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Use of waste and low energy material in building block construction

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Abstract

A newly proposed concept of a plastic carton soil blocks as masonry units for low-cost environmentally friendly construction is proposed. A test system was designed to perform rigorous and comprehensive measurements on seven types of soil block specimens encased in thermoplastic cartons. The cartons were similar to "ice cream tubs" of dimensions 165x60x120mm, thus making a building block/brick of reasonable handling size. Some of the test specimens also had soil mixed with palm or plastic fibres. The soil content was placed in the plastic cartons and compacted with compaction table and then with a compression machine before testing for strength.

Thermoplastic carton soil blocks without the addition of fibres as an enhancement were measured with a minimum compressive strength of 17.5MPa. In the case of the fibre enhanced soil block, the compressive strength increased with increase in fibre content. With fibre addition of 1.5% (by weight), the compressive strength of the thermoplastic cartons increased by 28.5% and 38% respectively for palm and plastic fibres, over the plain thermoplastic carton soil block without fibres. Additionally, stiffness is also greatly improved.

Keywords: Fibre enhanced soil blocks, waste plastic containers, low cost building blocks

1.0 Introduction

There has been problem of rising costs of building in the developing countries for sometime. This is especially in rural areas where the local income has often not increased at the same pace as the national average, and this has been a source of concern to governments.

Building materials is one aspect of an internal factor needing urgent attention, since materials constitute about 65-70% of the cost of construction in such areas. Therefore, a rise in the cost of certain prime materials is very quickly fed into eventual significant increases the building costs. In developing countries, over-dependence on imported materials and the cost of local transportation are some of the major contributing factors to the rising cost of construction.

The local production of construction materials leaves much to be desired. The major raw materials (e.g. clinker for cement, Aluminium sheets, steel etc.) to feed into this industry are all imported. Even though construction timber is one material that is "home-grown," in most developed countries its cost is also high due to its value as an export commodity to generate income and foreign exchange. It is against this background that this current research is being carried out to identify alternative building materials that are durable, readily available and cost effective for local consumption.

The purpose of this investigation is to study the performance of compacted thermoplastic carton soil block (TCSBs). They are an appropriate building material which should be a viable alternative to more expensive building materials such as concrete blocks, bricks or stone, and be largely dependent on local raw material and labour.

2.0 Soil blocks

Many different materials are used around the world for walling. Where quarried stone and timber are not readily available, earth is the most common material used. Earthen architecture has been used for centuries in many different parts of the world according [2]. Archaeological evidence in very dry areas has also shown that earth building was a highly popular material for dwelling construction. Earth is still used today in many parts of the world where access to other forms of building material is restricted by location or cost.

Each building material has its own advantages and disadvantages. Some of the problems with existing building materials are their poor use of environmental resources, poor quality control of the finished product and consequently a significant variation in durability. Alternative building materials that might have suitable strength and durability, and yet also are environmentally sustainable, are being sought after by researchers. There are various soil blocks which are popularly used as walling materials in construction in West Africa sub-region and typically in Ghana, as detailed below.

2.1 Kiln-fired brick

Parsons [3] describes two methods of brick production in terms of cost and shows quite clearly that where labour costs are low, kiln-fired brick production would be economically unsuitable. Kiln-fired brick production requires a high capital investment and a significant amount of infrastructure to support production. Brick production needs to be located near high quality clay deposits; and operatives need to be fairly highly skilled. Production output is often very high; typically 10,000 - 30,000 bricks per day [6], and needs to be continuous in order to achieve high efficiency and the greatest return on investment. The characteristics of such kiln-fired bricks are highly desirable because the material has a high wet-compressive strength and deteriorates very little over time even in the harshest of climates.

2.2 Clamp-fired brick:

These can be inexpensive in monetary terms because the raw materials can usually be dug from the ground fairly locally and the energy required to fire the brick could come from collected firewood. Clamp-fired bricks are of a lower quality than kiln-fired bricks and can tolerate the use of smaller and poorer sources of clay deposits. Forming the blocks requires a wooden or metal mould and after forming they are laid out to dry. After drying they are stacked into a clamp where fires are lit inside [3]. These fires raise the temperature of the blocks to the point where the particles bond together [5, 6]. Thorough firing is necessary and this can take several days. The finished blocks can have geometric irregularities and they thus require a thick layer of mortar between the blocks, sometimes as thick as 20mm [6]. Furthermore, if the blocks are poorly fired then they may need to be rendered as well to achieve adequate durability. However, fired blocks are usually considered attractive and so they are not generally rendered unless necessary.

