1. Introduction to clay-based materials

The use of clay-based materials has a long and pre-historic background. The association of clay building materials with mud huts is correct but not sufficient. There has been serious rethink and modernizing, and clay-based materials can now produce aesthetically pleasant construction, such as sometimes witnessed in the careful use of rammed earth as shown in Figure 1. It will be seen later that good workmanship can be achieved for both individual and also large-scale housing projects using unfired clay materials, in both developed and developing countries.

Figure 1 – Modern look created by clay-based materials, as in the careful use of rammed earth in construction in Wales, United Kingdom.

Over the last few decades, clay-based materials have started to gain recognition and the respect they once had in the past.
This is credit to clay-based materials enthusiasts, who have brought to the fore the well-recognized and indisputable benefits of these materials. These benefits include low-impact on the environment, in particular if the materials are not fired, and their ability to passively control interior humidity. The down side to the materials include the bad reputation these materials have, especially when compared to the apparent advantages of energy intensive materials such as Portland cement and to some extent lime. Another notable drawback is the often slow speed of construction, and the sensitivity clay materials sometimes have when one has to balance cost and immediate and long-term performance. While some approaches may require little or no prior experience, others such as the modern and beautiful appearance shown in Figure 1 require extra care during construction in order to maintain material mixing regimes and the resultant uniformity in density, strength and colour.

This chapter points out, in brief, the disadvantages of fired and energy-intensive building and construction material systems, but more importantly highlights the properties and benefits of unfired clay-based systems. The author of this chapter has dealt in detail on the subject of durability of compressed earth materials in a recent book (Pacheco et al., 2015). For this reason this chapter will only highlight the key durability aspects of these materials, without having to fully detail the various tests for the determination of durability of clay-based materials.

Clay-based materials are either in fired or unfired forms. In the fired category, the material is mixed with a significant amount of water, and either extruded or moulded in a timber, plastic or steel mould into a regular shape. There are reports of sand moulds also being used (Sutton et al., 2011). Before firing, the cast or extruded bricks or blocks are allowed to condition or dry slightly to reduce the water content, so as to reduce the shrinkage upon firing. Firing of clays not only drives out the free water used in the mixing process, but also any water that is chemically combined or adsorbed in the inter-layers of the clay mineral structure, and the type of interlayer metal cations. The variable amounts of water molecules trapped in the clay microstructure. The firing also goes further to dehydroxylate (removal of –OH group) and/or decarboxylate (removal of CO₂) any carbonates present, and sinters the materials (if temperature is high enough, typically above 1000°C) to a very robust fired product. The loss of free and chemically bound water reduces the swelling potential associated with clay soils. Considering that some soils can exhibit excessive swelling potential as high as 2000%, the firing process is very effective in imparting volume stability to a target clay soil material. The strong bonding reduces the weakening effects of porosity and imparts chemical resistance. Firing is however expensive due to its high energy intensity, and represents about 85% of the energy involved in the manufacture of fired clay-materials (Heath et al., 2009). This is a major problem in both developed and developing countries alike. Figure 2 shows the activities of a community project near Mumias in Western Kenya, that makes hand-made fired bricks.

A visit to the area by the author revealed serious problems of tree cutting to provide firewood for firing bricks, causing significant community tensions due to domestic energy requirements and also environmental issues. This chapter however does not aim to address this category of fired clay-based materials. The aim of the chapter is to address the re-emergence of unfired clay-based materials. These unfired systems, compared to their fired counterparts, have a relatively lower energy consumption due to the absence of the firing process. It is however best to start by addressing the target raw material itself – clay soil.

2. Structure and properties of clay soils

The term “clay” is generally used in two contexts. In the more general context, the term “clay” is used to refer to generally fine-grained loosely bound natural soil material, irrespective of its composition or origin. In the more strict and scientific context, the term “clay” is used to refer not only to the fine-grained nature of a soil material, but also to the presence of certain properties whose origin is traceable to the presence of certain “clay” minerals. In this stricter context, clays are distinguished from other fine-grained soils by both the fine particle size and by their mineralogy. For this reason, other fine-grained soils such as silts that do not have a significant proportion of clay minerals are, strictly speaking, not viewed as clays.

