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Wall Building

Case Study

building advisory service and information network

# Production of red mud building materials in Jamaica:

## Case Study 1: Production of cement stabilized red mud bricks

### Introduction

Before the end of the decade of the 1980's red mud became a major concern in world environmental discussions, and international attention focused on Jamaica alongside Australia and Guinea which by then were the world's three largest producers of bauxite and alumina.

A number of studies designed to mitigate the negative effects of red mud have been undertaken by the bauxite companies that operate in Jamaica over the years; but because these were always private, very little of the results have been published or shared in any significant way with the international scientific community, or even with the relevant departments of the Government of Jamaica.

In 1986, the Building Research Institute (BRI) in Jamaica designed a Research and Development project to seek to identify at least one commercial use for red mud that would conceivably reduce the accumulation of this waste material in designated storage areas. This particular project involved the use of the processes involved in the stabilized soil technology, to produce red mud building bricks. Subsequent to that, the Jamaica Bauxite Institute (JBI) successfully secured funds from the IDRC (International Development Research Council) in Canada to undertake another project also directed at the development of building components from red mud.

The latter project was pursued between 1987 and 1995, and in addition to the JBI, involved the University of Toronto and The University of the West Indies. By the time the project was concluded in 1995, several modifications were applied to its original format and scope, and the new final phase was actually sponsored by Alcan Jamaica LTD, one of the largest processors of bauxite in Jamaica.

This is the first of two case studies that are intended to showcase Jamaica's efforts to develop useful avenues for red mud, which is by far the most voluminous waste that arises from commercial and industrial activities in the country. This particular study focuses on the BRI cement stabilized red mud project whilst the other will highlight the JBI/IDRC project.

### The bauxite and alumina industry in Jamaica

Bauxite is the ore from which the mineral Alumina is extracted by a particular industrial process, and subsequently converted to the notably lightweight metal, Aluminium, in another industrial process.

For more than thirty years bauxite and alumina together have been Jamaica's largest commodity export products, amounting to more than 60% of such exports in 1997.

It is typical throughout the Jamaican bauxite/alumina industry which uses the Bayer refining process exclusively, that for every tonne of alumina produced from bauxite, an almost equivalent quantity (1 tonne) of waste product (bauxite tailing) called red mud is produced. This material is pumped from each plant as a bright red coloured slurry and has been disposed of traditionally by dumping in natural depressions, and more recently by dry stacking on gentle slopes.

Over the past forty years, millions of tons of red mud have accumulated in red mud lakes and dry stacking areas associated with four processing plants operated by three private companies throughout central Jamaica. These were virtually ignored by environmentalists in the earliest years but in more recent times, evidence has been supplied to vindicate long held suspicions that hazardous chemicals which includes caustic soda, that are contained in red mud, have been seeping into water aquifers and are possibly contaminating ground water supplies.

| Oxide | Gibbsitic Mud (wt %) | Boehmitic Mud (wt %) |
|---|---|---|
| $Al_2O_3$ | 16.52 | 16.35 |
| $SiO_2$ | 3.05 | 7.99 |
| CaO | 5.68 | 9.06 |
| $P_2O_5$ | 1.32 | 0.91 |
| $Fe_2O_3$ | 49.53 | 42.33 |
| $TiO_2$ | 6.80 | 5.99 |
| $Na_2O$ | 1.40 | 4.60 |
| L.O.I | 13.40 | 10.20 |

*Table 1: Chemical composition of Jamaican red muds*

With the intervention of some of the more active international environmental activist organizations, this problem has become a universal one but particularly so in countries such as Jamaica, with relatively large bauxite/alumina industries. The resulting controversy has spawned global efforts to find meaningful uses for red mud. These efforts have included the production of a variety of building materials; and in Jamaica, projects have been pursued with the main objective of producing building bricks and blocks from red mud in combination with other materials.

### Jamaican red mud

Of the four plants that produce red mud as a by-product, three of them process gibbsite-rich bauxite and consequently the resulting red muds are gibbsite-rich, whereas the other for obvious reasons, produces boehmite-rich red mud. The chemical composition of gibbsite-rich and boehmite-rich muds are listed in Table1.

### Basic Philosophy of Project

The Jamaica Building Research Institute, as part of its pre-project activities and with limited resources, conducted a number of logistical and site studies at different storage areas (ponds and dry stacking areas) and as a result, only the mud from Alcan's (Ewarton) dry stacking area was used in the actual project.

In the selection of possible Research and Development projects that could be pursued towards the development of one or more types of building materials from Jamaican red mud alone, or in combination with additives that would be relatively inexpensive, a number of preliminary studies were done which involved investigations of:

- Qualitative physical and chemical properties of the muds from all four factories to identify fundamental similarities and differences;
- The utility of red mud as it relates to its potential to replace aggregates or extenders in industrial or commercial processes that do not require chemical combination of these types of materials;
- Natural bonding properties of red mud;
- Drying dynamics of red mud.

