# Statistical Models for Predicting the Optimum Gypsum Content in Cement Mortar

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**Abstract**

One of the most important problems in concrete industry in Iraq is deterioration due to internal sulfate attack that causes damage of concrete and hence reduces its compressive strength, increases its expansion and may be lead to its cracking and destruction. Linear regression analysis is used to predict the optimum $SO_3$ content (O.G.C) on the basis of cement chemical composition, Blaine fineness and age. Three models are presented, the first one is an early age model (less than or equal to 7-days). Then a late age (greater than 7-days) model was developed based on the predicted optimum $SO_3$ content of early age and late age. The third model was an all ages model and it is a general model specially for OPC. The important results obtained are the positive effect of $C_3S$, $C_3A$ and $C_4AF$ on optimum $SO_3$ content in cement mortar. The effect of $C_3A$ on optimum $SO_3$ content is about twice that of $C_4AF$. The study also showed a trend of positive and important effect of the fineness of cement.

**Keywords:** optimum $SO_3$ content (O.G.C), total effective $SO_3$ content, early age model, late age model, all age model

## نماذج أحصائية لتوقع نسبة الجبس المثلى في مونة السمنت

**الخلاصة**

من أهم المشاكل التي تواجة صناعة الخرسانة في العراق هو التلف بسبب مهاجمة الكبريتات الداخلية مسببة أضرار بالخرسانة وبالتالي تقلل من مقاومة الانضغاط وتزيد من التمدد و الذي يؤدي الى تشقق الخرسانة و تلفها . أستخدمت طريقة تحليل الانحدار ، للتنبؤ بنسبة الكبريتات المثلى والتي تعرف بـ( O.G.C) بالاعتماد على التحليل الكيميائي للسمنت و النعومة مع تأثير العمر . قدمت ثلاث نماذج في صبات مونة الاسمنت ، كان الاول للاعمار المبكرة . ثم طور النموذج الثاني للاعمار المتأخرة و المعتمد على القيمة المثلى المتوقعة للكبريتات من الاعمار المبكرة مع تاثير العمر. النموذج الثالث هو لكل الاعمار و هو نموذج عام وخاصة للسمنت البورتلاني الاعتيادي .وكان من أهم النتائج التي تم التوصل اليها التأثير الايجابي لـ (C3A ، C4AF و C3S) على نسبة الكبريتات المثلى في مونة السمنت. وكان تأثير C3A حوالي ضعف تأثير C4AF.كما أظهرت الدراسة التاثير الايجابي و الفعال لنعومة الاسمنت على نسبة الكبريتات المثلى .

## 1. Introduction

Sulfate attack is the reaction between sulfates present in solution with cement .Calcium sulfates react with calcium aluminates and water, to form calcium sulfoaluminates while other sulfates react with $Ca(OH)_2$ to form calcium Sulfates which react with calcium aluminate hydrate and water.One of the main sources of sulfate that causes damage of concrete structures is the sand used. In the central and southern regions of Iraq, most sands are

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contaminated with sulfates mainly in the form of gypsum. About 95% of the sulfates in sand are in the form of calcium sulfates [Al-Rawi (1977)] [(1)]. Al-Rawi (2002) [(2)] found that the allowable sulfate content in sand could be increased without a significant loss in strength provided that sulfate content in cement is reduced. They presented the theory of effective sulfate content in concrete ingredients and developed the following formula which is based on this theory:

$SO_3(\text{effective}) = 0.9 - 0.25\sqrt{F.M}$ …(1)

Where F= fineness modules of sand

**Determination of the Statistical Model Variables**

**2.1 Collecting Data**

In order to build a regression predictive model, there should be sets of data that cover a wide range of variation of the independent variable. A survey was carried out of the literature to obtain the required data that covers internationally and locally published literature from (1946 to 2002) as presented in **Table 1**.

**2.2 The Independent Variables**

Following the selection of the independent variables, the data were processed to obtain the information presented in **Table 2** that include:

1. Main compounds of cement.
2. Total alkalis as equivalent $Na_2O$ ($Na_2O$equ. = $0.658K_2O + Na_2O$.
3. Cement surface area (Blaine fineness).

**2.3 The Dependent Variables**

The value of optimum $SO_3$ content has to be predicted from the relationship between compressive strength and different $SO_3$ content as presented in **Table 3**. The decision was based on the observed variation of $SO_3$ content with maximum compressive strength and the change of $SO_3$ content with age of the same mix.

**3. Preliminary Statistical Analysis**

The analysis focused on the calculation of the following measures of central tendency and dispersion of data .The number of data was 178.

1. Mean, median and mode (central tendency)
2. Minimum and maximum, range and standard deviation (dispersion).

The calculated measures of central tendency and dispersion are presented in **Table 4**

**3.1 Correlation Analysis**

Two types of correlation coefficient obtained which were Person and Spearman [SPSS manual] between dependent and independent variables are presented in **Table 5 and 6** respectively. The first one is used for linear relationship and the second coefficient for non linear relationships. Following the calculation of the correlation coefficient, the value obtained should be examined to determine its significance .This is achieved by comparison between calculated ($r_c$) and the critical correlation coefficient ($r_c$) at a specified level of significance. The critical correlation coefficient ($r_c$) can be calculated using the equation given below [Draper and Smith (1982)] [(3)]and [Bland (1985)][(4)].

$$r_c = \frac{t_{a/2}}{\sqrt{t_{a/2}^2 + n - 2}}$$

Where: $a$ = the level of significance.
t = the standard t variable.
n = number of sample data pairs.

**4. Development of a Model for Optimum $So_3$ Content in Cement**

The Predictive developments first models (early –late ages) are made in two stages based on age of the product. The first stage focused on data for the age in the range (1-7) days and the second stage for ages higher than this range .Overall ages is predicted in the second model.

**4.1 Early- Age Model**

Following the separation of the data for early ages (less than 7-days), Partial correlation of cement model (early ages) between optimum $SO_3$% and other compounds presented in Table 7.