The special and easily observable properties that may suggest presence of clay minerals in a soil are primarily evident when the clay soil is in contact with water. These properties include significant cohesion, shrinkage, and expansive or swelling behaviour. The genesis of these properties is in the microstructure of the clay, and the composition of trace metal cations. The variable amounts of water molecules trapped in the clay mineral structure, and the type of interlayer metal ions combine to result in the familiar clay soil properties.
mentioned, as well as its colour. For this reason, to both soil experts and non-experts, it is well known and established that clays are plastic in the presence of water, become hard, brittle and non-plastic upon drying or firing, and shrink upon drying to show significant cracking. Clay soils can appear in various colours depending on their mineral composition, ranging from deep orange-red to brown to gray to white.

3. Unfired clay materials systems

Unfired clay materials can be formulated using clay without any additional materials, but basic clay-water compaction (mud, cob, sod, adobe, rammed earth etc.). Cementitious binders can be used, with or without the addition of one or more other ingredients. The systems that use only water and natural ingredients obviously have the lowest environmental impact, but unfortunately also offer a narrower range of “utility” as almost all have no significant load-bearing capacity. There is a wide range of possible additives, having varying levels of environmental impact.

4. Clay materials without additives

The most basic historic clay-based materials capitalize on inherent clay properties, in particular its cohesive nature. Simple techniques have merely involved the selection of clay deposits. It is possible to find significant deposits of clay without having to remove any coarse materials. However, clay is a versatile material and this makes it an attractive construction material. It is able to include a significant amount of coarse material while remaining plastic. Traditional houses have been built with clayey silt, clayey sand, and with boulder clay. In its wet plastic form, clay can be molded into a regular shape, usually but not limited to a cuboid form. The regular shape is especially necessary if the wet material is to be sun-dried for later use. Alternatively, the wet material can be placed in either panel formwork as in rammed earth, or in a cage-like open formwork as in traditional huts. The wet cohesive materials sticks together and form a solid irregular mass.

5. Industrial additives

Soils can be strengthened by other unfired processes, such as soil stabilization techniques. When soils are stabilised with lime and/or Portland cement, a colloidal product predominantly comprising of a calcium silicate hydrate (C-S-H) gel is formed, although aluminium phases and traces of iron may also be present. The complex gel gradually changes with time by partially crystalizing, resulting in strength gain in a mechanism very similar to that in Portland cement hydration. The composition of this colloidal product is dependent on material ingredients used: the compounds of calcium, silicon, aluminium and traces of iron coming from the lime or Portland cement used as stabilizer; aluminium and silicon from the soil, and finally the water added for the stabilisation process. This colloidal CaO-Al2O3-SiO2-H2O system is beneficial for strength development although it is prone to ingress of water and other elements. The quantity and long-term development of this colloidal product influences the total porosity, and affects strength and volume stability. The minimization of pores is obviously beneficial to strength in construction materials in general (Benavente et al., 2004; Molina et al., 2011). When well protected, all goes well, and the materials develop significant strength to enable applications in roads, foundations, bricks, blocks and other products of soil-stabilisation. Compared with the behavior of the raw soils, the stabilized materials show little of no expansion potential upon stabilization, unless there are other deleterious mechanisms at play, such as the presence of sulphates in the system.

Depending on the prevailing environment, for both soil- and cement-based systems, the hydration products from lime and/or Portland cement (i.e. complex C-A-S-H gels) are prone to attack in aggressive solutions (O’Farrel et al., 1999, 2000; Beaudoin et al., 2001; Kinuthia et al., 2003; Snelson and Kinuthia, 2010; Wild et al., 1996, 1998, 1999, Miqueleiz et al., 2012; McCarthy et al., 2014). Such deleterious mechanisms may exist when the target clays for stabilization contain certain compounds, such as sulphates (Kinuthia et al., 1999; Kinuthia and Wild, 2001; Higgins et al., 1998, 2002). The sulphates may also emanate from other sources such as deicing salts, or underground water movements caused by either natural flows and/or artificial occurrences. Examples include situations such as broken effluent pipes, especially from industrial developments with resultant liquid or soluble solid wastes containing sulphate or other chemicals and compounds. The deleterious effects of these reactions can be mitigated or eliminated altogether by using some industrial waste and by-product materials as will be seen in next section.

