Iranian Journal of Engineering Geology
Autumn 2021, Vol.14, No.3

Investigation of different grinding aids effects on the cement quality and grinding efficiency; case study: Urmia Cement Plant

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Abstract

In this study, the effects of four grinding aids with three different levels on the three important characteristics of the cement, namely the specific surface area, the compressive strength of the concrete and the grinding efficiency (energy saving), have been evaluated in the clinker grinding process. In the first step, by kinetic grinding tests, the required grinding time to reach to the Blaine value of Ordinary Portland Cement (OPC) of the Urmia Cement Plant (3636 cm2/g) was obtained, which was 78.24 minute by 2.19% deviation. Then, 13 laboratory grinding tests were performed by using of Urmia cement and four grinding aids (in 3 different doses of 0.02, 0.05 and 0.08%) and the results were compared. The results showed that the combination of Triisopropylamine 0.08% (TIPA-0.08) with a Blaine number of 4032 cm2/g and a grinding efficiency of 31.57% had the greatest effect on the fineness and grinding efficiency. On the other hand, the prepared samples of the all combinations were used to test the compressive strength of 2, 7 and 28 days. The results showed that the highest increase of compressive strength for all ages was obtained by TIPA-0.08 which was 36.92%, 31.23% and 21.85% for 2, 7 and 28 days, respectively.

***Key words**: Cement, Concrete, Blaine Value, Compressive Strength, Grinding Aid, Grinding Efficiency.*

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1. Introduction

Cement production is one of the most energy-consuming industries in the world and in many parts of the world, 50 to 60% of the direct costs of cement production are related to energy costs (Jiangfeng et al., 2009). Theoretically, at least 1.6 GJ (gigajoules) of heat is required to produce each ton of clinker (Liu et al., 1995), but, in practice, the specific energy consumption for factories with modern furnaces is about 2.95 GJ per ton, and in some countries, this figure even reaches 5 GJ per ton (Khurana et al., 2002). Also, about 110 to 120 kWh of electricity is consumed to produce each ton of cement (Alsop, 2001). Figure 1 shows the share of energy consumed by each production process of a cement plant.

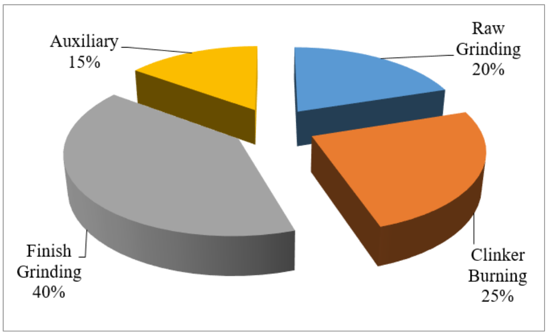

Fig. 1. Share of energy consumption of different units of a cement factory (Khurana et al., 2002)

Grinding of the clinker is the last and most consumed stage of cement production, which alone consumes about 40% of the total energy required to produce one ton of cement. The purpose of the clinker grinding is to achieve a certain amount of fineness (granulation) in the final product that can provide its desirable characteristics such as hydration rate, compressive strength, water content, and so on. To define the fineness of the product particles in the cement industry, the parameter of the "specific surface area" of the particles is used. This parameter is the sum of the areas of all the particles per unit mass of cement in square centimeters per gram, which is also known as Blaine Value or Cement Softness (ASTM, 2018).

The Blaine value is very important in the production and operational stages of the cement industry. Given that the reaction between cement components with water and the surrounding environment is a physicochemical reaction, so the role of the particle surface (i.e. Blaine value) in the overall efficiency of these reactions and achieving the desired conditions is important. In the cement industry, the effect of Blaine value can be examined from two perspectives:

- The first view is from the grinding point of view, in which the goal is to increase the efficiency of the grinding system with respect to energy savings or to increase the mill discharge for the desired Blaine value of the plant.
- The second view is from the perspective of the properties of concrete made of cement, in which properties such as compressive strength, tensile strength, setting time, etc. are considered.