Although some definitive results were obtained from these exercises it was difficult to adduce conclusive trends primarily because a lack of essential equipment and other resources curtailed their effectiveness. After a process that involved the elimination of many technologies for a variety of reasons, it was decided that the most practical way of using red mud as a building material at the time was to use it as one would use a proven soil to produce building bricks with the stabilized soil technology.

*Fig. 1: Bricks produced with a CINVA ram and stacked on the ground for drying*

It is significant that Jamaican clays in general, and in particular, red coloured terra-cotta type clays almost always have relatively fine particle sizes and high plasticities which are the chief physical characteristics normally used to explain why they are notably poor soils for the application of stabilized soil technology. Red muds, on the other hand, have very fine particle sizes, which are similar to clays, but unlike clays, they have very low plasticities.

The unique combination of a fine particle size and low plasticity was seen as a good reason to apply the technology to red mud. In addition, the mineralogy of the mud which is typified by high iron and the presence of residual aluminium oxides, made it easy to choose Portland cement or lime as the stabilizer given that either of these stabilizers tend to form agglomerations of hydrated cement or lime phases with available fine particles of the participating materials. In this particular case, cement was the obvious choice since it is less costly than lime in Jamaica.

### Materials and equipment

*Red mud*

Red mud for the purpose of R & D work is usually collected from the driest part of the mud lake or dry stack because nobody wants to transport unwanted water for several miles to an R & D facility. The mud accumulated at the Alcan (Ewarton) dry stack contains about 4% moisture at any given time. About the same level of moisture would be associated with mud from the driest section of any of the traditional mud lakes; but generally, the dry stack is more accessible and hence all mud for this project derived from the Alcan (red mud) dry stack. A front-end loader or a backhoe can easily remove mud from the dry stack and load a lorry. Similarly, where small quantities are needed for experimental work, it is normally removed from the dry stack with a shovel and used to fill plastic bags.

Untreated mud from the dry stack has particle size distribution ranging from 5cm (2") down to sub-micron size, with a high concentration of particles larger than 0.6cm (1/4") in size. This is due to agglomeration of the naturally fine particles during the process of solar drying in the dry stack.

In order to use the mud from the dry stack to manufacture bricks or other building materials using this technology, it has to be ground mechanically to give a desirable blend of coarse and fine particles. The BRI project involved the use of a simple hammer mill fitted with a 0.6cm screen, to reduce the natural dry mud (in lumps) to a particle size spread ranging in size from 0.6 cm (1/4") to dust. In handling dry red mud it is necessary for handlers to wear polypropylene gloves, and for crushing, it is essential for handlers to wear respirators. Furthermore, it is preferable to undertake all activities inclusive of drying, crushing, mixing and fabrication of bricks in open air, possibly within the confines of an open shed.

*Portland cement*

A single factory in Jamaica, which accounts for all the markets for this commodity since there is no notable importation, produces Portland cement. Because of this monopoly situation no effort was made to establish standards for the stabilizing cement. However, it is noteworthy that Jamaican cement is marketed as a very fine-grained material.

*River sand*

Although there are a few areas in the country in which wind blown sand is mined from natural dunes for construction purposes, river sand is almost ubiquitous in the building and construction industry. This sand which is used for mortar and concrete preparation is mined from the lower reaches of rivers and subsequently screened before use. Typical construction sand has a size range of 0.5-1.00mm.

*Equipment*

The stabilized soil building materials programme was started at the BRI a number of years before the red mud brick project was conceived and as a result of the years of experience with this technology, as much as three different types of fabrication equipment for brick-making were acquired. These are:

