Developing Relationships among Grindability, Chemical Composition and Particle Size of Raw Material Mix at Aruwakkalu Limestone for Cement Production

Mendis BSM, Jayathunga THGS, Madurapperuma HH, *Rohitha LPS, Dharmarathne PGR and Hemalal PVA

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka
*Corresponding author – rohithasudath@yahoo.com

Abstract

In this research study, the relationship among chemical constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Cl^-, SO_3, Na_2O and K_2O) and raw meal grindability are investigated on raw meal samples taken from the output of ball mill. The X - ray Fluorescence analysis is used to check the chemical composition and grindability is checked in the form of residue test of No 212 sieve residue.

The distribution curves of the variables were analyzed to examine the skewness of the distribution. The Pearson's Coefficient of Correlation analysis was performed on each two variables to identify any linear mathematical relationship between variables. The time series analysis was carried out to find the best fitting curve between grindability and the variables. Scatter plot analysis was finally performed and the results show the effect of chemical components and particle size distribution of raw meal were found to be range correlated on the raw meal grindability. The most suitable chemical constituent range to improve the grindability of raw meal are given based on 68% , 95% and 99% confidence intervals. The quality parameters such as Lime Saturation Factor, Alumina Ratio and Silica Ratio also evaluated based on chemical constituent values of 68%, 95% and 99% confidence intervals.

Keywords: Alumina Ratio, Lime Saturation Factor, Pearson's Coefficient of Correlation, Raw Meal, Silica Ratio, X - Ray Fluorecense (XRF)

1. Introduction

In the processing plant of the Siam City Cement (Lanka) Ltd, the production rate and ball mill efficiency become low when a raw meal load with low grindability is fed into the ball mill. In this situation, a sample from the low grindability raw meal load is taken and checked the grindability of the sample by a lab scale Ball Mill in order to identify whether the problem has occurred due to a Ball Mill defect or a change in the chemical composition of the raw meal load. However, it takes about two days to check the grindability of a sample. Thus it is not possible to check the grindability of every limestone load in the laboratory. At the time when a sample is taken to the grindability test and it's results are released, that load is already fed to the process. On account of these reasons, Siam City Cement (Lanka) Ltd emphasizes the importance of developing a method to optimize the grindability of raw meal on its chemical composition.

The cement making process of the Siam City Cement (Lanka) Ltd, has a facility to check the chemical composition of a limestone sample within 30 minutes in the laboratory. Hence, the company has taken action to check the chemical composition of limestone for every four hours period for the crusher outputs and hourly check for the blending cyclone feed (ball mill output).

Grindability can be mainly affected by the chemical composition of the raw materials or Ball Mill performance. Chemical composition, moisture content, particle size also could be identified as affecting factors of raw material to it's grindability[1]. In this case ball, mill performance is in its optimum stage and moisture content remains constant at 7%. Because of that the chemical and physical factors of raw material are the mainly influencing factors to the low grindability.

This research determines the relationship among grindability, percentages of chemical constitutents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Cl^-, SO_3, Na_2O and K_2O) and particle size distribution of the raw meal irrespective of the ball mill conditions and the other factors affecting the grindability.

2. Methodology

Sample size calculation was carried out based on the following formula(1) [2].

$$ME = Z\sqrt{\frac{p(1-p)}{n}} \qquad (1)$$

ME = desired margin of error
Z = Z score for example, 1.645 for a 90% confidence interval, 1.96 for a 95% confidence interval.
P = probability
n = sample size

The confidence interval of 99%, desired margin of error 0.025 and assuming p = 0.5 the sample size required was 2660.

The analysis was carried out based on the data recorded by the company during the year 2016. Nevertheless, three samples were collected hourly using the raw meal auto sampler in the ball meal output for us to get familiarize with the operation procedure of XRF analyser. Furthermore, sample size was reduced by coning and quartering to 200 g.

2.1 Test Procedures

The size reduced samples were heated on the hot plate till particles show considerable low cohesion (until it reaches 7% moisture content). The weight of 200g of the sample was fed to the disc mill and operated for 60 seconds. The disc mill output was used to prepare the tablets for XRF analyzer. The tablet was prepared by the pressed powder method. These tablets then used as an input for the XRF analyzer and the chemical composition results were shown with in few seconds.