Grinding aids have a great impact on the final quality, cement properties, and the efficiency of the grinding system of cement plants, and the reduction of energy consumption of grinding circuits using these materials has been proven (Lai et al., 2013; Toprak et al., 2014). The effects of additives in the cement industry can be examined in two separate sections: the first part is related to the stages of cement production and the second is related to the stage of cement application. In the cement production stage, the use of these additives is done under the name of grinding aid, because the main purpose of these materials is to reduce the specific energy consumption (energy consumed per unit mass) in the cement production or increase plant capacity; by maintaining the desired characteristics of the produced cement. In the cement consumption stage, additives are more important from the point of view of improving the physical and chemical properties of the produced concrete, and improving properties such as compressive and tensile strength, setting time, etc.

In this study, the effect of four types of grinding aids (amine and calcium nitrate base) with different doses on three very important properties of cement, namely the specific surface area (Blaine value) of producing cement, the compressive strength of producing concrete and energy saving in clinker grinding process has been evaluated.

2. Methodology

In this study, Portland cement type 1 of Urmia Cement Plant has been used, which has a Blaine value of 3636 cm^2/g and the following specifications (Table 1).

Table 1. Chemical composition of Portland cement type 1 of Urmia cement plant

Chemical composition	LOI	Na_2O	K_2O	MgO	SO_3	Fe_2O_3	Al_2O_3	SiO_2	CaO
Amount, %	2/08	0/23	1/11	1/70	2/54	3/09	4/89	20/67	63/56

All the experiments of this research have been performed on the prepared samples of the clinker mill feed on the Urmia cement plant, gypsum, and other additives of this plant.

According to the planning made in this research, 13 sample combinations are required to perform the experiments. One of the samples will be used for testing without grinding aid (Blunk) and the other 12 will be used for 4 different grinding aids with 3 different levels for each of them.

The best way to prepare suitable specimens for grinding experiments is to use of the feed of the industrial clinker mill. For this purpose, the clinker mill feed of the Urmia Cement plant was sampled. Then, according to the chemical composition of Urmia cement, the necessary additives such as gypsum, oxides, etc. were added with appropriate percentages to obtain a feed similar to the industrial mill feed. These materials are crushed in the jaw and roll crushers to prepared materials by F_{100} less than 2.36 millimeters. Each grinding experiment is carried out with 1 kg of material by using of the laboratory scale ball mill with 22/40 cm diameter and 30/50 cm length. In addition, each experiment is repeated 6 times to provide the material required for concrete tests.

In this study, to obtain the optimal grinding time, eight kinetic grinding experiments with times of 3, 7, 15, 30, 50, 70, 90, and 110 minutes were performed on the blunk sample. Then the Blaine value of each grinding time was determined and the diagram of the Blaine value – grinding time of the experiments was drawn (Figure 2).

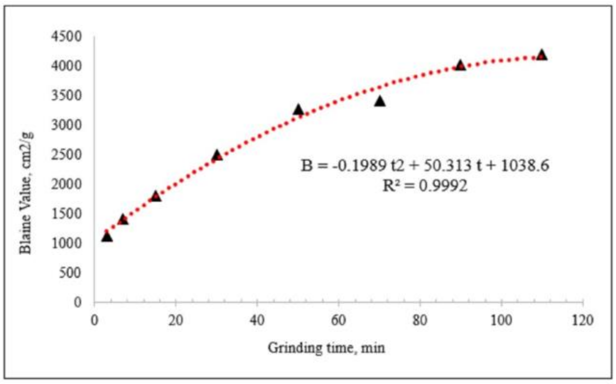

Fig. 2. the Blaine value – grinding time diagram of the blunk material kinetic test

According to the obtained mathematical relation, the time to reach the Blaine value of 3636 cm^2/g was calculated as 78/24 minutes. By obtaining the grinding time required to reach the desired Blaine value of the plant (t), all subsequent tests are crushed for 78.24 minutes and the results obtained from Blaine values, compressive strengths, and energy efficiencies will be compared together.

3. Results

A grinding test of 78.24 minutes was performed on all samples containing different amounts of grinding aid. For each sample – combination, 6 repetitive tests were performed to provide the required sample volume for compressive strength tests. To increase the accuracy of the data and eliminate possible errors, 3 samples of these 6 samples were randomly selected and their Blaine values were determined. Then, the average value of these three numbers was introduced as the Blaine index of each sample – combination. A total of 78 grinding tests was performed and 13 representative Blaine values were obtained for all sample – combinations. The summary of the results is shown in Figure 3.

