West Africa Built Environment Research (WABER) Conference
WABER 2021 Conference, 9-11 August 2021, Accra, Ghana
Proceedings Edited by Laryea, S. and Essah, E.
ISBN 978-0-620-95367-2

WATER ABSORPTION QUALITY OF CLAY BRICKS MADE BY EMERGING MANUFACTURERS IN SOUTH AFRICA

Bonga PraiseGod Khuzwayo[1]
Department of Civil Engineering and Geomatics, Durban University of Technology, South Africa

Masonry walling comprising clay units in South Africa is required to comply with SANS227, in addition to other South African National Standards. The water absorption quality of clay masonry is an important characteristic since it determines the flexural strength of masonry walls. The prevalence of substandard materials and the inability to enforce construction standards by statutory bodies and the existing legislation in South Africa (SA) creates a breach between the intentions of the designer and what can be achieved physically on site. Two sites in Qwaqwa and Newcastle, South Africa, where clay bricks are manufactured by the community, were identified. From these sites, 11 samples of each unit type, namely; low (11 number off) and high (11 number off) burnt units were purchased from each site over a 12-month period. These samples were newly made clay bricks. A total of 264 units per site (11 units x 2 types x 12 months) were purchased from developing/local entrepreneurs/manufacturers, for testing for the water absorption quality. Considering only the manufacturing site and the water absorption of brick purchased from them, they produced the following results: (1) Qwaqwa had 27.3% with a standard deviation of 6.6; (2) Madadeni had 34.3% with a standard deviation of 9.6. In view of the site only and with respect to the brick type, the investigation yielded the following means: (1) Qwaqwa had 32.2% with a standard deviation of 7.5 which means that the data is more spread out; (2) Madadeni had 29.4% with a standard deviation of 10.1, which means that the data is more spread out. Even though hard burnt has a slightly higher value than low burnt, the difference in the water absorption is not significant ($p = 0.287$). Besides the water absorption quality being far above the recommended range of between 12% and 20%, the water quality varies significantly. Citizens who purchase clay bricks for the construction of their homes have little or no knowledge of the hidden water absorption quality problem which significantly affects the flexural strength of structural elements, such as cantilevered masonry retaining walls and walls required to have flexural strength. The South African Bureau of Standards must enforce good quality of clay bricks made by emerging manufacturers in South Africa.

Keywords: clay bricks; flexural strength, masonry walling, water absorption quality

INTRODUCTION

Stiff, sticky, fine-grained soil, such as clay, is molded when wet, dried and baked to make masonry units such as bricks and blocks, pottery and/or other ceramic items. They consist of extremely fine particles, making them immensely flexible when wet.

[1] bongak@dut.ac.za

'Brick 'as a term, covers an extensive number of products produced through the mixture of clay, composing and shaping it, before drying it slowly and then baking it, in an oven or fire source. Mineralogical and textural fluctuations transpire as the temperature increases (Cultrone and Sebastián, 2009). Clay units are the most popular building material in the construction industry, having been used for over a thousand years (Al-Sibahy and Edwards, 2017). However, according to tests done on prehistoric fired bricks and pottery remains in kiln-like structures from the Middle Neolithic archaeological site of Xinjie in Shaanxi Province, in China, the construction of clay bricks in East Asia started about 5000-5300 years ago, which seems earlier than initially assumed. The sporadic occurrence of different size fired clay bricks suggests that it was not until the Qin Dynasty that bricks, made with locally available loess, were widespread (Yang et al., 2014).

There are other types of masonry units manufactured, using various materials and techniques, such as adobe. This is an earth brick/block indigenously made using natural soil and fibre materials. It is widely utilised in developing countries, such as China, India, Iran, Turkey and Botswana (Wu et al., 2013). In fact, China has been using adobe to build houses from as early as the Shang dynasty (1500 -1000 B.C.), showing that adobes have been utilised in the construction industry for thousands of years. Earth brick/block construction is commonly found in less-developed countries where it is often used to imitate sturdier structures using unreliable building materials. The use of adobe is associated with low income status. The existence of earth brick construction dates from the early agricultural societies that existed, according to our present understanding, from around 12,000 to 7000 BC. Although this material is associated with low income status, it is also found in developed countries, where there is a growing consciousness of the significance of earth construction (Pacheco-Torgal and Jalali, 2012).

