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CONTROLLING RISING DAMP IN NEW BUILDINGS: FIELD TRIALS OF PROPOSED TREATMENT METHODS

AGYEKUM, K.,[1], AYARKWA, J.[2] and KORANTENG, C.[3]

[1,2]*Department of Building Technology, KNUST, Kumasi, Ghana*
[3]*Department of Architecture, KNUST, Kumasi, Ghana*

Rising damp is a widespread phenomenon and a major cause of decay of masonry materials. Preliminary investigations and field surveys have revealed that the problem of rising damp has assumed an alarming dimension in residential buildings in Ghana. This study aimed at exploring treatment methods to control the problem of rising damp through field trials. An experimental approach was employed. Fourteen prototype walls (Test Walls), made up of seven Standard Manufactured Sandcrete Block Walls, SB, and seven Commercially Manufactured Sandcrete Block Walls, CB, were constructed, conditioned, subjected to various treatments and monitored for a period of 10 months (300 days). The treatments applied included polyethylene damp proof courses, damp proof coatings and reducing the porosity of the base materials using dense concrete. The monitoring was carried out with reference to the two major seasons (i.e. rainy and dry seasons) in Ghana. The findings from the study revealed that as at the time of monitoring, although all the treatments applied were performing well, the damp proof coatings applied to treat the walls, together with the dense concrete base walls were performing better than those treated with the polyethylene damp proof courses. The proposed treatments if adopted could control the problem of rising dampness, especially in the construction of new buildings.

***Keywords*:** Buildings, Damp Proof Coatings, Damp Proof Courses, Ghana, Rising damp, Test Walls.

1 INTRODUCTION

Rising damp is a widespread phenomenon and a major cause of decay of masonry materials (Franzoni et al., 2013; Alfano et al., 2006). When mild, it causes crumbling of exterior masonry and staining of interior finishes (Franzoni et al., 2013; Rirsch and Zhang, 2010; Alfano et al., 2006). When severe, it causes health hazards to building occupants due to humidity levels and mould growth (Franzoni and Bandini, 2012; Rirsch and Zhang, 2010; Alfano, 2006; Lourenco et al., 2006). Severe rising damp, accompanied with high concentrations of salts, may cause extensive fretting and crumbling of the lower parts of walls (Franzoni et al., 2013; Rirsch and Zhang, 2010; Alfano et al., 2006).
Ghana, a tropical country characterized by high rainfall with relatively high and even temperatures, experiences dampness among many public and private buildings. Preliminary investigations and field surveys have revealed that the problem of rising damp has assumed an alarming dimension in residential buildings in Ghana (Agyekum et al., 2014; Agyekum et al., 2013). This is because one out of every ten residential

buildings is affected by the problem. A large number of literature studies have been devoted to studying the problem of rising damp and its harmful effects (Franzoni, 2014; Franzoni et al., 2013; Franzoni and Bandini, 2012; Franzoni and Sassoni, 2011; Rirsch and Zhang, 2010; Kim et al., 2007; Alfano et al., 2006; Karoglou et al., 2005; Charola, 2000; Warscheid and Braams, 2000). Despite the several methods proposed to control the problem of rising dampness, its removal from both historic and modern types of buildings still remains extremely challenging (Franzoni, 2014). Generally, the level of awareness of the problem among building occupants and construction professionals in Ghana is very high (Agyekum et al., 2013). This has led to the adoption of various methods such as the construction of aprons around wall bases, tiling of wall bases and replastering the affected areas to control the problem (Agyekum et al., 2014). However, all these methods have proved futile. The significance of the problem is also reflected by the diversity of products on both local and international markets. Owing to this wide and differentiated offer, together with the scarce and fragmented scientific information on the effectiveness of such methods, it has become very difficult for professionals working in the field to choose suitable interventions on sound basis. Despite the great effort spent over the last century to understand water capillary rise phenomenon, the problem of rising damp removal is still substantially open, as not only the technologies adopted in the field frequently fail, but their working principles in real masonries have not been fully elucidated yet (Franzoni, 2014). These problems incited the current study which sought to explore treatment methods to control the problem of rising damp during the construction of new buildings.

2 LITERATURE REVIEW

2.1 Definitions of Rising Damp

Rising damp is a strange phenomenon because experts in dampness issues do not exactly agree on what it is, and some to a large extent deny its existence (Burkinshaw, 2012). Rising damp is common in buildings around the world and it plays a major role in the decay of masonry buildings (Ahmad and Abdul Rahman, 2010). It results when porous masonry draws up water from the ground. The water rises up the wall, about a metre or more high and often deposits a horizontal ‘tide mark’. Below this mark there is discoloration of the wall that is characterized by a general darkening, patchiness and mould growth (Building Research Establishment, BRE Good Repair Guide 6, 1997). The amount of water absorbed by the wall, and the height to which it rises depend on the ability of the masonry to absorb moisture, the level of wetness of the soil, and the rate of evaporation of the moisture. There are three preconditions for rising damp: ground contact, ground moisture and porous construction (Burkinshaw, 2012; Hetreed, 2008).
A number of studies have been dedicated to defining the phenomenon of rising dampness. According to Oxley and Gobert (1989), rising damp results from the capillary flow of water from the ground. Melville and Gordon (1998) described rising dampness as ground water reaching the foot of a wall which tends to rise in the walling material and continues to do so due to capillary action to varying degrees of intensity. Burkinshaw and Parrett (2004), defined rising damp more comprehensively as moisture that travels upwards through the pore structure or through small fissures or cracks, or as water vapour against the forces of gravity, typically up a wall or through a floor from a source below the