Examination of the presented data provides clear evidence that for all variables the coefficients of correlation for linear relationship are substantially higher than that for nonlinear relationships. Furthermore all coefficients of correlation of the linear relationships are higher than the critical coefficient of correlation of (0.3419). Based on this result it was decided to use linear multiple regression technique for the development of the required statistical model.

Results of the performed regression analysis are presented in **Table 8**. These results, however, are not consistent with the adopted idea that the presented independent variables are the only variables which affect the optimum $SO_3$% content. The reason for this conclusion is the number of rejected decisions about independent variables at the 5% level of significance.

This model is presented in **Table 9** below together with other statistical parameters by using SPSS version 12 program [14].

Therefore the regression equation can be written as follows:

**Optimum $SO_3$ %( Early ages)** = 0.1997×MgO%+0.8380×Tot. Alk.% + 6.4244E-03×$C_3S$% -3.8936E-03 ×$C_2S$% + 2.7705E-02×$C_3A$% + 4.3430E-02×$C_4AF$% + 2.8828E-04×Blaine($cm^2$/gm) + 9.0768E-03×Time(Early ages)-days …….(2)

**Table 10** shows the coefficient of determination ($R^2$) is (0.976) .This has the implication that 97.6% of the observed scatter in the data is explained by the adopted model. This conclusion is consistent with result of comparison of the calculated F (136.521) with the tabulated critical F value of (2.315) at the 95% level of confidence.

Moreover, the calculated Durbin-Watson value is (2.237) which are within the accepted range of (1.5-2.5) and hence, a minimal random error would be expected.

A proof of the conclusion that the developed model results in minimal random error can found by examination of Fig. 1 which shows scatter plot of observed and calculated optimum $SO_3$%. The data shows no trend that is to say random variation since the data is distributed approximately equally above and below the 45◦ line.

Figures 2 to 5 show scatter plots of optimum predicted $SO_3$ and other independent variables values versus the residual. The data presented suggest the existence of random variation between variable values and their residual values. The data presented provide further confirmation to the conclusion that the developed model can be considered as the best selected model. The value of T-statistics should always be zero to confirm that the built model fits the data well [Draper and Smith (1982)].

$$T = \sum_{i=1}^{n} \text{Residuals} \times \text{Predicted value of optimum} SO_3\%$$

T- value of the developed model = -0.02, which is reasonably low value.

The distribution of residuals is shown in Fig 6. From this figure it is clear tat the residuals are almost normally distributed.

**4.2 Late- Age Model (Higher Than 7-days)**

The collected data of age greater than 7- days is analyzed statistically in a procedure similar to that presented for the age of 7-days and less. The results of the descriptive statistical analysis are shown in **Table 11**. Examination of the data presented indicates the existence of reasonable variation of the age and the optimum $SO_3$% content. This property is necessary for regression analysis.

The multiple linear regression method is used for the developed model for late ages. The regression coefficients obtained are presented in **Table 12.**

**Optimum $SO_3$ %( late ages)** = 1.08×$SO_3$ %( predicted for early ages) – 2.136E- 04×Time of late age (days)… (3)

**Table 13** shows that the calculated coefficient of determination ($R^2$) is (0.965). This has the implication that 96.5% of the observed scatter in the data is explained by the adopted model. This conclusion is consistent with the result of comparison of the calculated value of F (872.951) with the tabulated critical F value of (3.07) at the 95% level of confidence.

Moreover, the calculated Durbin-Watson value is (1.868) .This value is within the accepted range of (1.5-2.5) and hence, a minimal random error would be expected.

A proof to the conclusion that the developed model results in a minimal random error can be found by examination of Fig. 7 which shows a scatter plot of observed and calculated optimum $SO_3$%. Examination of the presented data indicates that the data distributed equally above and below the 45◦ line.

Examination of **Figs. 8** to **11** show scatter plots of predicted variables values versus the residual of each variable. The data presented suggest the existence of a random variation between the variable values and their residual values. The data presented provide further confirmation to the conclusion that the developed model can be considered as the best selected model. The value of T-statistics should always be zero to confirm that the developed model fits the data well [Draper and Smith (1982)] (3).

T-value of the developed model = -0.53, which is a reasonably low value.

The distribution of residuals is shown in **Fig. 12** from this figure it is clear tat the residuals are almost normally distributed.

**4.3 All- Age Cement Model**

It may be argued why developing two models depending on age of mortar specimens. The answer is that combining data in one model will result in less accurate model for the reason that the chemical composition and Blaine fineness remain constant while age and optimum $SO_3$% will vary.

The results of linear and non linear (Pearson and Spearman) correlation analysis are presented above .The data presented suggest that the linear model provides better fit for the data. More reliable evidence to this conclusion can be found using partial correlation analysis. From the partial correlation presented in Table 14, all coefficient of correlation of the linear relationship are higher than the critical coefficient of correlation of (0.137) except for the relation with time, which is lower than the critical value and in general it is higher than the nonlinear relationship .

This result was expected prior to the analysis as explained at the beginning of this section. The multiple linear regression analysis is used for model development.

The regression equation coefficient, standard error, t- value and the decision are presented in **Table 15** .The sample size of this model is 143.

**Optimum $SO_3$%(All ages)** = 0.281×MgO% + 0.901×Total Alk.% + 1.963E-03×$C_3S$% - 2.924E-03×$C_2S$% + 4.015E-02×$C_3A$% + 2.993E-04×$C_4AF$% + 2.993E-04×Blaine($cm^2$/gm)+ 2.862E-04×Time(All ages)-days……(4)

Although the developed model for cement mortar is general for all ages, it has the problem of rejected MgO and Blaine. These rejections are in contrast with the currently available knowledge. To conclude the performance of this model, further statistical analysis was made as presented herein the following sections. **Table 16** shows that the coefficient of determination ($R^2$) is (0.967). This has the implication that 96.7% of the observed scatter in the data is explained by the adopted model. This conclusion is consistent with the result of comparison of the calculated F (500.292) with the tabulated critical F value of (1.94) at the 95% level of confidence.