Clay bricks are utilised for various purposes ranging from residential, and commercial to public buildings (Molnár and Larsson Ivanov, 2016). Their core function is that of walling up a building to provide usable safe and comfortable space. Masonry walls are made up of arranged bricks/blocks that are attached to each other through a mortar bed and head joints (Noor-E-Khuda and Albermani, 2019). Burned clay bricks are common in South Africa and are used as reinforced or unreinforced walling, with unreinforced being popular. Unreinforced masonry walls can be used as both structural and non-structural walls in the construction industry (Li et al., 2017). Clay bricks are required/expected to have a water absorption capacity of 12% to 20%. However, 12% has been proven to be the ideal water absorption capacity when using engineering units (The Clay Brick Association of Southern Africa, 2021). An adequate bonding between clay units and mortar is needed to execute a design, safely, depending on the flexural strength (Rao et al., 1996). Tests have shown that moisture affects mechanical properties of brick, mortar and masonry, notably decreasing the compressive strength of a brick and cement mortar. Some of the attributes that make clay units common, in addition to their better performance when compared to other construction materials, include compressive strength, durability, thermal and acoustic insulation, fire insulation and classical appearance.

Clay units are believed to provide employment opportunities for both skilled and unskilled labour, which makes them popular in countries with developing

economies. Their excellent thermal mass affords them the ability to absorb mass-energy during the day and to release it at night, smoothing the high-temperature variations (Al-Sanea et al., 2013). This is important because over 30% of primary energy is consumed by structures to preserve their indoor temperature, which changes due to heating and cooling loses (Rashid et al., 2019). The construction industry is known to provide many employment opportunities for both experienced and inexperienced, professional and unprofessional individuals (Marglin, 2017). With the ever-increasing demand for construction work, some individuals have identified new business opportunities, while others have tried to produce some of the materials themselves. It is for this reason there is a surge in people working at the micro, small and medium to large operations making construction materials such as clay bricks. However, understanding is needed as to how the construction industry is supposed to function with regard to providing good-quality materials which includes the role they play in legislation compliance, in the provision of safe structural environments and quality systems. The majority of manufacturers do not possess the required knowledge and skills, which has resulted in the production of poor-quality clay units. South Africa is no different from other countries such as Zimbabwe, as indicated in Figure 1 taken by the first author during an exploratory study in SADC countries.



Figure 1. Manufacturers of clay bricks in Zimbabwe

Manufacturing construction clay materials, such as bricks, tiles and blocks, by firing is the most beneficial method in the industry when compared to other methods such as cementing, and this, it is believed, will last for the next two decades (Monteiro and Vieira, 2014). The core challenge for the masonry industry is the shortage of skilled artisans that are capable of providing quality construction work (Bosiljkov et al., 2010). Furthermore, the quality of materials and production procedures are compromised by manufacturers who do not comply and use substandard materials (Day, 2011).

LITERATURE REVIEW

Bricks are divided into two types: material-oriented and process-oriented bricks. The process of producing clay bricks consumes enormous amounts of energy whilst producing a significant carbon footprint, as it involves firing. On the other hand there are cement products such as cement bricks (and blocks) which also face challenges. Future research in the construction of bricks faces a challenge of skepticism towards innovative bricks, as cement and lime-based calcium-silicate-

hydrate bricks have proven to be unsustainable (Zhang et al., 2018). The majority of low-cost and original construction materials (such as unburned clay bricks) have been shown to be interestingly low on carbon, easily accessible, and less waste-handling issues (Nordby and Shea, 2013). With respect to burnt bricks, the kiln firing, where the ultimate properties of the brick are achieved, is regarded as a highly complex process in brick making. However, the drying process has also presented its own set of composite processes and problems that prove difficult for the operator to control, making it equally complex in firing. Drying has proven to cause defects that cannot be fixed by firing (Slevin and Whalen, 1998).

Mechanical behaviour of the bricks manufactured by old-style technologies using high-temperature exposure depends on the quality of the firing. The high porosity and low density of bricks from traditional technologies induce low thermal conductivities which limits the effects of heat on the material. Such low quality bricks should be used as siding and filling elements in structures and they are not suitable for structural purposes (Bidoung et al., 2016). Clay bricks consume an enormous amount of clay, which contributes to environmental degradation, as large amounts of clay soil have to be mined. The mining process affects the soil and vegetation, thus when done carelessly/excessively without rehabilitation steps being taken, soil erosion is the result (Santhosh et al., 2013). Many regions in the world have limited natural resource material for producing the traditional bricks, which presents a threat to the environment and to sustainable development (Zhang, 2013).