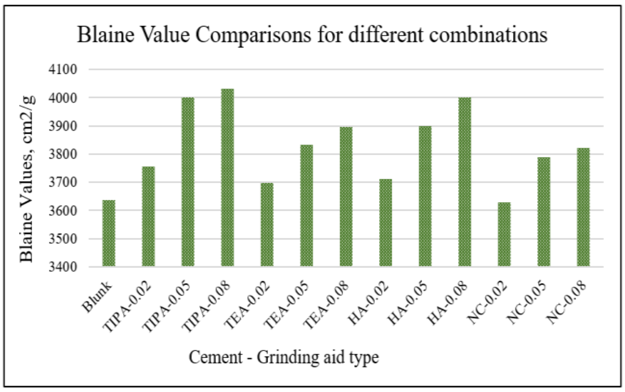

Fig. 3. Blaine Value Comparisons for different combinations

Compressive strength of concrete blocks prepared from cement obtained from different sample-combinations at different ages of 2, 7, and 28 days was measured using a loading device. In this research, cubic samples with dimensions of 15 cm and mixing design with aggregate: cement: water ratio of 3: 1: 0.5 have been used. A total of 39 blocks was made with different cement-grinding aid composition and a compressive strength test were performed on them. The results of the compressive strength tests are as shown in Figures 4 to 7.

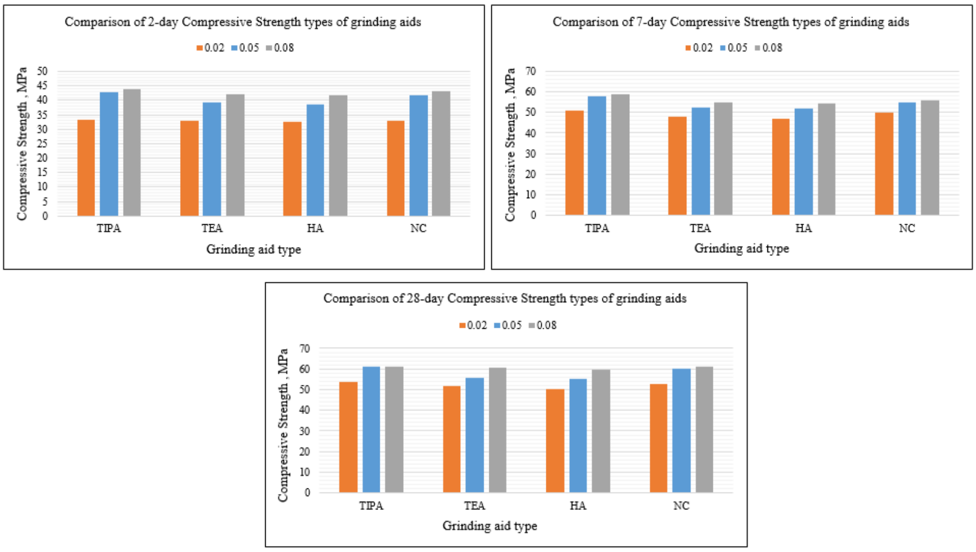

Fig. 4. Results of compressive strength tests of different samples

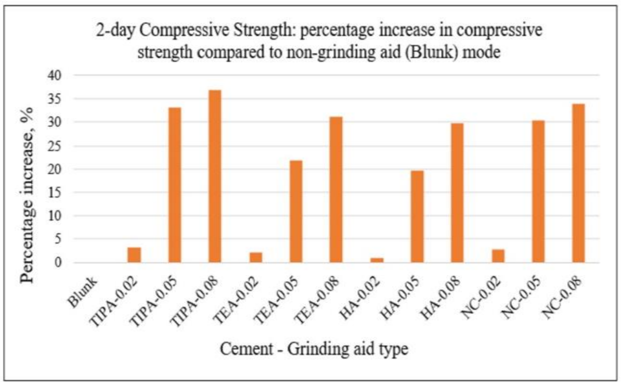

Fig. 5. Percentage increase in 2-day compressive strength compared to non-grinding aid (Blunk) mode

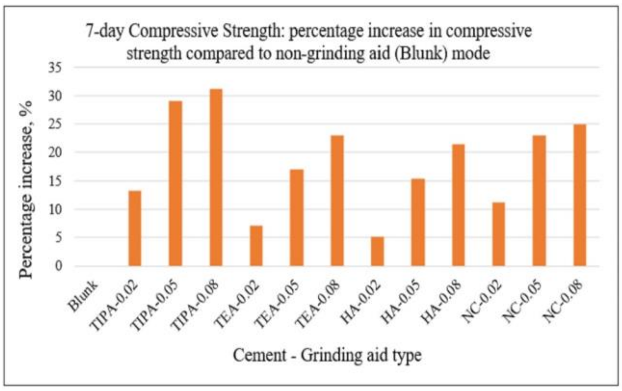

Fig. 6. Percentage increase in 7-day compressive strength compared to non-grinding aid (Blunk) mode