Moreover, the calculated Durbin-Watson value is (1.398) which is not within the range of (1.5-2.5). This is attributed for the autocorrelation between the selected independent variables. The consequence of the existed autocorrelation is that the model will result in an error of estimate may be larger than would be acceptable. Figures **13** to **16** shows scatter plots of optimum predicted $SO_3$, $C_3S$, $C_3A$ and fineness Blaine variables values versus the residual of each variable. The presented data suggest the existence of non random variation between variable values and their residual values. Based on the presented statistical analysis, it is concluded that the model is not capable of producing reliable estimates of the optimum $SO_3$ content. Therefore, the two developed models explained earlier in this section can be used with 95% confidence except for SRPC which can be used as the alternative model.

## 5. Conclousions

Regression models for predicting the O.G.C (as total effective $SO_3$) in cement mortar were developed. These models were built using regression analysis. The choice of the best model was according to the following considerations:

- Statistical analysis.
- The best model is that best fits the factors considered (positive and negative trends and the values of the regression coefficients.
- Validation of the models was by testing and checking the data collection.

According to the results obtained in this study for the models of cement mortar, the following could be concluded:

### 5.1 Development of Models for Cement (Early, Late Age and All age Model)

1. The examination of the data presented for all variables indicates that the coefficients of correlation for linear relationship are substantially higher than that for nonlinear relationship.
2. In general, statistically, it was found that the MgO content of cement positively affects the optimum $SO_3$

content and this due to the low amount of MgO in cement.

3. It was proved statistically that the effect of $C_3S$ on optimum $SO_3$ content is positive.

4. The positive effect of $C_3S$ is about double the negative effect of $C_2S$ in the early age model of cement mortar.

5. The main shortcoming of all the ages model is the high value of regression coefficient for $C_2S$ compared with $C_3S$ and this may be due to the effect of age.

6. The effects of $C_3A$ and $C_4AF$ on optimum $SO_3$ content are positive.

7. The effects of $C_3A$ and $C_4AF$ compounds are higher than $C_3S$ and $C_2S$ in early age cement mortar model.

9. The effect of Blaine fineness is positive.

10. Blaine fineness and $C_3A$ were found as the main factors affecting the optimum $SO_3$ content in both early age and all ages development models for cement mortar.

11. The positive effect of age is to increase the optimum $SO_3$ content with increase of age in all ages model.

12. It is proved statistically that the optimum $SO_3$ content increases with increase of age in the late age model.

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**Table 1: The collected data**

| Author | Year | No. data | work | Type of cement |
|---|---|---|---|---|
| Lerch[5] | 1946 | 12 | mortar | 12-commercial clinkers : (2-high $C_3A$ and low Alkali), (5-high or moderately high $C_3A$ and high or moderately high alkali) ,(3-low $C_3A$ and low alkali) and (2-low $C_3A$ and high alkali) |
| Meissner[6] | 1950 | 8 | mortar | Type I,II,III,IV for high and low alkalies |
| Frigione [7] | 1975 | 1 | mortar | Chemical composition |
| Jelenic[8] | 1976 | 2 | mortar | Approximately the same chemical composition and different in alkalis. |
| Ali[9] | 1981 | 6 | mortar | Same chemical composition with 1:2.75 (mix) and different $SO_3$ level as shown in Table(3,3) |
| Zari[10] | 1981 | 8 | mortar | (4-OPC with 1:2, 1:3, 1:4, 1:5 mix) and (4-SRPC with 1:1:2, 1:1.33:2.68, 1:2:4 and 1:3:6 mix). |
| Soroka [11] | 1986 | 3 | Cement paste | The same chemical composition with different in Blaine. |
| Abdul-Latif[12],[13] | 2001 | 3 | mortar | Different chemical composition |

