STABILISED INTERLOCKING RAMMED EARTH BLOCKS: ALTERNATIVES TO CEMENT STABILISATION

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Abstract:
Southampton Solent University with the Good Earth Trust promotes projects in Africa that utilise interlocking rammed earth blocks. The earth used is typically a sandy clay or lateritic soil (red murram), stabilised with between 5-7% cement to improve the strength and durability of the blocks. Only a small quantity of water is necessary to compact the material in the ram and to allow for the hydration of the cement. The interlocks between the blocks reduce the need for 10mm mortar joints. Testing with different soils, surface treatments, lime and cement stabilisers were conducted at Southampton Solent University, UK (Browne, 2005). Ongoing tests at Makerere University in Uganda are researching the use of enzymes and polymers in providing innovative low carbon alternatives to cement. This paper introduces the use of this technology and assesses the different stabilising options to produce low carbon earth blocks.

Key words: Interlocking stabilised soil blocks (ISSB); reduction of CO_2

Rationale:

The Good Earth Trust promotes the use of rammed Interlocking Stabilised Soil Blocks (ISSB) and testing of this technology has been undertaken at Southampton Solent University with a Makiga Engineering Services Limited manually operated ram, (Browne, 2005). Testing at Makerere University, Uganda is developing alternative methods of improving this technology. Stabilisation and surface treatments are also being considered.

There is growing pressure to promote at scale this technology for both cost and environmental reasons, chiefly in the reduction of carbon dioxide. Stabilisation of earth blocks is usually achieved with cement or lime. New low carbon alternative stabilisers are emerging.

Background:

Earth has been the basic material for construction for thousands of years, from the simple moulded sun dried earth brick, better known as 'adobe', to the modern extruded clay fired bricks. There are many references to the use of earth both in book form (Lunt, 1980) and easily accessible information from the Internet.

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Initial, research undertaken in 1960's by the Thailand Institute of Scientific and Technological Research, Bangkok, focussed on soil – cement blocks made with the CINVA ram, which was developed originally in Columbia in 1956. Between 1984 and 1990 this research, with German Appropriate Technology (Weinhuber, 1995) led to the development of interlocking blocks, where projections fit exactly into the depressions in the blocks placed above and at the sides as seen in figure 1 below:

Figure 1: Interlocking Stabilised Soil Block (ISSB) using a Makiga Ram

A booklet produced by GTZ (1994), described a technical co-operation project initiated in 1980 between the Government of the Federal Republic of Germany and the Government of the Republic of Kenya. It reviewed several low cost housing projects in Kenya. In chapter two it described soil stabilisation and the use of a range of different presses. Appendix B and C were used as a guide in this project to the various soil types, strength and ratios used for cement stabilisation.

Element Appropriate Technology Centres (Cogan, 2003), produce a handbook, which described the Makiga press and explained in outline the block design and its uses. Whilst providing an overview to the subject, it was found to be lacking in the description of the technology for the different soil types and manufacture of blocks.

The UK Building Research Establishment overseas building notes (Carroll, 1992), provided guidance to testing and manufacture of bricks and blocks. It recognised the early development and history of soil block presses to which the Makiga owes many of its' features, typically the CINVA ram. "One of the earliest machines for making stabilised soil blocks was the CINVA-Ram press, developed in the early 1950's in Columbia. It develops about 2 MN/m^2 (2 N/mm^2) compacting pressure by means of a simple hand operated lever mechanism. The blocks produced are 290 x 140 x 90mm thick" (Carroll, 1992).

Compressive testing by Browne (2005) at Solent University of handmade soil blocks, typically produce 2 N/mm^2 and machine testing has a history of providing strengths in excess of 4 N/mm^2. Therefore strength is not viewed as an issue as historical data showed that this was an adequate strength for the application and use of the blocks in low rise, low cost housing projects. A typical internal cavity wall load-bearing block in the UK is manufactured to a compressive strength of 3.5 N/mm^2 as for example the 'Celcon Standard Block'. However, the durability of soil blocks, particularly where they are to be used in exposed and damp conditions is of a concern.

To address this, cement or lime is added to stabilise and increase the durability of soil blocks. In some African countries there is a history of using proteins to provide an enzyme type reaction. Proteinic casein, in the form of whey – a product formed by the souring of milk, sometimes mixed with animal blood, has been used for stabilisation. One proprietary mix, mentioned by Davis, (2003) is known as Poulh's soup and is a mixture of diluted casein and brick dust beaten to a paste. In Mali wet mud is fermented with rice husks and 'rested' for several days prior to use. Another similar material is the cellulosic properties in termite mound earth giving rise to polymeric binders. Also, surface treatments such as render and paints can be applied to blocks to resist the passage of moisture.