Due to various forces such as pursuance of environmental care, low cost, technological advances and/or other drivers, there is no longer what may be considered conventional or classical materials for clay masonry. Changes have been encountered with either the materials used and/or their use in non-classical applications. For this reason, marginal natural materials that have hitherto not been considered in building and construction have become viable. The use of marginal naturally occurring materials does not however attract much attention compared with the use of industrial and agricultural waste streams, primarily because of the negative environmental impact of these waste and by-product materials. A few examples will now be discussed.

Ground Granulated Blastfurnace Slag (GGBS): This is an industrial by-product material that results from the manufacture of steel from iron ore in a blastfurnace. The material has successfully been applied in the concrete industry, where it results in reduced use of Portland cement, an energy-intensive material with a significant negative environmental impact. Use of GGBS also results in improved durability in concrete. The material has had very little impact in masonry until in recent times. Figure 4 shows higher compressive strength values being obtained using formulations containing GGBS, as long as there
is significant lime to activate the slag. Kimmeridge clay is a sulphate-bearing stiff clay from Oxfordshire in UK which has been very difficult to stabilise using lime alone. Figures 4a and 4b suggest best stabilisation of this difficult soil using a total stabiliser content of at least 6%, and $0.5 < \text{slag/lime ratio} < 2$. Considering that slag is a by-product material that is in most cases less expensive relative to lime or Portland cement, there are benefits to using a blended binder that results in the use of reduced amounts of traditional binders in masonry. The optimal slag/lime ratio changes to unity with higher levels of slag, for clay soils with little or no sulphate, thus increasing profitability. This is demonstrated in Figure 4, where the non-sulphate-bearing kaolinite is stabilised with Lime-GGBS blends, with and without artificially dosing the kaolinite with small amounts of sulphate (gypsum).

The successful stabilisation of both sulphate and non-sulphate bearing clay soils using lime-GGBS blends can be exploited for clay-based building materials. This has been demonstrated by various researchers in partnership with the author. (Kinuthia et al., 1999; Wild et al., 1996, 1998, 1999; Kinuthia and Oti, 2012; Oti and Kinuthia, 2012; Oti et al., 2008a, b; 2010a, b, c, d), who have also demonstrated the significant reduction in swelling potential in lime-stabilised clay soils by gradually replacing the lime used in the stabilisation process with GGBS.

The significance of this outcome is further demonstrated in Figure 5, which shows unfired building bricks made with a sulphate-bearing clay soil (Lower Oxford Clay in the United Kingdom), stabilised using blended binder comprising of lime and GGBS.

Using industrial by-products in a sustainable manner so as to achieve robust clay-material systems obviates the brick firing process and also reduces the use of traditional binders of lime or PC. The bricks shown in Figure 5 were made during a pilot industrial trial at Hanson Brick Company Ltd. at their fired clay brick plant at Stewartby, in Bedfordshire. Hanson Brick Company Ltd. is one of the largest manufacturers of the well-known fired clay “London” brick in the UK. The company’s mould was used in the trials for the bricks shown in Figure 5. The unfired bricks have proven to be very robust, and have shown phenomenal resistance to repeated freezing and thawing (Oti et al., 2010c), which is one of the most severe tests for durability of both soil- and cement-based materials.

Pulverized Fuel Ash (PFA): For many years, coal has been a dominant source of energy worldwide. The waste from this industry ranges from unusable mining debris, collectively referred to in various terms such as coal waste, colliery spoil, colliery waste, coal mining waste, coal mine tailings, and possibly other terms, to the usable pulverized fuel ash (PFA) which results from the burning of coal as a fuel. The burnt waste is predominantly the fine particulate material collected from the flue gasses, mainly by electrostatic precipitation. It is commonly referred to as fly ash (FA) in America and other places, or as pulverized fuel ash (PFA) in the United Kingdom and some parts of Europe and beyond. There is also the relatively coarser waste referred to as bottom ash (BA). As the name suggests, BA is collected from the bottom of the coal burning boilers. Although PFA’s classical application is in concrete
where the benefits include enhanced workability, reduction in the amount of Portland cement used, improved later strength, enhanced durability such as increased resistance to sulphate and chloride forms of attack, its use in clay masonry is not very widespread. As with GGBS, it has been demonstrated that PFA can also be used in the manufacture of durable clay-based masonry (Rahmat et al., 2011, McCarthy et al., 2014).

Wastepaper Sludge Ash (WSA: Most paper is coated with clay and limestone to create smooth surfaces to write on. When the paper is then recycled, the clay and the limestone remains in the sludge from which the recyclable cellulose fibrous material is removed during recycling. When this sludge is combusted to reduce volume of waste going to landfill, the clay and limestone are heated in the process, undergoing more or less a similar heating process as Portland cement, albeit at lower temperatures. Thus, WSA possesses appreciable and useful cementitious potential.

Successful development of a novel cement utilizing wastepaper ash and blastfurnace slag has been reported by Nidzam and Kinuthia (2010, 2011a, 2011b). The cement was developed by combining an industrial waste (WSA) with a by-product material (GGBS) for replacement of Portland cement. This has enabled the development of ‘green’ cement for masonry. This cement has performed very well in terms of strength and durability, and sometimes better in terms of appearance compared with the traditional Portland cement. Besides strength development (Nidzam and Kinuthia (2010, 2011a, 2011b)), Figure 7 shows that it was also possible to successfully suppress swelling potential by using WSA-GGBS blended binder on the expansive Lower Oxford clay used in demonstration projects earlier.

Similar approaches are possible elsewhere, using waste and/or by-product materials that are available in significant quantities, including agricultural waste. Other examples of commonly encountered industrial waste and by-product materials that have applicability in unfired systems in both soil- and cement-based building and construction materials and components include waste glass (Chidiac and Mihaljevic, 2011); waste tyres (Snelson et al., 2009); shale, slate, colliery waste and other forms of recycled aggregates (Baojin et al., 2013; Bryson et al., 2012; Corinaldesi, 2009; Debieb et al., 2010; Kinuthia et al., 2009; Oti et al., 2010e, 2010f;); and brick dust (O’Farrell et al., 1999, 2000; Kinuthia and Nidzam, 2011). The research work involving the utilization of waste materials is advanced, and involves observation of different parameters and informed balancing to optimize performance. In this regard, after observing enhanced strength upon stabilizing clay with a waste-based binder such as WSA, the next step was to establish the volume stability as shown in Figure 7.

Once satisfied with all the parameters, pilot and full scale trials demonstrated the full realization of success. The whole journey from ‘cradle to grave’ requires a multi-disciplinary approach, with key stakeholders and players from research, laboratory, field and the entire procurement chain including government. Significant patience is also required, so as to overcome the many hurdles of research and product development and its many frustrations. The reported pilot trials, and as will be seen later in the remaining sections of this chapter some clay-based materials, have gone through such a process and full-scale factory production of clay-based materials is on the increase.

Figure 7 – Significant reduction in linear expansion by the combined use of Wastepaper Sludge Ash (WSA) and Ground Granulated Blastfurnace Slag (GGBS) in the stabilization of an expansive sulphate-bearing clay soil.

6. Agricultural additives

For most countries, many major industrial activities are directly or indirectly related to agriculture. For these countries, any major breakthrough in the development of sustainable infrastructure cannot afford to ignore waste from the agricultural sector. The author has been brainstorming on this agenda, in liaison with like-minded co-workers for some time. Initial focus has been in activities that produce large agricultural waste streams, including the growing of palm oil and sugarcane (Mofor et al., 2009), rice (Billong et al., 2011), and of fibrous materials for fibre-based soil-cement blocks – bagasse, straw, kenaf, bamboo, jute, com, durian (Khedari et al., 2005). In Cameroon, inspired researchers at the Mission de Promotion des Materiaux Locaux (MIPROMALO) – a local materials promotion authority – based in Yaoundé have provided valuable collaborative support. In Kenya, initial collaboration has been with local higher education institutions as well as with environmentally conscious local industries and environmental lobby groups, particularly those in the agricultural sector. In both Kenya and Cameroon, the initial focus has been in sectors that produce large agricultural waste streams, including the palm oil industry in Cameroon, and the sugarcane industry in Kenya.
Enthused by the success of UK-based research into the utilization of waste materials in the development of sustainable civil engineering infrastructure, scoping studies have been carried out to establish the key waste streams in Kenya and Cameroon. The findings in these two African countries are very typical of many other developing countries, in terms of the socio-economic stature and practices, level of technology, need for basic infrastructure and also commonality in future aspirations.

There is acute shortage of cement in many developing countries. For this reason, the use of fine particulate wastes in cementitious systems by way of replacement of Portland Cement (PC) has been a common option for many researchers. This has lead to interest in the use of agricultural waste in civil engineering construction. In the more advanced cases, after utilising the agricultural waste in electric power generation, the secondary waste produced is fine-particulate or agglomerated ash. With determination, persistence and combined synergies with equally committed peers of varied backgrounds and expertise, these ashes can be exploited for building and construction materials.

Traditionally the high volume changes observed in building materials made with clay-systems have been mitigated by enhancing tensile strength by incorporating fibrous constituents (Moropoulou, et al., 2005; Khedari, et al., 2005). This is an old technology, and unfired bricks have been strengthened with straw in practices that are centuries old. However, the research and full-scale commercial application of masonry products made incorporating agricultural materials and agricultural waste and by-products is in its formative years. Most research groups have only managed to demonstrate potential. Preliminary work on bagasse ash from the growing of sugarcane by Mofor et al., (2009) has demonstrated possible potential savings in Portland Cement of about 50% and there is also potential for clay-based materials using this waste material.

### 7. Construction using clay-based systems

The increased use of clay-based materials in building and construction has challenging practical implications, relative to cement-based materials, at all stages of their use. Undertaking research in clay-based materials is also challenging, due to low strength and variability in other performance characteristics. There are also equal if not more difficult challenges to execute research findings into practice, at various stages of infrastructure development – materials manufacture or formation, storage, construction and eventually on their durability.

#### 7.1 Formation

Unfired clay systems may be formulated in the same manner as fired systems, the only difference being the firing process. Heath et al (2009), for example, undertook research work on unfired clay systems by starting with wet extruded bricks that were originally meant for firing. An alternative process to extrusion is the use of a purpose made moulds. For fired bricks, the extruded or wet moulded material is allowed to condition to reduce the excess moisture prior to firing. The moisture conditioning has been observed to minimize volume changes upon firing so as to maintain shape, volume and dimensional stability. After this conditioning, systems meant to be used in unfired applications may be allowed to dry further (Heath et al., 2009). This approach is sometimes unsuitable for unfired systems due to the excessive water content used, and most unfired systems are designed to contain less water from the start, by compacting in a semi-dry state. This results in denser and stronger material. In the absence of additives such as stabilizers (lime, Portland cement or any other emergent stabilizers), the control of moisture is less restrictive. However, with hydraulic stabilizers, especially Portland cement, careful control of the amount of water used is essential.

Ability to handle the freshly made unfired clay materials is critical, for both manual and automated production (see Figure 8a). The automated handling is the more critical one, as massive losses can be incurred if larger production batches are damaged during early movement. In order to minimize breakage, most unfired clay-based materials have rounded or chamfered edges, unlike their fired or cement-based counterparts (see Figure 8b).

![Figure 8](image)

**Figure 8 – Unfired brick illustrating (a) Possible automated production, with likelihood of edge breakage (Bricks produced by author during trials at P D Edenhall concrete brick plant at Bridgend, South Wales, United Kingdom; (b) Rounded or chamfered edges ready for use in clay-based construction**
7.2 Storage

Storage of unfired clay products is also critical, as heavy losses can be incurred if the material is left unprotected during storage. For this reason, unfired clay materials, without exception, are routinely protected in some manner during storage, no matter how ineffective the protection might be as shown in Figure 9. This extra care continues to be critical during service life, depending on the type of use. As most unfired systems are used for either internal walling or inner leafs in outer walls (Birch, 2005, McGregor et al., 2014), the more critical care is during the storage prior to, and during, construction.

Figure 9 – Protection of cement-stabilized (unfired) clay bricks at a community brick project (co-operative) in Kenya (please note grass cover on pile, to reduce effect of rain).

7.3 Construction

Experience with large-scale factory-type production of unfired clay-based materials is rare and quite recent. During automated production, the control of compaction moisture content, the handleability of the freshly compacted product, the care needed during early transport to storage/curing yard, the subsequent and continued care during loading on trucks all pose problems. The significant product losses during transport and during construction have all discouraged large-scale investment.

In recent times, clay-materials and environmental enthusiasts have faced these problems head on, so as to address the emerging environmental, aesthetic and inherent passive advantages of clay-based materials. This has started to stimulate growth and market in unfired clay-based materials and their acceptance in construction. Heavy losses continue to be incurred during construction but better understanding of the handling, care and use of these materials will ensure that losses remain minimal as may be noted in Figure 10. Production of unfired clay materials in most developing countries has predominantly remained manual. In both developed and developing countries, there is a slow shift from individual or single applications to larger materials consumption as in local housing projects. The next few decades are likely to witness more research and application of clay-based materials in large housing and construction projects. Achievement of good workmanship is not limited to developed countries, and this can be achieved irrespective of country as shown earlier in Figure 1 for rammed earth in Wales, United Kingdom, and also on a large scale housing project in Cameroon as shown in Figure 10.

Figure 10 – Low-cost housing using locally available materials (unfired bricks) and labour in Cameroon illustrating impressive workmanship and minimal material losses during construction.

Innovation in the use of unfired clay materials has already been demonstrated in uses as varied as rammed earth, clay bricks, and clay blocks, stabilized in various ways ranging from use of traditional stabilizers such as lime and/or Portland cement, and/or in combination with other natural, industrial or agricultural waste streams. Innovation can also take the form of block shape and type of application of the materials, such as that demonstrated by an interlocking and also curved block shown in Figure 11a. When curved, the blocks can be used for the construction of circular houses and/or of water tanks as illustrated in Figure 11b. The interlocking block can also be used in the normal construction of buildings (usually without curvature). The blocks are typically made using cement-stabilized clayey soil, and their use in water-retaining structures demonstrate the durability and robustness of the resulting material if well constructed and protected.

7.4 Durability of unfired clay materials

The analysis of the influence of the material ingredients that constitute unfired clay systems, together with the prevailing environmental condition, has suggested that it is very important that the limits of applicability and care during service are critical considerations. Unfired clay systems stand little chance in flooding situations. Therefore, clay systems exposed to the elements demand far higher expectations in terms of robustness compared to those used for internal walls or other protected environments (Dias et al., 2014; Janssen et al., 2012; Obuzor et al., 2011a, b, 2012). On the other hand, the level of
care during service is also critical. Careful maintenance regimes are recommended for any unfired clay system. Biological actions including micro-organism and plant growth thrive in damp conditions, particularly moulds and fungi. Other effects such as torn or inelastic sealants, cracked pointing mortar, blocked weep holes, standing water, missing damp-proofing, worn coatings, among other critical factors are key concerns.

Figure 11 – Innovative manufacture and applications of unfired clay materials. The curved blocks have been used for the construction of water tanks.