2.2 Data Analysis

The research study has been carried out based on chemical analysis and raw meal residue test data of the entire year 2016[3]. Data consists of hourly records of chemical composition and the residue test results of the raw meal. These data were subjected to test for normality, time series analysis and scatter plot analysis.

3. Results and Discussion

3.1 Normality Test

Normality test is performed for SiO_2, Al_2O_3, Fe_2O_3, CaO, LSF, SR, AR and No 212 sieve residue. The main reason for the analysis of normal distribution is to check the accuracy of the predicted population parameters, which are required for the following analysis methods.

The statistical parameters of the Silicon Dioxide, Aluminium Oxide, Ferric Oxide and Calcium Oxide, are summarized in Table 2.

Table 2 - Statistical parameters of chemical constituent percentages

variable	SiO_2	Al_2O_3	Fe_2O_3	CaO
μ (mean)(%)	13.98	1.57	2.15	44.14
σ(standard deviation) (%)	0.56	0.17	0.29	0.60
-1<Z<1(%)	68.49	70.79	72.57	70.29
-2<Z<2(%)	95.45	95.67	95.94	95.34
-3<Z<3(%)	99.69	99.32	98.90	99.34
Skewness(S_K)	0.09	0.61	1.11	-0.45

The above table shows that the skewness values of all variables are nearly equal to zero. This implies these chemical parameters follow the standard normal distribution approximately.

Furthermore, it shows there is no any significant variation of these chemical parameters in the raw meal over the observed year of 2016, which ultimately gives smooth operation and constant value for the quality parameters.

Figure 1 to Figure 4 show the normal distribution curves of SiO_2, Al_2O_3, Fe_2O_3, CaO, which follow almost perfect bell shaped curves.

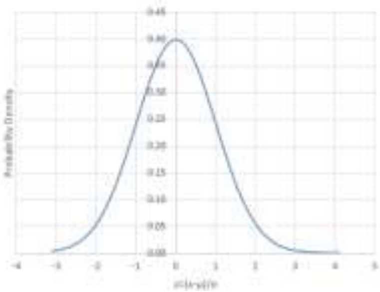

Figure 1 - Distribution of standardized Silicon Dioxide percentage

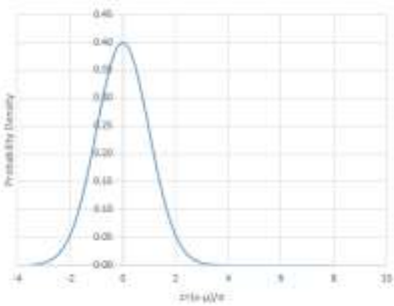

Figure 2 - Distribution of standardized Aluminium Trioxide percentage

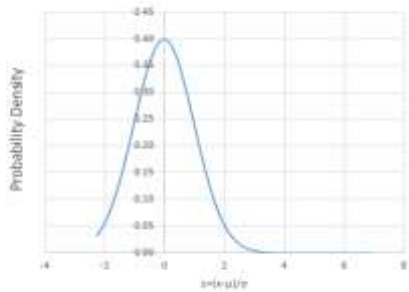

Figure 3 - Distribution of standardized Ferric Oxide percentage

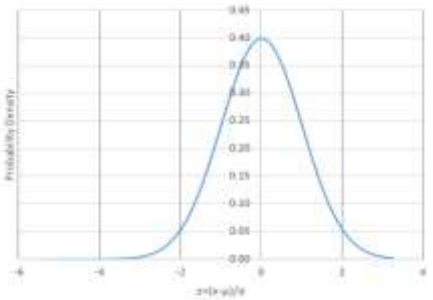

Figure 4 - Distribution of standardized Calcium Oxide percentage

The statistical parameters of the quality ratios such as Lime Saturation Factor(LSF), Silicon Ratio(SR) and Alumina Ratio(AR) and residue test results of the No 212 sieve resdue, which are estimated for ball mill output are summarized in Table 3.

