Correlation between Swelling Index of Bentonite Clay and the Strength of Pellets

Frans Waanders, Esbè Ungerer, and Elvis Fosso-Kankeu

Abstract — In this study the swelling index, plasticity index and linear shrinkage of bentonite clay and activated bentonite clay were determined. The clay was activated with the addition of 6.5%, 7.5%, 8.5% and 9.5% sodium hydroxide or sodium carbonate. In the industry the swell index tests are used as a pre-screening method for qualitatively assessing the quality of bentonite to be used in pelletizing projects. Therefore, pellets were formed of fine magnetite with the addition of 1% bentonite clay or 1% of the activated bentonite clay as binder and baked at 300°C, 400°C or 500°C temperatures. The compressive strength of the pellets produced was determined in order to characterize the pellets.

It was found that the maximum swelling index of sodium hydroxide activated clay was obtained with the addition of 7.5% NaOH and the greatest load at break was with the addition of 7.5% NaOH baked at 500°C for two hours. The maximum swelling index of sodium carbonate activated clay was obtained with the addition of 9.5% Na_2CO_3 and the greatest load at break was with the addition 6.5% Na_2CO_3, baked at 500°C for two hours. The swelling index was relatively constant after the addition of 6.5%, 7.5% and 8.5% Na_2CO_3 with a slight increase at the addition of 9.5% Na_2CO_3.

Based on the results obtained in this study, both the untreated and activated sodium bentonite pellets meet the standards set by the industry, therefore, the extra cost of activating the clay cannot be justified.

Keywords— Activate, bentonite, binder, pelletizing, swelling index.

I. Introduction

THE large amounts of fine hematite or magnetite waste, resulting from the beneficiation of the iron ore, can be utilized when it can be bound in the form of pellets to be used in the production of steel. At Sishen Mine approximately 3.5 Mt/a of slimes material, is produced during beneficiation, and discarded to the tailings dam [1].

Clay, as the binder, along with the moisture added, give the raw materials adhesive properties so that nucleated seeds can grow into good quality pellets. The binder holds the particles in the agglomerate together while the water is removed during drying and the pellet is heated to sinter the grains together [2].

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As the swelling capacity of bentonites, in the presence of water, is an indication of the quality of the bentonite, the industry has been using swell index tests as a pre-screening method for qualitatively assessing the quality of bentonites. Sodium carbonate or sodium hydroxide acts as an activator to increase the swelling index of the bentonite clay [3].

A sodium-based bentonite is found in South Africa in the Southern Cape in the district of Heidelberg, as well as in the Free State near Koppies [4]. According to the British Geological Survey 16 600 000 metric tons of bentonite were mined in the world in 2013 and only 180 000 metric tons of that were produced in South Africa [5].

Water chemistry affects bentonite binding through the expanding of the moisturised bentonite clay and the lessening of the electrostatic attraction between the individual platelets. The dry strength of iron ore pellets is improved in two ways by the addition of bentonite, namely: 1) Interparticle distances are decreased and Van der Waals forces are thus increased. 2) A solid bridge of toughened gel that reinforces particle contact points is formed permitting the platelets to slide across each other and spread like a deck of cards pushed across a desk. As the expansion is directly linked to the amount and type of interlayer cations present between the clay platelets, the correlation between the addition of different concentrations of NaOH or Na_2CO_3 and the swelling index and strength of pellets have to be determined. Methods for assessing bentonite quality focus on either directly or indirectly determining the expandability of the bentonite [6].

II. Methodology

A. Categorizing bentonite clay

The Swedish soil scientist, Albert Atterberg defined seven limits of uniformity to categorise fine-grained soils but in present engineering practice, only two of the limits, the liquid and plastic limits, are regularly used and the third limit, called the shrinkage limit, is used occasionally [7]. The three limits as well as the swelling index, were determined, using different concentration additions of sodium carbonate or sodium hydroxide.

B. Swelling index

Five bentonite mixtures, containing 0%, 6.5%, 7.5%, 8.5% and 9.5% of NaOH and four bentonite mixtures containing 6.5%, 7.5%, 8.5% and 9.5% Na_2CO_3 were prepared. A sample of 2 g of each mixture was dusted over the whole surface of

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distilled water in a calibrated 100-mL cylinder in additions of less than 0.1 g over a period of about 30 s and allowed to stand for at least 10 min between the additions. After an elapsed time of 24 h, the swell volume of the bentonite defined by the interface between the sediment and the supernatant was measured, and recorded in units of mL/2 g [8].

