-270.6514-
			1600C	-427.40000-*	71.39505	.000	-648.1486-	-206.6514-
	1000C	dimension3	800C	66.40000	71.39505	.935	-154.3486-	287.1486
			1200C	-231.00000-*	71.39505	.037	-451.7486-	-10.2514-
			1400C	-321.00000-*	71.39505	.002	-541.7486-	-100.2514-
			1500C	-425.00000-*	71.39505	.000	-645.7486-	-204.2514-
			1600C	-361.00000-*	71.39505	.000	-581.7486-	-140.2514-
	1200C	dimension3	800C	297.40000*	71.39505	.004	76.6514	518.1486
			1000C	231.00000*	71.39505	.037	10.2514	451.7486
			1400C	-90.00000-	71.39505	.803	-310.7486-	130.7486
			1500C	-194.00000-	71.39505	.108	-414.7486-	26.7486
			1600C	-130.00000-	71.39505	.472	-350.7486-	90.7486
	1400C	dimension3	800C	387.40000*	71.39505	.000	166.6514	608.1486
			1000C	321.00000*	71.39505	.002	100.2514	541.7486
			1200C	90.00000	71.39505	.803	-130.7486-	310.7486
			1500C	-104.00000-	71.39505	.693	-324.7486-	116.7486
			1600C	-40.00000-	71.39505	.993	-260.7486-	180.7486
	1500C	dimension3	800C	491.40000*	71.39505	.000	270.6514	712.1486
			1000C	425.00000*	71.39505	.000	204.2514	645.7486
			1200C	194.00000	71.39505	.108	-26.7486-	414.7486
			1400C	104.00000	71.39505	.693	-116.7486-	324.7486
			1600C	64.00000	71.39505	.944	-156.7486-	284.7486
	1600C	dimension3	800C	427.40000*	71.39505	.000	206.6514	648.1486
			1000C	361.00000*	71.39505	.000	140.2514	581.7486
			1200C	130.00000	71.39505	.472	-90.7486-	350.7486
			1400C	40.00000	71.39505	.993	-180.7486-	260.7486
			1500C	-64.00000-	71.39505	.944	-284.7486-	156.7486

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Table 22: Bulk density(g/cm^3) Tukey HSD

(I) Tempreture (^{0}C)		(J) Tempreture (^{0}C)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	800C	dimension3	1000C	-.26200-	.09027	.075	-.5411-	.0171
			1200C	-.38200-*	.09027	.004	-.6611-	-.1029-
			1400C	-.53400-*	.09027	.000	-.8131-	-.2549-
			1500C	-.63400-*	.09027	.000	-.9131-	-.3549-
			1600C	-.47200-*	.09027	.000	-.7511-	-.1929-
	1000C	dimension3	800C	.26200	.09027	.075	-.0171-	.5411
			1200C	-.12000-	.09027	.766	-.3991-	.1591
			1400C	-.27200-	.09027	.059	-.5511-	.0071
			1500C	-.37200-*	.09027	.005	-.6511-	-.0929-
			1600C	-.21000-	.09027	.222	-.4891-	.0691
	1200C	dimension3	800C	.38200*	.09027	.004	.1029	.6611
			1000C	.12000	.09027	.766	-.1591-	.3991
			1400C	-.15200-	.09027	.555	-.4311-	.1271
			1500C	-.25200-	.09027	.093	-.5311-	.0271
			1600C	-.09000-	.09027	.914	-.3691-	.1891
	1400C	dimension3	800C	.53400*	.09027	.000	.2549	.8131
			1000C	.27200	.09027	.059	-.0071-	.5511
			1200C	.15200	.09027	.555	-.1271-	.4311
			1500C	-.10000-	.09027	.873	-.3791-	.1791
			1600C	.06200	.09027	.982	-.2171-	.3411
	1500C	dimension3	800C	.63400*	.09027	.000	.3549	.9131
			1000C	.37200*	.09027	.005	.0929	.6511
			1200C	.25200	.09027	.093	-.0271-	.5311
			1400C	.10000	.09027	.873	-.1791-	.3791
			1600C	.16200	.09027	.487	-.1171-	.4411
	1600C	dimension3	800C	.47200*	.09027	.000	.1929	.7511
			1000C	.21000	.09027	.222	-.0691-	.4891
			1200C	.09000	.09027	.914	-.1891-	.3691
			1400C	-.06200-	.09027	.982	-.3411-	.2171
			1500C	-.16200-	.09027	.487	-.4411-	.1171

*. The mean difference is significant at the 0.05 level.

Table 25: Apparent porosity (%) Tukey HSD

(I) Tempreture (^{0}C)		(J) Tempreture (^{0}C)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	800C	dimension3	1000C	3.35800*	.95855	.020	.3942	6.3218
			1200C	4.49200*	.95855	.001	1.5282	7.4558
			1400C	6.89000*	.95855	.000	3.9262	9.8538
			1500C	8.58400*	.95855	.000	5.6202	11.5478
			1600C	7.27200*	.95855	.000	4.3082	10.2358
	1000C	dimension3	800C	-3.35800-*	.95855	.020	-6.3218-	-.3942-
			1200C	1.13400	.95855	.840	-1.8298-	4.0978
			1400C	3.53200*	.95855	.013	.5682	6.4958
			1500C	5.22600*	.95855	.000	2.2622	8.1898
			1600C	3.91400*	.95855	.005	.9502	6.8778
	1200C	dimension3	800C	-4.49200-*	.95855	.001	-7.4558-	-1.5282-
			1000C	-1.13400-	.95855	.840	-4.0978-	1.8298
			1400C	2.39800	.95855	.163	-.5658-	5.3618
			1500C	4.09200*	.95855	.003	1.1282	7.0558
			1600C	2.78000	.95855	.075	-.1838-	5.7438
	1400C	dimension3	800C	-6.89000-*	.95855	.000	-9.8538-	-3.9262-
			1000C	-3.53200-*	.95855	.013	-6.4958-	-.5682-
			1200C	-2.39800-	.95855	.163	-5.3618-	.5658
			1500C	1.69400	.95855	.504	-1.2698-	4.6578
			1600C	.38200	.95855	.999	-2.5818-	3.3458
	1500C	dimension3	800C	-8.58400-*	.95855	.000	-11.5478-	-5.6202-
			1000C	-5.22600-*	.95855	.000	-8.1898-	-2.2622-
			1200C	-4.09200-*	.95855	.003	-7.0558-	-1.1282-
			1400C	-1.69400-	.95855	.504	-4.6578-	1.2698
			1600C	-1.31200-	.95855	.744	-4.2758-	1.6518
	1600C	dimension3	800C	-7.27200-*	.95855	.000	-10.2358-	-4.3082-
			1000C	-3.91400-*	.95855	.005	-6.8778-	-.9502-
			1200C	-2.78000-	.95855	.075	-5.7438-	.1838
			1400C	-.38200-	.95855	.999	-3.3458-	2.5818
			1500C	1.31200	.95855	.744	-1.6518-	4.2758

*. The mean difference is significant at the 0.05 level.

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