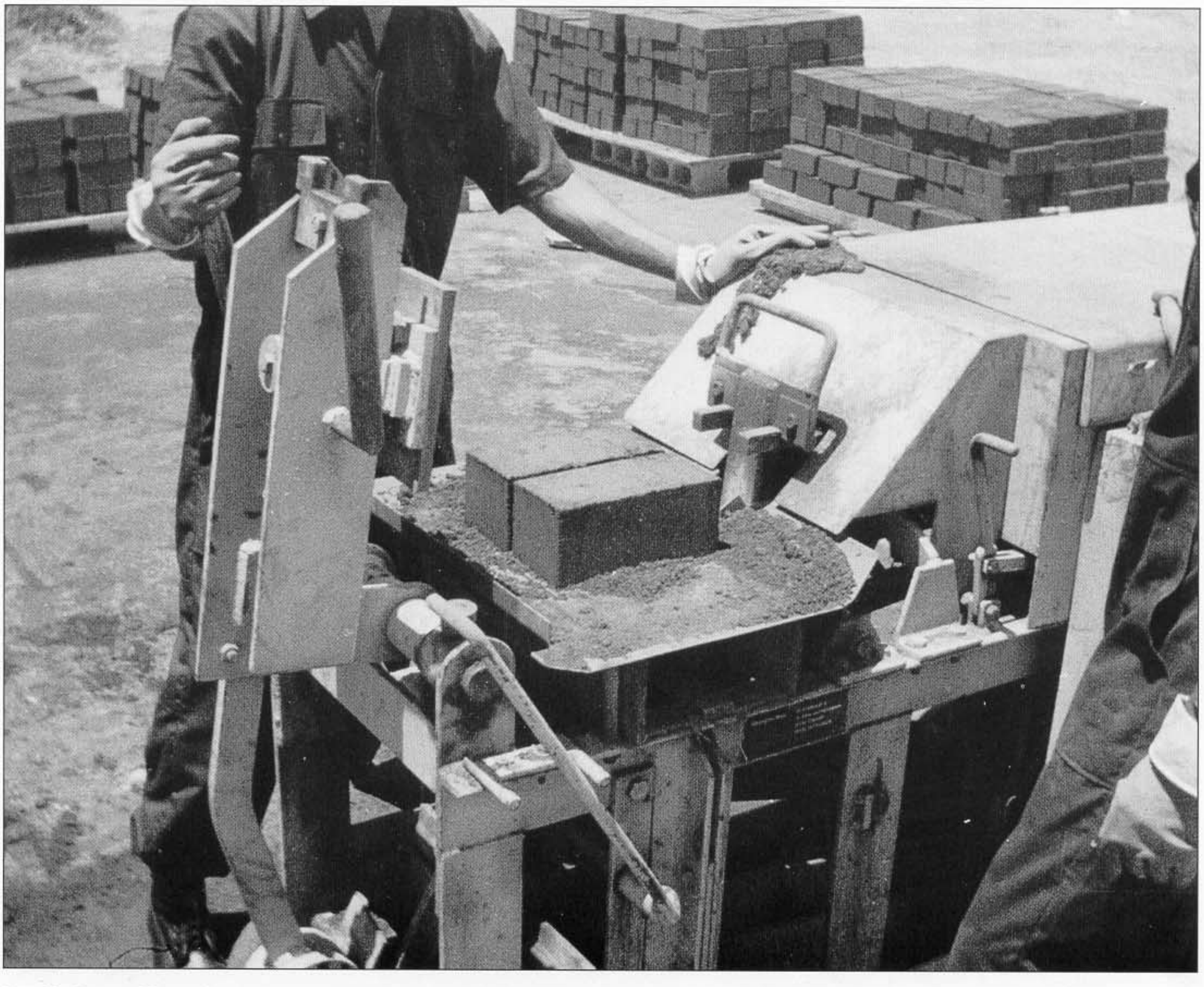

*Fig. 2: Demoulding of bricks*

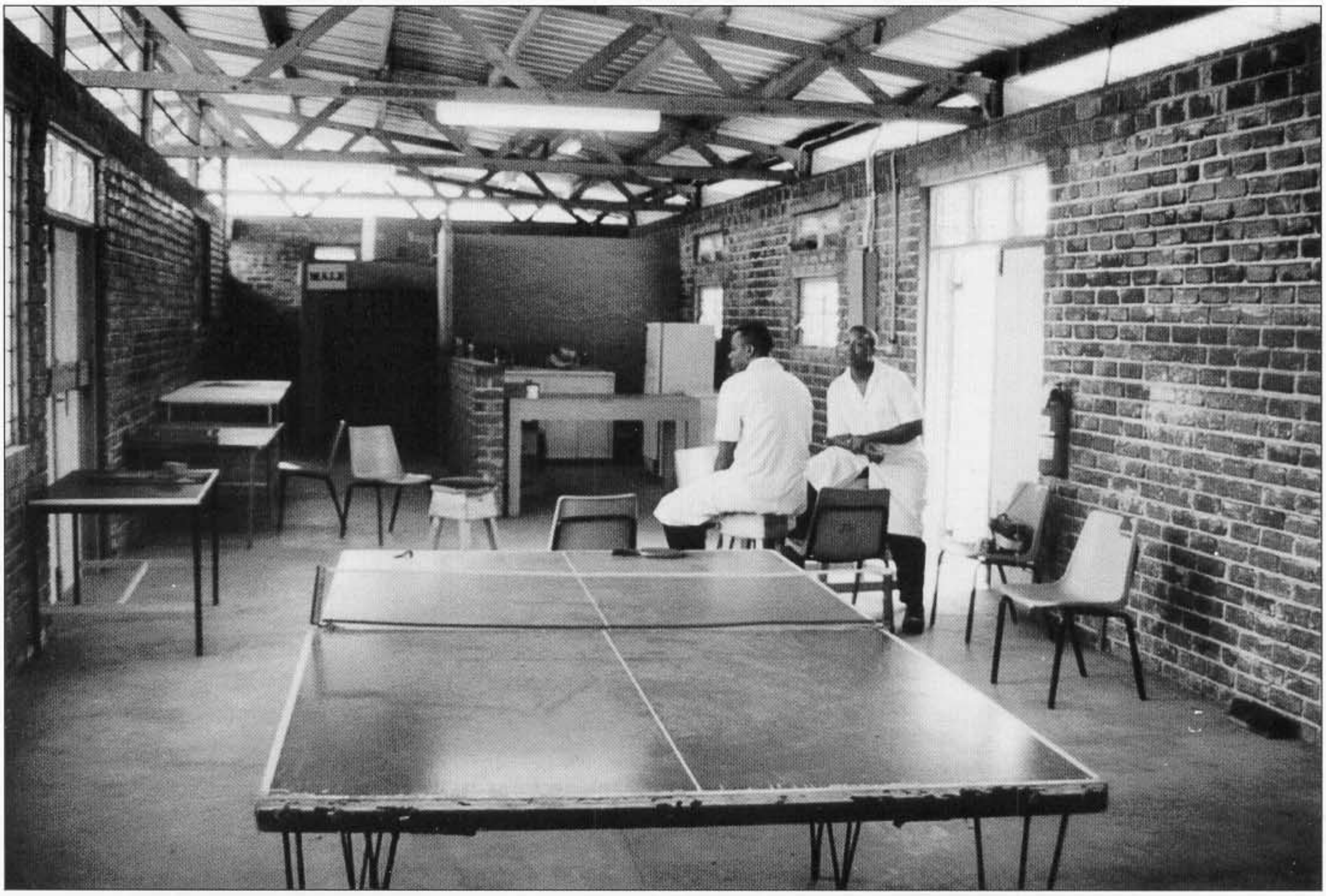

*Fig. 3: Interior of JBI "Red Mud Demonstration Building" (Sports Pavilion)*

### 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 10m 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; carbide 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 pozzolanic cements 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 pozzolanic 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 ($Fe_2O_3$). 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:

$^{238}U$, $^{232}Th$, $^{40}K$.