The soil used in block making varies considerably in different locations depending upon the geology. Typically, in tropical areas the soil is a laterite with similar properties to fine grained sedimentary clays produced from primary chemical weathering of rocks often containing quartz. The minerals of kaolinite, goethite, hematite and gibbsite that are formed contain aluminium, and iron oxides causing the red-brown colour of laterites.

Depending upon the clay content and shrinkage properties, the amount of cement stabilisation will vary. Typical ratios are 1:20 (5%), but can increase to 1:10 with higher levels of clay. Where the clay content is above 30%, the effectiveness of cement stabilisation is questionable. Sands and fine gravels of no more than 6mm diameter can be added to the mix in preparation for ramming in the machine.

Curing of both cement and lime stabilised blocks has to be achieved correctly to allow for full hydration of the stabiliser in the block. 'How to make low-cost building blocks _ stabilised soil block technology', by Davis (2003) recommends stacking the blocks one day after manufacture to allow the air to get in, and cure for one month (lime 6 weeks), which unfortunately can dry out the blocks too quickly and not allow for the full chemical reaction and hydration of the stabiliser, resulting in less durable blocks. Three days is the minimum period to keep the blocks moist, by covering with damp hessian, palm leaves, sand or to sweat under plastic sheets. They should then be kept covered in the shade for 28 days before use. Details for the specification and curing of concrete, (British Standards Institution, 2006), can also be used as guidance for the curing of earth blocks.

The key document used to conduct the testing of the ram was the instruction and operations manual provided with the Makiga Engineering press (Magika Engineering Services Ltd., 2005). It was used as the basis for the trials at Solent University, (Browne, 2005), and proved to be invaluable.

Earth blocks have a low embodied energy and are therefore being promoted to reduce the carbon dioxide expelled by conventional fired bricks. The construction of interlocking stabilised soil blocks also removes the requirement for the10mm mortar joints used in fired brick construction. The manufacture of earth blocks is normally on site with earth taken from a borrow pit with no transport implications apart from the stabiliser. Carbon trading commitments and funding credits will provide an incentive to change production from fired bricks to this technology. The addition of cement stabilisation lessens the embodied energy differential between the fired brick and the stabilised earth block. It is therefore beneficial to consider alternative stabilisers for earth blocks.

Both Davis (2003) and Longland (1985) suggest the use of lime as an alternative to a cement stabiliser in earth blocks, especially where the soil is between 20-30% clay. The production of lime requires less heat to produce than cement, however the proportion of hydraulic lime needed in a soil mixture is higher, thus reducing the carbon saving advantage over cement, typically, 1:20 cement compared with 1:12 lime stabilisation. A research project funded by the World Bank with Mekerere University, Uganda is investigating the use of various pozzolanics in lime that will increase the strength and reduce the amount of lime required.

Lime Technology are promoting an increase in the use of lime in the UK, very much on the sustainability platform, with products such as limecrete, hemplime, adobe \ lime walling and hemp blocks. There is scope for technical transfer of these appropriate technologies.

Typically, there is 2 kg of CO_2 emitted in the production of a 25 kg bag of Ordinary Portland Cement (OPC). Savings are being achieved by blending waste, such as fly ash and clinker into cement production. Manufacturers are also switching away from coal to carbon-neutral fuels such as biomass to heat the kilns. This has an impact upon the drive to produce low carbon alternatives to fired bricks or concrete blocks.

There are many patented enzyme complexes, non-bacterial multi-enzyme based formulas that alter the properties of earth materials and increase strength, density and durability of earth roads. Research is being conducted at Makerere University in Uganda to use an enzyme in the production of earth blocks, under the name of Ecoblox from TerraFusion.

Polymer reaction in earth blocks is not extensively known and the Geopolymer Institute is a key reference to its use.

Consideration is now given to a number of alternatives to improving soil blocks.

Lime stabilisation:

Calcium carbonate in various types of limestone are burnt and slaked to produce hydrated, hydraulic or natural-hydraulic limes (NHL). Normally, NHL is mixed with the soil to produce stabilised blocks. Lime is preferred where there is a local supply and cement would have to be transported and stored in a dry place. Also where the soil has a particularly high clay content, lime is used or aggregate has to be added to the earth for cement stabilisation. The process for lime production involves kilning at temperatures between 900-1100°c, as opposed to 1500-1800°c for cement. The CO_2 expelled is partly absorbed back over time with lime, but some of these advantages are not great, when the proportions of lime to soil are so much greater than with cement stabilisation.

