Production of red mud building materials in Jamaica:
Case Study 2: Production of silicate bonded bricks and pozzolanic cement from Jamaican red mud

Introduction

Parallel to Research and Development work carried out on red mud by bauxite companies that operate in Jamaica, as well as public sector organizations such as the Jamaica Building Research Institute (BRI), in the 1980s, the Physics Department of the University of the West Indies undertook its own preliminary investigations on the material at the time, with the similar objective of identifying at least one industrial or commercial use for it.

By 1986, it was able to form an alliance with the Jamaica Bauxite Institute (JBI), a Government of Jamaica statutory organization, and secured funds from the IDRC in Canada to undertake a major R & D project in collaboration with the University of Toronto. The main objective was to develop methodologies for use in the production of building materials from Jamaican red mud. This project became known as the JBI/IDRC red mud project.

It was undertaken between 1987 and 1995, and involved two major phases of product development: the earliest phase involved the fabrication of 100% red mud bricks followed by the inducement of additional strength to each brick by soaking in sodium silicate solution, while the latter phase involved the production of a red mud pozzolanic cement that is capable of producing bricks and hollow blocks. In culmination, a demonstration building was constructed (completed in 1998 due to prolonged shortage of funds) with walls of silicate bonded bricks, on the property of the JBI. This building is being used as a Sports Pavilion by that organization.

Like the other demonstration building that was constructed with cement stabilized red mud bricks by the BRI previously, this building is under constant evaluation at present, as it has been since the commencement of its construction in 1992.

Preliminary investigations

Prior to the implementation of the IDRC project the University of the West Indies through the instrumentation of Dr. Arun Wagh of its Physics Department, undertook its own project to characterize the red muds from the various storage areas that exist. As a result, certain basic properties identified were sequestered as motivators for a wider R & D project that was expected to result in the development of a saleable product of low or negligible environmental impact that would consume high volumes of red mud. Some of the motivating characteristics are as follows:

- Approximately 15% of each mud consist of residual alumina, which was not recovered in the Bayer process that produced the mud. A high proportion of this material is amorphous;
- If red mud slurry as pumped from any of the refineries is allowed to dry naturally, it develops relatively high compressive strength of the order of 2.8 MPa (400psi).

These factors, for different reasons significantly influenced the decision to pursue both the silicate bonded and the pozzolanic cement, red mud building materials projects.

Silicate bonded red mud bricks

Brick fabrication

Laboratory investigations dictated that before fabrication, dry red mud from the Alcan dry stacking area with natural material size ranging from 5cm to 0.6cm (2" to 1/4"), should be ground to yield particles that are as fine as it is practical to make them. However, it was agreed that in terms of the application of possible commercial ventures in the future, it would be advantageous to limit the crushing to -40 mesh.

The crushed red mud was mixed with water only, before pressing with a semi-automatic brick press. Pressing was done after approximately 18% w/w water was mixed into the dry mud. After pressing, about 15% of the material had to be recycled without the need for adjustment of the water level, due to spoilage caused by handling. However, this period of fragility proved generally to be short since by the next day these bricks could be handled easily and even stacked. The bricks produced were 20 cm x 10 cm x
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average volume</td>
<td></td>
</tr>
<tr>
<td>porosity</td>
<td>37%</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>5 MPa (725 psi)</td>
</tr>
<tr>
<td>Efflorescence</td>
<td>Slight or nil</td>
</tr>
<tr>
<td>Silicate absorbed</td>
<td>7% w/w</td>
</tr>
<tr>
<td>Leaching with water</td>
<td>pH &gt; 10</td>
</tr>
</tbody>
</table>

*Table 1: Properties of silicate bonded red mud bricks*

After three weeks of drying, and without water curing, the bricks are ready for use. It is noteworthy that for the first two to three weeks after silicate application they appear slightly illuminated due to the presence of the silicate, but once completely dry, no discernable surface features are apparent (Table 1).

**Conclusion of Phase 1 of the Project**

At the commencement of the project, the sodium silicate solution which is the only imported ingredient used in any of the red mud brick formulations, was credited with having an insignificant cost input as compared to the cost of material (red mud) procurement plus labour for its preparation, fabrication of bricks, and a realistic rate for the rental of the brick press.

Within three years of the project's operation, stark realities directly related to the Jamaican economy significantly modified the calculations, to the extent that silicate bonded red mud bricks were no longer considered viable in light of its new inability to compete directly with contemporary concrete building materials.

