Properties of South African Activated Bentonite and the Importance of its Consistency for Foundry Use

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Abstract

Bentonite is a 2:1 phyllosilicate clay mineral in the montmorillonite group. It is locally mined and processed for various industrial applications including its use in the foundry industry as a binder of greensand used for making casting moulds. In this instance, crude bentonite is Na-activated by addition of soda ash. In this paper different foundry properties of a typical local Na-activated bentonite are measured over time. Statistical analysis is conducted on experimental data to assess the consistency of the clay material in terms of its physico-chemical integrity for foundry use. The causes of variations in foundry properties originated from the activation process employed. The paper makes practical recommendations with regards to the use of local activated bentonite in greensand systems.

Keywords: *Bentonite activation; casting moulds; consistency, foundry properties*

1. Introduction

Whilst a number of new moulding processes involving various types of binders such as silicates, resins, and oils have been introduced into foundries in recent years, the most popular and widely used moulding media in the world is clay-bonded sands also called greensands (Nyembwe, 1999).. Greensands are the major moulding materials in South African iron foundries and are the most widely used. Though African steel foundries opt sometimes for resins bonded sand processes, the greensand technology still occupies an important part in the production of small and medium casting sizes. Clay-bonded sands are versatile and economical moulding materials. They are applicable in the production of most sizes, types and composition of castings. Furthermore, they lend themselves to simple hand and rapid mechanised production units (Beeley, 2001).

The sand binder clays exclusively used in South African greensand foundries are activated bentonites: large deposits of calcium bentonite are found here in South Africa. The calcium bentonite is mined and chemically treated by adding sodium carbonate (soda ash) to convert it to activated bentonite for foundry use. Activated bentonites have better foundry properties that are closer to those of sodium bentonites than calcium bentonites (Brown, 2002; Chakrabarti, 2005).

Figure 1 shows the flowsheet of a typical activated bentonite processing plant in South Africa. Front end loader truck is used for mixing the crude and calcium bentonite. The mix is then ground before classification (Nyembwe, 1999).The activation process is carried out in two steps: mixing of soda ash with calcium bentonite crude, followed by a hot milling of the mix. As reported in Nyembwe (1999), most bentonite used in South African foundries is activated with 2 to 3 % soda ash.

Much has recently been published on the constitution, physical and chemical properties of bentonites, as well as on the activation process (Boylu, 2011; Karimi & Salem, 2011; Karagüzel, *et al*, 2011). However there are still some areas of local bentonite foundry use that need further investigation. The limitations include: the difficulty to predict bentonite performance in foundries based on its physical or chemical properties, the establishment of accepted foundry bentonite specifications, and the elimination of multiples variables in bentonite control test procedures as actually performed in foundries. Concerning the elimination of multiples variables in bentonite control test procedures as actually performed in foundries the methylene blue requirement test of bentonite which is widely used in South African foundries for the determination of greensand system live clay has so many variations in the test procedures used that the results from one plant often have no relationship with the results reported from another. Studies (Hoyt, 1991) have been carried out on this particular test regarding factors like the sample drying, sample mixing, and the dispersion methods, to name a few. This study investigates other variables of this particular test such as sample preparation, methylene blue concentration, and of other bentonite test including moisture determination, viscosity test, bonding test, and others. This work also includes a measure of precision and reproducibility of various bentonite tests as the literature is silent regarding this aspect.

