PROPERTIES OF SUDANESE MANUFACTURED ORDINARY PORTLAND CEMENTS

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مُسْتَخْلَص

هذه الدراسة تقارن بين ست علامات تجارية من الأسمنت البورتلاندي العادي المنتج في السودان بإستخدام إختبار تحليل التباين (ANOVA) . ولتتحرى مطابقتها للمواصفة السودانيه والأوروبيه وبالإضافه إلي الإدعاءات المحلية بأن بعض العلامات تتفوق على الأخريات. جمعت بيانات الأسمنت الكميائية، الفيزيائية والميكانيكية من وحدات ضبط الجودة لكل مصنع و أيضا جمعت عينات من الوكلاء المحليين لكل مصنع ومن ثم أجريت عليها إختبارات لنفس الخصائص المذكورة آنفا. لقد لوحظ أن كل العلامات تتطابق مع المواصفتين السودانيه والأوروبيه للاسمنت البورتلاندي العادي 42.5N فيما يتعلق بمحتوى الأكاسيد الكيمائية ودرجة النعومه و زمن الشك الإبتدائي .و أما لمقاومه الضغط وفقا للمواصفتين فأن ثلاث علامات قد صنفت كأسمنت بورتلاندي عادي عيار 42.5N بينما صنفت الاخريات كأسمنت سريع التصلد عيار 42.5R والذي يجب ان لا يستخدم في الاجواء الحارة. بينما يمكن أن تصنف علامة واحده كاسمنت بورتلاندي عادي عيار 52.5N وفقا المواصفه الاروبية. ولقد أوضح تحليل التباين اختلافا ملحوظا بين هذه العلامات خصوصا في مقاومة الضغط ومن ثمّ تؤيد تفضيل المستهلكين لعلامات معينة.

الكلمات المفتاحية: الأسمنت البورتلاندي العادي المنتج في السودان، وحدات ضبط الجودة في مصانع الأسمنت، تحليل التباين (ANOVA)

ABSTRACT

This study compares properties of six locally produced ordinary Portland cement brands in the Sudan using Analysis of Variance (ANOVA). It investigates their compliance with Sudanese and European standards. Furthermore, to examine consumers' claims that certain brands outperforming others. Chemical, physical and mechanical cement properties have been collected from Quality Control Unit (QCU) of each factory. Also samples have been collected from local dealers for each factory and tested for same aforementioned properties. It has been observed that all brands comply with the Sudanese and European specifications for ordinary 42.5N Portland cement with regard to levels of chemical oxides, fineness & initial setting time. However, for compressive strength, according to both standards, three brands are classified as 42.5N, while the other are 42.5R, which should not be used in hot climates. However, one brand could also be dually classified as rapid hardening cement 42.5R or ordinary Portland cement 52.5N by the European Standard. The ANOVA has shown significant differences between these brands especially in compressive strength hence supporting preferences of consumers to certain brands.

Keywords: *Sudanese produced OPC cements, Quality control units in cement factories, ANOVA*

1. Introduction

In the last decade, four ordinary Portland cement (OPC) factories have been established in the Sudan, besides the existing two factories, this upgraded the annual production up to about 8176000 tons as maximum design capacities.

Cements must have certain qualities in order to play their part effectively in structure. When these properties lie within a certain specified range of standard values, the engineer is confident that in most of the cases the cement performance will be satisfactory. In addition, based on these properties it is possible to compare the quality of cement from different sources. A number of tests are performed in the cement factories' laboratories or using a third party facilities of to ensure that the cement is of the desired quality and it conforms to the requirement of the relevant standards.

The raw materials used in Portland cement production are lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products, and apart from a small residue of uncombined lime, which has not had sufficient time to react; a state of chemical equilibrium is reached.

Chemical components in Portland cement are combined to from different potential compounds. The amounts of these potential compounds are responsible for various physical properties of Portland cement.

This paper compares properties of six locally produced ordinary Portland cement brands in the Sudan using Analysis of Variance (ANOVA). It investigates their compliance with Sudanese and European standards. Furthermore, to examine consumers' claims that certain brands outperforming others as far as compressive strength is concerned.

2. Materials and methods

2.1 Materials

Data of OPC brands of cement produced by six factories; namely Alsalam, AlShamal (*Mass*), Altakamol (*Sakhr Al Sudan*), Atbara, Berber, and Nile (OPC).