The turnaround resulted from the fact that the Jamaican dollar ($) was devalued by more than three hundred percent (300%) in under two years which consequently elevated the cost of sodium silicate several fold, primarily because it is imported. After this realization, further studies on this material were discontinued and a new project designed, namely, the production of a pozzolanic cement based on red mud. This phase of the project was partly sponsored by Acan Jamaica Ltd; the only bauxite company operating two separate refineries in the island.

**Red mud pozzolanic cement**

This project arose primarily from knowledge gained at the time that the bauxite/alumina industry in Japan had developed a pozzolanic cement from red mud generated in that industry. This was further reinforced by a number of papers given by Ko Ikeda, a Japanese research scientist from the University of Yamahauchi in Japan, on the subject.

The essence of the project is the use of gypsum and portlandite (hydrated lime) as activators to effect cementitious behaviour in red mud, and the use of fly ash to stabilize the products. The Jamaican project was pursued because like Japanese red mud, Jamaican muds possess residual alumina of the order of 15%, and in addition, all the other additives, namely gypsum and hydrated lime for the purpose of activators, and fly ash as stabilizer, are available at low cost in Jamaica.

**Bagasse ash**

Bagasse ash is the Jamaican version of contemporary fly ash; this material arises from the burning of bagasse (sugar cane plant from which all juice is already extracted) as fuel in the sugar industry. Bagasse ash is high in silica as expected but departs from expectations only because it contains a considerable amount of organic which does not in any way affect its usefulness in the pozzolanic cement. Like red mud, a considerable quantity of bagasse ash is generated each year as a waste product, in this case by the local sugar industry which, it seems, would be relieved if there were some possibility of using it to commercial use. At present, it is dumped in the sugar cane plantations where it is supposed to serve as a low grade fertilizer, but spokespersons in the sugar industry have cited environmental and other associated problems that would be curtailed if other means were found to dispose of it.

**Gypsum fines**

Gypsum occurs naturally in eastern Jamaica and a notable export market has built up around it over the past forty years. In addition, the sole Portland cement factory in Jamaica uses more than 100,000 tonnes per year, and local producers of plaster of paris use additional quantities. The different export and local markets for gypsum specifies the size of a material required and the Gypsum Company is obliged to comply with the specifications.

In almost all cases the market wants materials coarser than 10mm (3/8") which means that finer materials have to be rejected. This fine gypsum is known as

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>1.49</td>
</tr>
<tr>
<td>Porosity (Vol, %)</td>
<td>~18.00</td>
</tr>
<tr>
<td>Compressive Strength (MPa)</td>
<td>5.17</td>
</tr>
</tbody>
</table>

*Table 2: Some physical properties of red mud pozzolanic cement*
gypsum tailings or gypsum fines, which up until now has no specific use. Gypsum fines with almost no value was used in this project and it is expected that if a commercial venture is established, it will still be accessible free of cost.

_Carbide lime (slaked lime - Ca(OH)₂):_

The material used in the project is a byproduct of the production of Acetylene by manufacturers of Industrial gases. Carbide lime is a form of slaked lime and is produced as a liquid that is disposed of in special storage ponds located close to the plants. Similar to gypsum fines, this material is available free of cost. Apart from this source, however, there are other sources of lime in Jamaica.

**Pozzolanic red mud cement production technology**

The materials formulation for Jamaican red mud cement involves 40%-45% red mud, 35%-40% fly ash, and smaller proportions of carbide lime and gypsum fines.

The project has identified that the binding phase in the cement is formed by pozzolanic reactions between the Alumina phase (Boehmite and Gibbsite), lime, and gypsum, resulting in a binding material called Ettringite. Bagasse ash is also known to participate in separate chemical reactions forming silicate-bonding phases, which add to the overall strength of the cement. To date these secondary silicate reactions are yet to be defined since they occur as non-crystalline phases and could not be detected by available routine analytical techniques such as x-ray diffraction. Significantly, however, the formation of Ettringite which is the major bonding mechanism involved in this technology, also occurs in the production of typical Portland cement, at the point at which gypsum is added principally to retard setting. In this case, however, this particular process is merely a secondary one, which is quite different from that in the formation of red mud cement.

_Mixing of raw materials and fabrication of red mud cement building materials_

All material ingredients are dry mixed after weighting, and water subsequently added. Similar to the BRI project, a batch of 60 kg (dry basis) was convenient for mixing with shovels on a concrete surface. In most cases, however, it is conve-

![Fig. 1: Hollow building block of “Red Mud Pozzolanic Cement”](image)

ment to retrieve carbide lime from the storage pond only in liquid form, in which case the percentage solids is calculated and a specific volume added to the cement mixture. Finally, a fixed amount of water is added and thoroughly mixed before it is either:

- Pressed as bricks or
- Moulded as hollow blocks.