2.3 Compressed and Stabilised Soil Blocks (CSSB)

These blocks use the same parent material as plain earth blocks but offer a significant advantage in wet compressive strength. Improved strength and stability in wet climates is generally achieved by a combination of two methods of stabilisation. One method is to compact the soil by applying some mechanical effort to reduce the voids in the material. Increasing the density of the material gives it a higher compressive strength and also reduces the potential for ingress of moisture into the block as evidence in [4]. CSSB can also be stabilised with the addition of a chemical stabiliser that helps to bind the particles together. While cement or lime is expensive additives, they are also generally widely available, and thus they are the typical chosen additive, even though the results can be disappointing unless the procedure has been applied carefully. The greater the level of compaction, the greater is the compressive strength of the block and the more effective any added stabiliser becomes [4]. CSSB compacted to higher densities are usually also more dimensionally consistent and therefore can be laid using a thinner mortar surround (e.g. 10 – 15mm) [6]. Some CSSB still need to be rendered or waterproofed in order to enhance their protection from climatic conditions and the weather [4] but generally, the rendering of CSSB can be avoided through higher levels of compaction or higher quantities of stabiliser.

3.0 Materials used and testing method.

3.1 Material used

3.1.1 Plastic container

Most of the samples were produced using an open cuboid shaped polyethylene container dimension of 165x120x60mm.

3.1.2 Soil

Typical top soil from the local Cardiff region was used. The soil was firstly passed through a 20mm sieve before it was characterised to assess its grading curve and consistency limits. Table 1 shows the summary of the characteristics of soil used.

3.1.3 Oil palm and plastic fibre

The palm fibre came from oil palm nuts, and was brought in from Ghana, while the plastic fibres were polythene fibres obtained in the U.K.

Table 1 Characteristic of soil used

Cohesion coefficient C’	40 kPa
Angle of shear resistance Φ	21˚
Elastic modulus E	10.6 MPa
Poisson ratio v	0.33
Moisture content	10%
Liquid limit	35%
Plastic limit	24%
Plasticity index	11%
Maximum shrinkage at 6 days	2.18%
Organic content	1.9%
Maximum dry density	1762 kg/m^3
Moisture content	12%
Clay content - intermediate	11%

3.2 Testing method an testing program

A test system was designed to perform rigorous and comprehensive measurements on seven types of plastic carton soil block specimens in this study. The materials consist of the plastic containers, soil, oil palm fibres and plastic fibres, see Fig. 1. The plastic carton was used as an external container and as well as a tensile hoop stress provider. The soil used was the principal core fill material, while the fibres were used as enhancement. The soil and in some cases soil- fibre mix were placed in the plastic cartons and compacted with compaction table and then with compression test machine before the test.

Figure 1 Plastic carton with soil and fibre

4.0 Experimental results

4.1 Compressive strength

The compressive strength of plastic carton containing soil at the dry state was tested using compression testing machine. Table 2 summarises the strength characteristics of the thermoplastic carton soil without any enhancement and with fibre enhancement. Thermoplastic carton soil block without addition of fibres has the lowest compressive strength of 17.5 MPa as compared with those with fibre addition. In the case of fibre enhanced soil block, the compressive strength increased with increase in weight fraction of fibre content, for both types of fibre, as shown in Table 2 and Figures 3a and 3b.

Table 2 Experimental strength results

Specimen	Max compressive strength (MPa)
A	17.5
$B_{0.75}$	18.7
$B_{1.0}$	20.5
$B_{1.5}$	22.5
$C_{0.75}$	19.7
$C_{1.0}$	22.7
$C_{1.5}$	24.2

A - soil block without any fibre
B_X - soil block with x% oil palm fibre
C_x - soil block with x% plastic fibre

At the lowest level of 0.75% oil palm fibre and plastic fibre addition, compressive strength was 6.8% and 12.5% respectively higher than blocks without fibre. At 1.0% and fibre addition, the compressive strength increased, by 17% and 29.7% for the palm and plastic fibre respectively. At 1.5%, the corresponding values are even higher at 28.6% and 38.3% increase. It should be noted that strength values (i.e. around 20MPa) are very respectable strengths for building blocks.