ground. According to Trotman et al. (2004) rising damp is the upward transfer of moisture in a porous material due to capillary action. Alfano et al. (2006) defined rising damp as the upward vertical flow of water through a permeable wall structure. In the BRE Digest (2007), the issue of rising damp was not defined but it was demonstrated as walls that stand in water or saturated soils. This means that a low level penetration damp could also be rising damp. According to Burkinshaw (2009), wall base damp must involve a significant amount of moisture sourced from the ground to be 'rising damp'. Rising damp from the ground is sometimes referred to as 'true rising damp'. Rising damp usually presents itself by salty yellowish brown patches of plaster/decor just above skirting board height (Burkinshaw, 2012).

2.2 Mechanism of Rising Damp

The absorption and transport of moisture in porous building materials is a complex phenomenon, and it combines the effects of various factors (Franzoni, 2014; Baker et al., 2007). There have been many efforts devoted to understanding the capillary transport mechanisms in porous building materials. In this review, only the most prominent ones among them are discussed.

The capillary rise of water is a phenomenon that occurs through the prevalence of the adhesion forces between water capillary surfaces compared with the cohesion forces of the water itself (Franzoni, 2014). Dullien and Batra (1970) and Rostagni (1951) were the first to investigate water rise in an ideal, cylindrical tube of radius 'r' (Franzoni, 2014). In later studies, Amoroso and Fassina (1983) expressed the water rise height 'h' as $h = (2\tau \cos\theta) / (\rho g r)$, where θ is the contact angle between water and capillary surfaces, ρ the liquid density, τ the surface tension and g the acceleration due to gravity (Franzoni, 2014). For porous building materials such as bricks, stones and mortars, characterized by high wettability in the presence of water ($\theta \approx 0^o$), the Jurin law can be simplified as $h \approx 15 / r$ (h in m and r in μm) (Franzoni, 2014; Sandrolini and Franzoni, 2007). The maximum height of water rise is much lower in actual masonry. It results from the interaction among the rate of water ingress in a wall (Franzoni, 2014), the rate of evaporation (l'Anson and Hoff, 1986) and the microstructural characteristics of materials used in the wall construction (Franzoni, 2014). This establishes a dynamic equilibrium as a result of the balance between water uptake from capillary rise and water loss from evaporation. Researchers, through field observations, have indicated that the height of rise of water in walls of buildings is usually around 0.5-1.5 m (Hall and Hoof, 2007; Heiman, 1982), up to about 4 m (Spennemann, 2001).

3 MATERIALS AND METHODS

The study sought to explore treatment methods to control the problem of rising damp through field trials. An experimental approach was employed. Fourteen prototype walls (test walls) which were made up of seven standard manufactured sandcrete block walls, SB, and seven commercially manufactured sandcrete block walls, CB, were constructed, conditioned, treated and monitored over a period of ten months.

3.1 Characteristics of Materials used in the Construction and Treatment of the Test Walls

The standard manufactured sandcrete blocks (SB) were composed of sharp sand, cement and water (Lewis, 1959). The other sandcrete blocks manufactured to the commercial standards (CB) were also of similar materials.

The properties of the sand used for the two different blocks complied with BS 1200 (1976). The sand used was clean, sharp river sand that was free from all deleterious matter. It was also sand that had passed through 4.70 mm zone of British Standard test sieves. It had a specific gravity of 2.6 and an average moisture content of 0.90%. Also the coefficient of uniformity of the sand was 2.95.

Ordinary Portland cement from Ghana Cement Works Limited, conforming to the Ghana Standards Board Specification No. A2 (1995) was used for the production of the sandcrete blocks. The same material with the same specification was used for the render. The water used was fresh, colorless, odorless and tasteless potable water free from organic matter (BS 1200, 1976). Tests carried out at the West African Building Research Institute has confirmed that the strength of sandcrete blocks like other cement products increase with decreasing water cement ratio. As a result of this, the addition of the water to the mixture was based on the standard specification of 0.45 water to cement ratio. Anything beyond this could have contributed to prolonged setting time, and a reduction in the relative strength of the sandcrete block.