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 $^{40}K$ 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:

- $^{238}U$ and $^{232}Th$ 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-

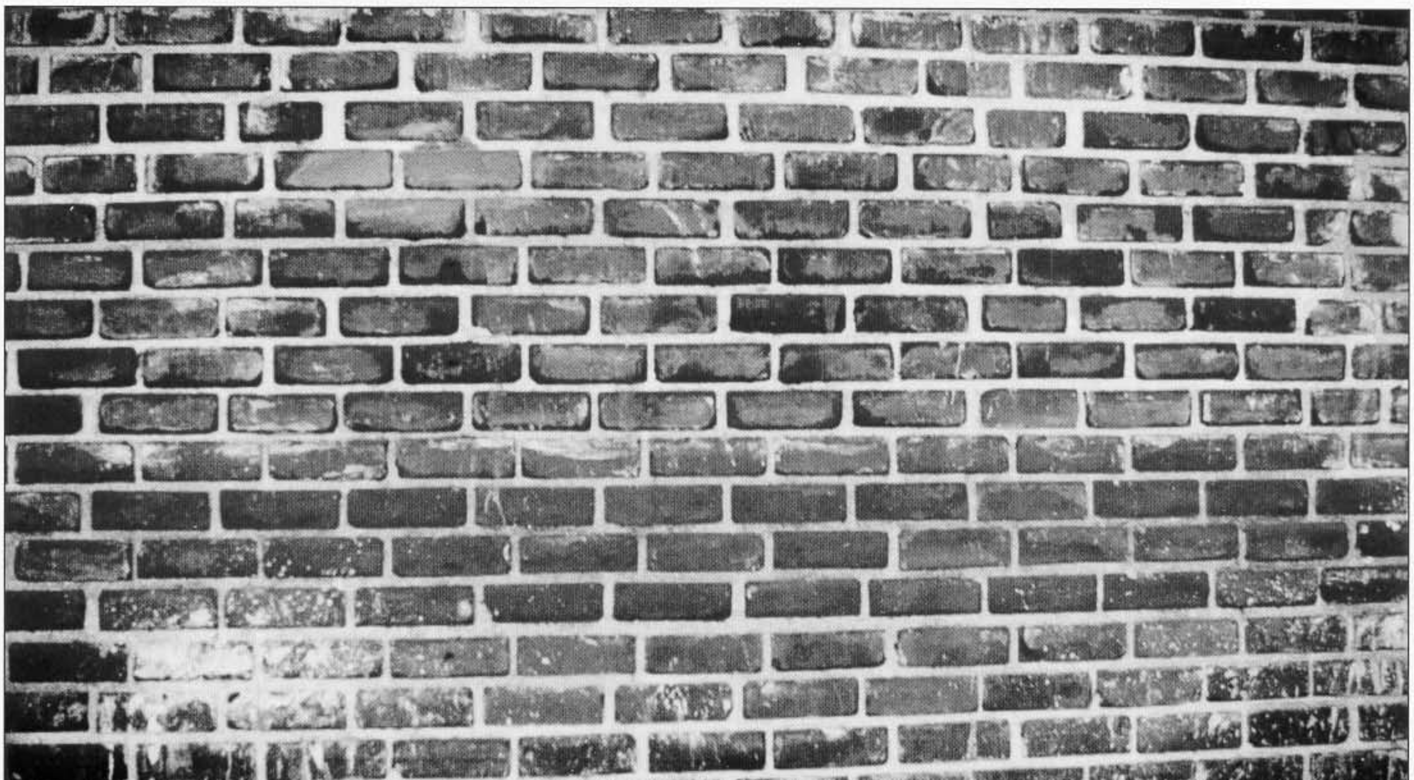

*Fig. 4: Close-up of brick masonry of JBI Sports Pavilion*

| Type of House | Gamma Component | Radon Component | Total |
|---|---|---|---|
| BRI Red Mud Building | 0.80 | 0.64 | 1.44 |
| Hypothetical Building with walls of: 100% Red Mud | 1.25 | 0.82 | 2.07 |
| Typical Concrete Building | 0.51 | 0.35 | 0.86 |

