

Potential Commercial Processes for the Utilization of Bauxite Residues

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Abstract

The single most serious waste challenge in the production of aluminum is the generation of bauxite residues (red mud) in the alumina refinery process. Unique solutions for small amounts of material arise and research is being done on many higher technology solutions. This paper will cover a potential relatively simple technology solution for the conversion of large amounts of the waste product for the manufacture of brick building products on an industrial scale. Utilization of the J.C. Steele, stiff extrusion process and the combination of standard brick manufacturing technology can produce single manufacturing plant sites to convert up to 500,000 tons per year of bauxite residues. This paper will describe this potential and review the steps to evaluate if a particular alumina refinery's residues are a candidate for this process.

Keywords: Bauxite Residue, red mud, brick, stiff extrusion, J.C. Steele.

1. Background

There has been a tremendous amount of work done in the area of recycling and reuse of this difficult material. This author has spent his career in the area of aluminum dross and more recently SPL recycling. Bauxite residues are a new area of focus, I however have found, when looking at the development of a recycling process, examining and applying simple industrial solutions to waste issues that may have been over looked before can be surprisingly beneficial. Non-related industries can provide surprising solutions. I want to stress that I am new to this material and it's recycling solutions. I have read many good papers on the current status of this technology and hope this paper generates discussions on why the "stiff" extrusion technology may or may not be a good solution for some portion of this waste material.

In almost every paper that I have researched on bauxite residues, construction materials is always one of the simple solutions mentioned. Yet, the actual estimated use in this industry is very small compared to the total generation of this waste. 100,000 – 300,000 tons was an estimate given in 2015 [1]. This use amounts to less than .25% of the annual amount of red mud generated. My assumption is that there are two primary reasons for this. First these materials can be very different from site to site. Where a solution may be good at one site it is not at another. Second, solutions seem to be somewhat site sensitive depending on commercial aspects of potential products. The current cost of disposal of this material is estimated to be \$4-12/ton [2]. This is very low and part of the difficulty in getting a viable commercial solution for this waste generation challenge. The economics of producing a high volume, real product of commercial value and positive social impact to developing countries however is worth the effort and evaluation.

2. JC Steele – Stiff Extrusion Process

The J. C. Steele and Sons company was founded in 1889 in Statesville, NC USA and has served the brick industry from the time of it's formation. Steele had the benefit of many local customers to work with in developing machinery, parts, and ideas for the brick making process. Over time, this reach expanded to current day with 11 locations and close to 400 employees

worldwide. The company is internationally recognized for its expertise in the stiff extrusion process, or extruding a product durable enough to be handled immediately following extrusion. Steele's stiff extrusion technology allows brick makers the ability to extrude a "stiffer" column. This column stiffness allows manufacturers to extrude a product durable enough to be handled immediately following extrusion. In most cases, brick manufacturers using Steele extruders set products directly on kiln cars for both drying and firing. This is the most efficient, commercial manufacturing process for brick making. Steele extruders deliver the reliability for high volume production with a simple process.

Steele specializes in scalable process solutions, with single-line systems producing 10-100 TPH. The equipment provides a combined turnkey product, plant and application engineering to ensure a reliable stream of high-quality feedstock.

Since 1998 it has expanded to processing various waste products for reuse applications. Such as pelletizing nickel, iron and steel waste for direct reduction back to nickel, pig iron or steel.

3. The Material Evaluation Process

Appraising if a particular red mud source is suitable for producing bricks or iron pellets is the next step in the broader evaluation of the feasibility of this process for the industry. We are actively soliciting representative samples of material from sites that would find the economics and social benefits of this idea a real potential. Below is a description of such a test with the positive results. Smaller representative samples are typically first qualitatively analyzed before more extensive testing to judge the materials extrudability.

The international customer came to J.C.Steele for testing in 2012 to evaluate the potential of making bricks from their bauxite residue. Two samples of raw materials were supplied for evaluation; one clay and the other "red mud". The purpose of the test was to evaluate the potential of using the red mud as a component in the extrusion of fired ceramic brick and block.

The clay, local to customer's site was supplied as-mined and had not been ground. Therefore, it was first ground and screened to 10 mesh (2.0mm). The red mud was delivered wet and actually had the consistency of thick mud.