The materials used to treat the walls to control the capillary rise of water consisted of polyethylene damp proof courses, damp proof coatings labelled as ‘A’ and ‘B’, and dense concrete bases. Damp proof coating ‘B’ is an elastic isolation material modified with special colophores, which provide excellent water insulation. It is liquid plastic, elastic when dry, flexible, strong, endures mechanical blows and highly impermeable to water. It is applied to all walls which require water insulation, ground, roof, terrace, etc. The damp proof coating ‘A’ is a two-pack, modified epoxy paint cured by polyamid. Pack A: BB 4301 3,2L is 8 parts in volume and Pack B: SB 5733 0.4L is one part in volume. The product is applied over carbon steel, concrete, wood, aluminium/galvanized surfaces, which are to be buried or immersed in salt or fresh water. It is also applied to damp proof walls affected by moisture and rising dampness, both internally and externally. The density of the concrete used as a treatment method was 2,438 kg/m3 (1:3:6 concrete mix) after a 28-day curing state. This density fell within the range of 2,200-2,600 kg/m3 regarded as density of normal weight concrete (Neville, 1999).

3.2 Manufacture of the Standard and Commercial Sandcrete Blocks

Both the standard and commercial sandcrete blocks were manufactured in an approved block-making vibrating machine and conformed to BS 2028 (1975). Both of the blocks were of sizes 115 mm × 225 mm × 460 mm. The standard mix proportion used to manufacture the standard block was 1:6, that is, one part by volume of cement to 6 parts by volume of coarse sand (Lewis, 1959), whereas a mix proportion of 1:8 was used to manufacture the commercial sandcrete block. A mix proportion of 1:8 was used because in real cases that is what is used on many Ghanaian construction sites. Standard and commercially manufactured sandcrete blocks were used to determine whether the issue of quality control contribute to the problem of dampness in buildings constructed with such materials. Also, sandcrete blocks of different mixes were used in this study to determine whether differences in the mix proportions of the blocks contribute to the susceptibility of the materials to damp penetration. All the blocks manufactured were of the load bearing capacities. BS 2028 (1975) recommends a maximum bulk density of 1,500 kg/m^3 for such blocks.

Figure 1. Volume batching of fine aggregates and cement

The cement and sand in the proportions stated earlier were mixed in approved mixers with sufficient water to ensure that uniform mixes were achieved. The mixes were then fed into an electrical block molding machine in layers, each layer being thoroughly tamped into position.
After the blocks were removed from the machine moulds, it was cured and carried to the site where the test walls were constructed. The production of the sandcrete blocks were personally supervised to ensure that the mix proportions and the materials preparations adhered to that required for the study.

3.3 Tests Conducted on the Two Types of Sandcrete Blocks

To determine the quality of the two types of sandcrete blocks manufactured, some tests were performed to determine the bulk densities, the water absorption capacities and the compressive strengths of each block after curing for 28 days. The tests performed are described in the following subsections to include:

3.3.1 Bulk Density Determination

Density is a measure of how much particles of an element or material is squeezed into a given space (Baiden and Tuuli, 2004). The more the particles are closely packed, the higher the density of the material (Baiden and Tuuli, 2004). Three samples each of the standard and commercially manufactured sandcrete blocks were tested. Each sample of the standard and commercially manufactured sandcrete blocks was labeled and numbered. Each was weighed in the dry state during which the masses were recorded. A 50 kg capacity mass scale of 500 g graduations was used to determine the bulk densities of the samples. The dimensions (length, breadth and height) of each block were then taken. From these dimensions, the volume, and thereafter, the bulk densities were calculated using the results. The bulk densities of the samples were calculated using the formula:

$$\text{Bulk density} = \frac{\text{Weight of block after immersion in water(Ww)} - \text{Weight of dry block(WD)}}{\text{Volume of block (L×B×H)}}$$

3.3.2 Water Absorption Test

The water absorption capacity of a block is the weight of water a block unit absorbs when immersed in water at normal day temperature for a stated length of time (Baiden and Tuuli, 2004). It is expressed as a percentage of the weight of the dry unit of block (Baiden and Tuuli, 2004). In determining the water absorption capacity of the block samples, three samples each of the standard and commercially manufactured blocks, whose weights had been taken in the dry state and recorded, were fully immersed in water for 24 hours. After the 24 hours, the wet block samples were then removed and weighed. The difference between the dry and wet weights of each block was then calculated by subtracting the dry weight from the wet weight. From this, the water absorption capacity was expressed in percentage as follows:

$$\text{Water Absorption} = \frac{\text{Wet weight of block (Ww)} - \text{Dry weight of block (WD)}}{\text{Volume of block(VB)}} \times 100\%$$

The ASTM C140 (2001) recommends maximum water absorption capacity of 240 kg/m^3.

3.3.3 Compressive Test

Compressive strength is defined as a unit's ability to withstand an axially applied load whether on the edge or bed face of the block (Baiden and Tuuli, 2004). The compression testing machine was used. Compressive strength test to BS EN 12390 (2009) was performed at 28 day ages using 3 samples each of the labeled standard and commercially manufactured blocks. The blocks were crushed on the edge in order to obtain the crushing loads. The compressive strength of each block was calculated by the formula:

$$\text{Compressive strength} = \frac{\text{Maximum crushing load (N)}}{\text{Minimum surface area (mm}^2\text{)}}$$

A minimum compressive strength at 28 days of 2.75 N/mm^2 is recommended for load-bearing walls and 1.4 N/mm^2 (minimum) is specified for non-load bearing walls by the National Building Regulation of Ghana (1989).