Table 3: Dose equivalents for houses made of different materials (msv/y)

ceivably live in a house. This included, for example, the closure of doors and windows of the red mud building save for the top segment of the metal louvre windows, which were only partly opened, for several weeks.

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 1.44msv/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.

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# 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 1980's, 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:

- Jamaican red muds contain approximately 1.5% Caustic Soda;
- The muds from all plants are very fine averaging 60% less than 1 micron (1 $\mu$) in size;
- The fine particle size avails an inordinately high amount of specific area for possible agglomeration or binding of any kind;
- The muds consist primarily of a crystalline phase but also have an important but much smaller amorphous phase characterized by extremely fine or powdery material which tend to coat the larger particles. It is considered an ideal medium for the propagation of bonding with the use of an external bonding agent such as sodium silicate;
- Nearly 50% of all muds consist of Iron Oxide ($Fe_2O_3$) which ensures that the deep red colouration of the mud is unlikely to change with time;
- 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

| Parameter | Measured Data |
|---|---|
| Average volume porosity | 37% |
| Compressive strength | 5 MPa (725 psi) |
| Efflorescence | Slight or nil |
| Silicate absorbed | 7% w/w |
| Leaching with water | pH > 10 |

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

10 cm units that proved to need about three days of air drying/curing before the silicate solution could be applied.

*Application of sodium silicate solution*

Sodium Silicate is sold commercially in many grades depending on the concentration and viscosity. It is, however, not produced in Jamaica. On the basis of earlier experimentation, it was agreed that a particular brand of low viscosity sodium silicate solution, known as N-Silicate was the most suitable and consequently it was imported from the USA.

The silicate application technology developed in this project is as follows:

The sodium silicate is applied (after 20% dilution) to each brick from an open tray into which the silicate is first poured and the brick subsequently placed so that about 50% of the brick is submerged in silicate solution. After about 10 minutes, the lower half of the brick is sufficiently saturated with silicate and is withdrawn from the tray, and immediately flipped so that the other half can be immersed into the silicate solution in the tray.

After 20 minutes each brick should be completely soaked with silicate solution. In an efficient operation, a worker is able to work with about 40 bricks at a time given that each will take less than 15 seconds to be immersed. This means that after 40 bricks are immersed, 10 minutes would have elapsed and the very first brick would be ready to be overturned.

After saturation with sodium silicate solution, each brick is placed on a flat surface and is to remain there for one entire day before further handling. After that period of time, the bricks can be stacked as required.

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 (J$) 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 Alcan 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 Yamaguchi in Japan, on the subject.

The essence of the project is the use of gypsum and portlandite (hydrated lime) as activators to elicit 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 organics 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 putting 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 the 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

| Parameter | Average Value |
|---|---|
| Density (g/cc) | 1.49 |
| Porosity (Vol. %) | ~18.00 |
| Compressive Strength (MPa) | 5.17 |

*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 by-product 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.

*Fig.1: Hollow building block of "Red Mud Pozzolanic Cement"*

## 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 convenient 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, samples 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).