Table 3 - Parameter estimation for quality ratios and No 212 sieve residue

variable	LSF	SR	AR	No 212 sieve residue
μ(mean)	99.4	2.57	1.58	1.92%
σ(standard deviation)	3.5	0.18	0.17	0.28%
-1<Z<1	67.92%	69.37%	68.62%	67.57%
-2<Z<2	95.52%	95.34%	95.59%	95.28%
-3<Z<3	99.69%	99.52%	99.34%	99.58%
skewness(S_K)	-0.04	-0.15	0	0.13

The Lime Saturation Factor is used for kiln feed control. The larger variation in the LSF results in, makes the raw meal difficult to burn, which tends to cause unsoundness of cement and causes slow setting with high early strength[4]. Since there is no any significant variation in LSF over the observed time period, the LSF values lie within the company's threshold value range of 96 - 106.
Figure 5 shows the distribution curve of LSF.

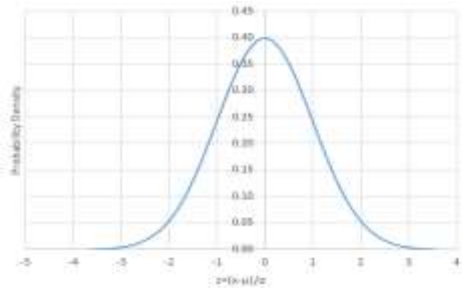

Figure 5 - Standardized distribution of LSF

The large variation in Silicon Ratio (SR) and Alumina Ratio (AR) in the clinker can be an indication of poor uniformity in the kiln feed[5]. These variations may result in harder to burn and high fuel consumption, deteriorate the kiln lining and tends to cause unsoundness of cement[6]. Since the calculated skewness values of the SR and AR are nearly zero, SR and AR also lies within the target value range upheld by the company.
The Figures 6 and 7 show the distribution graphs of SR and AR respectively.

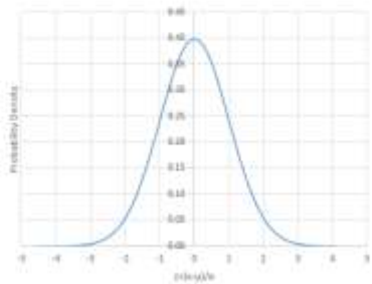

Figure 6 - Standardized distribution of SR

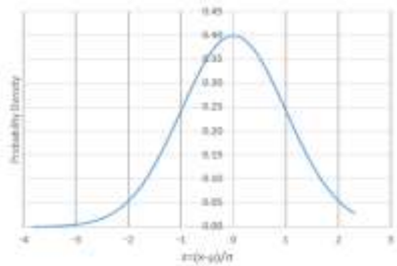

Figure 7 - Standardized distribution of AR

The value of No 212 sieve residue also shows negligible skewness value and the distribution curve follows the perfect bell shape as shown in Fig: 8.

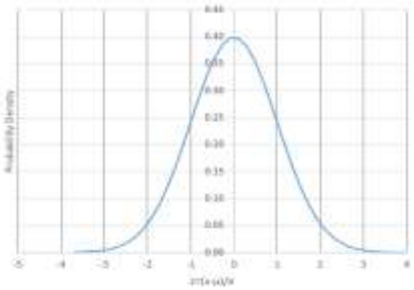

Figure 8 - Standardized distribution of No 212 sieve residue

3.2 Time Series Analysis

The time series analysis results show the mathematical trendline relationship among No 212 sieve residue, chemical constituents such as SiO_2, Al_2O_3 and CaO, LSF, SR and AR. The relationship between CaO% of the raw meal data obtained and respective No 212 sieve residue is shown in Figure 9. The overall relationship (solid line) shows, there is a decrease in residue with the increase in the CaO%. It means grindability increases with the increase of CaO%.

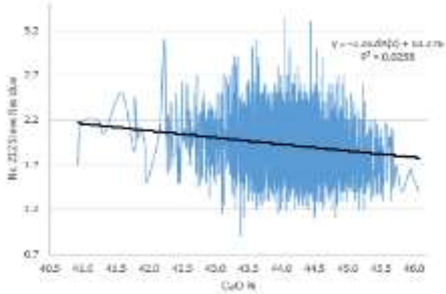

Figure 9 - Graph of CaO% vs. No 212 sieve residue

The relationship between SR of the raw meal and respective No 212 sieve residue is shown in the Figure 10. The overall relationship (fourth order polynomial) shows there is a increase in residue with the increase in the SR. It means grindability reduces with the increase of SR.