3.4 Location of Test Walls

The biggest variable in a test of this kind is the ground moisture condition (Burkinshaw, 2012). The experimental test walls were constructed at Deduako, a suburb of Oforikrom Sub-Metro which falls under the Kumasi Metropolitan Assembly in the Ashanti Region of Ghana. This location was chosen because of the swampy nature of the site which made

it easier for a true rising damp scenario to be replicated. It was also chosen because of its nearness to the researchers, which made monitoring to be very easy.
The site is generally underlain by granite which is a later intrusion into the lower birimian rocks. The soil type found in this location is mostly residual in nature with covering of weathered argellateous phyllite from the country rock (Kesse, 1985).

3.5 Construction of the Test Walls

Fourteen masonry test walls, 2.1 m high and 2.0 m long were constructed at Deduako. The walls were not erected under sheds in order to ensure their complete exposure to the inclement weather. The construction of the fourteen test walls started on the 1st of July 2014 and ended on the 24th of July 2014.
The first set of walls, made up of seven free standing walls were constructed of the standard sandcrete blocks of mix proportion 1:6, whilst the second set of walls, also made up of seven free standing walls were constructed of the commercial sandcrete blocks of mix proportion 1:8. The commercial sandcrete blocks were used to replicate to an extent the kind of blockwork commonly adopted in the construction of residential buildings in Ghana.
The first six walls for each type of sandcrete blocks (both SB and CB) had the same thicknesses and each wall consisted of several courses laid in stretching bonds to heights of 2.1 m and lengths of 2.0 m in a single width. Cement and sand mortar of a mix proportion of 1:4 as specified by the National Building Regulation of Ghana, Section 32(2) (1989) was used to join the sandcrete blocks for the wall construction (Lewis, 1959). All the block walls were finished with 13 mm thick sand and cement render (1:5), applied in several layers.
The seventh test walls for the SB and CB comprised of mass concrete bases of heights 900 mm above ground, and each with a mix ratio of 1:3:6. The top levels above the 900 mm concrete bases were continued with sandcrete blocks up to the heights of 2.1 m each.

Figure 2. Erected Test Walls- Test walls from SBs are on the extreme left whiles those from the CBs are on the extreme right.

3.6 Proposed Treatments for the Test Walls

Several treatments were identified in literature and through personal interactions with construction professionals. The various treatments applied to the walls are presented in Table 1 for the SBs and CBs respectively.

Table 1. Treatment codes for standard and commercially manufactured sandcrete block (SB) walls matched by the types of treatments.

Treatment Code	Explanation	Type of Treatment
SB1 & CB1	Standard and commercially manufactured sandcrete block walls with 0.15 mm thick damp proof course (dpc).	Polyethylene dpc with a thickness of 0.15 mm.
SB2 &CB2	Standard and commercially manufactured sandcrete block walls with 0.13 mm thick dpc.	Polyethylene dpc with a thickness of 0.13 mm.
SB3 & CB3	Standard and commercially manufactured sandcrete block walls with 0.12 mm thick dpc.	Polyethylene dpc with a thickness of 0.12 mm.
SB4 & CB4	Standard and commercially manufactured sandcrete block walls with damp proof coating ‘A’	Damp proof coating ‘A’ applied to walls.
SB5 & CB5	Standard and commercially manufactured sandcrete block walls with damp proof coating ‘B’.	Damp-proof coating ‘B’ applied to walls.
SB6 & CB6	Standard and commercially manufactured sandcrete block walls with no treatment (control test walls).	Control test walls (No treatment applied).
SB7 & CB7	Standard and commercially manufactured sandcrete block walls with concrete bases.	150 mm thick concrete bases to heights of 900 mm each.

3.6.1 Applying the Polyethylene DPC’s

Figure 3. Diagrams showing how the polyethylene DPCs were laid

Figure 3 shows how the polyethylene DPCs for the test walls 1, 2 and 3 (for both SBs and CBs) were laid, whilst Figure 4 shows the complete set of walls with the different polyethylene DPCs in place as described in Table 1.

Figure 4. Test Walls after the DPCs were laid

3.6.2 Applying the Damp Proof Coatings

In applying the damp proof coating ‘A’, the wall surfaces were thoroughly cleaned and dried, free of dirt, grease, oil, soap, rust and other contaminants. The soil of the adjoining walls was excavated about 3 feet (900 mm) deep. A catalyzer was mixed with the epoxy paint, stirred and left to stand for 30 minutes. The damp proof coating ‘A’ was then applied on the perimeters of the walls, 3 feet from the soil and allowed to dry.

Also, before the damp proof coating ‘B’ was applied to the walls, the surfaces were prepared free from rust, dirt, etc. The product was thinned with water in the rate of 40% and applied to the walls. After drying first coat, the second and third coats were applied without dilution and allowed to stand for 48 hours after which the walls became completely dried.

Figure 5 Surface of test wall being prepared to receive the damp proof coatings

Figure 6 Surface views of test walls after the damp proof coatings ‘A’ (left) and ‘B’ (right) were applied

Figure 7. Test walls 4 and 5 after they were treated with the damp proof coatings ‘A’ (left) and ‘B’ (right)

Test walls 6 for each of the different wall constructions (SBs and CBs) were left untreated to serve as controls. These walls were untreated to have reference walls against which to evaluate the effectiveness of the treatments applied to the other walls (Figure 8). For Test walls 7 of the two different constructions, concrete bases were erected to heights of 900 mm above ground levels (Figure 9).

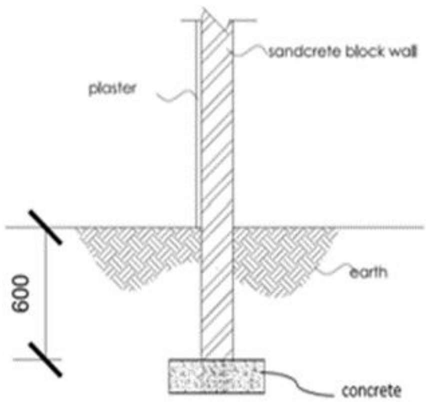


Figure 8. A section of control test wall constructed without any treatment

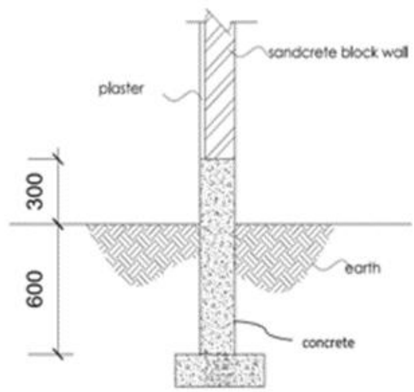


Figure 9. Creation of a barrier against capillary flux (Test Wall 7)

3.7 Methods Used to Measure the Capillary Rise of Water in The Walls

The constructed test walls were left for about a month after which measurements were taken. Both visual and non-destructive testing were carried out. Non-destructive tests were conducted because the researchers wanted the walls to stand until after a period of about two years, to enable a more adequate data to be obtained. After the first measurement of the moisture contents and capillary rise of water, subsequent measurements were carried out monthly until the time this study was conducted. Moisture contents were measured on the walls using the PCE MMK1 moisture meter with deep probes (Figure 10), and the height of reach of the water was measured using a steel tape. The moisture measurements with the moisture meter was carried out at 20 mm intervals up to the height of visible damp. The measurements were carried out in two seasons, that is the rainy season and the dry season. This was very important to be able to monitor the effect of the seasonal changes on the capillary rise of water in the walls. The measurements with the deep probes were carried out at three different depths for each height measured (i.e. 0-25 mm, 25-50 mm and 50-75 mm). This was done to determine whether the walls were actually wet (both externally and internally), and that the height attained is a true scenario of the height of reach of the water. For the purposes of this study, researchers were only interested in the maximum height of reach of the capillary water rise, and so only the results on the height of reach of the water in the walls were considered.

Figure 10. PCE MMK1 moisture meter with deep probes attached

4 RESULTS AND DISCUSSION

The results for the various tests conducted, and the monitoring of the test walls are presented to include:

4.1 Results from Tests Conducted On Block Samples

Results from the bulk density, water absorption and compressive tests performed on samples of the standard and commercially manufactured sandcrete blocks are presented. These tests were very significant because in using sandcrete blocks for the construction of external walls in humid climates, the density, water resistance abilities, among others are important in order to minimize moisture and rain water ingress into the interior of the building (Oyekan and Kamiyo, 2008).

4.1.1 Bulk Density Test

Table 2 shows the results of the bulk densities obtained for the standard and commercially manufactured sandcrete blocks. The results showed that significant differences existed between the bulk densities of the standard manufactured sandcrete blocks and the commercially manufactured sandcrete blocks. The average bulk densities of the standard manufactured sandcrete blocks exceeded the commercially manufactured sandcrete blocks by 21.78% and the BS recommended minimum bulk density (BS 2028, 1975) of 1500 kg/m3 by 53.47%. The average bulk densities of both standard and commercially manufactured sandcrete blocks also exceeded the BS recommended bulk density of 1500kg/m^3 (BS 2028, 1975). The results show that both the standard and commercially manufactured sandcrete blocks used in this study were sufficiently compacted.