Data was collected from Quality Control Unit (QCU) of each factory. This data has contained the following physical and mechanical properties: compressive strength, setting time, consistency, fineness and soundness. It also enlists chemical properties such as mineral oxides concentrations, loss on ignition (LoI) and insoluble residue (IR).

Furthermore, two samples were collected from certified agencies for each factory in Khartoum area according to (BS-EN-196-7:2007) procedure [2]. It is noteworthy that despite the requirement of the Sudanese Standard to stamp the date of packing on bags, the bags of all brands are not fulfilling this requirement.

2.2 Tests & Statistical Analysis Methods

Several physical, mechanical and chemical tests were carried out for the agent' samples corresponding to the properties reported by the QCU data. The physical tests were carried in two different laboratories (University of Khartoum (UofK) –Faculty of Engineering (FofE) – material laboratory & Building and Road Research Institute (BRRI) namely, compressive strength according to (BS-EN-196-1) [1], setting time as per (BS-EN-196-4) [4], consistency according to (BS-EN-196-3-2005)[3], fineness according to (BS-EN-196-6:2010) [6] which it was carried out in Sudanese Standard and Meteorology Organization (SSMO) laboratories.

The chemical tests were carried out in two different laboratories (Sudanese Petroleum Corporation-Petroleum Laboratories Research &Studies (PLRS) (Induced Coupled Plasma (ICP)-wet method) and Ministry of Minerals–Geological Research Authority of Sudan-Chemical Laboratory (GRA) (X-ray Florescence (XRF)-dry method). These tests include, chemical properties such as mineral oxides concentrations, LoI and IR according to (BS-EN-196 -2:2005) [2].

Statistical analysis was carried out using Analysis of Variance (ANOVA) and T- & F-tests to determine whether there is significant difference between pair-wise data of the six cement brands.

3. Results and Discussion

3.1 Physical and Mechanical Tests

Results of the aforementioned tests, together with QCU data, are depicted graphically in ***Figures 1-6***. The factories names are randomly masked by numbers for confidentiality reasons.

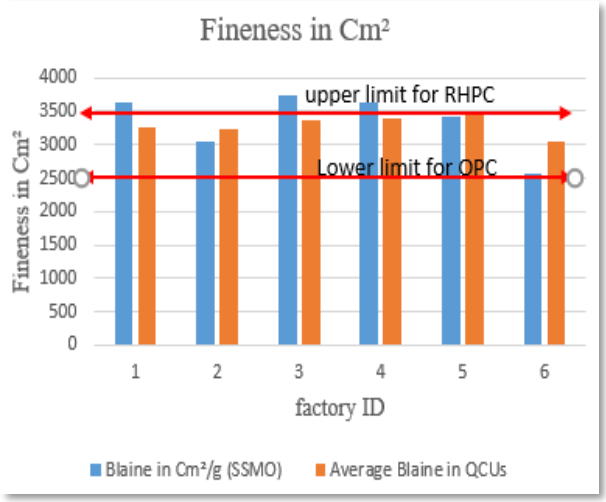

Figure 1: Fineness test result in both SSMO and QCUs

Figure 1 shows that all brands comply with OPC criteria for fineness, and also noting that three of these brands have exceeded the minimum fineness required for RHPC according to [4], hence could be considered three brand OPC and the other is RHPC.

However, for compressive strength, according to both Sudanese and European standards, as inferred from Figure 2, three brands are classified as 42.5N, while the other four are 42.5R as they surpassed the