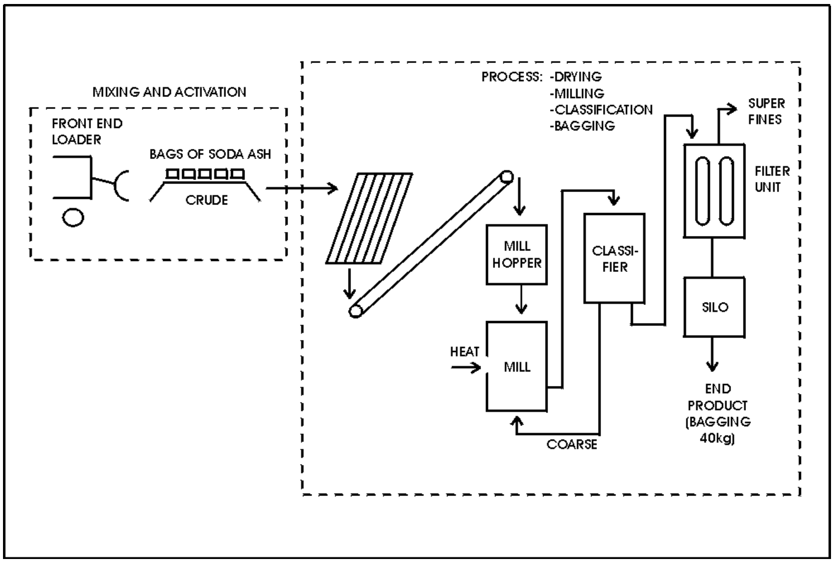

Figure 1. Flowsheet of a typical activated bentonite processing plant

In addition to the above problems other difficulties are encountered in the use of bentonite in South African foundries regarding its quality control tests and its consistency. No control test of bentonite supplies in foundries is carried out in most South African foundries. The bentonite is supplied into the foundries with a certificate for which the content means nothing to most foundrymen. As long as the greensand can develop desired green compression strength for a predetermined level of bentonite in the system sand, then everything is fine by the foundry men. It is a well known fact that the green compression strength test in spite of its predominant application in foundries is one of the most misleading test for bentonite quality . Many casting defects and other greensand difficulties originate from poor bentonite quality (low tensile strength, and low durability to name a few) even when the greenstrength is high or meets the specifications. It is well establish that the quality of bentonite will depend on the activation process. Most of the bentonite properties are a function of the soda ash addition and the efficiency of the addition process used. This can easily be controlled in foundry by the viscosity test. The latter is simple and correlates well with the percentage addition of soda ash.

There is a need not only for the training of people involved with the greensand in South Africa, but also for studying South African bentonites consistency. It will then be possible to know which properties vary, and what the relationship between the various properties is. Such a study could allow better use of bentonite in foundries and an improvement of local bentonites.

The effects of variations in some bentonite testing procedures, the measure of precision and reproducibility of tests and the consistency of some South African bentonites are the principal objects of this experimental work on bentonite.

2. Methods

The bentonite properties studied in the experimental work are:
(1) Viscosity
(2) Moisture
(3) Swelling capacity
(4) Cation exchange capacity
(5) Methylene blue requirement
(6) Green compression strength
(7) Dry compression strength

The test procedures for the determination of these properties were according to BCIRA or SABS.

The bentonite used all along the experimental work was an activated bentonite with the following suppliers' specification:
(1) Viscosity: 23 - 25
(2) Moisture: 8 - 12

2.1. Experiment on reproducibility and precision

A 10 kg bentonite sample was used for this experiment. In the first part of the experiment the precision and the reproducibility of bentonite tests according to the recommended test procedures (BCIRA or SABS) were examined. To that end, each test studied was performed 5 consecutive times on the sub-samples collected from the initial sample and from the results obtained; the different statistical data were calculated (average, standard deviation, coefficient of variation and range)

In the second part of the experiment, the effects of variations in some bentonite test procedures were also investigated. This was the case of the following tests:

(1) The moisture determination for witch the effect of temperature (110 and 135 ^oC) and drying time (e.g. 7 and 30 minutes) were studied.
(2) The methylene blue requirement test for which the influences of the sample preparation (i.e. dry and as received sample), and methylene blue preparation (i.e. concentration) were investigated.

These variations in bentonite test procedures are the most encountered in South Africa. Sub-samples collected from an initial bentonite sample were submitted to the tests using different test procedures.

2.2. Experiment on sampling

In this experiment, the aim was to check whether there is variation of bentonite properties in different bags of a foundry intake. The aim was to determine if a sample from a bag can represent the whole delivery. To that end, for each delivery of bentonite in foundry, samples of about 100 g were collected from five different bags and tested for viscosity, moisture, swelling capacity and methylene blue requirement. This experiment was conducted for a period of a month.