**Table 2: Calculated on chemical compositions and surface area of Cements (Blaine).**

| Author | Serial | Calculated | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total Alk. % | $C_3S$% | $C_2S$% | $C_3A$% | $C_4AF$% | Surface area (Blaine)gm/cm$^2$ |
| Lerch[5] | 1 | 0.27 | 45.5 | 28.4 | 14.3 | 6.7 | 3780 |
| | 2 | 0.21 | 70.00 | 8 | 12.5 | 7.6 | 3970 |
| | 3 | 0.69 | 41.4 | 32.2 | 13.1 | 7.3 | 4050 |
| | 4 | 0.59 | 62.5 | 13 | 11.2 | 7.7 | 3810 |
| | 5 | 1.07 | 48.2 | 27.8 | 11 | 7.8 | 4280 |
| | 6 | 1.47 | 47.9 | 29 | 10.1 | 7.6 | 4400 |
| Lerch | 7 | 0.94 | 46.00 | 30.6 | 8.1 | 9.3 | 4070 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lerch[5] | 1 | 0.27 | 45.5 | 28.4 | 14.3 | 6.7 | 3780 |
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| | 4 | 0.59 | 62.5 | 13 | 11.2 | 7.7 | 3810 |
| | 5 | 1.07 | 48.2 | 27.8 | 11 | 7.8 | 4280 |
| | 6 | 1.47 | 47.9 | 29 | 10.1 | 7.6 | 4400 |
| Lerch | 7 | 0.94 | 46.00 | 30.6 | 8.1 | 9.3 | 4070 |
| | 8 | 0.33 | 28.00 | 53.5 | 5.1 | 9.6 | 3190 |
| | 9 | 0.17 | 47.60 | 30.9 | 4.8 | 13.2 | 3410 |
| | 10 | 0.20 | 37.40 | 51.9 | 2.4 | 5.7 | 3220 |
| | 11 | 1.10 | 26.00 | 49.1 | 6.2 | 14 | 4250 |
| | 12 | 0.95 | 46.00 | 26.3 | 5.7 | 14.7 | 4040 |
| Meissner[6] | 1 | 0.67 | 42.1 | 31.7 | 9.1 | 8.3 | 4025 |
| | 2 | 0.23 | 44.4 | 26.7 | 12.5 | 6.5 | 3520 |
| | 3 | 0.66 | 45.6 | 27.6 | 6 | 11.2 | 3770 |
| | 4 | 0.40 | 39.1 | 38.1 | 4.3 | 10.1 | 3610 |
| | 5 | 0.76 | 49.3 | 19.2 | 13.8 | 7.4 | 4530 |
| | 6 | 0.21 | 53.7 | 15.3 | 9.5 | 10.3 | 5120 |
| | 7 | 1.17 | 27.7 | 50.2 | 5.2 | 9.2 | 4000 |
| | 8 | 0.32 | 21.8 | 59.2 | 3.8 | 8.3 | 4025 |
| Soroka[11] | 1 | 0.51 | 46.5 | 27.5 | 11 | 9.1 | 2300 |
| | 2 | 0.51 | 46.5 | 27.5 | 11 | 9.1 | 3000 |
| | 3 | 0.51 | 46.5 | 27.5 | 11 | 9.1 | 4200 |
| Jelenic[8] | 1 | 0.76 | 69.00 | 5 | 8 | 9 | 4900 |
| | 2 | 0.48 | 64.00 | 13 | 10 | 8 | 4900 |
| Frigione[7] | 1 | 1.44 | 50.40 | 26.4 | 5.6 | 12.6 | 3200 |
| Ali [9] | 1-6 | 0.94 | 41.10 | 34.8 | 8.8 | 8.5 | 3000 |
| Zari[10] | 1-8 | 0.53 | 49.53 | 20.12 | 8.76 | 10.16 | 3278 |
| | 9-16 | 0.35 | 61.96 | 13.7 | 1.1 | 15.1 | 3124 |
| Abdul-Latif [12],[13] | 1 | 0.6 | 52.13 | 23.63 | 1.87 | 14.8 | 2900 |
| | 2 | 1.04 | 37.7 | 30.5 | 9.63 | 10.43 | 3360 |
| | 3 | 1.17 | 33.41 | 39.01 | 7.88 | 10.28 | 3360 |

Serial means the number of data for each author.

**Table 3: Optimum $SO_3$% of cement paste and mortar at different ages (by weight of cement)**

| Author | Serial | Optimum $SO_3$ Time in days 1-day | 3-days | 7-days | 28-days | 56-days | 90-days | 365-days |
|---|---|---|---|---|---|---|---|---|
| Lerch[5] | 1 | 2.40 | 3.50 | 3.00 | 3.00 | | 3.00 | 2.40 |
| | 2 | 3.00 | 3.00 | 3.00 | 2.40 | | 2.40 | 3.00 |
| | 3 | 3.50 | 3.50 | 3.50 | 5.00 | | 5.00 | 5.00 |
| | 4 | 3.00 | 3.00 | 3.00 | 3.00 | | 3.00 | 2.40 |
| | 5 | 4.00 | 4.00 | 4.00 | 4.50 | | 4.50 | 4.50 |
| | 6 | 5.00 | 5.00 | 5.00 | 5.00 | | 5.00 | 5.00 |
| | 7 | 3.50 | 3.50 | 3.50 | 4.00 | | 3.00 | 3.50 |
| | 8 | 1.90 | 2.40 | 3.00 | 1.90 | | 1.90 | 1.00 |
| | 9 | 2.40 | 1.90 | 2.40 | 2.40 | | 2.40 | 2.40 |
| | 10 | 1.50 | 1.50 | 1.90 | 1.90 | | 1.50 | 1.90 |
| | 11 | 4.00 | 4.50 | 4.50 | 3.50 | | 4.50 | 3.00 |
| | 12 | 3.00 | 1.90 | 3.50 | 3.00 | | 4.00 | 4.00 |
| Meissner[6] | 1 | | 3.21 | 3.55 | 3.97 | | | |
| | 2 | | 2.49 | 2.49 | 1.96 | | | |
| | 3 | | 2.70 | 2.70 | 4.90 | | | |
| | 4 | | 2.10 | 2.10 | 1.02 | | | |
| | 5 | 3.79 | 4.90 | 4.90 | | | | |
| | 6 | 2.91 | 3.44 | 2.16 | | | | |
| | 7 | | 3.11 | 3.39 | 2.66 | | | |
| | 8 | | 1.72 | 2.03 | 2.82 | | | |
| Frigion [7] | 1 | 2.80 | 2.80 | 2.80 | | | | |
| Jelenic[8] | 1 | 2.00 | 2.70 | 3.00 | 3.00 | | | |
| | 2 | 4.00 | 3.60 | 3.60 | 3.00 | | | |
| Ali[9] | 1 | | 2.38 | 3.06 | 3.06 | | | |
| | 2 | | 2.88 | 2.88 | 2.88 | | | |
| | 3 | | 3.38 | 3.38 | 3.38 | | | |
| | 4 | | 3.63 | 2.94 | 3.63 | | | |
| | 5 | | 3.19 | 3.19 | 3.88 | | | |
| | 6 | | 3.35 | 3.35 | 4.18 | | | |
| Zari[10] | 1 | | | 3.22 | 3.22 | 3.22 | 3.22 | |
| | 2 | | | 3.22 | 3.47 | 3.22 | 3.47 | |
| | 3 | | | 3.22 | 3.47 | 3.22 | 3.22 | |
| | 4 | | | 3.47 | 3.47 | 3.47 | 3.47 | |
| | 5 | | | 3.22 | 3.22 | 3.47 | 3.22 | |
| | 6 | | | 3.22 | 3.22 | 3.22 | 3.22 | |
| | 7 | | | 3.47 | 3.47 | 3.22 | 3.22 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 8 | | | 3.22 | 3.47 | 3.22 | 3.22 | |
| Soroka[11] | 1 | 2.00 | 2.00 | 3.00 | 3.00 | | 3.00 | |
| | 2 | 3.00 | 3.00 | 2.00 | 2.00 | | 3.00 | |
| | 3 | 3.00 | 3.00 | 4.00 | 3.00 | | 3.00 | |
| Abdul-Latif [12],[13] | 1 | | | 2.37 | 1.87 | | | |
| | 2 | | | 3.12 | 3.12 | | | |
| | 3 | | | 3.10 | 3.10 | | | |