C. Liquid limit

The liquid limit is defined as the water content at which a soil changes from plastic to liquid behaviour. The mixtures, prepared in B were thoroughly mixed with a small amount of distilled water until it appeared as a smooth uniform paste. A portion of the mixed bentonite clay was squeezed down into the cup of the Digital Soil Liquid Plastic Limit Penetrometer with a spatula to eliminate air pockets. By turning the knob on the penetrometer the cone was let down until it was just lightly resting on the surface. The red release button was pressed and the cone penetrated the clay. The digital value that was displayed was recorded.

D. Plastic limit

The liquid limit is defined as the water content at which a soil changes from plastic to semi-solid states. Using a portion of the same mixtures that were prepared in C, the clay was formed into an ellipsoidal mass and the mass was rolled between the fingers and the glass plate. When the diameter of the thread was 3 mm, the clay was kneaded into an ellipsoidal shape and rolled out again. This process was repeated until the crumbling of the clay prevented the formation of a thread 3 mm in diameter. The crumbled clay thread was dropped into a previously weighed can and weighed again. The cans were dried and weighed after two days.

E. Shrinkage limit

The shrinkage limit is defined as the maximum water content at which the reduction in water content will not cause a decrease in total volume of soil but the increase in moisture content will cause an increase in moisture content. The inside walls of the bar linear shrinkage mould were greased with a thin layer of petroleum jelly to prevent the adhesion of the soil to the linear shrinkage moulds. A small portion of the wet soil that were prepared in C was pressed evenly into the mould and entrapped air bubbles removed by thumping the mould lightly on the surface of the bench. The mould was completely filled and the surface level smoothed. This process was repeated for six moulds per percentage of the clay mixtures. The moulds were dried in an oven at 110°C for two days. The length of the dried clay was measured and the linear shrinkage was determined.

F. Strength of pellets

Five bentonite mixtures, containing 0%, 6.5%, 7.5%, 8.5% and 9.5% of NaOH and four bentonite mixtures containing 6.5%, 7.5%, 8.5% and 9.5% Na_2CO_3 were used to make 1000 gram mixtures with composition of 1% bentonite clay and 99% magnetite. Pellets were formed and air dried for two days. The pellets were baked at 300°C, 400°C and 500°C for two hours. Strength tests were performed on the pellets using the LRXplus.

G. Experimental calculations

The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit

(PI = LL-PL)

The plastic limit (PL), the percent moisture (A), is calculated as follows:

A = [(B –C)/C] x 100

A = Percent moisture

B = Mass of original sample

C = Mass of dry sample

III. Results And Discussion

A. Swelling index

In fig.1 it can be seen that the swelling index of bentonite clay had increased from 8.8 ml/2g to 18ml/2g with the addition of 6.5% NaOH. This is an increase of 104.5%. The addition of 7.5% NaOH had a maximum swelling index of 20ml/2g. The addition of 8.5% NaOH had a decrease in the swelling index with the same swelling as with the addition of 6.5% NaOH. The swelling index after the addition of 9.5% NaOH decreased again to 16ml/2g.

In fig.1 it can be seen that the swelling index of bentonite clay had increased from 8 ml/2g to 15ml/2g with the addition of 6.5% Na_2CO_3. An increase of 87.5%. The addition of 7.5% Na_2CO_3 led to a slight increase in the swelling index to 15.5ml/2g. The swelling index stays constant after addition of 8.5% Na_2CO_3. The maximum swelling index of 16ml/2g occurred after the addition of 9.5% Na_2CO_3.

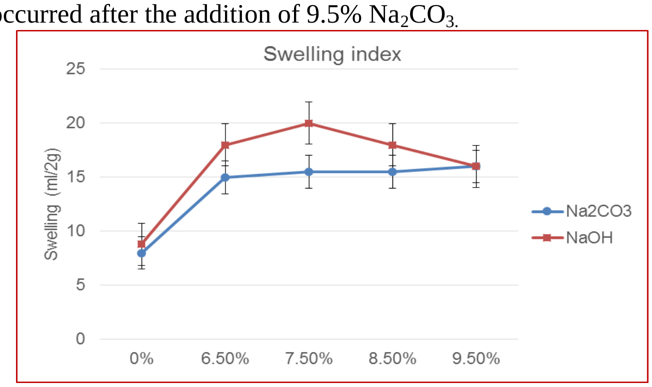

Fig. 1 Swelling index of NaOH and Na_2CO_3.