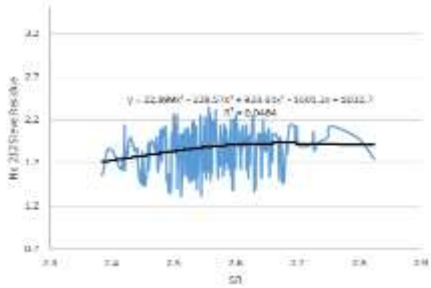

Figure 10 - Graph of SR vs. No 212 sieve residue

The fourth order polynomial trend line between SiO_2% present in raw meal and No 212 sieve residue shown in the Figure 11 has no any significant variation over the SiO_2% values.

The Al_2O_3% present in the raw meal and the respective No 212 sieve residue values show significant reduction of residue values in the higher Al_2O_3% content. The Figure 12 shows the fourth order polynomial relationship between Al_2O_3% and No 212 sieve reside values.

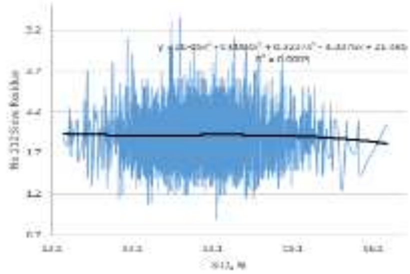

Figure 11 - Graph of SiO_2% vs. No 212 sieve residue

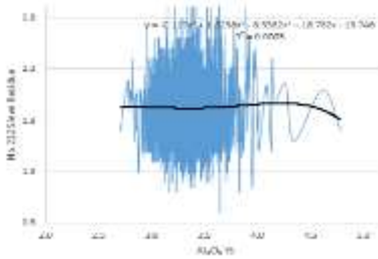

Figure 12 - Graph of Al_2O_3% vs. No 212 sieve residue

3.3 Scatter Plot Analysis

Scatter plot analysis is performed for SiO_2%, Al_2O_3%, Fe_2O_3%, CaO%, PSD < 25mm, PSD > 25mm and No 212 sieve residue within different confidence intervals such as 68%, 95% and 99%.

3.3.1 68% Confidence Interval

The 68% confidence interval value range of the SiO_2%, Al_2O_3%, Fe_2O_3%, CaO% and No 212 sieve residue is calculated based on μ-σ, μ+σ values of the each variable. Where μ is the mean and σ is the standard deviation of the variable. The Table 4 shows the 68% confidence interval value range of the mentioned variables.

Table 4 - Confidence interval of 68% values of the variables

Item(%)	μ-σ	μ+σ
CaO	43.55	44.74
SiO_2	13.42	14.54
Fe_2O_3	1.86	2.45
Al_2O_3	3.15	3.51
No 212 sieve residue	1.7	2.2

According to Table 4, the selection of SiO_2%, Al_2O_3%, Fe_2O_3% and CaO% with the above mentioned values result in a No 212 residue in between 1.7 and 2.2 under the confidence of 68%.

Figure 13 and figure 14 show the scatter plots of PSD < 25 mm and PSD > 25 mm in the raw meal with the respective No 212 sieve residue values. Graphs show all the values of PSD < 25mm and PSD > 25mm are result in residue in between μ-σ and μ+σ values. It implies that there is no any significant effect from the particle size distribution to the raw meal grindability.

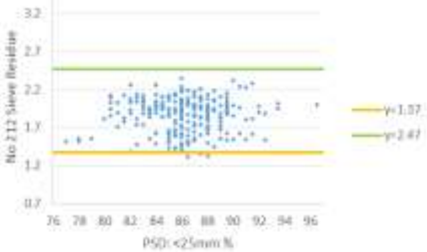

Figure 13 - Graph of PSD < 25 mm% vs. No 212 sieve residue

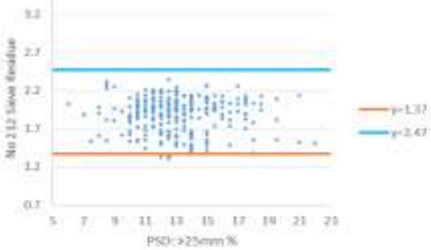

Figure 14 - Graph of PSD > 25 mm% vs. No 212 sieve residue

3.3.2 Confidence Intervals of 95% and 99%

Table 5 and Table 6 show the values of the variables in 95% and 99% confidence intervals respectively.