2.3. Experiment on variations

In this experiment, the aim was to study the variations of bentonite properties over a period of time by testing each of its delivery in the foundry during a month.

For each delivery of bentonite in the foundry, batches were selected according to the date of production. For each batch retained, a composite sample of 1kg from 5 bags was constituted and tested for moisture, viscosity, swelling capacity, cation exchange capacity, green compresssion strength, and dry compression strength, methylene blue requirement according to BCIRA or SABS testing procedures. The use of bentonite batch was found convenient in order:

(1) To obtained enough result over a period of a month even with very few foundry delivery.
(2) To study the variations of bentonite properties as a function of its day to day production.

3. Results and Discussion

3.1. Reproducibility and precision

Table 1 gives the reproducibility and the precision (standard deviation, coefficient of variation and range) obtained for the different bentonite test studied. It can be observed that:

(1) The viscosity determination shows a very high precision and excellent reproducibility of test results. The standard deviation, the coefficient of variation and the range were all found equal to zero.
(2) The moisture determination is one of the most imprecise and non re- producible test determination among all the test studied. The standard deviation, the coefficient of variation and the range were respectively found equal to 0.8, 7.3 % and 2.2. These high values obtained can be attributed to several possible reasons among which:
    i. A re-hydratation of the bentonite sample taking place after the test during the cooling. It is well known that bentonites easily adsorb water.
    ii. A non uniform distribution of water within the initial sample from which the sub-samples are collected.
(3) Although the cation exchange capacity and the methylene blue requirement determinations are based on the same principle of titration with methylene blue, they show different degree of precision and reproducibility. The CEC determination has a better precision and reproducibility than the MBR determination. The standard deviation, the coefficient of variation and the range were found respectively equal to 0.5, 0.65 and 1 in the case of CEC. These figures are lower than the ones found for the MBR. In this latter case, the following values were observed to be equal to 1.02, 2.5 and 3 for the standard deviation, the coefficient of variation and the range respectively. This observation is possibly due to the great number of factors involved in the preparation of the sample for titration in the methylene blue requirement determination:
(4) Use of silica sand which might contain impurities affecting the results.

(5) Imprecision in the weighing of the mix 0.5g bentonite 4.5g silica sand.
(6) Boiling of the sample creating bumping or foaming.
(7) The green compression strength was found to be more precise and more reproducible than the dry compression strength. The standard deviation, the coefficient of variation and the range were found respectively equal to 1.40, 1.54 % and 3.4 in the case of the greenstrength determination. In the case of the drystrength determination, the standard deviation, the coefficient of variation and the range were higher with values of 10.9, 2.73 % and 27.6 respectively. The reason for this difference in reproducibility and precision between these two tests is possibly due to the sample preparation in the dry compression test under the circumstances the drying in the oven.

In the second part of this experiment on reproducibility and precision of bentonite tests, the effects of variation in test procedures were also investigated. This was the case of the moisture determination test as well as the methylene blue requirement test.

Table 1. Reproducibility and precision of bentonite test results (BCIRA or SABS test procedures). One fixed sample was tested five consecutive time for each property.

	Test number					Statistical results			
Tests	1	2	3	4	5	Ave	Std	Cv [%]	Ran
Viscosity [second]	24	24	24	24	24	24	0	0	0
Moisture [%]	11.6	12.2	13.8	12.6	13.6	12.8	0.80	7.3	2.2
Swelling capacity [g/ml]	8.5	8.0	8.5	9.0	8.5	8.5	0.31	4	1
Cation exchange capacity [m.eq/100g]	74	73	73	74	74	74	0.5	0.6	1
Methylene blue requirement [ml]	41	42	40	40	39	40	1.02	2.5	3
Green compression strength [10^3 Pa]	90.6	91.6	88.9	92.3	89.6	90.7	1.40	1.54	3.4
Dry compression strength [10^3 Pa]	406.5	392.7	413.4	385.8	399.6	399.6	10.9	2.73	27.6

3.1.1. Moisture content test results

Table 2 gives the statistical results obtained when using three different testing procedures for bentonite moisture determination. Two factors affect and influence the moisture test result of bentonite:
(1) the drying time
(2) the drying temperature

Table 2. Effects of drying time and temperature on bentonite moisture test results (a group of of 5 sub-samples collected from an initial fixed bentonite sample were tested using different procedures then the statistical data calculated from the results obtained).