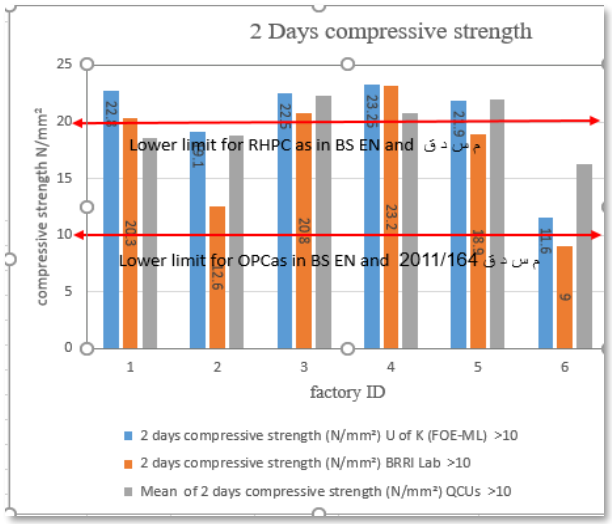

Figure 2: 2days compressive strength from laboratories and average of QCU data

minimum required for RHPC and 52.5N according to [8] and [5]. This is alarming since the rapid hardening cements should not be used in hot climates. However, for 28days compressive strength, ***Figures 2 & 3*** shows that two brands (factory ID 3 & 4) could also be dually classified as rapid hardening cement 42.5R or ordinary Portland cement 52.5N by the European Standard. result conformity. So according to these results only two brands are considered 42.5N OPC, and the rest are either 42.5R or 52.5N OPC.

The discrepancies between laboratories could be attributed to human errors or to different batches of standard sands as most of these factories and laboratories use a local make-up sands as standard sands.

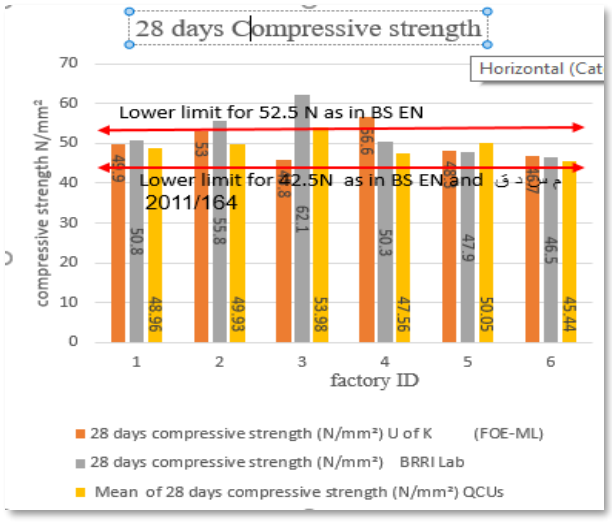

Figure 3: 28days compressive strength from laboratories and average of QCU data

Figures 4-6 show that all brands comply with OPC specifications for both consistency, initial and final setting times.