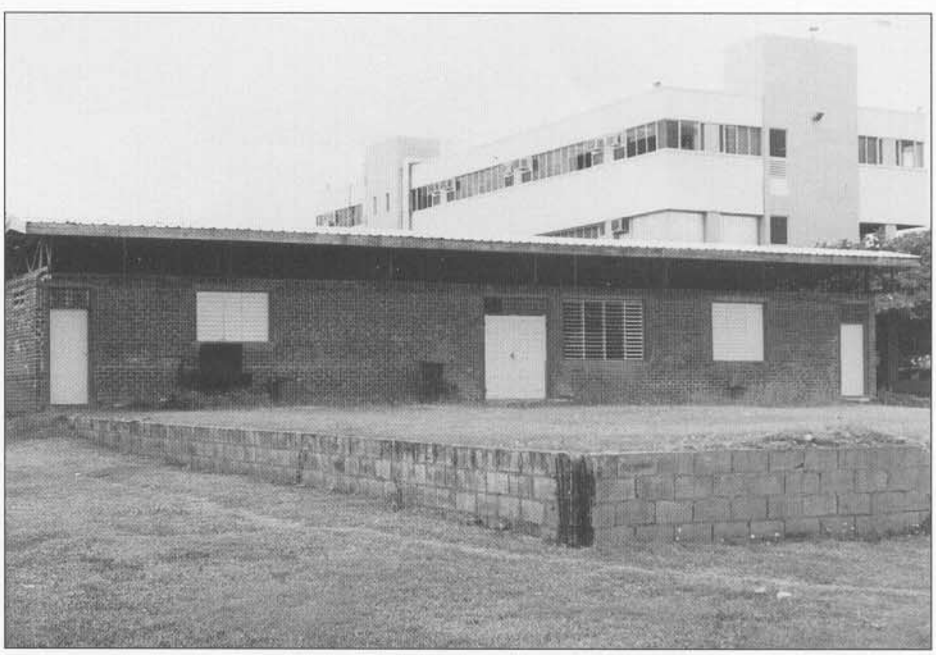

*Fig. 2: Front view of the "Red Mud" demonstration building at the Jamaica Bauxite Institute (Sports Pavilon)*

*Fig. 3: Wet mixing of raw materials just before pressing*

- Cinva-Ram Press
- Bre-Pak Press
- Platbrood Semi-Automatic Press.

All three were eventually used to produce red mud bricks. The Cinva-Ram press is perhaps the oldest known manually operated press associated with the stabilized soil brick technology and was first used in Jamaica as far back as the 1950's, long before any co-ordinated building materials development programme was started in the country. This press was used to produce red mud bricks as 10cm x 15cm x 30cm (4" x 6" x 12") units at a fixed forming pressure (Fig. 1).

The Bre-Pak press produces bricks in the dimensions of 29cm x 14cm x 8cm (11 1/2" x 5 1/2" x 3 1/2") and has the advantage of facilitating an increase of forming pressure by the use of an attached hydraulic jack, after the initial pressure is applied. As a result, it was used to fabricate red mud bricks at pressures of around 40 MPa (Megapascals); these largely yielded compressive strengths that exceeded 5 MPa. The problem with this machine, however, is that like the Cinva-Ram machine, the absence of any form of automation ensures that it is unsuitable for operation in a productive environment.

The Platbrood semi-automatic press is produced in Belgium. It is capable of producing over 100 bricks per hour if handled by two operators who, in addition to pressing, would measure and mix the material before pressing. This machine was demonstrated in the project to be capable of producing 720 bricks per 8-hour day, when operated by two untrained and inexperienced operators. At each pressing, two bricks in the dimensions of 20cm x 10cm x 10cm (8" x 4" x 4") are produced. It is estimated that the pressing pressure is about 27 MPa. The machine is essentially a compact diesel engine with a simple clutching system, which facilitate pressing and release of pressed bricks (Fig. 2). The machine was used in both the BRI and JBI projects and as a consequence produced several thousand bricks to facilitate the construction of two separate demonstration buildings. In spite of the dusty nature of the dry mud coupled with the relatively high alkalinity of the red mud brick formulations, the machine required very little maintenance. In general, it performed excellently in both of the red mud R & D projects pursued to date in Jamaica, and is highly recommended to people in other countries who may want to undertake commercial stabilized red mud brick making projects in the future.

## Mixing and fabrication

In the manufacturing of red mud bricks as with many other building materials, it is necessary to effect primary preparation to the separate components of the final mixture followed by stockpiling of each before the brick production process is started. Red mud requires drying and crushing, river sand requires screening, but the other component, cement, requires no special preparation since it has to be purchased as a refined product.

It was discovered during the course of the project that it was advantageous for the two operators to mix the material in 60 kg batches (dry basis) before pressing. In the mixing process used, the red mud, sand and cement were mixed dry at first by a shovel, after which water was added intermittently between more mixing until a total of about 18% w/w water was eventually added to yield a consistent mixture (Fig. 3). Special care had to be taken to avoid lumping which militates against smooth incident free pressing.

After weighting and mixing the first few batches of raw materials and water, the operators became familiar with the quantities and subsequently apportioned the separate components on a volume basis, based on their own judgements. In addition, they were able to develop a certain appreciation of the correct texture of the mixed material for pressing and made necessary adjustments to water quantity needs from time to time which was necessitated by changing climatic conditions throughout any given day.

A 60 kg batch would normally yield 28-30 bricks and significantly, almost all bricks fabricated with the fixed material formulation which consist of 50% red mud, 43% sand and 7% cement, were demoulded as smooth unscathed units, and very little recycling was necessary. This was not the case with stabilized soil bricks where even the very best soils resulted in about 15% of all bricks pressed, collapsing on handling and having to be recycled.

After drying, the bricks become brighter red in colour and resembles terra-cotta clay bricks to the extent that untrained eyes would be unable to make a distinction between the two types of bricks. Although relatively moist just after being demoulded, they are generally compact enough to enable stockpiling to two brick levels, and in 12 hours many more can be stacked thereupon. In making stockpiles, however, it is essential to ensure that as many surfaces as possible are exposed to air or direct sunlight to avoid abnormally slow drying/curing, which under ideal conditions can be completed in three weeks.