The bond strength is greatly affected by the water absorption of the brick components and mortar paste during construction. Moisture curing of the wall after construction also affects the strength. This was demonstrated by undertaking, in-plane shear and out-of-plane bending tests conducted on multiple brick wallets and infills, built with different pre- and post-construction moisture conditions (Maheri et al., 2011). It may be assumed that values of bond strength quality are directly influenced by compression strength but bond strength has proven to be closely related to the coarseness of the substrate, the petrographic features of the stone, the water absorption of the substrate, and to the grout applied (Luso and Lourenço, 2017). The strength of the mortar mix is important as it affects the strength of structural elements made of masonry. To give an example, the utmost strength or moment-carrying capacity of a masonry beam is greatly affected by the strength of the grout, verified by the sensitivity analysis (Zohreh Heydariha et al., 2017). The design of walls made with clay units, however, is different. Designers prioritise specifications for the water absorption, deemed critical in this case, as the bond mechanism between clay bricks and mortar yields dissimilar flexural strengths for numerous types of mortar class (Crofts and Lane, 2011). This is indicated in Figure 2 of the South African Bureau of Standards (1980).

The activities that are crucial in the design and execution of the construction are the accurate specifications and suitable measures for the total resistance-capacity increase of the masonry structural element (Juhásová et al., 2008). The poor performance of non-structural components, such as chimneys and balustrades, compromise the protection of occupiers in slightly damaged buildings mainly in historical centres, thus stressing the importance of detailed designs (Penna et al., 2014).

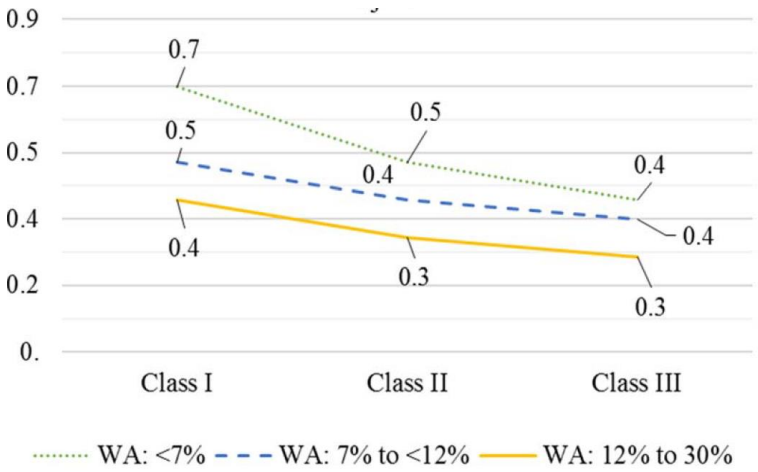


Figure 2. Characteristic flexural strength of clay units, fkx, in MPa for plane of failure parallel to bed joint

Natural materials like clay do not always meet the technical demands (Maubec et al., 2017). There are distinct clay soils comprising distinct kinds of clay minerals (Ouhadi et al., 2006). The conduct of clay soils relies heavily on the type of clay minerals included (Hamidi and Marandi, 2018). Quantitative mineral assessment of clay soils is a key step in ensuring accurate soil recognition and behaviour (Ouhadi and Yong, 2003). This is rarely practised by local unskilled clay brick producers. This presents difficulties to come even close to complying with technical requirements of clay bricks and ensuring consistent performance. The deposits of clay are created over several decades and contain a combination of several minerals of distinct grain sizes (Muñoz Velasco et al., 2014). The mineralogy of the clay products also influences the characteristics of their water retention (Ajayi and Horn, 2016).

Although the production of unfired clay bricks is relatively simple, the type and quantity of additives used, the optimum water absorption to maximise the compaction effort and the achievable dry density, must be carefully determined in order to achieve maximum strength and durability (Miqueleiz et al., 2012). Consequently, the clay fraction and plasticity index are unreliable indicators of the susceptibility to liquefaction of cohesive soils without taking into account the clay mineralogy and its distinct adhesive bond strength on the boundary layers (Tosti et al., 2013). It is these characteristics that contribute to the legendary unreliability of clay bricks made using even properly tested mined clay in terms of technical criteria such as compressive strength and water absorption quality.