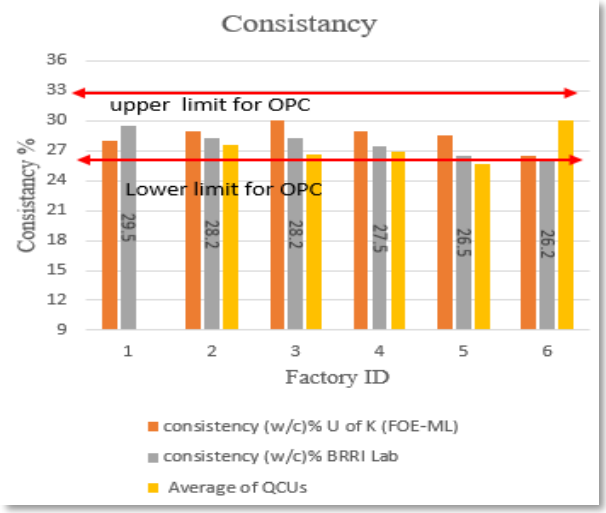

Figure 4: Consistency from laboratories and average of QCU data

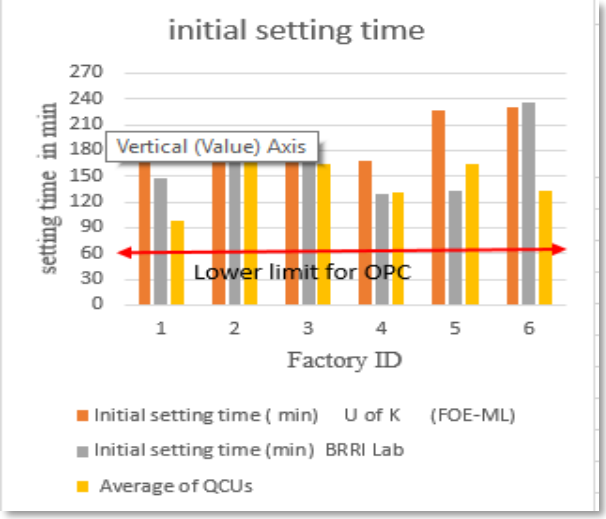

Figure 5: Initial setting time from laboratories and average of QCU data

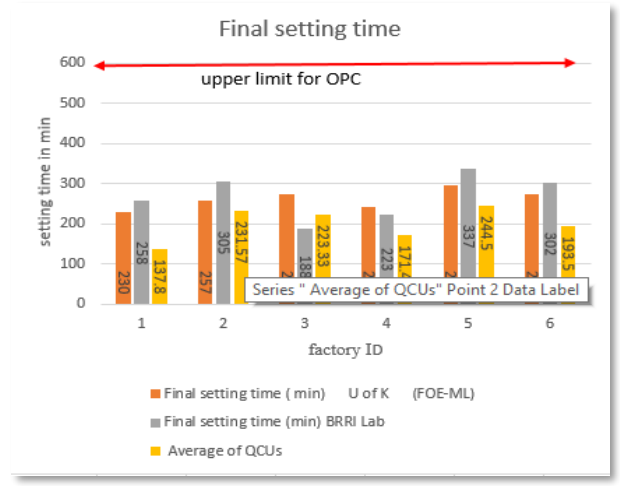

Figure 6: Final setting time from laboratories and average of QCU data

3.2 Chemical Tests

Figures 7 & 8 show that all brands comply with OPC criteria for both LoI and IR

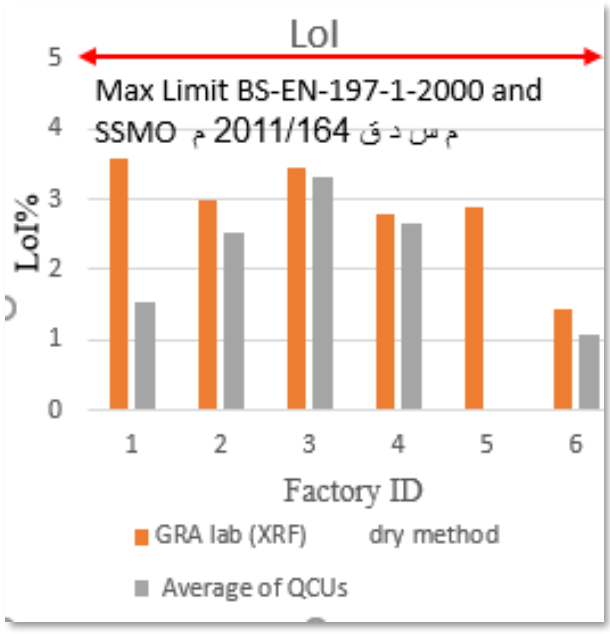

Figure 7: LoI from laboratories and average of QCU data

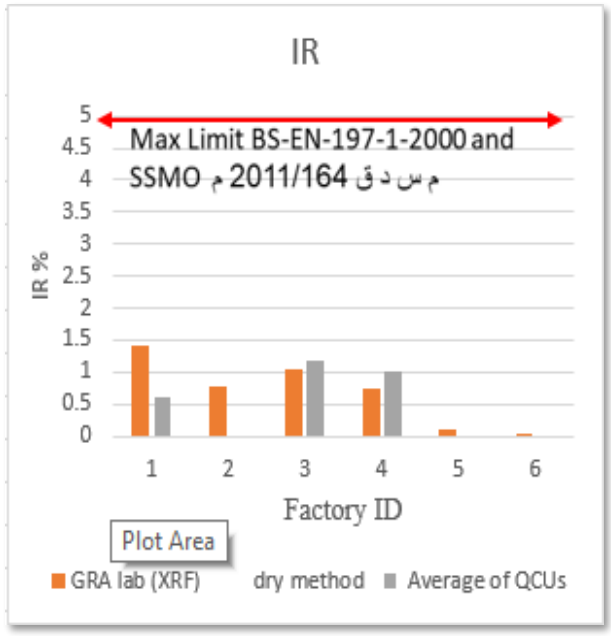

Figure 8: IR from laboratories and average of QCU data

Figures 9 & 10 show that all brands comply with OPC criteria for both MgO and Na_2O equivalent, except for the Na_2O determined by the XRF.