Completion of curing in three weeks is contingent on regular spraying with water over at least the first ten days after demoulding, but ideally every day for the period. A garden hose with an appropriate sprinkling head is best for this purpose but even if the water pressure is not particularly high it is recommended that sacking or fabric material or even newspaper might be used to cover the bricks before applying the water jet. This is to prevent pitting or other surface abrasions that may result from direct contact of water jets.

## Testing of bricks

The Jamaica Bureau of Standards (JBS) has been for many years developing Jamaican standards for all categories of building materials used in Jamaica. One of those recently completed is a product standard for clay bricks, which is essentially patterned from the ASTM standards. Although some of the parameters are easily achieved by cement stabilized red mud bricks, a major problem exist as far as compressive strength is concerned, and at present, interested parties are advocating for the relevant authorities to do the necessary research, and proceed to establish Jamaican standards that would cover not only red mud bricks but also stabilized soil bricks. It is believed that the results obtained from tests conducted on existing demonstration buildings made from these materials, will in the medium and long term, significantly assist in achieving this objective.

In many countries in which stabilized soil technology is contemplated, the considered acceptable compressive strength usually lies in the range 4-5.5 MPa. Cement stabilized red mud bricks produced in this project have consistently yielded compressive strengths that largely exceed 4.5 MPa. Many leaders in the country's building industry consider this satisfactory but there is need to get the relevant government authorities to join these leaders in arriving at a consensus.

In testing the bricks several parameters were explored but the most important ones were water absorption, compressive strength, durability (wetting and drying) and squareness.

Some of the notable properties of Jamaican cement stabilized red mud bricks are as follows:

- Bulk Density: 1380 kg/m$^3$
- Weight of Brick 4 kg
- Water Absorption 18% - 20%
- Abraison Loss 0.78%
- Compressive Strength 4.7 MPa (690 psi)
- Dimensions of Brick 20cm x 10cm x 10cm.

## Construction of demonstration building

Over 6,000 cement stabilized red mud bricks were made with the semi-automatic brickmaking machine, and cured over a period of one month before construction of the demonstration building was started. The building as it now stands, is about 37 sq m (400 sq ft) in size and consists of two rooms of unequal dimensions (Fig. 4). The larger room has three metal louvre windows which if opened allows significant solar illumination at daytime and also affords tremendous air change, while the other only has two small concrete louvre windows and requires artificial lighting even in daytime hours. These contrasting features in the design of the rooms were deliberately executed to facilitate the various tests that were planned for subsequent years.

In addition, it was designed to accommodate other relatively new building materials, particularly stone masonry blocks and concrete funicular shells, both of which are building materials technologies that were only shortly before transferred from India.

In the construction of the building, the strip footing foundation was immediately overlaid by 15cm x 15cm x 30cm concrete stone masonry blocks and brought up to a level of 1/2 metre above surface; this was done to ensure that the yet unproven red mud bricks would not be exposed to waterlogging that would result from possible sustained flooding.

All walls were constructed with stabilized red mud bricks while openings, lintels, the belt course and the roof were done with concrete; this includes the exclusive use of funicular shells as roofing material. The use of the English bond method of brick wall construction necessitated that steel reinforcement was not included in

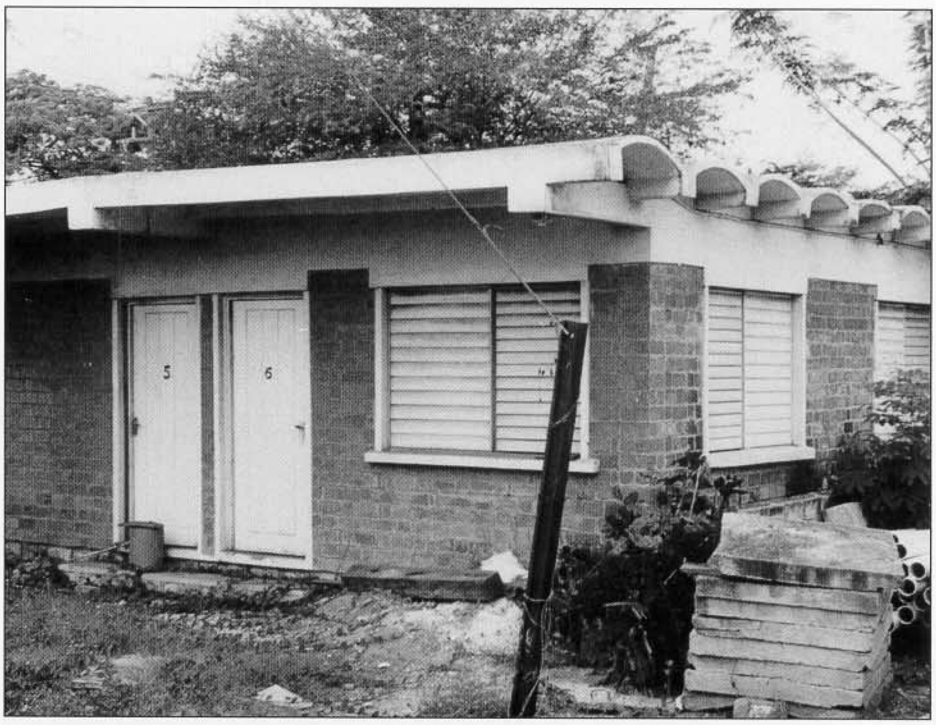

*Fig. 4: The BRI red mud demonstration building (1998)*

the construction of the walls, however, normal amounts were included in all other areas that did not include bricks.