The literature reviewed indicates that the physical properties of clay bricks significantly affects the of design performance of brick walls subjected to bending. Water absorption is the focus of this study and it is directly related to the bond strength. It is, therefore, important to understand how each factor contributes to another in order to provide a good-quality structural system. Although the excessive mining of clay to make clay masonry has far-reaching consequences for the environment, a lesser case scenario is that of obtaining good-quality clay masonry walls rather than both defective masonry walls and a degraded environment.

METHODOLOGY

The researcher identified two sites in Qwaqwa and Newcastle, South Africa, where clay bricks are manufactured by the community. From these sites, 11 samples of each unit type (low and high burnt units) were received from each location for a 12-month period. These samples were newly made clay bricks. There was a total of 264 bricks (11 units x 2 types, low and high burnt x 12 months) obtained from each site operated by developing entrepreneurs/ manufacturers. This yielded a total of 528 specimen tested from two (2) sites. The samples were tested for the water absorption quality. Conducting the test needed three (3) tools, as laid out in Clause 6.9 of the South African National Standard 227. These tools are: a forced-draught drying kiln capable of maintaining a temperature of at least 105 ºC; a lidded heating tank with a grid at the bottom to allow circulation of water all around the units; and a balance able to measure the mass of units to an accuracy of 0.1%. In this process, elements are dried in a kiln at a minimum temperature of 105 °C until the achievement of a constant mass (m1). The samples are dipped in clean water for 24 hours in a constant room temperature of 24-25°C.

The samples are then removed from the water, wiped with a wet cloth, with the mass (m2) measured immediately. After 24 hours of the immersion test, the samples are put in a grid inside a tank. The samples are then subjected to a 5-hour test where the temperature of the water is increased to boiling point for over a one-hour period and preserved at boiling point for 5 hours. The samples are kept in the tank without draining the water and left for 16-19 hours to cool off naturally. After this period, the specimens are removed from the water, wiped with a wet cloth before the mass (m3) is measured. The water absorption capacity of the specimens is then calculated according to Clause 6.9.4 (South African National Standard, 2007), namely: a) Calculate the cold water absorption of each unit (24 h cold water absorption, %(m/m) = (m2 – m1)/m1 × 100) and then calculate the average of the units; b) Calculate the boiling water absorption of each unit (5 h boiling water absorption, %(m/m) = (m3 – m1)/m1 × 100) and then calculate the average of the units; c) Record the individual results to the nearest 0,01 % and the average result to the nearest 0,1 %; d) Calculate the saturation coefficient of each unit (saturation coefficient = 24 h cold water absorption,%(m/m)/5 h boiling water absorption,%(m/m)) and record the individual results and the maximum result to the nearest 0,01 %. The two sites (Figure 3 and 4) were selected because they are open to the public to quarry clay and transform it to usable building material such as clay bricks and easy to drive to for purchasing clay bricks towards the end of each month.





Figure 3. (Left) Madadeni and Figure 4. (Right) Qwaqwa clay bricks manufacturers

Apparatuses used to conduct experiments are depicted in Figure 5, 6 and 7.

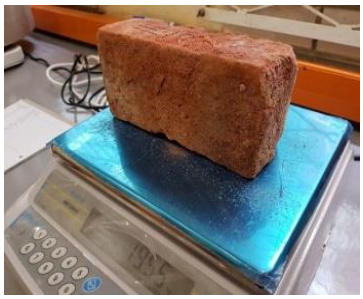


Figure 5. Scale used to measure the mass of clay bricks



Figure 6. Pot used to boil clay bricks



Figure 7. Oven used to dry clay bricks

A significance test, which is the act of comparing observable data to a claim (also known as a hypothesis) whose veracity is being assessed, was omitted from the research since it lacked a hypothesis and was purely exploratory in nature. Additionally, no experimental soil samples were taken because it was determined during the study's preparation that no samples, with consistent geological materials, would be obtained over a 12-month period because the area where the mine is quarried can vary significantly, even during a month of clay brick production. This means that the experimental soil samples will yield insignificant findings.

FINDINGS AND DISCUSSION

Table 1 (Qwaqwa) and Table 2 (Madadeni) provide average moisture contents. The trial began in February 2017 and concluded in January 2018. Although water absorption rates over 30% are considerably too high, they were tested since the public continues to purchase those bricks.