This correlates with work done by Tang *et al.* who found that the free-swell volumes of the bentonite clay at pH = 12.0 were approximately 25% larger than those at pH = 3.0. They concluded that the soil clusters became larger and that binding with OH^- led to formation of floccules resulting in the narrowing of inter-particle space and thus blocking of permeable paths [9].

TABLE I

pH VALUE OF BENTONITE CLAY WITH DIFFERENT CONCENTRATION ADDITIONS OF NAOH OR NA_2CO_3.

NaOH	pH	Na_2CO_3	pH
0%	8.6	0%	6
NaOH 6.5%	10.9	Na_2CO_3 6.5%	9.6
NaOH 7.5%	12.5	Na_2CO_3 7.5%	9.6
NaOH 8.5%	10.7	Na_2CO_3 7.5%	9.7
NaOH 8.5%	10.3	Na_2CO_3 8.5%	9.8
NaOH 9.5%	10.3	Na_2CO_3 9.5%	9.8
NaOH 9.5%	11	Na_2CO_3 9.5%	9.8

As seen in fig. 1 the maximum swelling index was found at the addition of 7.5% NaOH and it correlates with the highest pH of 12.5. The swelling index of Na_2CO_3 stays relatively constant and that correlates with the pH that stays relatively constant as well.

B. Plasticity index

In fig.2 it can be seen that the plasticity index of bentonite clay had decreased with the addition of 6.5 % NaOH. The addition of 7.5% NaOH had a minimum plasticity index. The addition of 8.5% NaOH had an increase in the plasticity index and after the addition of 9.5% NaOH an increase again.

The plasticity index of bentonite clay had decreased with the addition of 6.5% Na_2CO_3. The addition of 7.5% Na_2CO_3 led to a slight decrease in the plasticity index. After an addition of 8.5% Na_2CO_3 there was a large decrease in the plasticity index followed by a small decrease after the addition of 9.5% Na_2CO_3.

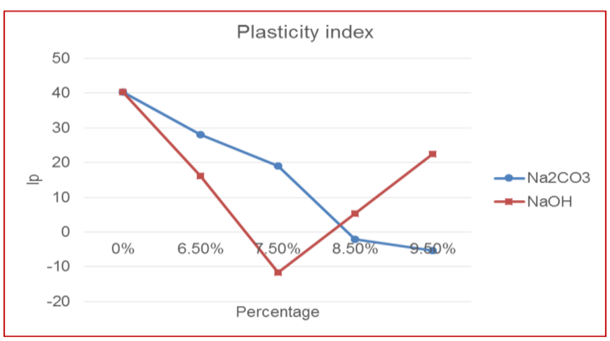

Fig. 1 Plasticity index of bentonite clay with different concentration additions of NaOH and Na_2CO_3

C. : Linear shrinkage percentage

In fig.3 it can be seen that the linear shrinkage percentage of bentonite clay had decreased steadily with an increase in the percentage of Na_2CO_3. The addition of 8.5% NaOH had a decrease in the linear shrinkage percentage. Sunde concluded that the large deviations stemmed from the varying geometry of the pellets [10].

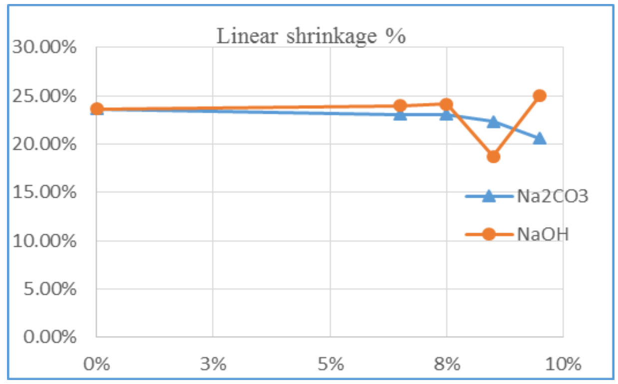

Fig. 3 Linear shrinkage percentage of NaOH and Na_2CO_3.

D. The load at break of bentonite clay with different concentration additions NaOH and Na_2CO_3

Maximum swelling index is at 7.5% NaOH and as can be seen in fig.4 the largest load at break is with the addition of 7.5% NaOH baked at 500°C.