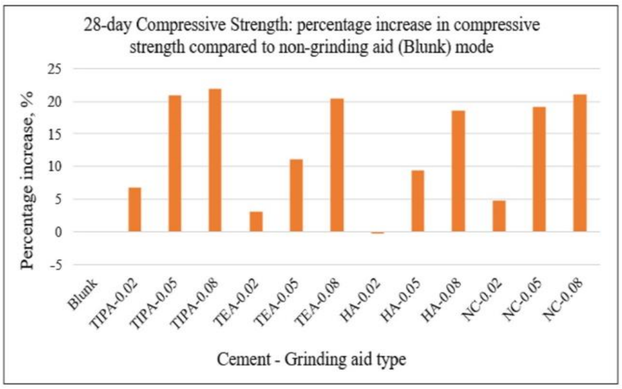

Fig. 7. Percentage increase in 28-day compressive strength compared to non-grinding aid (Blunk) mode

In the experiments performed in this project, the weight of all samples and their grinding time were constant and were equal to one kilogram and 78.24 minutes, respectively. Therefore, the constant weight of samples and grinding time means constant flow rate and power consumption of laboratory mill. On the other hand, the feed used for all experiments was the same and had the same particle size distribution. Therefore, grinding efficiency in this mill can be examined from the perspective of the grinding rate (production of finer particle product). The amount of energy required to grind the ore is calculated using the Bond relation (Equation 1) (Bond, 1952). To calculate the Bond ball mill work index, the kinetic grinding approach of the Hosseinzadeh Ghare Gheshlagh (2016), which is based on the Bond method (Equation 2), was used.

$$W = 10W_i\left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) : \frac{kWh}{t} \quad (1)$$

$$W_i = \frac{48.95}{D^{0.23}\, G_{bp}^{0.82}\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right)} : \frac{kWh}{t} \quad (2)$$

The amount of energy savings for different P80s, based on the energy consumption of the non-grinding aid (Blunk) mode, is obtained for all sample - combinations and compared with each other (Figure 8).

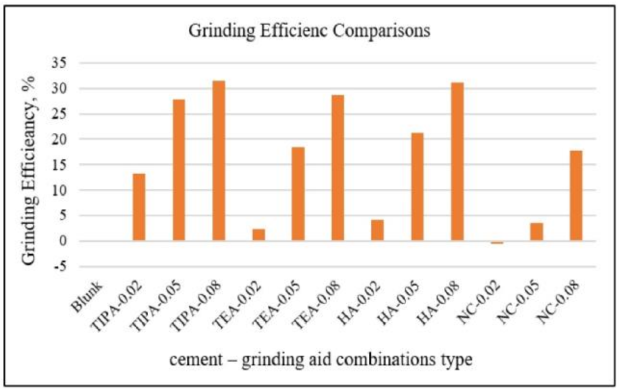

Fig. 8. Comparison of energy saving values obtained from grinding different cement – grinding aid combinations

4. Discussion and Conclusion

Adding grinding aid makes the mill product finer and increases the specific surface area of the product, i.e. increases the Blaine value, and this increases the grinding efficiency of the mill. In this research, by obtaining the optimal grinding time, grinding operations are performed on all samples and their Blaine values are determined (Figure 9).

