

Effects of Environmental Chemical Activity on the Durability and Deterioration of Compressed Stabilized Earth Blocks

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ABSTRACT

Provision of adequate shelter is still a major challenge. This is because of the high cost of building materials. A low cost walling material is required to reverse the massive problems of shelter backlog in developing countries. The compressed stabilised earth block (CSEB) is one such material. While its green properties are known, the durability of the material, especially as related to chemical activity and their effects, have not been researched. The key objective of this research was to investigate the durability and deterioration of CSEBs in relation to chemical action. The following were investigated; sources and types of chemical agents, nature of action, their effects, and common defect types. The methodology involved literature reviews and exposure condition survey. Various chemically associated deterioration agents, types, effects, modes and defects are described. Findings confirmed that premature deterioration was widespread, with defects exhibited mainly as: surface erosion, cracking, mass loss, disintegration, and creation of porous residues. Key chemical agents were identified. The established effects of these chemical actions included; build-up of internal stresses, bond weakening, volumetric changes, increased porosity, and segregation. It is possible to significantly raise the strength, improve the dimensional stability and wear resistance of CSEBs to the extent that they can be safely used in unrendered walls in the humid tropics through better pre-selection of constituent materials, processing methods, inter-granular bonding, reduction in voids, lowered water absorption, and improved design codes and standards. The findings are expected to positively contribute to the future widespread use of CSEBs.

Keywords – Chemical agents, durability, deterioration, earth-blocks, defects

1. INTRODUCTION

Compressed stabilised earth blocks (CSEB's) were promoted as having an indefinitely long service life. Unfortunately, it is now evident that even normal exposure conditions are actually more deleterious than

originally thought. Undesirable premature deterioration does occur. It is now common knowledge that defects are visible even to the casual observer and user. Some of these defects are a result of chemical activity. Defects in CSEB structures are presented as surface and bulk cracking and crazing, mass loss, appearance of porous residues, disintegration, and detachment of render. The main chemical agents include; sulfates, alkali, silica, carbonates, soluble salts, acids, calcium hydroxide. The sources of these chemicals include; soil, sand, clay, ground water, cement paste, and constituents of clay. The types of action include; expanded product formation within the cement paste, formation of gels, swelling of gels in the presence of water, crystallization within pores, dissolution of hydrated cement and calcium hydroxide, dissolution in water followed by leaching, and the hydrophilic attraction of water by clay. The effects of these chemical actions include; build-up of internal stresses, bond weakening, disintegration, build-up of expansive forces, volumetric changes of salt crystals, segregation, increase in porosity, swelling, and loss of bonding capacity. These deterioration phenomena have been witnessed in the wet humid tropical regions. While much research has been undertaken in the recent past on initial properties of CSEBs, very little similar research has been done on its durability and deterioration. Recent advances have been made in the durability research of comparable materials such as concrete. These are now well documented, and moves to redress identified shortcomings are following. By contrast, no durability or deterioration research work has been conducted for decades in the case of CSEBs. It is noted that the urgency is even more acute. This paper is presented in four sections. After this introductory section, the rest of the paper covers the materials and methodology, findings and discussions, and conclusion.

2. MATERIALS AND METHODS

Construction materials that last for long under normal or severe exposure conditions are generally regarded as being reliable and cost effective. This explains why durability and deterioration are perhaps now the two most commonly used words in the field of construction materials. It is therefore important to examine their

relevance to the performance of CSEBs. As can be expected, in practice several causes of deterioration will occur simultaneously. These can be compounded by cumulative as well as synergistic actions. Durability and deterioration research are therefore complex topics. The word durability originates from the Latin word '*durabilis*' which means 'lasting' [1]. In the context of most building materials, it can mean resistance to weakening and disintegration over time. According to [2], durability is defined 'as the ability of a building and its parts to perform its required function over a period of time, and under the influence of agents'. But according to [3], 'durability is a measure, albeit in an inverse sense, of the rate of deterioration of a material or component'. More recent definitions state that 'durability may be regarded as a measure of the ability of a material to sustain its distinctive characteristics, and resistance to weathering under conditions of use for the duration of the service lifetime of the structure of which it forms part' [1]. These definitions are too general to be of any practical use with CSEBs. The author proposes that the definition and concept of durability be based on three key parameters, namely: intended function of the material, the standardised conditions of its use, and the time the material is required to fulfil its functions

Deterioration has been defined as 'the time-related loss of quality of a material, usually under the influence of environmental agents' [1], [3], [4]. Premature deterioration has also been defined as 'failure to achieve the predicted service life' [2]. The predicted service life of a block can be obtained from recorded performance or from accelerated tests. Unfortunately, such records are not available. Failure due to the inability of a newly made block to fulfil its functions has to be clearly distinguished from failure brought about by alterations in properties over the service lifetime of a block. Indeed most building materials will have some of their properties altered over time although their durability may not always be called to question. The durability of a block can therefore be regarded as its ability to resist deterioration. It can be treated as the reciprocal of deterioration under pre-defined conditions. Due to deterioration however, the durability of a block is unlikely to remain constant. It may in fact change considerably. The implication is that durability of a block and its deterioration are likely to influence each other mutually but negatively. The more a block deteriorates the less durable it is likely to become over time. Depending on the constituent materials used in a block, and on the quality of the processing methods used, no two blocks might be easy to compare. Unacceptable deterioration will therefore vary from block to block, and from property to property. Block

properties that diminish over time reflect the past history of the block, both during and after manufacture.

The objectives of this paper were four, namely to: (i) identify the most critical chemically associated deterioration agents, their effects, and severity ranking; (ii) understand the main mechanisms involved, their modes of progression and propagation; (iii) suggest measurement techniques to quantify the main outputs of deterioration; and (iv) recommend selected remedial measures. There is very limited information available on the long term behaviour of CSEBs. This is partly because no prior research has been conducted in the area and partly because inspection and maintenance records on the performance of blocks are not available. In view of such circumstances, the use of a combination of various approaches was considered to be inevitable. The methodology included: (i) literature review in order to establish the level of current thinking, knowledge, and to provide the intellectual context for the entire research. (ii) documentation review of key surface and bulk properties of blocks sourced from major housing projects. (iii) exposure condition survey done through: inventorisation of CSEB buildings and characterising their exposure conditions, visual inspection of buildings to identify defect types and their severity, in-service condition measurement of the main defect types, and questionnaires and interviews for opinions, experiences and knowledge from stakeholders.

3. CHEMICALLY RELATED DETERIORATION

The findings from this research show that chemical based deterioration is widespread. The sources of chemicals are largely from the immediate environment where the blocks are produced and used. The deterioration of CSEBs can now be linked to the effects of chemical activity. According to literature sources, mechanisms associated with chemical action in CSEBs remain the least investigated [5]. Yet sources of potentially reactive chemicals in a block are soil and cement. Soils which constitute most of the bulk of a block contain minerals as well as contaminants. Some of these substances can remain dormant and stable when not in active contact with environmental elements such as rainwater, high temperatures, relative humidity, and gasses. Ordinary Portland cement as the main binder in blocks also contains potentially unstable chemical constituents even in the hardened cement paste phase. Contact with environmental agents can catalyse chemical reactions in cement hydrates [6].

The precondition for chemical reaction to start in most

cement based materials is the presence of moisture [2], [6]. Due to seasonal moisture variations from heavy rainstorms and humid conditions in the tropics, chemical reactions can be expected to occur within a block during its service lifetime. The rate of such reactions is likely to be influenced by variations in ambient temperatures. Environmental conditions found in the humid tropics therefore provide the best possible setting for chemical activity to occur in a block. Based on the nature of their action and resulting effects, deleterious mechanisms of chemical action can be broadly categorized into three groups, namely: leaching out effect (clay and calcium hydroxide), expanded product formation (internal stress generation), direct decomposition (of the cement binder). These are described each in turn.