Table 1 Qwaqwa

Brick Type	Month	Average mass (g)	Final Moisture (%) content of 11 clay bricks	Less than 7 %	7 % up to but not including 12 %	12 % to 30 %	More than 30%
Hard Burnt	February	2278	21.7	-	-	POOR	-
	March	2270	23.6	-	-	POOR	-
	April	2196	32.3	-	-	-	REJECT
	May	2107	38.4	-	-	-	REJECT
	June	2227	26.1	-	-	POOR	-
	July	2209	31.1	-	-	-	REJECT
	August	2175	29.0	-	-	POOR	-
	September	2236	30.0	-	-	-	REJECT
	October	2279	31.5	-	-	-	REJECT
	November	2198	36.0	-	-	-	REJECT
	December	2275	27.1	-	-	POOR	-
	January	2168	35.5	-	-	-	REJECT
Low Burnt	February	2421	22.8	-	-	POOR	-
	March	2467	20.6	-	-	POOR	-
	April	2467	16.3	-	-	POOR	-
	May	2375	24.8	-	-	POOR	-
	June	2203	35.0	-	-	-	REJECT
	July	2498	20.0	-	-	POOR	-
	August	2379	25.8	-	-	POOR	-
	September	2137	35.3	-	-	-	REJECT
	October	2495	16.0	-	-	POOR	-
	November	2387	24.7	-	-	POOR	-
	December	2267	32.1	-	-	-	REJECT
	January	2446	18.3	-	-	POOR	-

Various combinations relating to the water absorption and site, type of brick and month were analysed. Considering only the manufacturing site and the water absorption of brick purchased from them, they produced the following results: (1) Qwaqwa had 27.3% with a standard deviation of 6.6, which means that the data was more spread out; (2) Madadeni had 34.3% with a standard deviation of 9.6 which also means that the data was more spread out. There is a significant difference in the mean water absorption by site ($p = 0.005$). It is no surprise because there are distinct clay soils that contain various types of clay minerals. The conduct of clay soils is highly dependent on the included type of clay minerals. Quantitative mineral evaluation of clay soils is a crucial step in ensuring correct identification and behavior of soils. The partial eta squared value ($\eta 2 = 0.162$) also confirms that the site does play a significant role with respect to the water absorption ($\eta 2 > 0.14$ implies a large effect).

Table 2 Madadeni

Brick Type	Month	Average mass (g)	Final Moisture (%) content of 11 clay bricks	Less than 7 %	7 % up to but not including 12 %	12 % to 30 %	More than 30%
Light Burnt	January	1972	28.3	-	-	POOR	-
	February	1980	33.0	-	-	-	REJECT
	March	2198	25.9	-	-	POOR	-
	April	2098	31.6	-	-	-	REJECT
	May	2154	24.4	-	-	POOR	-
	June	2008	44.7	-	-	-	REJECT
	July	2196	27.8	-	-	POOR	-
	August	2108	31.3	-	-	-	REJECT
	September	2106	29.8	-	-	POOR	-
	October	2179	33.4	-	-	-	REJECT
	November	1975	45.2	-	-	-	REJECT
	December	1869	54.5	-	-	-	REJECT
Hard Burnt	January	2078	22.6	-	-	POOR	-
	February	2065	26.7	-	-	POOR	-
	March	1997	33.6	-	-	-	REJECT
	April	2067	29.6	-	-	POOR	-
	May	1976	35.4	-	-	-	REJECT
	June	2069	27.5	-	-	POOR	-
	July	2097	24.0	-	-	POOR	-
	August	1976	46.6	-	-	-	REJECT
	September	1899	46.9	-	-	-	REJECT
	October	1908	55.8	-	-	-	REJECT
	November	2019	38.1	-	-	-	REJECT
	December	2067	27.6	-	-	POOR	-

This corresponds to the literature study about possible technical performance of clay units due to varying mineralogical characteristics. In view of the site only and with respect to the brick type, the investigation yielded the following means: (1) Qwaqwa had 32.2% with a standard deviation of 7.5 which means that the data is more spread out; (2) Madadeni had 29.4% with a standard deviation of 10.1, which means that the data is more spread out. Even though hard burnt has a slightly higher value than low burnt, the difference in the water absorption is not significant ($p = 0.287$). This is also seen by the small effect $\eta 2$ value (0.025). With respect to the site and the brick type, there is a significant relationship between the water absorption and a combination of site and brick type ($p = 0.005$). The $\eta 2$ value (0.039) indicates a small to medium effect. The month (which signifies the date of mining) indicated a large effect ($\eta 2 = 0.213$) on the level of moisture. As seen

previously, the site and the month played a role in terms of the water absorption. In addition, the combination of site and month was also a large contributor to the water absorption. Since moisture absorption between hard and slight burnt brick is insignificant, the results per site per month were combined as indicated in Figure 8.