Table 5 - Confidence interval of 95% values of the variables

Item(%)	μ-2σ	μ+2σ
CaO	42.95	45.34
SiO_2	12.86	15.1
Fe_2O_3	1.56	2.74
Al_2O_3	2.97	3.69
No 212 sieve residue	1.37	2.47

Table 6 - Confidence interval of 99% values of the variables

Item(%)	μ-3σ	μ+3σ
CaO	42.35	45.93
SiO_2	12.3	15.66
Fe_2O_3	1.27	3.04
Al_2O_3	2.79	3.87
No 212 sieve residue	1.09	2.75

The selection of SiO_2, Al_2O_3, Fe_2O_3 and CaO percentage values in the raw meal corresponding to Table 5 and 6 result in mentioned No 212 sieve residue values based on 95% and 99% confidence interval.

4. Validation

The statistical analyze was done for the production line results of 2016. The conclusion was then made and the chemical compositions for easy, moderate and hard grindability were declared respectively. For the validation purpose, production line results from 2017 were analyzed and compared with the conclusion.
The validation results for the year 2017 January month shows;

- The percentage chemical compositions of SiO_2, Al_2O_3, Fe_2O_3 and CaO selected based on 68% confidence interval obeyed 65.5% of the residue test results.
- The percentage chemical compositions of SiO_2, Al_2O_3, Fe_2O_3 and CaO selected based on 95% confidence interval obeyed 91.05% of the residue test results.
- The particle size distribution of the raw meal in Aruwakkalu Limestone Quarry also shows there is no any significant effect to the grindability.

5. Conclusions

As per the research findings of this study, following conclusions were drawn:

The conclusions based on the normality testing;

- Percentages of SiO_2, Al_2O_3, Fe_2O_3, CaO and LSF, AR and SR follow the standard normal distribution approximately. Guarantees the unbiased estimation of statistical parameters of the population. Hence, the quality parameter such as LSF, AR and SR lies on the required quality target range upheld by the company.

The conclusions based on the results of the time series analysis;

- The mathematical relationship among the grindability and variables Silicon Oxide (SiO_2), Aluminium Oxide (Al_2O_3), Ferric Oxide (Fe_2O_3) Calcium Oxide (CaO), LSF and SR cannot be given in the form of polynomial, exponential or logarithmic manner. Since R^2 values do not equal to the unity.

The conclusions based on the results of the scatter plot analysis;

- The 68% confidence interval has the lowest value range for No 212 sieve residue (easy for grinding), but it comprised with the highest error.
- The 95% confidence interval has the middle value range for No 212 sieve residue (moderate for grinding) and it comprised with the lower error.
- The 99% confidence interval has the highest range for No 212 sieve residue(difficult for grinding) and it comprised with the lowest error.
- Since all the value ranges for particle size <25mm and >25mm are resulted in 68% confidence interval range, particle size does not show any significant impact on grindability.

Acknowledgement

We should thankful to Eng. W.M. Wedage, the Quarry Manager in Aruwakkalu Limestone Quarry for granting us the required permission to carry out the research. The Chemist, Mr. Lahiru Gunawardane, for providing their data for our project. Also Mr. Janaka Ariyadasa, Quality Assurance Manager and other staff members in Siam City Cement (Lanka) Ltd for their great support.

References

[1] Alsop, P. (2001) *Cement plant operations handbook for dry process plants*, Tradeship Publications Ltd.,Portsmouth, United Kingdom.

[2] Fuller, W.A. (2009) *sampling statistics*, iowa state university: john wiley & sons INC.

[3] Siam City Cement Lanka (LTD), 2016, Raw material Inlet Data. Unpublished internal document.

[4] Almeida, J., Rocha, M. and Teixeira, A. (2004) 'Spatial characteristics of limestone and marl quality in a quarry for cement manufacturing', *Geostatistics Banff 2004, Quantitative Geology and Geostatistics Series,springer, The Netherlands*, vol. 14, pp. 399-408.

[5] Callebaut, K., Elson, J., Balen, K.V. and Viaene, W. (2001) 'Nineteenth century hydraulic restoration mortars in th Saint Michael's Church (Leuven, Belgium)Natural hydraulic lime or cement?', *Cement and Concrete Research 31(3)*, pp. 397-403.

[6] Bhatty, J., Miller, F. and Kosmatka, S. (2004) 'Innovations in portland cement manufacturing' Portland Cement Association,Skokie,IL.