3.1 Leaching Out Effect

Leaching is a phenomenon that involves the washing out of soluble substances from a material [8]. There are two key sources of soluble substances in blocks: the calcium hydroxide found in the hardened cement paste, and the clay fraction likely to be found in residual unstabilised or partially stabilized matrix of a block [5]. Calcium hydroxide ($\text{Ca}(\text{OH})_2$) is known to easily dissolve in water [6], [9]. The dissolution process is irreversible once started, and is known to be facilitated by high temperatures, and the presence of carbon dioxide. Moreover, block properties such as water absorption and permeability, are likely to ensure that adequate moisture is absorbed and circulated within a block. Dissolved calcium hydroxide can be removed out of a block in either of two ways. It may simply be washed out of a block through surface flow on saturation during rainstorms, or it may be expelled onto the block surface by evaporation due to high temperatures. The phenomenon of leaching out of calcium hydroxide is also widely reported in concrete literature [1], [6], [10]. There is no justifiable reason to expect that similar occurrences would not occur in CSEBs.

Residues of unstabilised soil (usually clay) have been found in a stabilized block fabric [5], [11]. Even within the recommended limit of less than 30% by weight of a block which is generally tolerated, the presence of clay is a potential source of problems. Owing to its fineness and high specific surface area, not only can clay grains

obstruct the stabilization process, but they are also likely to compete for the mix-water required for the hydration of cement [12]. Clay can also coat the surfaces of coarse soil fractions (fine gravel and sand). Such coatings can inhibit the binding effect of cement on these particles. During rainy seasons, a block can rapidly absorb rainwater. The attraction of water by clay minerals has been explained by various mechanisms but ion exchange appears to remain the dominant mechanism [13], [14]. The amount and type of clay in a block can affect the degree of dispersion or flocculation. Kaolinite clays whose structure comprises platelets at a fixed distance are more stable in water, but are still capable of being disrupted. Illite and montmorillonite clays on the other hand, which mostly contain interlayer potassium favor hydration in their dispersal. The swelling of clay lattice is known to assist in the mechanism of dispersal. Dispersed clay in a block fabric can easily be washed out as moisture permeates and circulates within it during rainy seasons.

The combined effect of leaching out of both calcium hydroxide and dispersed clays from a block is likely to be more severe in CSEBs than in concrete. Extensive leaching is known to increase the porosity of a material. This can cause a block to become progressively weaker, and more permeable. A weakened block surface is more vulnerable to the direct abrasive action associated with driving rains. Since these mechanisms are likely to occur for the duration of the service lifetime of a block, deterioration over time can be expected. The effects of leaching can however be minimised in blocks if certain preventive measures are taken early enough. These include the following: the use of pozzolans and lime in combination with OPC during stabilization. Pozzolans and lime have the ability to fix both the calcium hydroxide present in hydrated cement paste and in any excess clay respectively; use of denser and more homogeneous blocks of low permeability (less than 1.10^{-5} mm/sec) and of low water absorption capacity (less than 15%); careful soil selection that avoids use of soil with excessive clay content (<30% when OPC is used as the sole stabilizer), and; focus on adequate curing of blocks.

3.2 Expanded Product Formation

Certain categories of chemical activity that can influence

the durability of CSEBs are associated with the formation of expanded products within a block. According to literature sources, such expanded products can occupy a greater volume within the block than the compounds which they replaced. By forcibly trying to occupy space that is not readily available, internal stresses can be generated within a block. Reactions of this category are well documented in concrete literature [6], [7], [9], [10], [15]. Apart from the occasional mention of the harmful effects of organic matter and other soil contaminants, no similar documentation of this phenomenon is covered in CSEB literature. Yet the potential for such effects may be even greater in CSEBs. The three main categories of reactions likely to affect the durability of CSEBs through expanded product formation include: sulfate attack (on cement hydrates); alkali-aggregate reactions (involving silica and carbonates), and; soluble salts crystallization (within the voids in a block). These are discussed in turn in the paragraphs that follow.