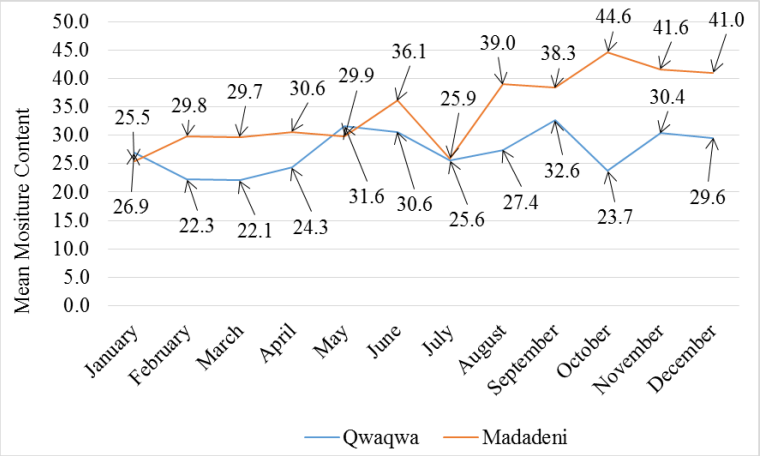


Figure 8. Average water absorption for a period of 12 months

Results prove that natural materials, such as clay, do not always correspond to technical demands (Maubec et al., 2017) in addition to the majority of manufacturers who do not possess the required knowledge and skills, which has resulted in the production of poor-quality clay units. Clay soils which consist of distinct kinds of clay minerals (Ouhadi et al., 2006) provide difficulties as the conduct of clay soils relies heavily on the type of clay minerals included (Hamidi and Marandi, 2018) which further affects the manufacturing process. Quantitative mineral assessment of clay soils is a key step in ensuring accurate soil recognition and behaviour (Ouhadi and Yong, 2003) and this is lacking in most clay bricks manufacturing processes. Necessary continuous testing of construction materials is rarely undertaken if not at all. This presents difficulties in coming even close to complying with technical requirements of clay bricks and ensuring consistent performance. The results highlight a need for continuous testing of all materials used in the manufacturing process to inform the public of the characteristics/limitations, including those presented by clay bricks they use to construct masonry walling.

CONCLUSION AND RECOMMENDATION

For the investigated sites, specifying clay units with less than 12% water absorption may compromise the level of intended flexure performance, as clay bricks that offer such performance do not exist. This is an issue because more ideal/satisfactory characteristic flexural strength of masonry made with clay units, fkx, in MPa for plane of failure equivalent to bed joint will be assumed. Even though hard burnt has a slightly higher value than low burnt, the difference in the water absorption is not significant ($p = 0.287$). This is also seen by the small effect $\eta 2$ value (0.025). With respect to the site and the brick type, there is a significant relationship between the water absorption and a combination of site and brick type ($p = 0.005$). The $\eta 2$ value (0.039) indicates a small to medium effect. The unavailability of such clay bricks from the merchants (12% to 20%) makes this almost impossible to

achieve in real masonry walling. Independent confirmation concerning the water absorption of clay units intended to be used in construction is absolutely necessary for designers of masonry walling. The South African Bureau of Standards (SABS) must promote and maintain standardization, quality and service provision related to the manufacturing of construction materials such as clay bricks. This study is the first to explore the water absorption quality of clay bricks made by emerging manufacturers in South Africa.

REFERENCES

Ajayi, A. E., & Horn, R. (2016). Comparing the potentials of clay and biochar in improving water retention and mechanical resilience of sandy soil. International Agrophysics, 30, 391-399.

Al-Sanea, S. A., Zedan, M. F., & Al-Hussain, S. N. (2013). Effect of masonry material and surface absorptivity on critical thermal mass in insulated building walls. Applied Energy, 102, 1063-1070.