Mitigating or remedial steps together with a strict adherence to manufacturer recommendations (Kelman and Spence, 2004) should be taken as early as possible. To prevent the biological actions mentioned, thorough disinfecting of wet zones is necessary to prevent mould growth. In case of problems, a thorough problem analysis is necessary before any remedial action is taken. Covering problems (for example cracks or loose material with render or other cover only serves to delay, and exacerbate the problem, leading to more expensive remedial measures later. In addition, expert help may sometimes be necessary, as inappropriate remedy or workmanship can appear an attractive repair and maintenance option but may have consequences at a later date, including serious ones such as loss of life.

For a long time, compressive strength has been used by many users as an indicator of durability. While to some degree this does reflect possible outcome during service life, it has also been established in both soil- and cement-based materials that strength alone is only one of the many factors determining durability. In concrete and unfired clay systems for example, tests involving ingress of water and chemicals, especially for applications of concrete in either marine or buried environments, form among the most severe test environments under which durability of concrete may be assessed. For unfired clay systems such as compressed earth, absorption of water has a significant influence on the durability, with and without the presence of any dissolved chemicals. For this reason, applications of buried unfired clay materials are extremely rare. Water absorption capacity tests are therefore very strong indicators of durability. Indeed, all the common tests for durability of compressed earth units are water-based or related. A detailed analysis of the durability of compressed earth units is covered by the author in Chapter 17 of Pacheco et al. (2015).

8. Future trends

There is an observable increase in the researched use of compressed earth masonry units. These units are increasingly being seen as industrialized materials, and no longer considered as only appropriate or applicable to traditional approaches for self-construction (Cid-Falceto et. al., 2012). Many examples exist of the increasing use of industrial and agricultural waste, and by-product materials in compressed earth masonry, and it is not possible to cover or quote them all here. However, a brief survey of the materials, techniques and applications of today’s masonry suggests a thriving on-going research and innovation-lead development of compressed earth masonry technology. There is also a gradual shift from the traditional fired clay masonry categories to unfired categories. While the fired categories adopted a blanket approach of firing clay irrespective of clay composition, there is a far wider variety of material selection and technology adopted for the unfired masonry category. This is because the durability imparted by the firing process is harder to mimic or achieve in unfired systems, resulting in the pursuance of alternative approaches to materials usage to include industrial and agricultural waste and by-product materials. There is also increasing use of synthetic (industrial) and natural fibres for reinforcement, chemical cementation, attention to particle matrix configurations and variable and careful selection of applicability scenarios. Fortunately, as mentioned earlier, there is also a gradual shift in emphasis from a blanket stipulation of standard properties and material expectations, relying rather on recommendations by the manufacturer for the appropriate usage, and also for the possible consequences of lack of adherence, by the end user, to these recommendations. The future will therefore most likely witness enhanced end user sensitivity to global changes in materials, technology and material failure mechanisms, and better or closer liaison with material manufacturers, coupled with a keen(er) awareness of relevant government policies, guidance and legislation. This development or trend is likely to enhance reliance on compressed earth masonry, and it is
hoped that mortgage lenders and insurance industries will be quick to respond to the fast changing landscape, resulting in an ever increasing adaptation of compressed earth masonry in future social and commercial housing. This scenario suggests an urgent need for a near universal harmonization, consensus building and characterization and/or classification of compressed earth-based building and construction materials, taking into account the wide range of materials and variable manufacturing methodologies likely to be encountered. In terms of further research work needed, tests on durability need to be well delineated, with those for fired systems adopting considerations that suit fired systems separate from those best suited for unfired systems. Those for unfired systems need in turn to differentiate between stabilized and non-stabilised compressed earth systems. Both test categories should embrace and embed the indicative tests of compressive strength and water absorption. The more severe cyclic freeze-thaw and wet-dry tests should be more in reference to stabilized systems, while the water spray and drip test methodologies being in specific reference to unstabilized systems. This task is beyond the remit intended for this chapter, but the chapter has managed to raise most of the factors that determine the durability of compressed earth units.

References


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