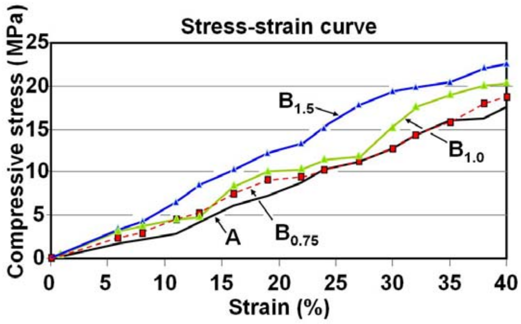

Figure 3a Compressive stress and strain relationships of soil blocks with oil palm fibre

Figures 3 show some experimental stress-strain curves for the soil blocks under compression. It can be seen that within the range of straining applied, the soil blocks had a fairly linear response even for strains up to 40%. Although these soil blocks could have achieved higher strength values before ultimate failure (usually upon a splitting of the plastic carton), a strain of 40% was deemed a practical limit and thus the stress at 40% strain was designated the maximum stress.

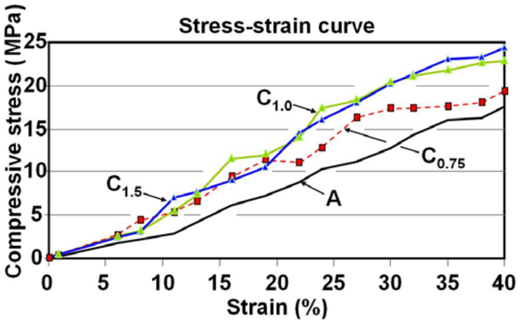

Figure 3b Compressive stress and strain relationships of soil block with plastic fibres

Since the tensile confining stress provided by the plastic carton was adequate to generate amply high compressive strengths for even a plain soil block (e.g. 17.5MPa at 40% strain), the advantage of fibre additions is actually not so much in the higher strengths achievable – true though that is – but in the ability to achieve high stresses at lower strains. The advantage is thus the higher stiffness generated by the fibre enhancement.

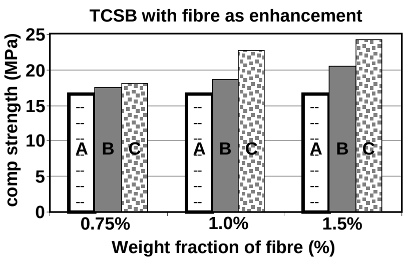

Figure 4 Summary of the compressive strength of TCSBs

In this respect, the use of plastic fibres as opposed to the palm fibres consistently produced the higher stiffness, as indicated in Figure 4. For the same fibre content of 0.75%, 1.0% and 1.5% by weight of soil, the strength at 40% strain of blocks C_x is about 5.4%, 11% and 6% respectively higher than blocks B_x. This could be expected since the plastic fibres are both stiffer and stronger than the natural palm fibres.

For increase in fibres content from 0.75% to 1.5% (i.e. an increase of 50% of fibre content) the compressive strength increase by only about 20% to 23%.

However, the stiffness of the block is much improved. For example, a stress of 15MPa is achieved at about 10.4% and 29.5% lower strain for 1% and 1.5% palm fibre, when compared with the plain soil block. The corresponding lower strain value for plastic fibres is about 33%. There is thus a clear advantage in adding fibres to the current newly proposed plastic carton soil block.

4.2 Durability of thermoplastic carton soil block (TCSB)

Though promising structural performance results have been reported, little is known about the long term durability of the block when exposed to the external weather for longer period of time. This section discusses some of the possible factors that might have an adverse effect on the performance of the block when used externally.

Thermoplastic polymers, like many other materials, are affected by weathering. For thermoplastic materials that are intended for continuous outdoor exposure, a material composition must be selected that has the necessary weather resistance for the specific conditions involved. This would generally focus on the effect of ultraviolet radiation exposure, as this is generally the main weathering factor that has the greatest impact on the performance of the thermoplastics. The long term durability of all thermoplastics can be improved by the incorporation of carbon black (about 2% by volume of basic polymer) and would result in the finished compound having greater capability to withstand UV rays and more severe weather conditions.

a) Sunlight

Sunlight emits a significant amount of ultraviolet radiation in the wavelength range of 290-400nm (National Institutes of Health report, 1989). The ultraviolet radiation that is absorbed by a thermoplastic material may result in actinic degradation (i.e., a radiation promoted chemical reaction) and the formation of heat. The energy may be sufficient to cause the breakdown of the unstabilised polymer and, after a period of time, there would be changes in the compounding ingredients.

b) Temperature

The daily range of temperature varies considerably both with season and location and can be quite large (e.g. 30°C difference between the coldest season and warmest period). Furthermore, heat from solar radiation can raise the temperature of directly expose thermoplastic carton soil block by as much as 20°C higher than ambient. Such large variation of temperature over an extended period can cause physical damage to the thermoplastic carton soil block. Therefore, it is important that heat stabilisers (e.g. 2% of carbon black) be incorporated into the compounding ingredients in order to offset the deleterious effects of high temperature.

c) Location

Location is also a factor that could affect the durability of the new building material. Less impact is found where there are fewer sunlight hours per year and where the radiation is less intense. For example, a six month period of exposure in Ghana is far more detrimental than the same period in United Kingdom due to the obvious extra hours of UV exposure in Ghana.

5.0 Conclusions and recommendation

5.1 Conclusion

The compressive strength obtained from the laboratory experiments on thermoplastic carton soil block was very promising. Such strength values of around 20MPa is about four times higher than chemically stabilised soil blocks stabilised without plastic cartons (from the authors' previous work). This is true even when the soil blocks had as high as 5% of cement content (by weight) which is approaching an economic limit. There is thus clearly a case for a larger scale study, and taking mitigating steps to ensure the durability of the TCSB as an alternative building material in construction of low cost housing, especially for disaster purposes and for low income earners in developing world.

It should also be noted that the proposed thermoplastic cartons and plastic fibres are actually environmentally friendly in that they are to be made from recycled plastic, which would otherwise be a waste material. Furthermore, there is no stringent specification for these cartons or fibres, since the current tests were conducted with disposable food cartons and recycled waste plastic fibres. The current newly proposed scheme of using plastic cartons with soil block thus achieves considerable improvements over the plain soil blocks (without plastic cartons) and at the same time provides a use for plastic waste which is abundant worldwide.

5.2 Recommendation

For the practical implementation of this research, ultraviolet stabilised carbon black systems are recommended for the manufacturing of the waste plastic containers which are intended to be used as the thermoplastic crate. Furthermore, it is clear that production of interlocking rectangular shape plastic crates from waste plastic containers, using injection moulding machine capable of moulding according to specifications would result in a better building block product where the individual blocks would have some additional mechanical connections between themselves. Such simple mechanical interlocking would also produce a wall more resistant to dynamic loading, as in the case of an earthquake. The interlocking shapes of these plastics soil block could also help to reduce the skill level needed for homeowners to build their own homes. In addition, several layers of blocks could be placed in the wall at a time, reducing construction time. This could be helpful in cases of shelter provision post a natural disaster.

Formulation of plastics with a minimum of two percent finely dispersed carbon black fibres, would greatly increase the weather resistance of the compound and give sufficient protection for continuous outdoor service [1, 7].

5.3 The way forward

The results of experiments conducted in this paper have provided some knowledge on the mechanical characteristics of the proposed thermoplastic plastic soil block. A numerical based analysis would be performed, to further establish the internal stresses and a fuller understanding of the interaction of forces between the constituent components of the plastic soil block with fibres.

The motivation for a theoretical analysis is threefold. Firstly a better understanding of the performance of thermoplastic crate soil blocks is obtained. Secondly, it would be possible to assess whether the magnitude of the theoretical stresses within the soil block are within the permissible stress, and thus unnecessary local "failure" could be avoided. And finally, when the confidence in the numerical model has been gained, this model could be used to more rapidly investigate effects of changes to the soil carton block geometry, material and configuration.

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