Al-Sibahy, A., & Edwards, R. (2017). Characterization of the clay masonry units and construction technique at the ancient city of Nippur. Engineering Structures, 147, 517-529.

Bidoung, J. C., Pliya, P., Meukam, P., Noumowé, A., & Beda, T. (2016). Behaviour of clay bricks from small-scale production units after high temperature exposure. Materials and Structures, 49, 4991.

Bosiljkov, V., Page, A. W., Bokan-Bosiljkov, V., & Zarnic, R. (2010). Review Paper, Progress in Structural Engineering and Material: Structural Masonry. STRUCTURAL CONTROL & HEALTH MONITORING, 17, 100-118.

Crofts, F., & Lane, J. (2011). Structural Masonry Design, Midrand, South Africa, Concrete Manufacturers Association,.

Cultrone, G., & Sebastián, E. (2009). Fly ash addition in clayey materials to improve the quality of solid bricks. Construction and Building Materials, 23, 1178-1184.

Day, P. (2011). SAICE's interaction with the South African Bureau of Standards. Civil Engineering: Magazine of the South African Institution of Civil Engineering. Yeoville: The South African Institution of Civil Engineers.

Hamidi, S., & Marandi, S. M. (2018). Clay concrete and effect of clay minerals types on stabilized soft clay soils by epoxy resin. Applied Clay Science, 151, 92-101.

Juhásová, E., Sofronie, R., & Bairrão, R. (2008). Stone masonry in historical buildings — Ways to increase their resistance and durability. Engineering Structures, 30, 2194-2205.

Li, Z., Chen, W., Chen, L., Fang, Q., Hao, H., Zhang, Y., Xiang, H., Yang, S., & Bao, Q. (2017). Experimental and numerical study of unreinforced clay brick masonry walls subjected to vented gas explosions. International Journal of Impact Engineering, 104, 107-126.

Luso, E., & Lourenço, P. B. (2017). Bond strength characterization of commercially available grouts for masonry. Construction and Building Materials, 144, 317-326.

Maheri, M. R., Motielahi, F., & Najafgholipour, M. A. (2011). The effects of pre and post construction moisture condition on the in-plane and out-of-plane strengths of brick walls. Materials and Structures, 44, 541-559.

Marglin, S. A. (2017). Wages, prices, and employment in a Keynesian long run. Review of Keynesian Economics, 5, 360-425.

Maubec, N., Deneele, D., & Ouvrard, G. (2017). Influence of the clay type on the strength evolution of lime treated material. Applied Clay Science, 137, 107-114.

Miqueleiz, L., Ramírez, F., Seco, A., Nidzam, R. M., Kinuthia, J. M., Tair, A. A. & Garcia, R. (2012). The use of stabilised Spanish clay soil for sustainable construction materials. Engineering Geology, 133-134, 9-15.

Molnár, M. & Larsson Ivanov, O. (2016). Clay brick masonry facades with cracks caused by corroding bed joint reinforcement – Findings from field survey and laboratory study. Construction and Building Materials, 125, 775-783.

Monteiro, S. N., & Vieira, C. M. F. (2014). On the production of fired clay bricks from waste materials: A critical update. Construction and Building Materials, 68, 599-610.

Muñoz Velasco, L., Muñoz Velasco, P., Morales Ortíz, M. P., & MENDÍVIL GIRÓ, M. A. (2014). Fired clay bricks manufactured by adding wastes as sustainable construction material – A review. Construction and Building Materials, 63, 97-107.

Noor-E-Khuda, S., & Albermani, F. (2019). Mechanical properties of clay masonry units: Destructive and ultrasonic testing. Construction and Building Materials, 219, 111-120.

Nordby, A. S., & Shea, A. D. (2013). Building Materials in the Operational Phase. Journal of Industrial Ecology, 17, 763-776.

Ouhadi, V. R., & Yong, R. N. (2003). Impact of clay microstructure and mass absorption coefficient on the quantitative mineral identification by XRD analysis. Applied Clay Science, 23, 141-148.

Ouhadi, V. R., Yong, R. N., & Sedighi, M. (2006). Influence of heavy metal contaminants at variable pH regimes on rheological behaviour of bentonite. Applied Clay Science, 32, 217-231.

Pacheco-Torgal, F. & Jalali, S. (2012). Earth construction: Lessons from the past for future eco-efficient construction. Construction and Building Materials, 29, 512-519.

Penna, A., Morandi, P., