Flowability of cement powder

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Abstract. The paper considers principal factors influencing fluid properties of cement powder. Analysis with a correlation regression method has shown that a variable factor which has not been previously quantitatively evaluated, influences the fluid properties.

1. Introduction

Diminishing flowability (mobility) of cement during large-scale handling operations with road and railroad transport in bulk or in tare creates significant problems, increasing time and labor costs of handling operations [1]. This may lead to quite significant delays.

Flow of powders is a combination of physical properties of material, environmental conditions and equipment used for processing and storage of the materials [2]. Behavior of a stream of powdered material has a complex nature and depends on many physical characteristics.

Causes, leading to deterioration of cement powder flowability, are not yet completely understood. The principle cause, according to many researchers, is a complex relationship between surface energy of single grains of cement and the stream of the same grains. Surface energy depends on multiple factors arising during the cement production process: fineness of cement, a type of grinding machinery, a rotary kiln type and a production method (wet or dry), burning and cooling temperatures, a cooling rate, etc. [3].

These factors play an important role in shaping other properties of cement, such as packed density, an angle of natural repose, caking ability in silos, duration of handling from storage and transportation reservoirs. Even slight change in the value of these factors may lead to significant changes in powder mobility: a reduction in grain size leads to lower flowability of the powder. To effectively manage and predict flowability values, it is important to understand its role and significance in cement handling and storage processes, as well as controlling mechanisms for this parameter.

There are several empirical regularities: hydrophobic powders flow better than hydrophilic ones; monodisperse powders flow better than polydisperse ones [4-5]. According to these empirical regularities, cements produced in closed-cycle mills with separators shall have higher flowability than those produced in open-cycle mills that have the same specific surface area. As evident from practice, open-cycle cement starts aggregating earlier. This is due to the fact that small particles are not removed from the grinding bodies action zone, thus they adhere to the grinding bodies and reduce grinding efficiency. The supplied energy is expended not only upon milling, but upon destruction of
newly-formed aggregates as well. That is why open-cycle mills do not allow for production of cements with specific surface area above 400 m\(^2\)/kg [6]. Challenges in evaluating influence from a multitude of factors onto cement flowability lay in impossibility to quantify the flow under concrete process conditions [7-9]. Thus, in these experiments the flowability was determined in the lab in accordance with the ASTM C1565-09 method with consideration of parameters that may be quantified.

2. Materials and methods
Samples of cement were taken at different points to study influence of different factors onto its flow: at unloading from silos (set 1) and right after an open-cycle mill (set 2).

*Set 1* - number of observations 92. For unloaded batch of CEM II/A-Sh 32.5B cement, the following parameters were determined: flowability as per ASTM C1565-09, rest on sieve no.008, Blaine specific surface area, moisture content, bulk density and maximum packed density.

*Set 2* - number of observations 30. For Set 2, cement samples were taken during industrial test of a grinding-intensifying process additive of a Litoplast AI series, produced by LLC Polyplast Novomoskovsk. The samples were taken from an output chute of a 4\(\times\)13.5 m open-cycle cement grinding mill, at equal intervals during 2 days. The grinding intensifier was supplied to a clinker transporter at a rate of 200 g per 1 tonne of cement when producing CEM II/A-Sh 32.5B type cement. For the samples taken, the main parameters were analyzed: cement temperature, chemical and material composition, fineness by specific surface and grain-size distribution. Cement temperature after the mill was measured with an integrated transducer and indicated at the mill operator's panel. The grain-size distribution of the cement was determined with a special instrument ANALYSETTE 22 manufactured by FRITSCH. As a result of the analysis, the weight ratio was determined for grains up to 3 micron, from 3 to 30 micron, from 30 to 80 micron and over 80 micron. Cement powder flowability was tested in accordance with ASTM C1565-09 directly after the mill and after cooling the sample in the lab to room temperature.

To study correlations between cement flowability and the multitude of factors, a correlation regression analysis was used, as implemented in STATISTICA software package. This method considers intercorrelation between parameters when dependency between them is not strictly functional and is distorted by irrelevant random factors.

To select the most informative regression model, a method of stepwise (ridge) regression was applied, pertaining to methods of a dimensionality reduction. It is applied when there is an excess of data and independent variables correlate with each other, that is, there is a multicollinearity [10].

Strength of relationship in the correlation analysis was determined with the Chaddock scale.

3. Results of statistical analysis

Set 1
Descriptive statistics for Set 1 data with the statement of variable parameters \(x_i\) and output parameter \(y\) are shown in Table 1. Output of the Multiple Regression module of STATISTICA software is given in Figure 1.

| Table 1. Descriptive statistics for Set 1 |
|-----------------------------------------|
| Value | Output parameter | \(x_1\) – rest on sieve no. 008, %wt | \(x_2\) – Blaine specific surface area, cm\(^2\)/g | \(x_3\) – cement moisture content, %; | \(x_4\) – weight ratio of slug, % | \(x_5\) – loose bulk density, g/l; | \(x_6\) – maximum compacted bulk density, g/l; | \(x_7\) – caking degree |
| Average | Y1 – cement flow, % | 25.54 | 8.376 | 293.45 | 0.028 | 10.59 | 1132.26 | 1591.83 | 0.712 |
| Minimum | | 16 | 5.5 | 267 | 0.01 | 2.1 | 1046 | 1327 | 0.63 |
| Average | | | | | | | | | |
As evident from the results, only one parameter – $X_2$ has a significant influence over the output variable (flow). The rest of the regression coefficients are insignificant, except for $b_3$. The value of determination coefficient is $R^2 = 0.098$. A regression model selected with it as the most informative from the point of view of explaining dispersion, includes only one factorial attribute - $X_2$ (cement powder specific surface area) (see Fig. 1):

$$Y = 52.44 - 0.058X_2$$

Accuracy of the obtained single-factor regression equation in describing the output variable, namely, cement powder flow, may be shown in Figure 2. Thus, the scatter chart characterized the shift of regression residue estimations. A determination coefficient is also one of the regression equation significance evaluation and it characterizes the degree of intensity of inter-variable link. Figure 3 illustrates co-dependency of considered parameter $Y$ and factor $X_2$.