**Table 4: Descriptive statistics analysis for cement mortar (all data)**

| Variable | Central tendency | | | Dispersion | | | |
|---|---|---|---|---|---|---|---|
| | Mean | Median | Mode | Std. deviation | Range | Minimum | Maximum |
| MgO% | 2.48 | 2.63 | 3.4 | 1.026 | 3.79 | 0.75 | 4.54 |
| Total Alk. % | 0.64 | 0.53 | 0.94 | 0.348 | 1.3 | 0.17 | 1.47 |
| $C_3S$% | 47.19 | 46.50 | 41.1 | 11.071 | 48.2 | 21.8 | 70.0 |
| $C_2S$% | 28.12 | 27.60 | 34.8 | 12.545 | 54.2 | 5.0 | 59.2 |
| $C_3A$% | 8.02 | 8.76 | 11.0 | 3.637 | 13.2 | 1.1 | 14.3 |
| $C_4AF$% | 9.84 | 9.10 | 8.5 | 2.685 | 9.4 | 5.7 | 15.1 |
| Blaine gm/$cm^2$ | 3643.7 | 3520 | 3000 | 611.12 | 2820 | 2300 | 5120 |
| Total eff. $SO_3$% | 3.14 | 3.12 | 3.00 | 0.832 | 4.0 | 1.0 | 5.0 |

**Table 5: Correlation matrix for dependent and independent variables (Person correlation)**

| Compound | MgO | Total Alk. | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | Blaine | Ages | $SO_3$% |
|---|---|---|---|---|---|---|---|---|---|
| MgO | 1.00 | .192* | -.008 | -.153* | .038 | .092 | -.203** | -.031 | .381** |
| Total Alk. | .192* | 1.00 | -.268** | .183* | .151* | -.014 | .206** | -.025 | .548** |
| $C_3S$ | -.008 | -.268** | 1.00 | -.951** | .069 | .146 | .133 | -.003 | .087 |
| $C_2S$ | -.153* | .183* | -.951** | 1.00 | -.195** | -.188* | -.156* | .037 | -.192* |
| $C_3A$ | .038 | .151* | .069 | -.195** | 1.00 | -.692** | .312** | .010 | .290** |
| $C_4AF$ | .092 | -.014 | .146 | -.188* | -.692** | 1.00 | -.201** | -.001 | .011 |
| Blaine | -.203** | .206** | .133 | -.156* | .312** | -.201** | 1.00 | .051 | .348** |
| Ages | -.031 | -.025 | -.003 | .037 | .010 | -.001 | .051 | 1.00 | .039 |
| $SO_3$% | .381** | .548** | .087 | -.192* | .290** | .011 | .348** | .039 | 1.00 |

**Table 6: Correlation matrix for dependent and independent variables (Spearman correlation)**

| Compound | MgO | Total Alk. | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | Blaine | Ages | $SO_3$% |
|---|---|---|---|---|---|---|---|---|---|
| MgO | 1.00 | .306** | -.064 | .006 | .007 | .078 | -.126 | .152* | .485** |
| Total Alk. | .306** | 1.00 | -.206 | .194** | .126 | .041 | .224** | -.07 | .523** |
| $C_3S$ | -.064 | -.206 | 1.00 | -.944** | .100 | .155* | .129 | .073 | .127 |
| $C_2S$ | .006 | .194** | -.944** | 1.00 | -.158* | -.180* | -.128 | -.064 | -.117 |
| $C_3A$ | .007 | .126 | .100 | -.158* | 1.00 | -.699** | .303** | -.126 | .211** |
| $C_4AF$ | .078 | .041 | .155* | -.180* | -.699** | 1.00 | -.255** | .137 | .016 |
| Blaine | -.126 | .224** | .129 | -.128 | .303** | -.255** | 1.00 | -.104 | .324** |
| Ages | .152* | -.07 | .073 | -.064 | -.126 | .137 | -.104 | 1.00 | .084 |
| $SO_3$% | .485** | .523** | .127 | -.117 | .211** | .016 | .324** | .084 | 1.00 |

*, Correlation is significant at the 0.05 level (2-tailed) **, Correlation is significant at the 0.01 level (2tailed) $r_c$ = 0.1227 for N= 178

**Table (7): Partial correlation for cement model (early ages) between optimum $SO_3$% and other compounds**

| Variables | Person correlation | Spearman correlation |
|---|---|---|
| MgO | 0.5265 | 0.2155 |
| Total alkalies | 0.5310 | 0.28445 |
| $C_3S$ | 0.5788 | 0.3337 |
| $C_2S$ | 0.5222 | 0.2722 |
| $C_3A$ | 0.5213 | 0.1869 |
| $C_4AF$ | 0.3871 | 0.3445 |
| Blaine | 0.5385 | 0.3304 |
| Time (early ages) | 0.4196 | 0.1555 |

**No.of data = 35**

**Table (8): Regression equation section for early age (removing $C_2S$ and $C_3A$ compounds)**

| Independent variable | Regression coefficient | Standard error | t- vale (Ho:B=0) | Decision (5%) |
|---|---|---|---|---|
| MgO% | 0.2386 | 0.1087 | 2.1938 | Reject Ho |
| Total Alk% | 0.8485 | 0.2731 | 3.1063 | Reject Ho |
| $C_3S$% | 1.1934E-02 | 8.7088E-03 | 1.3704 | Accept Ho |
| $C_4AF$% | 2.0615E-02 | 3.9039E-02 | 0.5281 | Accept Ho |
| Blaine gm/cm$^2$ | 2.9247E-04 | 1.1896E-04 | 2.4585 | Reject Ho |
| Time (early ages)-days | -5.14283E-03 | 0.0567 | -0.0906 | Accept Ho |