Table 2 Bulk densities of standard and commercially manufactured sandcrete blocks

Type of block	Sample Number	Actual volume of block (L×B×H) (m^3)	Weight of dry block before immersion in water (W_D) (kg)	Weight of block after immersion in water (W_W)	Difference in Weight (W_W-W_D)	Bulk density (W_D/ L×B×H)kg/m^3	Average bulk density (kg/m^3)
Commercial	1	0.012	22.600	24.400	1.800	1898.840	
(mix ratio	2	0.012	21.850	23.580	1.730	1835.750	1890.390
1:8)	3	0.012	23.050	25.000	1.950	1936.570	

Standard	1	0.008	19.250	19.900	0.650	2302.080	
(mix ratio	2	0.008	19.150	19.850	0.700	2290.120	2302.080
1:6)	3	0.008	19.350	20.150	0.800	2314.040	

4.1.2 Water Absorption Test

The test results of the water absorption capacities of the sandcrete block samples determined from the immersion are shown in Table 3. This test was very significant because it gave an indication of how the two sets of sandcrete blocks performed under moist or wet conditions.

Table 3 Water absorption capacities of standard and commercially manufactured sandcrete blocks

Type of block	**Sample Number**	**Actual volume of block, V_B (m^3)**	**Weight of dry block before immersion in water. (kg) (W_D)**	**Weight of block after immersion in water (kg) (W_W)**	**Change in weight (W_W-W_D)**	**Water absorption W_W-W_D/ V_B kg/m^3**
Commercial)	1	0.012	22.600	24.400	1.800	151.230
(mix ratio	2	0.012	21.850	23.580	1.730	145.350
1:8)	3	0.012	23.050	25.000	1.950	163.830
Standard	1	0.008	19.250	19.900	0.650	77.730
(mix ratio	2	0.008	19.150	19.850	0.700	83.710
1:6)	3	0.008	19.350	20.150	0.800	95.670

The results in Table 3 show that the standard manufactured sandcrete blocks had lower water absorption capacities than the commercially manufactured sandcrete blocks. This means that although all the two sets of blocks can resist water, standard manufactured sandcrete blocks are more durable and can withstand the elements of the weather with normal protection.

The high water absorption of the commercially manufactured sandcrete blocks is probably due to the high percentages of fines in those blocks (Olufisayo, 2013). As a result, such blocks should not be recommended for use in the construction of substructures, especially in waterlogged areas. This results further show that there is the possibility that rising damp can occur in both the standard and commercially manufactured sandcrete blocks if used in the construction of walls. However, the rise will be faster in the commercially manufactured sandcrete blocks because it has a high water absorption capacity. Oyekan and Kamiyo (2008) posited that when blockwork is to be constructed as channels for drainage, foundations, etc., the blocks to be used should have low values of water absorption coefficient and hence highly impermeable. Damp penetration in whichever way could weaken the blocks and eventually result in the collapse of the block work (Oyekan and Kamiyo, 2008).

4.1.3 Compressive Test

The results of the tests performed on the sandcrete blocks to determine their compressive strengths are shown in Table 4.

The results from Table 4 indicate that the mean compressive strength of the commercially manufactured sandcrete blocks was 0.38 N/mm^2 and that of the standard manufactured sandcrete blocks was 2.89 N/mm^2. The mean compressive strength of the commercially manufactured sandcrete block at 28 days' age of 0.38N/mm^2 fell far below the minimum compressive strength of 2.75 N/mm^2 recommended for load bearing walls and 1.4 N/mm^2 specified for non-load bearing walls by the Ghana National Building Regulation (1989).

Type of block	**Sample Number**	**Surface area of block material (A) (mm^2)**	**Crushing load (kN) (B)**	**Compressive strength of block (N/mm^2) [(B/A)×1000]**	**Mean compressive strength (N/mm^2)**
Commercial)	1	52900	20 kN	0.38	
(mix ratio	2	52900	20 kN	0.38	0.38
1:8)	3	52900	20 kN	0.38	
Standard	1	45200	135 kN	2.98	
(mix ratio	2	45200	130 kN	2.88	2.89
1:6)	3	45200	128 kN	2.83	

On the other hand, the mean compressive strength of the standard manufactured sandcrete block at 28 days' age of 2.89 N/mm^2 fell above the minimum compressive strength of 2.75 N/mm^2 recommended for load bearing walls and 1.4 N/mm^2 specified for non-load bearing walls by the Ghana National Building Regulation (1989). The results confirm that the standard block with a mix ratio of 1:6 was greater in strength than the commercial block with a mix ratio of 1:8. Comparing the results of Table 3 with that of Table 4, it can be seen that the sandcrete block (mix ratio of 1:8) with the highest water absorption capacity had the weakest strength and vice-versa. This implies that when those blocks are used in the construction of foundations, they could absorb much water, and because they are very weak, there could be structural problems.

4.2 Results from the Proposed Treatments of the Test Walls

Fourteen (14) test walls, made up of seven standard and seven commercially manufactured sandcrete blocks were constructed and monitored. Figures 11a and 11b

show the conditions of the two sets of sandcrete block walls 300 days (10 months) after they were erected.