Pozzolanic reactions with lime, such as mixing with fired brick powder or burnt rice husks or similar alkali strong plants, provide a type of potash (potassium carbonate) that will form similar properties to that of OPC. Thus reducing the quantity of lime needed.

Fly ash is comprised of the non-combustible mineral portion of coal, mainly particles rich in silica, alumina and calcium which are captured before the fine ash ‘flies’ into the atmosphere. GGBS, ground granulated blast furnace slag is similar and reduces the quantity of cement and CO_2 in a concrete. Chemically, fly ash is a pozzolan. When mixed with lime (calcium hydroxide), pozzolans combine to form cementitious compounds that can be used in soil blocks, providing the same advantages of OPC stabilisation.

Low carbon cements:

In the same way that fly ash can be used as a pozzolan for lime, it can also be incorporated into cement / concrete production, partially displacing the energy hungry cement. In a drive to reduce the environmental impact of cement, different low carbon alternatives are being developed. These will have a dramatic effect on the amount of CO_2 used in stabilising ISSB earth blocks. The material costs are not yet known.

Cenin Cements Ltd. (Russell, 2009) uses patented technology that can modify pozzolanics such as power-station fly ash, burnt clays and ash materials and chemically engineer them to create a reaction with Portland cement during the hydration process and improve the properties of concrete.

Novacem is developing a unique cementitious binder based on Magnesium Oxide (MgO). This cement uses almost half the CO_2 embodied energy of OPC in its manufacture, 200-400 kg CO_2 per tonne, compared with about 700 kg for Portland cement. The absorption of CO_2 by OPC is approximately 200 kg per tonne, but Novacem is about 2.5 times higher. It is expected to be competitive with Portland cement and could potentially be used instead of OPC in stabilising soil blocks, making them not only zero-carbon to produce, but also actually contributing to overall carbon reduction.

Enzymes:

These are bio-molecules or proteins that will create a catalytic chemical reaction in soils to produce blocks of similar strength and durability to cement or lime stabilised blocks. In enzymatic reactions, the substrate molecules of the clay are changed (polarity of electro-negativity, ion exchange of the atoms) and the characteristics of plasticity, liquid limit, shear strength, swelling and shrinkage are altered by releasing pore water in the clay molecule and providing more dense, cohesive and stable binding properties. The increased density lowers water permeability and discourages the migration of moisture through a block wall.

Leviev ECOroads, TerraFusion ECOroads, TerraZyme, Permazyme and many others use patented multi-enzymatic formulas as road stabilization that alter the properties of earth materials and increases the compressive strength, density and durability of earth roads and can be used to stabilise rammed earth blocks. The formula comes as a liquid concentrate and is added to water and mixed with 20-30% fine grained clay-soil. (1litre will treat approximately, $30M^3$ or $150m^2$ of 200mm thick wall). Curing is in the open for 3 days prior to use. Strength and permeability are equivalent or better than cement stabilisation. They are claimed by TerraFusion to be highly cost effective in comparison to cement or lime stabilisation.

Polymers:

Geopolymers are based on alumino silicates that create a chemical process to turn them into a binder that does not release CO_2, and takes place at temperatures lower than that needed for cement production. 300 kg of CO_2 per tonne is emitted, compared with 700 kg for OPC. Tests on Zeobond polymer cement, have shown that its E-Crete can achieve the same strength as OPC concrete. It has possibilities for use in earth block stabilisation.

The geopolymer low temperature geopolymeric setting block, (LTGS, Patent 80 20386, public domain 1980), as described by Davidovits (1988) is made from lateritic clay earth that reacts with a geopolymer. Two materials can be used to create a geo-polymeric cross-linking of clay soils. Sodium hydroxide, NaOH (caustic soda) or potassium carbonate, $K_2 CO_3$ (potash). Sodium carbonate is naturally in abundance in East Africa, typically in Lake Natron and other locations along the Rift Valley. When mixed with lime-enriched kaolinite in the laterite soils, the resulting caustic soda provides the reaction. The burning of highly alkali plants, such as rice husks produce potash. A 3% mixture of either material with the soil can be used in the stabilisation of rammed earth blocks. The blocks can be laid out and covered in black plastic sheets, which will provide a temperature in excess of 25°c for the reaction to begin. A chemical mineralogical reticulate reaction (three dimensional network) will take place that will produce blocks with a strength of at least 5 N/mm^2 over three days. Higher temperatures in excess of 60°c will provide compressive strengths greater than 8 N/mm^2, compared to a similar strength brick fired at 1000°c.