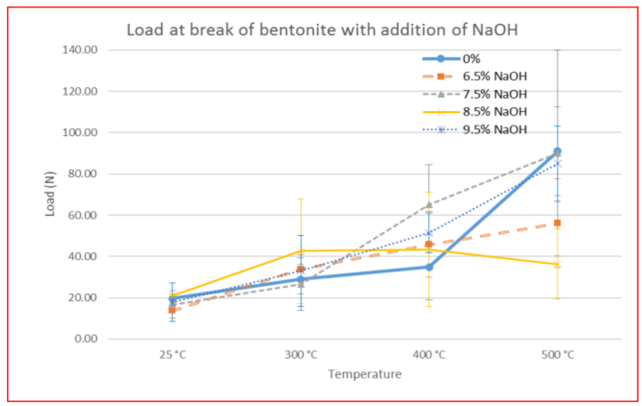

Fig. 4 Load at break of bentonite with different concentration additions of NaOH

The maximum load of 180N was found at an addition of 7.5% NaOH baked at 500°C for two hours. According to Kawatra and Ripke the minimum industrially acceptable dry pellet compressive strength is 22 N. All the loads at maximum load, as seen in fig. 5, are above the minimum of 22 N [6].

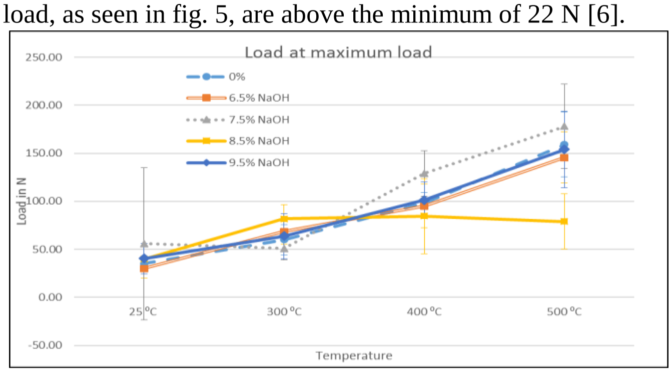

Fig. 5 Load at maximum load of bentonite with different concentration additions of NaOH

The maximum swelling index was at 9.5% Na_2CO_3 but as can be seen in fig.6 the largest load at break is with the addition of 6.5% Na_2CO_3 baked at 500°C for two hours.

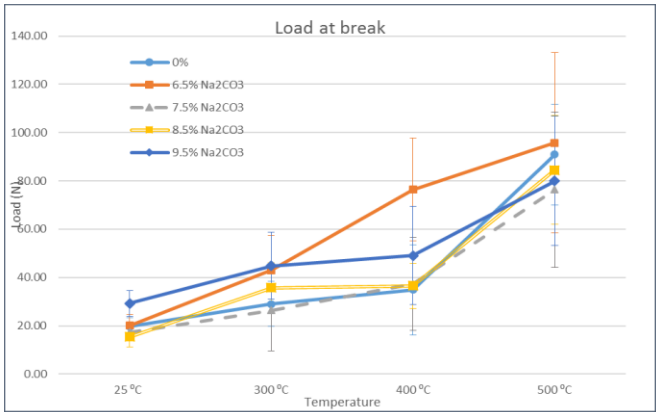

Fig. 6 The load at break of bentonite clay with different concentration additions of Na_2CO_3

The load at maximum load was 188.6 N found at an addition of 6.5% Na_2CO_3 baked at 500°C for two hours. The smallest value was 28.19 N at 25°C which still exceeds the minimum required value of 22 N.

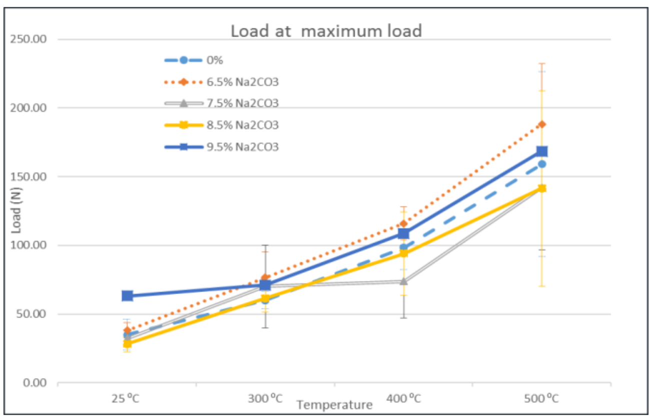

Fig. 7 Load at maximum load of bentonite with different concentration additions of Na_2CO_3.

IV. Conclusion

Based on the results obtained in this study, both the untreated and activated sodium bentonite pellets meet the standards set by the industry, therefore, the extra cost of activating the clay cannot be justified.

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