The estimation of determination coefficient $R^2 (0.098)$, obtained while implementing the method, shows what ratio of the variable variation is due to variation in the factor attribute; it shows that changes in cement powder flowability are completely determined by influence of factors which are still unaccounted for in the model.

![Figure 1. Results of regression analysis in Statistica.](image1)

![Figure 2. Distribution of regression residues depending on predicted values of flow.](image2)

![Figure 3. Results of correlation analysis in Statistica.](image3)
Set 2  
Descriptive statistics for Set 2 data with the statement of variable parameters $x_i$ and output parameters $y_1$ and $y_2$ are shown in Table 2.

### Table 2. Descriptive statistics for Set 2

| Value | Output parameters $y$ | Variable parameters $x_i$ |
|-------|-----------------------|---------------------------|
| $y_1$ - cement flowability after mill | $x_1$ - cement temperature at room temperature 25°C | $x_2$ - slug mass ratio in cement, %wt; |
| $y_2$ - cement flowability at room temperature 25°C | $x_3$ - Blaine specific surface area, $\text{cm}^2/\text{g}$ | $x_4$ - weight ratio of grains under 3 micron |
| Average | 41.22 | 16.58 |
| Minimum | 28.5 | 7.37 |
| Maximum | 50 | 25.06 |
| Standard deviation | 5.34 | 3.74 |
| Correlation coefficient between $x_i$ and $y_1$ | 0.05 | 0.01 |
| Correlation coefficient between $x_i$ and $y_2$ | -0.36 | 0.08 |

Results of correlation analysis have shown that linear correlation coefficients for two variables varied from -0.04 (factor $x_6$) to 0.31 (factor $x_2$) for output variable $y_1$ and from -0.36 (factor $x_1$) to 0.33 (factor $x_2$) - for variable $y_2$. That is, all the correlation coefficients demonstrate weak dependency between output variables $y_1$, $y_2$ and variable factors ($x_i$) according to the Chaddock scale.

The output of the Multiple Regression module for output parameter $y_1$ is shown in Figure 4, a).

![Figure 4. Results of correlation analysis in Statistica. a) for output parameter $y_1$; b) for output parameter $y_2$](image)

As evident from the data, all the regression coefficients are insignificant.

Determination coefficient $R^2$ calculated in the software shows that the ratio of dispersion of the dependent variable (cement flowability after mill), determined by influence from factors $X_1$-$X_7$ is just 0.169. The rest of the variation in flowability shall be explained with other factors, not covered by this experiment.

Similar results were obtained in regression analysis for influence from factors $X_1$-$X_7$ onto cement powder flowability at 25°C (Figure 4, b).

All the regression coefficients are insignificant, determination coefficient $R^2 = 0.24$ is just a little greater than the value obtained for cement flowability after mill.

Results of regression analysis for Set 2 have shown that out of all the studied factors the highest influence onto flowability after the mill and at room temperature are shown by slug content ($x_2$) and grain size composition ($x_4$-$x_7$). All the coefficients in the regression equation are characterized by
very low values, that is, almost every variable has insignificant influence over the output parameter. This fact is further supported with low values of determination coefficient $R^2$, whose value does not exceed 0.241 for total influence of the seven factors. That is, there is 24.1% probability that these factors influence the cement flow, the remaining 75.9% are covered by unknown factors.

4. Conclusion
As it has been demonstrated, the authors failed to find a dependency between cement flowability and all the variable parameters the authors had selected. It is an evidence of the fact that cement flowability under considered conditions is influenced by other random parameters, not accounted for in this experiment and requiring additional studies.

5. Acknowledgments
The article was prepared within the development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using equipment of High Technology Center at BSTU named after V.G. Shukho.

References
[1] Marinelli J, Carson J W 1992 Chem. Engineering Proc. Solve solids flow problems in bins, hoppers and feeders 88(5) 22-28
[2] Prescott K, Barnum R 2000 A On Powder Flowability Pharm. Technology 60-84
[3] Fleischer A.Yu 2013 Collected papers of International Conference CemEnergy
[4] Fitzpatrick J J, Ahrne L 2005 Chem. Engineering Proc. Food powder handling and processing Industry problems, knowledge barriers and research opportunities 44(2) 209-214
[5] Poluektova V A, Shapovalov N A 2016 International Journal of Pharmacy & Technology 8(4) 22716-22725
[6] Sprung C 1978 ZKG INTERNATIONAL 6 305-309
[7] Shahova L D, Chernositova E S, Denisova J V 2017 AER-Advances in Engineering Research 133 162-167
[8] Fitzpatrick J J, Barringer S.A, Iqbal T J. 2004 Food Engineering 61(3) 399-405
[9] Kamath S, Puri V, Manbeck H and Hogg R 1993 Powder Technol 76 277-289
[10] Shapovalov N A, Denisova J V, Poluektova V A 2016 International Journal of Pharmacy & Technology 8(4) 24976-24986