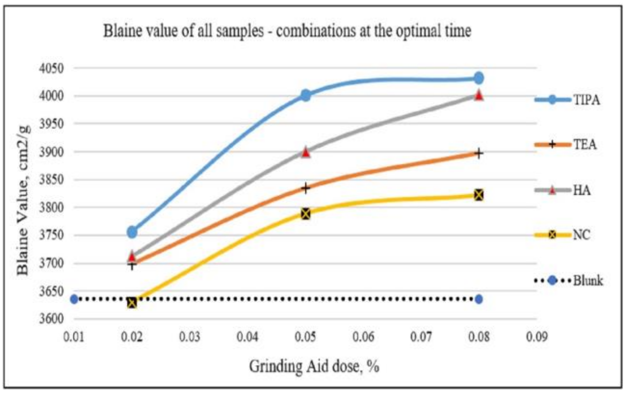

Fig. 9. Blaine value of all samples - combinations at the optimal time

The results of the grinding experiments show an increase in the grinding efficiency of the laboratory ball mill up to 31.57% for different types of grinding aid and different doses (except NC-0.02). The results show that in all three doses of 0.02, 0.05 and 0.08% used, the increase in the grinded product due to TIPA grinding aid was the biggest. This can be due to the high power of TIPA-based grinding aid in reducing the polarity of the clinker surface and, of course, reducing the clinker surface energy (Altun et al., 2015). On the other hand, with increasing the grinding aid dose, the rate of surface energy reduction also increases (Sverak et al., 2013).

On the other hand, the results of compressive strength tests show that the finer the cement, the higher the compressive strength of concrete at all ages tested. Fine-grained cement with water enters the voids of the cement-aggregate composition and reduces the ratio of voids to the total volume of concrete, and this increases the compressive strength of cement. The results of these tests show an increase in the compressive strength of concrete at all ages tested with the different grinding aids and their different amounts (Figure 10). The highest increase in the application of TIPA-0.08 was obtained with a 36.92% increase for 2-day Strength, 31.23% for 7-day Strength, and 21.85% for 28-day Strength (Figure 11).

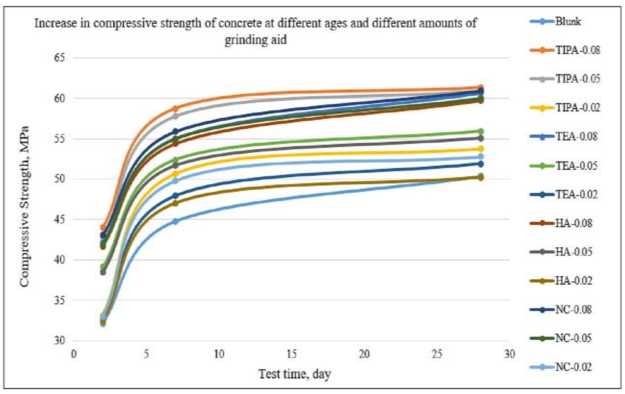

Fig. 10. Increase in compressive strength of concrete at different ages and different amounts of grinding aid

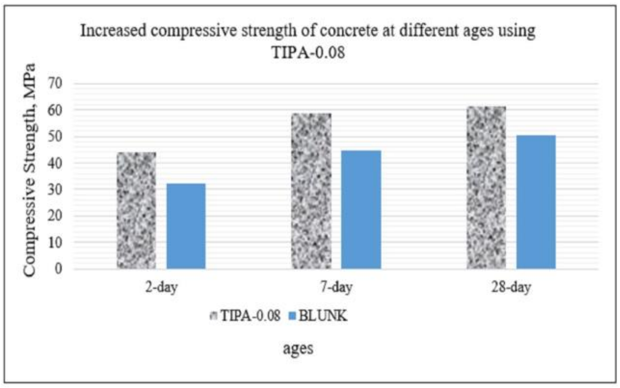

Fig. 11. Increased compressive strength of concrete at different ages using TIPA-0.08

However, the results of grinding and compressive strength tests of concrete show a relative agreement between the grinding efficiency and compressive strength of concrete, and as shown in Figure 12, increasing the finesse of particles has increased the compressive strength at all ages of concrete.

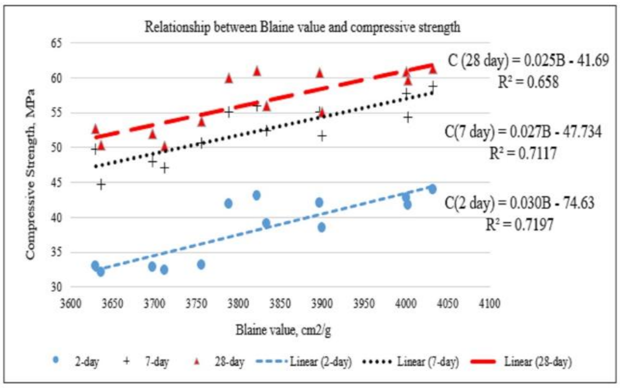

Fig.12. The relationship between Blaine value and compressive strength of concrete in 2-7-28 days

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