Sand-cement mortar was used in the brick wall construction, which was pointed for added aesthetics (Fig. 5). The only two doors used were of Timber, and internally, fixtures were installed to match the overall intended functions of the building. The larger side of the building was intended for use as a display area for the BRI's technologies while the other section was to be used as a canteen facility for workers at the Laboratory/Workshop facility.

Unfortunately, although the building was completed, it was never put to the intended uses and even to date it has never been used. This is a consequence of the closure of the Institute shortly thereafter, and the Government of Jamaica not subsequently finding use for it although it is located on one of Kingston's better properties. The aggregate of these circumstances is the fact that whatever results are obtained on the performance of the building envelope now, or in the immediate future, save for radiation studies, will be confined to the exterior of the building.

The results of the radiation studies carried out in this building are reported in the second case study which focuses on the production of silicate bonded red mud bricks and pozzolanic red mud cement in a subsequent project undertaken by the Jamaica Bauxite Institute. Although the results are preliminary and need to be embellished by other investigations, they are encouraging, to the extent that it is now believed that radiation might not be a factor as far as safety is concerned, in the rational use of red mud building materials to construct houses and other buildings in Jamaica.

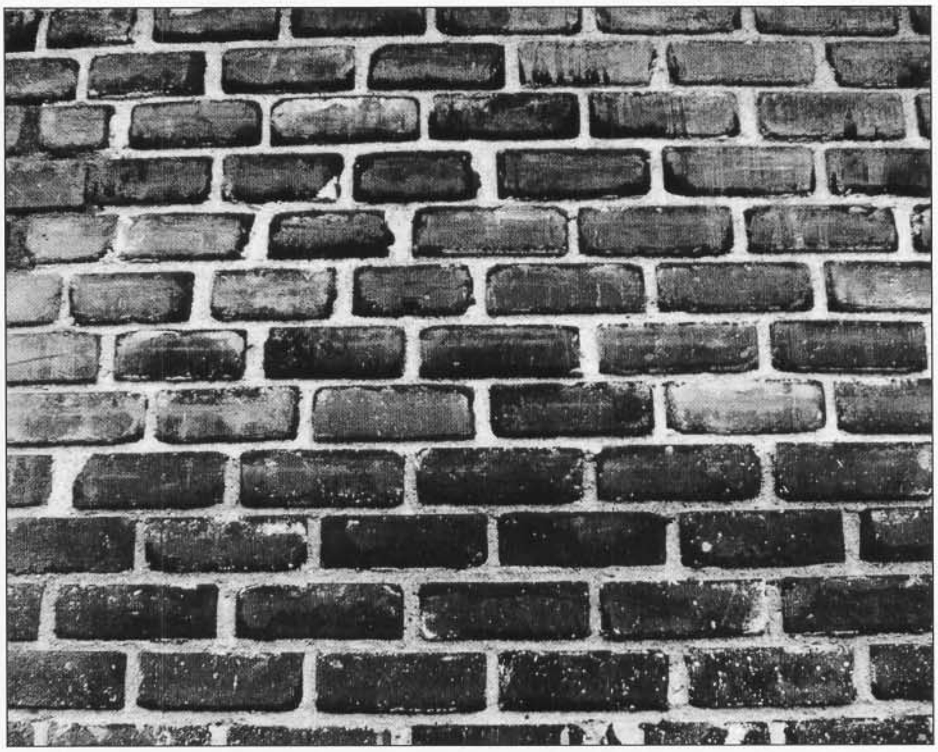

*Fig. 5: Close-up of brick masonry of BRI red mud demonstration building*

## Conclusions

After eleven years of existence, between 1987 and 1998, the demonstration building constructed primarily of cement stabilized red mud bricks in Kingston, Jamaica is characterized by the following:

- Good weathering of red mud bricks with no brick having signs of fatigue or peeling due to water saturation;
- Good bond of bricks and cement mortar;
- High resistance to the growth of fungus or other types of micro-organisms;
- No fading of the incipient red colour;
- No cracking that would suggest a need for steel reinforcement in brick masonry.

These results were obtained in spite of the fact that in the period 1990 -1993, a number of medium intensity earth tremors with considerable after-shocks were experienced in Jamaica.

In addition, although bauxite and red mud are noted internationally to have higher than normal levels of radiation, investigations carried out in the building over a period of time, have given early assurance that there is no inordinate risk of radiation exposure if such a building is used as a permanent dwelling.

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