To evaluate the use of this red mud in an extrusion body, various mixes were prepared and extruded on a 76-mm diameter auger lab extruder. The mixes ranged from 25% to 90% red mud. All were extruded using a 28.6mm square die. To evaluate the suitability of the material for thin-walled extrusions, successful mixes were also extruded through the same square die with a large center core to produce thin extruded cross-sections.

Following the test, all samples and remaining materials were sent to Clemson University for further evaluation. The results were that this material was a good candidate for stiff or semi-stiff extrusion. Extrusion and drying were acceptable at red mud content up to 75%. Extrusions with more than 75% red mud were not successful. Final determination of brick quality after kiln drying had not been done in this testing program.

4. Experimental – Description of Test Setup

A Hobart laboratory mixer was used to simulate the mixing with water and pugging of the ground feed material in the open tub of the pug sealer. The laboratory extruder simulates the processing of the material through the sealing auger and die, into the vacuum chamber, and then final extrusion. The laboratory extruder consists of two chambers with a sealing die between. The rear chamber is fitted with a 3-inch diameter sealing auger that pushes material through the

sealing die. The second chamber can be subjected to vacuum. It is also fitted with a 3-inch diameter auger that extrudes material through a tapered die. A PC-based data system monitors and records extrusion data.

Wet screens were used to determine particle size distributions. A calibrated compression tester was used for sample strength measurements and moisture content was measured using a moisture balance. A soil penetrometer was used to measure column stiffness.

Test Procedure

Simulation of single pugging and extrusion - Ground material was combined with water and mixed in a Hobart laboratory mixer, then processed through the laboratory extruder under vacuum. The intent is to simulate the typical extrusion scenario of processing material through a pug sealer and then extruder. Particle size analyses were performed using wet screens from 4 mesh (4.75mm) to 325 mesh (45 micron). All test samples were extruded using a 1.125" (28.6mm) square die, Figure 1.

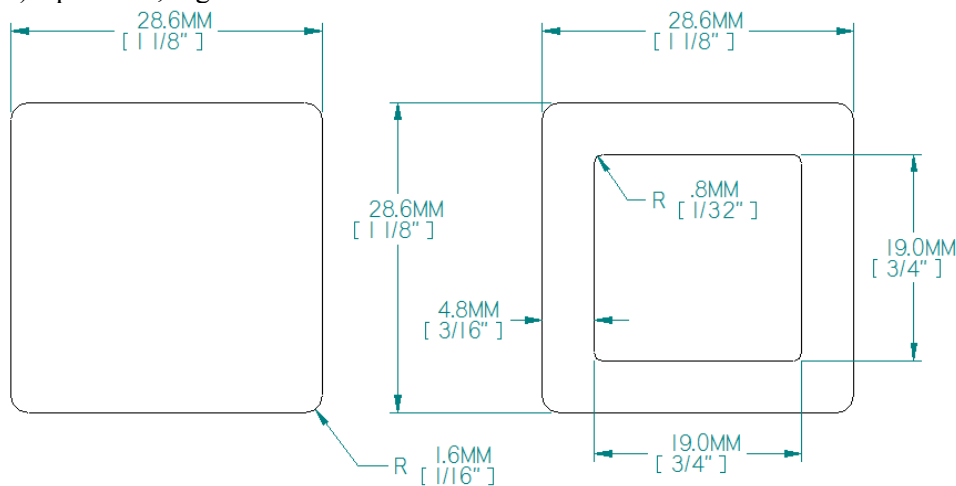


Figure 1. Square die used for extrusion.

The following data and observations were recorded:

- Extrusion amperage
- Extrusion throughput
- Penetrometer reading (kg/cm²)
- General extrusion characteristics
- Moisture content at extrusion

A square die was used for the basic extrusion test and a center core was added to simulate thin-walled extrusions.

To evaluate green strength of the extruded bars, a Modulus of Rupture test was performed. Per ASTM C67, Structural Testing Methods for Sampling and Testing Brick and Structural Clay Tile Paragraph 5, Modulus of Rupture (Flexure Test), Figure 2.