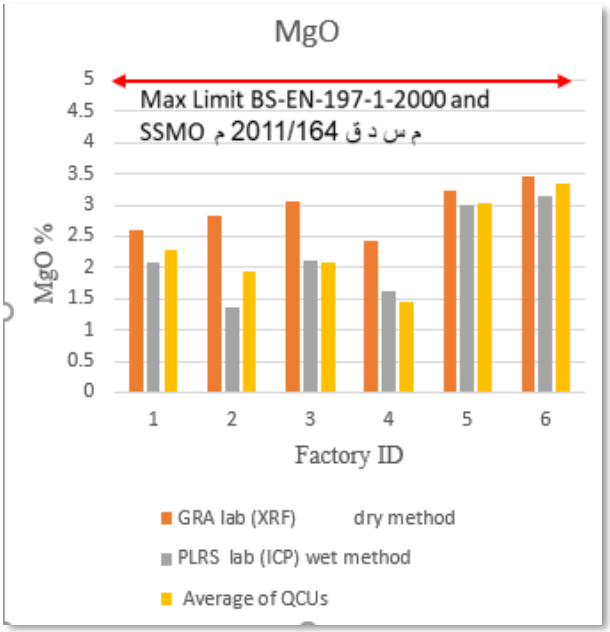

Figure 9: MgO concentration from laboratories and average of QCU data

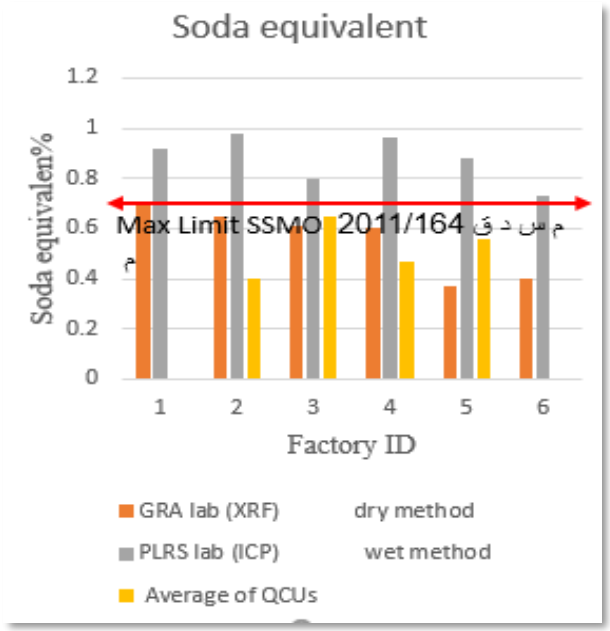

Figure 10: Na_2O (Soda) equivalent concentration from laboratories and average of QCU data

With regard to the discrepancies between results of the wet (ICP) and dry XRF methods, may be due to the fact that XRF does not exclude the IR from the total or could be errors due to calibration of either method.

3.3 Statistical Analysis

For the Statistical analysis: it is assumed that:

- Null hypotheses $\mathbf{H_0}$: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ (means of the six brands are equal), provided that the variances are equal.

The alternative hypothesis $\mathbf{H_a}$: at least one of the means is different. ANOVA assumption: if F calculated is greater than the F critical, the null hypothesis is rejected, i.e. there is a significant difference between means otherwise there is no significant difference. To test the equality of means for all these brands statistically, ANOVA test has been applied for data that have been verified by Levene's test [9] to have equal variances. These are namely 2days & 28days compressive strength, MgO and SO_3 and their one-way ANOVA results are listed in Tables 1-4 respectively. On the other hand, T &F tests have been applied for the rest of the data that has not satisfied the ANOVA assumptions of equal variance which are carried out but not included in this Paper.

Form Tables 1-4, all value of (F critical ≤F calculated), so it may be concluded that: there is no strong evidence to support the null hypotheses (equality of means). However, ANOVA does not reveal which mean differs from which, so if the result of the test is significant (p-value ≤ α=0.05) or (F critical ≤F) then it is a must to perform individual comparisons between pairwise of Groups by using Posthoc test: Bonferroni-Holm [9]. This has been applied to the 2 & 28days compressive strength and the results are listed in

Table 5 and ***Table 6*** respectively. However, if equality of variance has not been met the t -test for unequal variance is used.

Table ***5*** and Table 6 show that all tested pairwise factories are significantly different with respect to equal means hypothesis, except in three occasions for 2days and 4 occasions in 28days results. This strongly supports the consumers' claims that certain brands outperforming others as far as compressive strength is concerned. This fact has also been observed in Figure 3 and Figure 2.