3.2.1 Sulfates

Sulfates occur widely in natural soils in most parts of the world [8]. The type of sulfates vary greatly. But the common ones in soil are calcium, sodium and magnesium sulfates. These are mostly found in clayey soils rather than in sandy soils. The inclusion of significant amounts of sulfates in CSEBs cannot be ruled out since no tests have so far been devised for their detection during soil selection. In the presence of sufficient amounts of moisture, sulfates present in soil can readily dissolve in water and react with certain hydrated cement products namely, calcium hydroxide and calcium aluminate [9]. The dissolution of sulfates in water can create a sulfate solution within a CSEB fabric. The sulfate solution might then react with both the $\text{Ca}(\text{OH})_2$ and the hydrated C_3A to form calcium sulfate (gypsum), and calcium sulphoaluminates compounds (ettringite) respectively [10]. The volume of these two by-products is much greater than that of the original substrates in the block. As these products expand in order to occupy more space within a block, and when this expansion is restrained by adjacent particles and phases within the core of the block, significant internal stresses are generated. The generated stresses are capable of disrupting bonding within the block. This can in turn result in a weakened block of lower strength, rigidity and hardness. The reactions are irreversible and their deleterious effects are noticeable within only a few years of their occurrence. The damage in blocks is commonly presented as defective edges and corners. These can also be followed by spalling and cracking of

the block surface. The severity of sulfate attack on CSEBs depends on a number of factors. They include: type and amount of sulfates present in the soil, type of cement used, and the bulk properties of a block. The effect of sulfate attack on CSEBs is not investigated experimentally in this study.

3.2.2 Alkali Aggregate Reactions

Alkali Aggregate Reactions (AAR) can also be expected to occur in CSEBs. According to literature sources, the reaction is essentially an inter-constituent material reaction also with the potential to form expanded products in a block. The reaction can occur between the active silica and carbonate containing soils and the alkalis (Na_2O and K_2O) present in minute quantities in OPC [10]. Alkalis may also be present in remote amounts in most soils [12]. Two kinds of alkali-aggregate reactions, both potentially harmful to blocks, are distinguished: Alkali-silica reactions (ASR), and Alkali-carbonate reactions (ACR). These phenomena and the mechanisms involved are also widely reported in concrete literature [9]. Defects on blocks resulting from AAR reactions will most likely appear as map cracking and spalling, occurring mainly on the surface of the block. Cracking of the star shaped pattern is the most common, but not necessarily the only type. Factors likely to influence AAR reactions in CSEBs include the following: availability of moisture, high temperature environments (10°C - 40°C), concentration of alkalis in cement and soil, concentration of active silica and carbonates in soil, and porosity and permeability of the block. From these factors, the main preventive measures for AAR in CSEBs should involve procedures that attempt to lower the alkali content in the cement while it is still in the plastic state. The addition of pozzolans to the soil-cement-water mix at the time of stabilization could be helpful. The main reason for using pozzolans is that they easily combine with the alkali content of the cement and soil, thus effectively lowering the alkali content. AAR can therefore be avoided in CSEBs by using low alkali cements, non-reactive soils and pozzolans blended with OPC.