Figure 11a. The seven test walls constructed with the standard manufactured sandcrete blocks

Figure 11b. The seven test walls constructed with commercially manufactured sandcrete blocks

Table 5 shows the capillary rise of water recorded at various heights at the bases of the different walls. The table shows that between August 2014 and November 2014 (rainy season), water rose to different heights in the different walls. The peak values were recorded in November 2014 (colored in pink). Furthermore, Table 5 shows that between December 2014 and May 2015 (dry season), the water levels dropped at the different heights within the different walls. The minimum values were recorded in May 2015, where the dry season was almost ending, making way for the rainy season.

Table 5 Capillary rise of water recorded at various levels in different walls

HEIGHTS OF RISE	BLOCK TYPE	RAINY SEASON				DRY SEASON					
		August 2014	September 2014	October 2014	November 2014	December 2014	January 2015	February 2015	March 2015	April 2015	May 2015
	SB1	70 mm	75 mm	79 mm	81 mm	55 mm	40 mm	40 mm	40mm	38mm	30mm
	CB1	215 mm	228 mm	230 mm	235 mm	150 mm	95 mm	82 mm	80mm	80mm	75mm
	SB2	73 mm	78 mm	80 mm	83 mm	64 mm	43 mm	43 mm	41mm	40mm	38mm
	CB2	220 mm	230 mm	235 mm	238 mm	162 mm	100 mm	85 mm	83mm	80mm	78mm
	SB3	75 mm	80 mm	82 mm	85 mm	64 mm	45 mm	45 mm	43mm	40mm	38mm
	CB3	235 mm	240 mm	243 mm	245 mm	164 mm	98 mm	85 mm	80mm	78mm	74mm
	SB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 6	72 mm	75 mm	78 mm	201 mm	78 mm	65 mm	50 mm	45mm	42mm	35mm
	CB 6	215 mm	250 mm	265 mm	320 mm	195 mm	150 mm	95 mm	90mm	86mm	80mm
	SB7	100 mm	80 mm	50 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB7	112 mm	85 mm	55 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	Capillary rise of water increased with month in the rainy season				Capillary rise of water measured is maximum	Capillary rise of water decreased with month in the dry season					Capillary rise of water measured is minimum

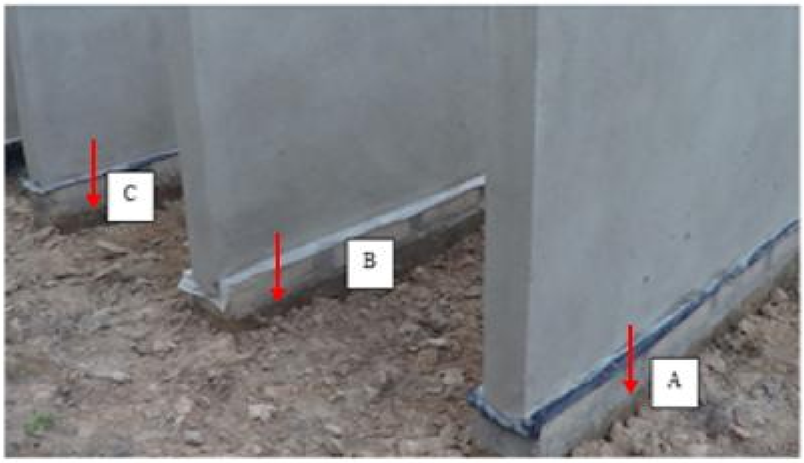
The impacts of ground water conditions on the capillary rise of water in the walls are further discussed under the following sub-headings to include:

4.2.1 Results from the Test Walls Treated with Polyethylene DPCs

The monitoring was carried out with reference to the two major seasons (i.e. rainy and dry seasons) in Ghana. Within the first four months (August 2014- November 2014, rainy season-Table 5), water had risen to average heights of 81 mm and 235 mm in the walls constructed with the standard and commercially manufactured sandcrete blocks and treated with polyethylene DPCs respectively. From the fifth to the tenth months (December 2014- May 2015, dry season-Table 5), the heights of the water in the walls had dropped to 30 mm and 75 mm in the two sets of walls respectively. This finding shows that the seasonal changes affected the rise and fall of water in the masonry walls.

The ability of the water to rise in the walls under investigation depended on factors such as ground and soil conditions, environmental factors, climatic factors, etc. of the area.