**Table (9): Regression equation section for cement mortar (Early age)**

| Independent variable | Regression coefficient | Standard error | t- vale (Ho:B=0) | Decision (5%) |
|---|---|---|---|---|
| MgO% | 0.1997 | 0.1328 | 1.503 | Accept Ho |
| Total Alk% | 0.8380 | 0.2938 | 2.852 | Reject Ho |
| $C_3S$% | 6.4244E-03 | 1.4925E-02 | 0.430 | Accept Ho |
| $C_2S$% | -3.8936E-03 | 1.1479E-02 | -0.339 | Accept Ho |
| $C_3A$% | 2.7705E-02 | 0.0480 | 0.577 | Accept Ho |
| $C_4AF$% | 4.3430E-02 | 5.8683E-02 | 0.740 | Accept Ho |
| Blaine $cm^2/gm$ | 2.8828E-04 | 1.5674E-04 | 1.839 | Accept Ho |
| Time (early ages)-days | 9.0768E-03 | 6.3560E-02 | 0.123 | Accept Ho |

**Table 10: General statistical concept for mortar models (Early ages)**

| ANOVA | | | | | $R^2$ | Root mean square of error |
|---|---|---|---|---|---|---|
| Source | D.F. | Sum of squares | Mean square | F value | | |
| Model(Reg.) | 8 | 320.94 | 40.12 | 136.521 | 0.97875 | 0.5421 |
| Error(Res.) | 27 | 7.93 | 0.294 | | | |
| Total | 35 | 328.87 | 9.396 | | | |

**Table 11: Descriptive statistics analysis for cement mortar (Late ages)**

| Variables | Mean | Stan. deviation | Minimum | Maximum |
|---|---|---|---|---|
| Opt. $SO_3$% predicted(early ages)-days | 2.9941 | 0.4579 | 1.99 | 4.00 |
| Opt. $SO_3$%(late ages) | 3.2179 | 0.8899 | 1.00 | 5.00 |
| Time(late ages)-days | 93.409 | 111.8822 | 28.00 | 365 |

No. of data =66

**Table 12: Regression equation section for cement mortar (Late age)**

| Independent variable | Regression coefficient | Standard error |
|---|---|---|
| Time (late ages)-days | -2.136E-04 | 0.001 |
| Opt. $SO_3$(predicted of early ages)% | 1.089 | 0.988 |

**Table 13: Calculated statistics for Mortar models (late ages)**

| ANOVA | | | | | $R^2$ | Root mean square of error |
|---|---|---|---|---|---|---|
| Source | D.F. | Sum of squares | Mean square | F value | | |
| Model(Reg.) | 2 | 708.901 | 354.451 | 872.951 | 0.965 | 0.6372 |
| Error(Res.) | 64 | 25.986 | 0.405 | | | |
| Total | 66 | 734.888 | | | | |

**Table 14: Partial correlation for cement model (all ages) between optimum $SO_3$% and other compounds**

| Variables | $SO_3$%(Person correlation) | $SO_3$%(Spearman correlation) |
|---|---|---|
| MgO | 0.4624 | 0.4934 |
| Total alkalies | 0.4686 | 0.3653 |
| $C_3S$ | 0.2734 | 0.2478 |
| $C_2S$ | 0.2512 | 0.1947 |
| $C_3A$ | 0.3421 | 0.2132 |
| $C_4AF$ | 0.3171 | 0.1742 |
| Blaine | 0.3731 | 0.3405 |
| Time (all ages) | 0.0009 | 0.0896 |

**Table 15: Regression equation coefficients and other statistical measures (all age)**

| Independent variable | Regression coefficient | Standard error | t- vale (Ho:B=0) | Decision (5%) |
|---|---|---|---|---|
| MgO% | 0.281 | 0.052 | 5.428 | Reject Ho |
| Total Alk% | 0.901 | 0.160 | 1.452 | Accept Ho |
| $C_3S$% | 1.963E-03 | 0.008 | 0.258 | Accept Ho |
| $C_2S$% | -2.924E-03 | 0.006 | -0.472 | Accept Ho |
| $C_3A$% | 4.015E-02 | 0.023 | 1.622 | Accept Ho |
| $C_4AF$% | 3.917E-02 | 0.030 | 1.292 | Accept Ho |
| Blaine $cm^2/gm$ | 2.993E-04 | 0.000 | 3.533 | Reject Ho |
| Time (All ages)-days | 2.862E-04 | 0.001 | 0.44 | Accept Ho |

**Table 16: General statistical concept for Mortar models (All ages)**

| ANOVA | | | | | $R^2$ | Root mean square of error |
|---|---|---|---|---|---|---|
| Source | D.F. | Sum of squares | Mean square | F value | | |
| Model(Reg.) | 8 | 1449.39 | 181.174 | 500.292 | 0.967 | 0.6018 |
| Error(Res.) | 135 | 48.889 | 0.362 | | | |
| Total | 143 | 1498.28 | | | | |