3.2.3 Soluble Salts Crystallization

Soluble Salts Crystallization (SSC) can occur within the pores and voids spaces of a block. According to literature source, the crystallization of salts results in expanded product formation [9]. As before, such products have the potential to generate significant internal stresses within the pores and void spaces in a

block. The phenomenon is widely reported in concrete literature. Soluble salts are commonly found in most soils especially sandy soils. Sandy soils won from rivers can also contain appreciable amounts of soluble salts. Amounts as little as 6% of the mass of the sand are enough to trigger off such reactions. The most common salts are usually sulfates and chlorides [9]. Although these salts could easily be removed by washing of sand, the procedure is rarely followed in most developing countries. Sand is normally imported from various sources to improve the particle grading of soils needed for stabilization. The soluble salts are however not reactive in the solid form in which they are normally present in the sand. They will only become reactive in solution. The alternate wetting and drying of block surfaces provides an ideal setting for such reactions. The mechanism of SSC is thought to be as follows:

When soluble salts in solution are present in a block fabric, they are likely to permeate into its capillary pores. Due to high temperatures leading to evaporation, moisture is driven off from the solution causing the salts to crystallize within the pores and voids spaces of the block. The volume of the crystals increase as the pore spaces get filled. But any further increase can be resisted by the rigid block fabric. This leads to the creation of significant stresses within the pores in the block. The induced stresses can cause cracking and disintegration at the surface of the block. Progressive deterioration of the block surface can then take place as moisture and temperature variations occur over the service lifetime of the block. The deterioration mechanism is known to be unaffected by the type of cement used. Limits on the soluble salts content of soil (especially its sand component) should therefore be specified during soil selection for CSEB production. Due to the threat from SSC, use of CSEBs below the foundation level is still prohibited [16]. Moreover, even blocks used at short distances above ground level in the lower courses of a wall may also be vulnerable to deterioration from SSC. The lower layers of a wall can be plastered to minimize such incidences.

3.3 Direct Decomposition of the Cement Binder

Direct decomposition of cement within a CSEB can occur due to attack from acidic conditions. No OPC is known to be resistant to acid attack [9]. The direct decomposition of OPC can lead to the progressive breakup of the bonds that hold the CSEB fabric together

and progress towards the interior. The phenomenon is widely reported in concrete literature [8]. Defects assessment conducted during the fieldwork confirmed the occurrence of chemically induced deterioration in blocks. Further future research is recommended in the area of chemically induced deterioration in CSEBs.

4. CONCLUSION

While much research has been undertaken in the recent past on initial properties of CSEBs, very little similar research has been done on its durability and deterioration. Recent advances have been made in the durability research of comparable materials such as concrete. These are now well documented, and moves to redress identified shortcomings are following. By contrast, no durability or deterioration research work have been extensively conducted for decades in the case of CSEBs. It was noted that chemical action related deterioration mechanisms in blocks remained the least investigated and documented of all deterioration modes. Yet such reactions are potentially detrimental in CSEBs due to the various minerals found in both soils and OPC hydrates. It can be further concluded that the effects of environmental agents can lead to the premature deterioration of blocks. The durability of a block can therefore be regarded as its ability to resist deterioration. Durability and deterioration influence each other mutually but negatively. Chemical related activity was found to be one of the main causes of premature defects in CSEBs. The others include water and biological associated agents.

Common defects in CSEB structures resulting from chemical activity are presented as surface as well as bulk cracking and crazing, mass loss, appearance of porous residues, disintegration, and detachment of render. The seven key chemical agents identified include; sulfates, alkali, silica, carbonates, soluble salts, acids, calcium hydroxide. The six sources of these chemicals include; soil, sand, clay, ground water, cement paste, and constituents of clay. The five types of chemical action include; expanded product formation within the cement paste, formation of gels, swelling of gels in the presence of water, crystallization within pores, dissolution of hydrated cement and calcium hydroxide, dissolution in water followed by leaching, and the hydrophilic attraction of water by clay. The nine identified effects of these chemical actions include; build-up of internal stresses, bond weakening, disintegration, build-up of expansive forces, volumetric changes of salt crystals, segregation, increase in porosity, swelling, and loss of bonding capacity. These deterioration phenomena have been witnessed in the wet humid tropical regions.

Further research is recommended on all aspects of chemically-related deterioration mechanisms.

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