Figure 12. Water rise at the bases of the walls constructed with SBs and treated

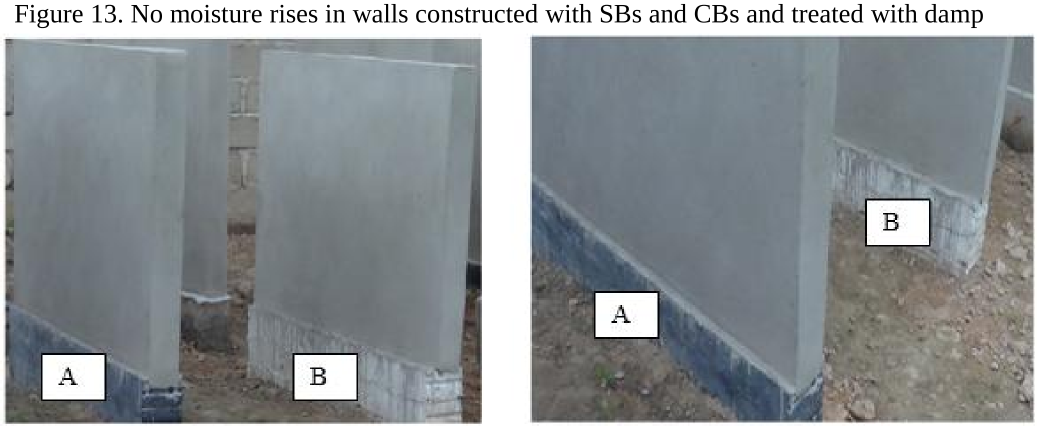


with three different DPCs - 0.15 mm thick (A), 0.12 mm thick (B) and 0.13 mm thick (C)

4.2.2 Results from the Test Walls Treated with the Damp Proof Coatings

Figure 13 shows the two sets of walls which were treated with the damp proof coatings. The monitoring revealed that 300 days into the treatment of the walls, the damp proof coatings 'A' and 'B' seemed to be working perfectively. Moisture content measurements with the PCE MMK1 moisture meter with deep probes showed no traces of water at the bases, and the inner parts of the walls were considerably dry. This is because the entire perimeters of the wall bases were completely covered with the coatings, which filled the pore spaces within the sandcrete blocks, making it difficult for water to rise in the walls.

Figure 13. No moisture rises in walls constructed with SBs and CBs and treated with damp



proof coatings 'A' and 'B'

4.2.3 Results from the control test walls

For the Test walls that were untreated to act as controls, water had risen to heights of 201 mm and 320 mm in the standard and commercially manufactured sandcrete block walls respectively during the first four months (Table 5). From the fifth to the tenth months (dry season), the water levels had dropped to 35 mm and 80 mm (Table 5) in the two sets of walls.

Fig 14. Water observed at height over 320 mm for the CBs

This finding shows that during the rainy season when the water table in the area was higher, water was transported by capillarity into the walls. However, in the dry season when the water table dropped, the quantity of water in the walls dropped.

4.2.4 Results from Test Walls with Concrete Bases

Test wall 7 for the two sets of sandcrete blocks were constructed with dense concrete bases. Ten months into the monitoring, results from the moisture measurements at the bases of the walls constructed with dense concrete showed no traces of moisture. The concrete bases were very dense and did not permit the ingress of water by capillary action easily.

5 CONCLUSIONS

The study sought to explore treatment methods to control the problem of rising dampness at the root source (thus during the construction of new buildings). Fourteen prototype test walls were constructed with different treatment methods applied. The test walls were constructed with sandcrete blocks manufactured to standard and commercial specifications. Bulk density, water absorption capacity and compressive tests were conducted on the two sets of sandcrete blocks to determine their suitability or otherwise for the intended study. The bulk densities of the standard and commercially manufactured sandcrete blocks were consistent with BS 2028 (1975) recommendations. This indicates that the level of compaction of these blocks were acceptable and unlikely to affect strength development. Also, although the water absorption capacities of the two different types of blocks tested were lower than the maximum limit recommended in ASTM C 140 (2001) of 240 kg/m^3, that of the commercially manufactured sandcrete blocks was high, therefore more likely to be less durable and could be an easy route for rising water from the ground. Results of the compressive tests performed on the two sets of sandcrete blocks showed that the standard manufactured sandcrete blocks with mix ratio of 1:6 was greater in strength than the commercial block with a mix ratio of 1:8. The standard block with the higher compressive strength had a lower water absorption capacity. The commercial sandcrete block which had the least strength had higher water absorption capacity. This means that because water can easily rise in the commercial block, the least strength makes it inadequate to be used especially in the construction of substructures. The results further showed how each of the treatments applied to the walls performed over a period of 300 days (10 months). The findings further revealed that as at the time of monitoring, although all the treatments were performing well, the walls treated with the damp proof coatings, together with those with the dense concrete bases were performing better than those treated with the polyethylene DPCs. The constructed test walls should offer insights into the potential for moisture to rise up in solid block walls from the ground. The proposed treatments have also shed light on the effectiveness of some treatments applied to walls to control the capillary rise of water from the ground into the superstructure. This study has further provided knowledge on how basic construction principles could be used to control the problem of rising dampness, especially, in the construction of new buildings. With the annual growth of housing stock increasing yearly in Ghana, the proposed treatment methods if properly implemented, should devoid new trends of buildings of the problem of rising dampness. This will provide adequate time for existing buildings with the problem to be studied and remedied. The study recommends a cost benefit analysis to be performed on the damp proof coatings and the dense concrete bases. Furthermore, it is recommended that simulation tests be performed to understand what is expected to occur after two, or more years. The results obtained from the simulation could assist in validating the conclusion. This will assist surveyors in advising clients on how they would achieve better value for their money, whilst they attain quality in the methods they use to control the problem.

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