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Wall Building
Case Study
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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 μ) 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.

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

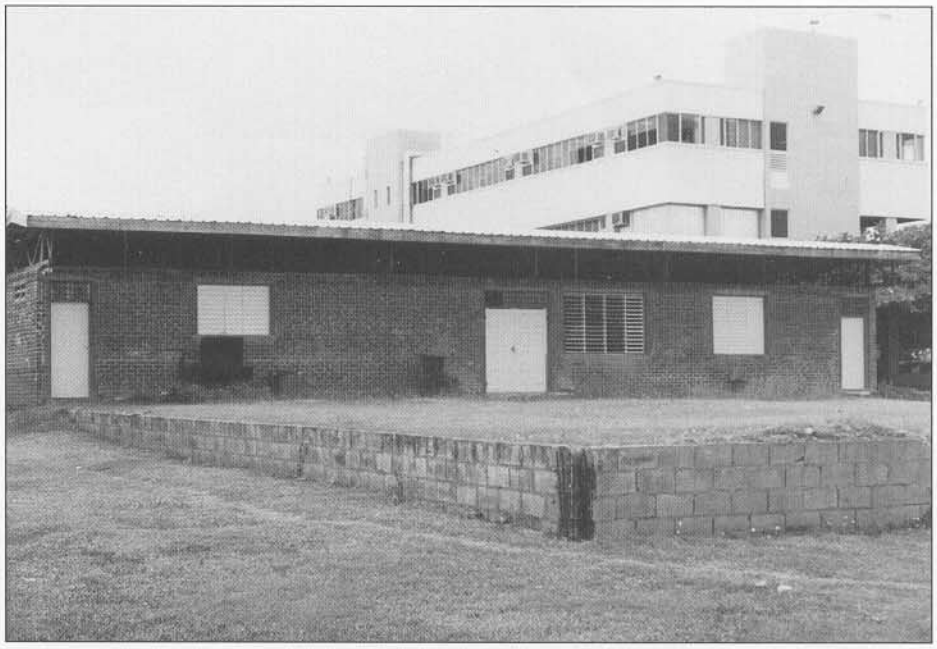

Fig. 2: Front view of the "Red Mud" demonstration building at the Jamaica Bauxite Institute (Sports Pavilon)