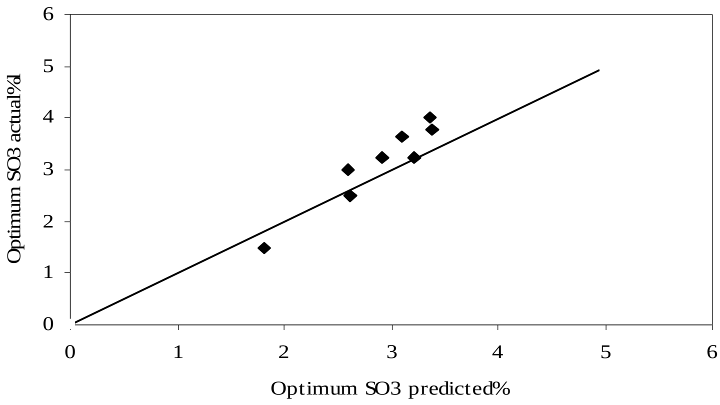



**Figure (1): Relationship between optimum$SO_3$- predicted and optimum $SO_3$**

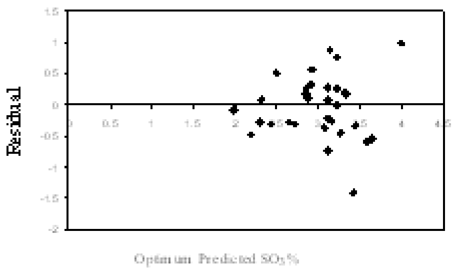



Figure (2) Relationship between predicted optimum $SO_3$% and residuals

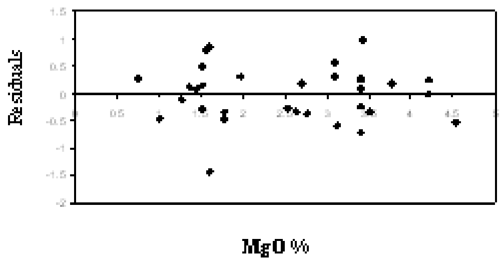
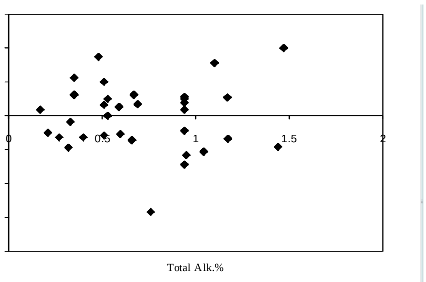



Figure (3) Relationship between predicted optimum MgO% and residuals




gure. 4:Relationship between Total Alk.% and residuals

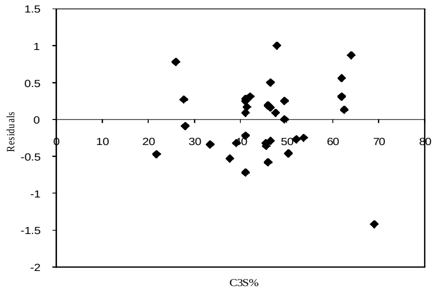
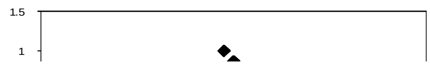
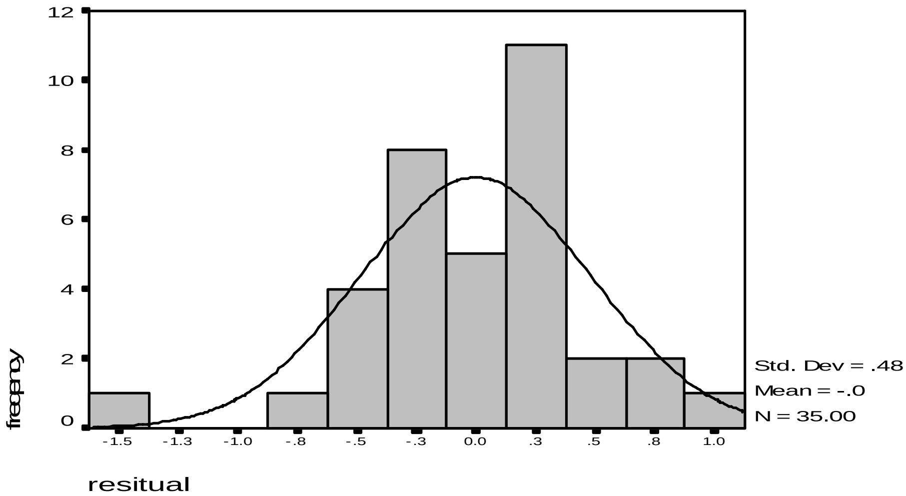



Figure. 5:Relationship between C3S% and residuals






**Figurer 6: Residuals distribution for cement mortar (early age)**

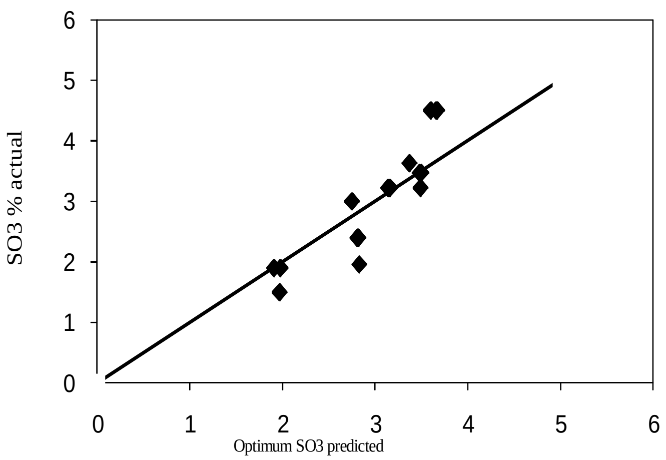



Figure. 7:Relationship between optimum SO3 predicted and optimum SO3% actual

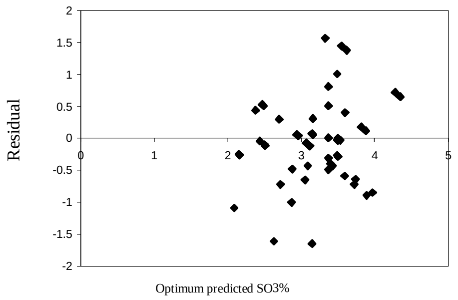



Fig. 8: Relationship between optimum SO3-predicted % and residuals

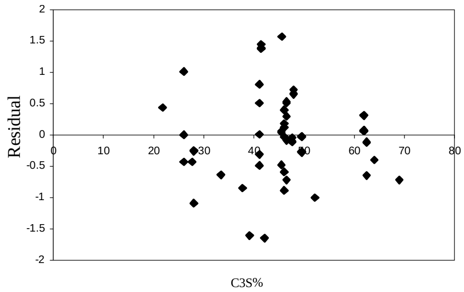
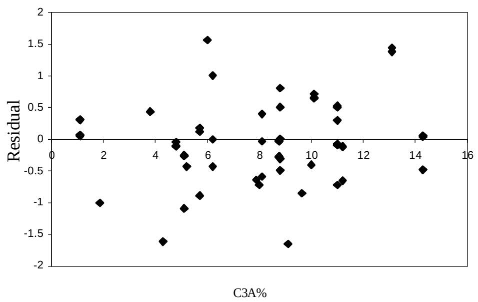