4. Conclusions

1. All the cement brand complies with the 42.5N, OPC but most of these brands fulfilled the specifications of RHPC or 52.5N. It should be noted that the use of RHPC in tropical concreting is not desirable.
2. The Sudanese standard specification clearly requires stamping the date of packing on bags, the bags of all brands are not fulfilling this requirement.
3. It is observed that there are discrepancies between physical and mechanical results between different laboratories, as well as between methods of chemical analyses. These discrepancies may be attributed to many reasons such as local make-up standard sand for strength, as well as inclusion of IR in the XRF quantification of the oxides or simply due to human errors or calibration of the chemical analysis methods.
4. For 28days compressive strength of all tested pairwise factories are significantly different with respect to equal means hypothesis, except in three occasions. This strongly support the consumers' claims that certain brands outperforming others as far as compressive strength is concerned

Table 1: One way ANOVA results for 2 days compressive strength**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	503.28	5.00	100.66	33.26	1.07486E-23	2.27
Within Groups	523.59	173.00	3.03			
Total	1026.87	178.00				

***SS=sum of square, df = degree of freedom, MS=means square, F= calculated from the tables, P-value= statistical value, and Fcrit= calculated from F Distribution Table for 95% confidence level, K =number of Groups, N number of observations*

Table *2*: One way ANOVA results for 28 days compressive strength

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1215.79	5.00	243.16	32.20	3.75E-23	2.27
Within Groups	1313.96	174.00	7.55			
Total	2529.75	179.00				

Table 3: One way ANOVA results for Magnesium oxide (M).

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	69.87	5.00	13.97	65.92	2.34765E-38	2.27
Within Groups	36.89	174.00	0.21			
Total	106.76	179.00				

Table 4: One-way ANOVA results for Sulphur trioxide (S).

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	53.05	5.00	10.61	481.61	6.8683E-100	2.27
Within Groups	3.83	174.00	0.02			
Total	56.89	179.00				

Table 5: Post hoc test-Bonferroni-Holm for 2 days compressive strength results

Test	Pairwise	Leven's test	Critical Value	P value	Significant
2 days Compressive Strength	4 to 6	Equal Variance	0.003	1.63 E-19	Yes
	4 to 1	Equal Variance	0.005	6.21 E-08	Yes
	4 to 2	Equal Variance	0.007	0.000112	Yes
	4 to 5	Equal Variance	0.010	0.019857	No
	4 to 3	Equal Variance	0.008	0.001233	Yes
	6 to 1	Equal Variance	0.004	5.26 E-08	Yes
	6 to 2	Equal Variance	0.006	1.17 E-05	Yes
	6 to 5	Equal Variance	0.003	6.41 E-21	Yes
	6 to 3	Equal Variance	0.002	2.99 E-22	Yes
	1 to 2	Equal Variance	0.050	0.726156	No
	1 to 5	Equal Variance	0.004	7.95 E-11	Yes
	1 to 3	Equal Variance	0.003	2.13 E-12	Yes
	2 to 5	Equal Variance	0.006	4.63 E-07	Yes
	2 to 3	Equal Variance	0.004	2.91 E-08	Yes
	5 to 3	Equal Variance	0.025	0.357099	No

Table 6: Post hoc test-Bonferroni-Holm for 28 days compressive strength results

Test	Pairwise	Leven's test	Critical Value Value	P value	Significant
28 days Compressive Strength	4 to 6	Equal Variance	0.006	0.00207	Yes
	4 to 1	Equal Variance	0.01	0.05041	No
	4 to 2	Equal Variance	0.008	0.00547	Yes
	4 to 5	Equal Variance	0.007	0.00386	Yes
	4 to 3	Equal Variance	0.006	0.00207	Yes
	6 to 1	Equal Variance	0.003	2.6E-07	Yes
	6 to 2	Equal Variance	0.003	1.4E-07	Yes
	6 to 5	Equal Variance	0.003	1E-07	Yes
	6 to 3	Equal Variance	0.003	1.3E-19	Yes
	1 to 2	Equal Variance	0.017	0.17026	No
	1 to 5	Equal Variance	0.013	0.12877	No
	1 to 3	Equal Variance	0.003	2.63E-12	Yes
	2 to 5	Equal Variance	0.05	0.88666	No
	2 to 3	Equal Variance	0.004	6.28E-07	Yes
	5 to 3	Equal Variance	0.004	1.46E-6	Yes

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