Unlike any other red mud building material produced in Jamaica, the cement is able to produce hollow building blocks in typical block dimensions and with the same equipment used to fabricate the concrete equivalent (Fig. 1). For bricks, about 17% water is added whilst for hollow blocks, 29%-31% water is added which makes the mixture an almost extrudable paste. In the project, some of these blocks were fabricated with a hand-operated mould that is normally used by operators in the informal sector to produce concrete blocks.

Bricks produced with the cement are similar in appearance to other red mud bricks and in addition, they are best cured by the procedure used to cure cement stabilized red mud bricks (Table 2).

![Fig. 2: Front view of the “Red Mud” demonstration building at the Jamaica Bauxite Institute (Sports Pavilion)](image)
Construction of the demonstration building of red mud cement bricks at the JBI

In 1992, when the JBI took the decision to construct the demonstration building for use as its sports pavilion, it was intended to use all the products of the project for its construction (Fig. 2). Unfortunately, only the silicate bonded red mud bricks were eventually used since routine tests conducted on bricks and blocks produced from the cement revealed a number of technical faults which were highlighted by (1) loss of strength with time and (2) mediocre weathering characteristics.

By the time the final report of the project was written in the latter months of 1995, all the external walls of the building were completed, in addition to the roof and other aspects. At present, the building is still unfinished due to shortage of funds but tests on the building envelope are ongoing.

The silicate bonded bricks used in the construction were fabricated as 20cm x 10cm x 6cm (8" x 4" x 2 1/2") units, which means that the thickness was reduced from the usual 10cm for which the mould was designed and also departs from the size of the bricks made in the BRI project. This size, however, represents the standard size for bricks produced in Jamaica and many other countries, principally by the extrusion of clay. This size was achieved by inserting a spacer (timber) of desired thickness into the mould just before it is filled with material for pressing (Fig. 3).

The building, which was only recently completed, is very attractive and the particular hue assumed by the silicate bonded bricks is a large contributor (Fig. 4). Close inspection of the walls that have been in place for the past five years, reveal a number of minor faults due to weathering. These include the formation of white coloured carbonate material at some of the brick/mortar interfaces. Generally, however, the faults are considered minor and should be surmounted by simply fine-tuning the material formulation and the production process.

As far as the red mud cement is concerned, a relatively short-term project to address the problems identified has been designed, and now awaits funding for its execution. Despite the problems, however, the cement is thought to be of immense potential, particularly since:

- It is versatile, being adaptable to the production of either bricks or blocks;
- It is composed of four different industrial by-products namely, red mud from bauxite processing; gypsum fines (tailings) from the gypsum mines; carbone lime, a by-product from the production of industrial gases; and bagasse-ash, a by-product from the sugar processing industry;
- It hardens readily and acts like other known pozzolan cement for a long time, before it loses strength. This particular problem was also identified with Japanese red mud cement and the Japanese researchers are also optimistic that it can be corrected without significantly affecting the cost of producing the cement.

Study of the compatibility of reinforcing steel bars with red mud cement

The possibility of using red mud pozzolan cement to fabricate standard size hollow building blocks to compete with concrete blocks necessitated that this investigation was done. This is primarily
because considerable amounts of reinforcing steel is used in normal building construction as required by the authorities since the country lies in a relatively active seismic belt.

It was done on the basis that corrosion of reinforcement steel is normally influenced by:

- Initial pH of the material while it sets;
- The porosity of the cement once it sets;
- External attacks of chlorides and sulphur ions through the pores;
- Intrusions of water of low pH.

The necessary experiments, which involved the measurement of several parameters, were designed and carried out. Subsequently, the results were compared with known results for Portland cement.

It was eventually concluded that when a steel bar is embedded in red mud cement, its surface corrodes at a very slow rate due to the high pH of the fresh cement. Early reaction results in the formation of a corrosion layer of Iron Oxide (Fe₂O₃). This layer becomes permanent and very little corrosion continues after the cement sets (three to four weeks) at which time the pH is significantly reduced to a near neutral position. The basic inference is that generally the corrosion of reinforcing steel in red mud is considered similar to that in Portland cement, which means that it is fairly benign.

**Radiological properties of Jamaican red mud building materials**

The study of radioactivity in red mud buildings in Jamaica, has been carried out largely by Dr. Willard Pinnock, a lecturer at the University of the West Indies (UWI). Like this writer, Dr. Pinnock has been involved with all of the red mud projects pursued by academic and public sector agencies in Jamaica over the past fifteen years.

The study, which started as an independent exercise was incorporated into the JBI/IDRC project at what was considered an appropriate time. It undertook to estimate the levels of radiation (as doses) that an occupier of a room made of red mud building materials would be exposed to over specific periods of time.