Fig. 9: Relationship between C3S% and residuals




Fig,10: Relationship between C3A% and residuals

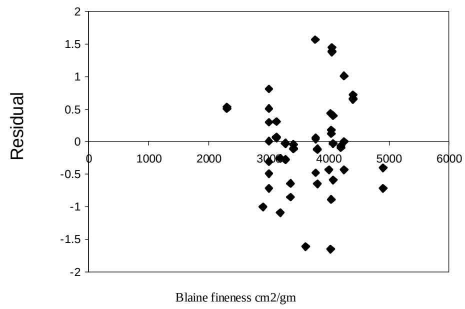
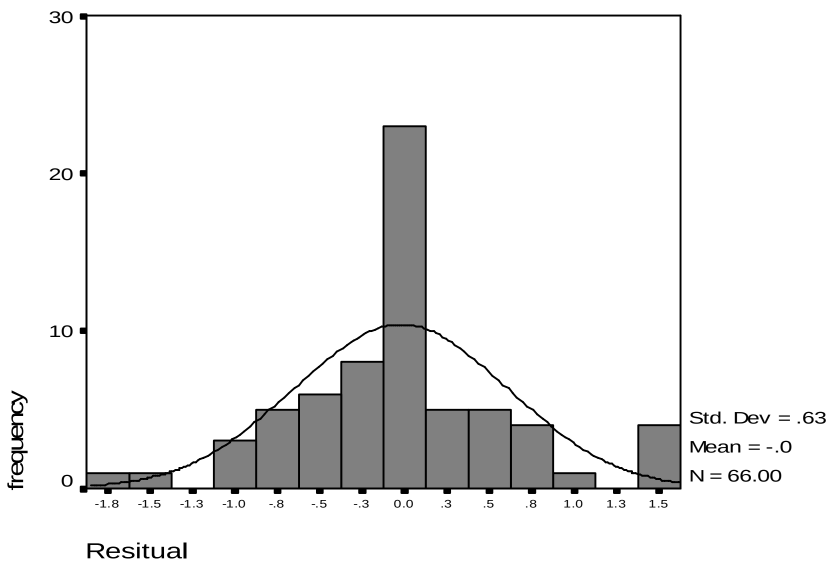



Fig. 11: Relationship between Blaine cm2/gm and residuals




**Figurer 12: Residuals distribution for cement mortar (Late age)**

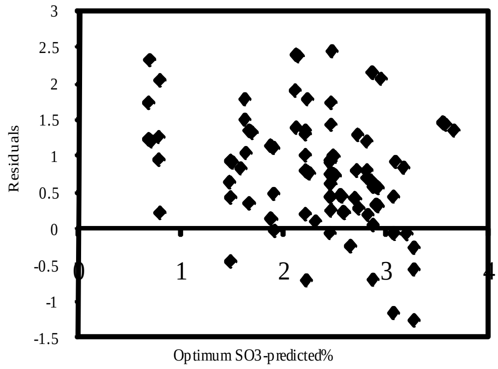



Fig.13 :Relationship between optimum SO3-predicted% and residuals

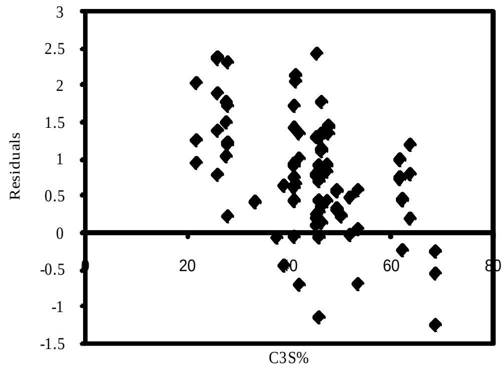



Fig.14 Relationship between C3S% and residuals

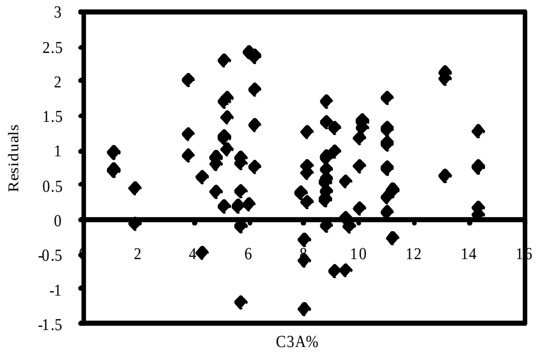



Fig. 15:Relationship between C3A and residuals

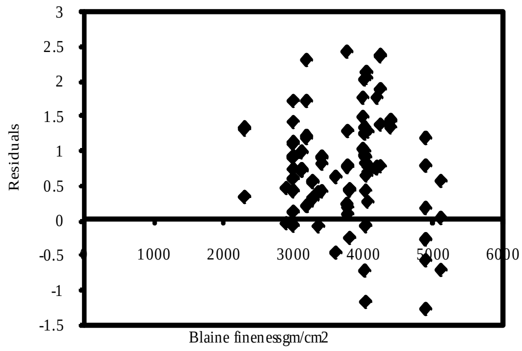



Fig. 16:Relationship between Blaine and residuals