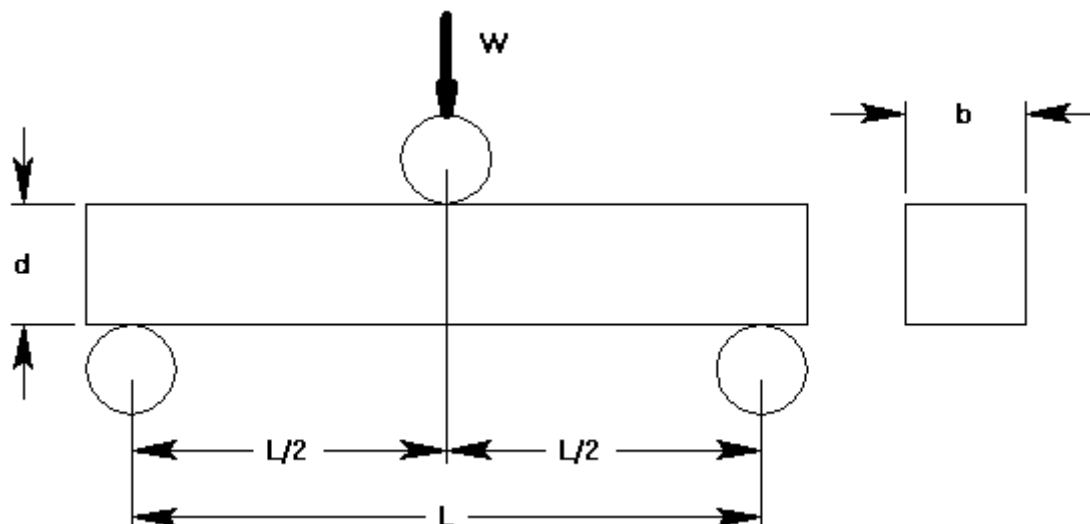


Figure 2. Configuration for the determination of the modulus of rupture.

MOR = Modulus of Rupture (lb/in²) = $3WL/2bd^2$ where:

W = Maximum Load (lbf)

L = Distance between supports (inch)

b = bar width (inch)

d = bar depth (inch)

Extruded samples were dried and observed for cracking or other drying-related problems. Fast drying means that the green bars were placed into the dryer, at temperature, shortly after extrusion. The Extrusion Plasticity Factor (EPF) was also calculated, which is an indicator of ease of extrusion and is simply the penetrometer reading divided by the extrusion motor amperage.

5. Results and Discussion

Results for the wet screen particle size distribution are presented in Table 1. CPFT stands for Cumulative Percent Finer Than. That is, the fraction of the material's particles that pass thru the screen and therefore smaller than the screen mesh size.

Table 1. Wet screen particle size distribution.

Mesh #	Dia (mm)	Red Mud CPFT
4	4.75	100%
8	2.36	100%
16	1.16	100%
30	0.6	99%
50	0.3	97%
100	0.15	90%
200	0.075	83%
325	0.045	81%

Wet basis moisture is measured as a percentage, by weight, of the total raw material/water mix. The moisture content of the red mud as received was 27.1% wet basis.

Table 2. Extrusion test data.

Extrusion Test Data					
Test Specimen 2012-	1023-01	1023-02	1212-01	1212-02	1023-03
Clay Content	75%	50%	40%	30%	25%
Red Mud Content	25%	50%	60%	70%	75%
Extrusion Data					
Moisture Content (% wet basis)	14.7%	14.2%	17.1%	18.0%	18.1%
Penetrometer (Kg/cm ²)	3.6	4.0	3.1	2.8	2.9
Vacuum Level (Inches Hg absolute)	1.2	1.1	1.1	0.9	1.1
Extrusion Amps	2.70	2.80	2.60	2.80	2.60
EPF	1.33	1.43	1.19	1.00	1.12
Extrusion Efficiency	19.7%	13.3%	15.6%	14.7%	12.4%
Green Strength MOR (psi)	50.0	45.0	35.0	25.0	20.0
Drying Data					
Drying Temperature (°F)	200	200	200	200	200
Drying Temperature (°C)	93	93	93	93	93
Drying Time (hours)	24	24	24	24	24
Drying shrinkage (%)	2.5%	3.0%	3.2%	3.4%	3.5%
Fast Drying Experience	good	good	good	good	good
Fired Sample Data					
Firing Temperature (°F)	1,832	1,832	1,832	1,832	1,832
Firing Temperature (°C)	1,000	1,000	1,000	1,000	1,000
Total Linear Shrinkage (%)	3.0%	4.0%	4.4%	4.5%	5.0%
Ignition Loss (% weight)	9.0%	10.5%	10.8%	11.1%	11.2%
Lamination Tendency Observed	none	none	none	none	none
Water Absorption, 24-hour cold (%)	20.2%	22.4%	22.4%	22.6%	22.7%
Compressive Strength (psi)	2,412	2,232	2,190	2,110	2,055
Compressive Strength (MPa)	16.6	15.4	15.1	14.5	14.2