It was designed with the understanding that bauxite is known to have small amounts of the following radionuclides:

\[
^{238}\text{U}, \, ^{232}\text{Th}, \, ^{40}\text{K}.
\]

Significantly also, it has been well known that red mud contains about twice the amount of these sources of ionic radiation as it was before in the form of bauxite.

The red mud demonstration building associated with the earlier BRI project became the subject of most of the experiments carried out, and since the bricks used to construct this building consisted of only 50% red mud, plus sand and cement, the results obtained were extrapolated to reflect the expectations for a building with walls of nearly 100% red mud, such as the JBI building.

After it was agreed that the level of \(^{40}\text{K}\) radiation associated with red mud was proven in many previous studies to be similar to that of river sand and gravel and therefore generally acceptable, the study became concerned primarily with:

- Direct gamma radiation through the body and
- Inhalation of the decay products of the inert gas, radon, which would be present in the air within such a house.

Doses due to gamma radiation were measured by thermo-luminescent detectors while radon levels were measured using strips of CR39 plastics as track etch detectors that register counts produced by radon and its daughters. In order to use a reliable model to predict the radon related dose levels, it was necessary to measure other parameters on which radon dose levels depend. These include:

- \(^{238}\text{U}\) and \(^{232}\text{Th}\) activity concentrations in the walls;
- Air turnover rates and
- Radon levels outdoor.

All tests were carried out in worst case situations in which a person could con-

**Fig. 4: Close-up of brick masonry of JBI Sports Pavilion.**
Table 3: Dose equivalents for houses made of different materials (msv/y)

<table>
<thead>
<tr>
<th>Type of House</th>
<th>Gamma Component</th>
<th>Radon Component</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRI Red Mud Building</td>
<td>0.80</td>
<td>0.64</td>
<td>1.44</td>
</tr>
<tr>
<td>Hypothetical Building</td>
<td>1.25</td>
<td>0.82</td>
<td>2.07</td>
</tr>
<tr>
<td>with walls of:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% Red Mud</td>
<td>0.51</td>
<td>0.35</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 3 indicates the estimated dose equivalents, based on the experiments carried out, of houses made of two different types of red mud based materials, and the other from concrete.

From Table 3, the total value of 0.86 msv/y (millisievert per year) estimated for a house of concrete is taken as background dose level since concrete is the most acceptable building material internationally, and in addition, it is the most used building material in Jamaica. From the other results, the BRI house made of bricks of 50% red mud, has an estimated dose level of 1.44 msv/y which is 0.58 msv/y above background, and the JBI house has an estimated dose level of 1.21 above background, in worst case scenarios.

On the basis of these results, it is believed that building construction with either material would be acceptable in Jamaica. However, a direct recommendation would not be made immediately to the Jamaican authorities, not the least of which is the Bureau of Standards, since there is every justification for additional investigation to be done in the two available red mud buildings, and also for the other situations/conditions to be simulated and evaluated.

Conclusions

Silicate bonded red mud bricks

The development of a process to produce silicate bonded red mud bricks was successful. It was demonstrated that carefully selected sodium silicate solution significantly increased the compressive strengths and afforded good overall appearance and stability to bricks made of 100% Jamaican red mud. The cost of the silicate solution became a problem in Jamaica because it is not produced in the country and its importation in an economic environment in which a high percentage of imports are restricted by punitive tariffs, makes it uncompetitive with conventionally used concrete products. It is, however, possible that if the desired silicate is produced in Jamaica, given the abundance of one of the two main ingredients, silica sand, that the cost of silicate per brick can be significantly reduced, which would make it competitive.

Outside of Jamaica, this technology could provide a good opportunity for countries that are able to either produce or import the silicate cheaply, to effectively use their stockpiles of red mud.

Red mud pozzolanic cement

This pozzolanic cement is more versatile than other red mud building material formulations, being able to produce both bricks and hollow blocks. It is notable that most new construction projects involve the use of hollow blocks primarily because it enables easy inclusion of reinforcing steel.

The problem of reduced strength with time is believed to be only superficial and consequently a short-term project has been designed to correct it. This new dimension will only be implemented when the requisite funds are identified.

Rational Research and Development work in red mud building materials internationally, may very well concentrate on fine-tuning this technology. The type of cement produced may vary from country to country since it will be dependent on the nature and quantity of residual alumina contained in the respective muds.

References

- McLeod, Dave W.: Production of Pozzolanic Cement from Jamaican Red Mud; Final Report to Alcan Jamaica Ltd (1995), Jamaica Bauxite Institute

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