Test procedures	Ave	Std	Cv [%]	Ran
Sample dried at 110^{o}C for 30 minutes (SABS procedure)	12.8	0.8	6	2.2
Sample dried at 110^{o}C for 7 minutes	4.0	2.3	60	6.0
Sample dried at 135^{o}C	14.8	0.3	2	1.0

When the drying time is reduced from 30 min (SABS) to 7min, the content of moisture decreases and the precision and reproducibility become very bad. The average of results on 5 sub samples tested, the standard deviation, the coefficient of variation and the range for a drying time of 30 minutes are presented in Table 2. These values were much lower than the ones obtained with a drying time of 7 minutes. In the latter case the average, the standard deviation, the coefficient of variation and the range were respectively found equal to 4, 2.27, 60 %, and 6. It seems that the release of bentonite free water is time depend at constant temperature.

On the other hand, when the temperature increases, e.g from 110 ^oC to 135 ^oC the precision and reproducibility of the moisture test are improved plus the result of moisture increased. The average, the standard deviation, the coefficient of variation and the range were respectively found equal to.12.8, 0.8, 6 % and 2.2 at 110 ^oC and 14.8, 0.3, 2 % and 1.0 at 135 ^oC (Table 2).The increase observed in moisture content at high temperature is probably due to the heat damage of the bentonite with some loss of its combined water.

3.1.2. Methylene blue requirement test results

Table 3 and 4 illustrate the influence of two factors in the methylene blue requirement determination:

(1) The methylene blue concentration
(2) The sample preparation

From table 3, it can be observed that: When the concentration of MB increases, the results of methylene blue requirement are slightly low (Table 3). This is the case when one switches from a commercial brand of MB with a different chemical composition (e.g mass equivalent 3.2g) to another (e.g. mass equivalent 3.5g). From table 4, it can be observed that: Concerning the sample preparation, carrying out the methylene blue requirement with as-received bentonite or with the bentonite previously dried gives different results of methylene blue requirement. It seems that drying the bentonite sample gives high methylene blue requirement result.

Table 3. Influence of methylene blue concentration on the methylene blue requirement test results of bentonite (5 different bentonite samples were tested with the two solutions).

Mb solution concentration	**Samples**				
	1	**2**	**3**	**4**	**5**
3.2 g/l	43	43	42	41	42
3.5 g/l	41	42	40	40	39

Table 4. Influence of sample preparation (drying) on the methylene blue requirement test results of bentonite (5 different bentonite samples were tested using the two different procedures).

Test procedure	**Samples**				
	1	**2**	**3**	**4**	**5**
Sample" as received " (SABS procedure)	41	43	45	40	41
Sample dried at 110^oC for 30 minutes prior to the test	44	45	45	43	44

3.2. Sampling

Table 5 gives the typical results obtained in this experiment. Some variations of results were obtained in the samples collected from five different bags of a foundry intake. Table 6 presents the statistical results obtained from the data in table 5. These results are compared to the ones obtained in table 8. It can be observed that:

(1) The viscosity varies in different bags of a batch with a range of 2, higher than the range 0 found during the experiment of viscosity test precision and reproducibility. However the viscosity remains in the supplier specifications.
(2) The moisture is consistent in the batch as the standard deviation (0.96) and the coefficient of variation (3) for the batch variation are in the same order with the ones found in the "test of precision and reproducibility (respectively 0.8 and 2.2).
(3) The methylene blue requirement and the swelling capacity vary as the statistical results of the batch variation are much higher than those of the "test of precision and reproducibility". Furthermore no specifications exist for these bentonite properties, it is therefore difficult to judge if the variations of MBR and S.I in different bags of a batch are acceptable or intolerable. However care must be taken when establishing the bentonite calibration curve to control the whole greensand system. The use of one bag only can give misleading results which can create serious problems on casting quality or konckout.

Table 5. Typical variations of properties in different bags of a bentonite supply (samples were collected from 5 different bags of a delivery and tested)

Properties	Samples				
	1	2	3	4	5
Viscosity [second]	10.0	10.8	10.6	12.4	9.6
Moisture [%]	24.0	23.5	23.5	25.5	23.0
Swelling capacity [g/ml]	44	44	42	42	40
Mb requirement [ml]	11.5	11.5	12.5	11.0	9.5

Table 6. Statistical results of variations of properties in different bags versus statistical results of test reproducibility and precision

Properties	Variation of properties in different bags of a supply				Results of reproducibility and precision of tests		
	Ave	Std	Cv [%]	Ran	Std	Cv [%]	Ran
Viscosity [second] Spec: 23 - 25	24	0.9	3.5	2	0	0	0
Moisture [%] Spec: 8 - 12	11	0.96	8.9	3	0.8	6	2.2
Swelling capacity [g/ml] No spec.	11.2	0.9	8.7	3	0.31	4	1
Mb requirement [ml] No spec	42	1.49	3.5	4	0.5	1.2	1

3.3. Variations of properties

Table 7 gives the results of properties in the bentonite foundry intakes over a period of four months. The statistical results obtained for the properties are compared to the ones found during the experiment on reproducibility and precision (Table 8). It can be observed that all the bentonite properties investigated exhibit important variations. The statistical data (STD, Cv, Ran) are much higher than those found during the test of precision and reproducibility.

Table 8. Statistical results of variations of foundry intake properties versus statistical results of test reproducibility and precision.

Properties	Variation of bentonite foundry intake properties				Results of reproducibility and precision of tests		
	Ave	Std	Cv [%]	Ran	Std	Cv [%]	Ran
Viscosity [second] Spec: 23 - 25	23.4	0.8	3	2.5	0	0	0
Moisture [%] Spec: 8 - 12	10.2	1.3	13	4.4	0.8	6	2.2
Swelling capacity [g/ml] No spec.	10	1.2	12	3.5	1	4	0.31
Cation exchange capacity [m.eq/100g] No spec.	77	4.3	5	14	1	0.6	0.5
Mb requirement [ml] No spec.	41	4	9	14	1	1.2	0.5
Green compression strength [10^3Pa] No spec.	78.6	9.07	11.5	26.8	1.40	1.54	3.4
Dry compression strength [10^3Pa] No spec.	403.5	50.9	12.6	144.7	10.9	2.73	27.6

Figure 2 is a plot of the results obtained in Table 7. It can be observed that:

(1) No trends of properties have been found, the variations are random
(2) Some correlation exist between properties
(3) The methylene blue requirement and the Base Exchange capacity vary accordingly.
(4) As the greenstrength increases, the drystrength decreases and vice versa.
(5) No other correlations between properties although for the moisture and the viscosity, it seems that when the bentonite is a little bit dry the viscosity is high and vice versa but this was not absolute.

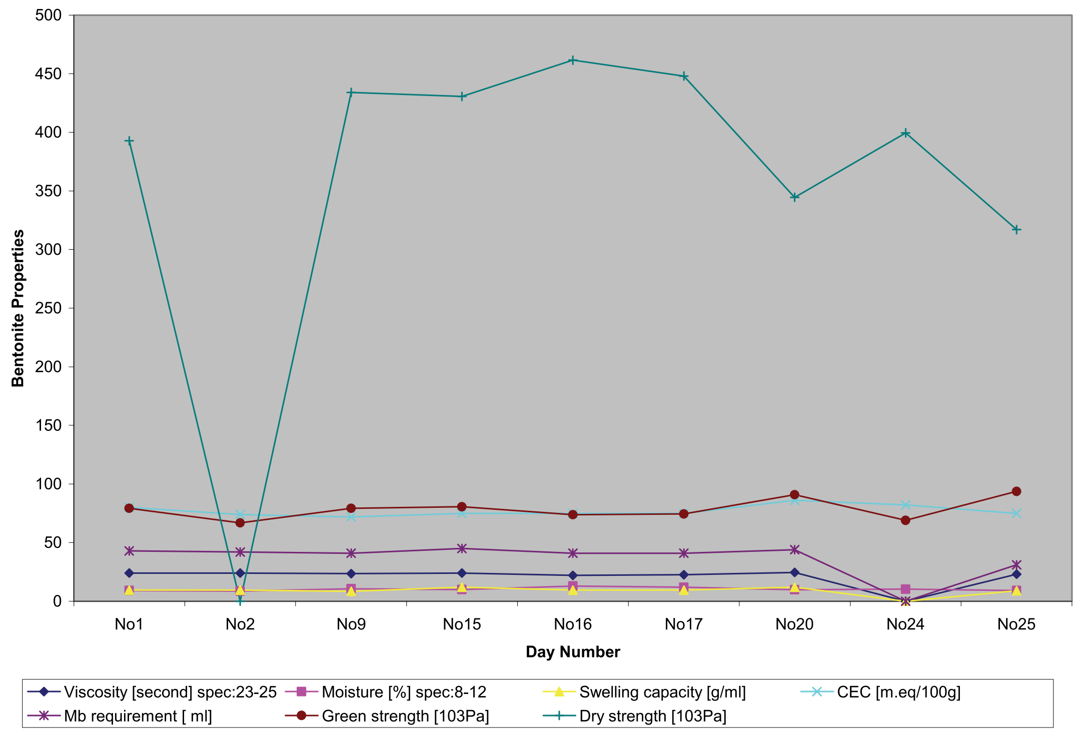

Figure 2. Typical variations in properties of bentonite foundry intakes over a period of time. Graph showing the random scattering of different property values

Table 7. Variations of properties in bentonite foundry intakes over a period of time. A composite sample was obtained for each delivery and tested the properties (BCIRA or SABS test procedures).

Days	**Properties**						
	Viscosity [second] spec:23-25	**Moisture [%] spec:8-12**	**Swelling capacity [g/ml]**	**CEC [m.eq/100g]**	**Mb requirement [ml]**	**Green strength [10^3Pa]**	**Dry strength [10^3Pa]**
1	24	9.2	9.5	80	43	79.2	392.7
2	24	8.6	9.5	74	42	66.8	-
9	23.5	10.6	8.5	72	41	79.2	434.1
15	24	10	12	75	45	80.6	430.6
16	22	13	9.5	75	41	73.7	461.6
17	22.5	12	9.5	75	41	74.4	447.9
20	24.5	9.8	12	86	44	90.9	344.5
24	-	10.2	-	82	-	68.9	399.6
25	23	9.2	9	75	31	93.7	316.9

From table 7 it can also be observed that some properties were out of specification. This was the case of the viscosity (days 16, 17) and the moisture (day 16). These results cannot be attributed to testing errors. It is interesting to notice that every time a strange result in a bentonite property appeared, it is not isolated but it is escorted by 2 or 3 strange results in other properties. Referring to table 7, this was the case on days 16, 17, 20 and 25. These observations indicate that on those days there was undoubtedly something which did change in the bentonite characteristics.

4. Conclusion

From the three types of experiment (experiment on precision and reproducibility, experiment on sampling, experiment on variations) carried out on bentonite, we can conclude that:

(1) The bentonite tests except the viscosity test have non negligeable degree of imprecisions leading to variation of results.
(2) Two factors: drying time and drying temperature were found to influence profoundly the bentonite moisture results. The concentration of the methyl bleu Mb concentration and the preparation of bentonite sample were also found to affect the CEC and the MBR determination.
(3) Although the moisture and the viscosity were found to be consistent in different bags of a batch, that was not true for the other properties. Therefore one bag of a batch can not represent the whole batch.
(4) Bentonite exhibit quite important variation of properties in different batches of a delivery and therefore in different deliveries over time. The variations in bentonite properties of foundry intakes over time are random, with little correlation between them.

5. Recommendations

Users of local bentonites need to be aware of the variations in bentonite properties. These variations can cause variations of greensand properties leading to scrap casting. Proper testing of bentonites in the foundries will ensure that properties are accurately determined and correct additions of the clay are made during the greensand preparation and recycling.

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