Red Mud sample is presented in Figure 3 and clay sample (before grinding) is presented in Figure 4.

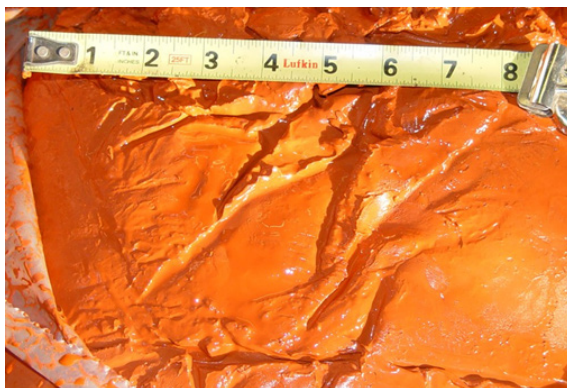


Figure 3. Red Mud sample.



Figure 4. Clay sample before grinding.

Extruded bars are visible in Figure 5 and fired bars, cut cross-sections are seen in Figure 6.



Figure 5. Extruded bars.



Figure 6. Fired bars, cross-sections.

6. Conclusions and Recommendations

This material as supplied from this source was a good candidate for stiff extrusion on J.C. Steele equipment assuming that this sample is representative of the actual raw material stockpile.

- The red mud is very fine-grained and moderately plastic.
- Extrusion was successful for mixes with up to 75% red mud. However, the higher the red mud content the lower the green and fired strengths and the higher the water absorption and dried/fired shrinkage.
- Mixes with more than 75% red mud were not successful due to poor extruded column formation.
- Fast drying was successful – no cracking observed.
- Green strength MOR is adequate.
- Fired appearance was good, but it appears that the firing temperature was too low as indicated by poor strength, high water absorption, and low fired shrinkage.
- Fired and cut bars showed that there was no extrusion lamination tendency.
- If the moisture of this red mud sample (27% wet basis) is typical, some initial drying will be required for mixes with high percentages of the red mud.

Due to good plasticity, extrudability, and fine grain size, thin-walled product can be stiff extruded with this raw material. Further evaluation will be required to determine the mix ratio, extrusion moisture, column stiffness, and firing temperature that provide the best results.

This testing procedure as performed at the J.C. Steele laboratory in North Carolina is the first step in determining if the potential exist to produce a brick product from the bauxite residue generated at a site.

These test results are very comparable to another similar test on the brick properties of brick manufactured from red mud, done by the University of Ghana in 2013 [3]. The study noted good brick formation results and very good properties at a kiln firing temperature of 1100°C.

7. Step Two – Manufacturing Facility Evaluation

J.C. Steele & Sons is a provider of grinding, mixing, and extrusion equipment, the drying and firing data is for initial evaluation information only. Their partner firm Direxa Engineering is a brick manufacturing facilities design and supply firm and would use this data as a basic of design information for accessing the potential of the entire brick making facility. It would be Direxa's responsibility to evaluate with the customer the other equipment supply, such as the dryer and kiln, cutting and handling equipment, and the die design to determine material properties that will affect the design of their supplied equipment.

8. Summary

The alumina production industry would be well served if an economical method could be developed to convert the bauxite residues in commercial products. The stiff extrusion process as manufactured by J.C. Steele has successfully tested materials and turned them into useful brick shapes. Further testing, product evaluation and economic evaluations need to be completed on a site by site basis to see if this process can help reduce the amount of this waste going to land fill storage. GPS Global Solutions is actively pursuing test sites for evaluation process.

9. References

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