Surface treatments:

Not only can the durability of a block be improved by stabilisation, the application of various coatings will also improve them. Testing of various surface treatments was conducted at Solent University with plain, stabilised lime and stabilised cement earth blocks. The rationale was that moisture vulnerable areas of block walling could be treated with different easily available materials, rather than carbon hungry cement renders.

The "Geelong test" (New Zealand Standards) was used to drip water at a controlled rate onto the block samples from a height of 400mm, as shown in Figure 2 below:

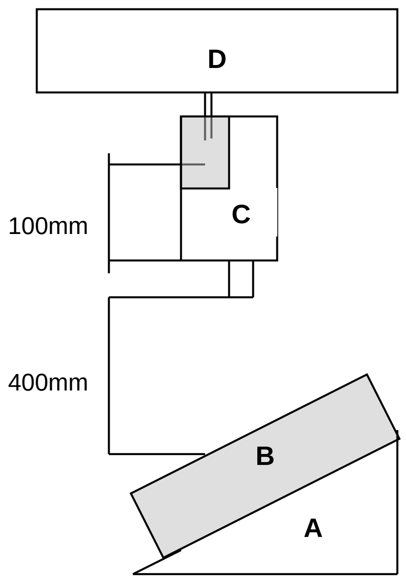
Figure 2: Geelong test rig

A – Test Bed.

B – Rammed Earth Block.

C – Drip Generator.

D – Water Hopper.



Coconut, cotton, linseed, vegetable oils, shea butter and animal fats, goat hair, ash and sand can be painted to vulnerable wall surfaces. Table 1 below indicates the rank rating from the test results:

Table 1: League table of drip testing results

Rating	Type of brick	Coating	Depth (mm)	Rating	Type of brick	Coating	Depth (mm)
1st	Cement	Engine Oil	0	7th	Cement	Sand	7
1st	Lime	Engine Oil	0	7th	Lime	Goat Hair	7
1st	Plain	Engine Oil	0	7th	Lime	Sand	7
2nd	Cement	Animal Fat	1	8th	Lime	Cooking Oil	8
3rd	Cement	Goat Hair	2	9th	Lime	Ash	9
3rd	Cement	Gravel	2	10th	Plain	Animal Fat	12
3rd	Lime	Animal Fat	2	11th	Plain	Cooking Oil	20
4th	Cement	Cooking Oil	4	12th	Plain	Gravel	50
5th	Cement	Plain	5	13th	Plain	Plain	100
5th	Lime	Gravel	5	13th	Plain	Goat Hair	100
6th	Cement	Ash	6	13th	Plain	Ash	100
6th	Lime	Plain	6	13th	Plain	Sand	100

Cement stabilised rammed soil blocks were the most moisture resistant and with an additional coating of oil (old engine oil) or animal fat this was significantly improved. The pictures in Figure 2: below indicate in the left of each picture, untreated and in the right hand side oil treated surfaces.

Plain **Lime** **Cement**

Figure 3: Pictures of untreated (left) and oil treated surfaces (right side)

Conclusions:

The use of adobe for housing has a long history. In the past 60 years there has been a growth in the use of high energy fired bricks and concrete blocks in developing countries. The adoption of rammed earth blocks has also grown, but at a much slower pace. The new high compression manual and mechanical rams produce better quality earth blocks. The interlocking types reduce the need for cement mortars in the construction of walls. The stabilisation of rammed blocks with lime and cement is relatively new, and is now taking a more prominent role in less developed countries, due to the drive to reduce CO_2 emissions and deforestation from brick firing kilns. The introduction in developed countries of unfired bricks indicates a growing interest in low embodied energy products.

Low carbon cements are being developed and could be used in stabilising soil blocks. However, unless there is local in-country production, the environmental and financial cost of importing these cements will negate their use. Enzyme stabilisation also has similar import issues. The effectiveness of these liquids for earth roads is proven, but there is a need for more research into the application for ISSB.

Geopolymers offer an exciting proposition, particularly as the raw materials can be sourced locally in Africa. The results from the Geopolymer Institute are positive and indicate that chemical reactions can alter the soil and help to produce robust blocks, but further testing and trials need to be conducted by local producers of blocks.

The Good Earth Trust in collaboration with Dr. Moses Musaazi of Makerere University in Uganda is conducting trials with enzymes and geopolymer stabilised blocks. Preliminary results are expected in late 2009.

Recommendations for further research:

Although, research of the development of various low carbon cements is being undertaken, the application of these cements in stabilised earth blocks has yet to be investigated. The use of enzymes and polymers in block manufacture is at an embryonic stage and requires further research, particularly in those countries that use ISSB technology.

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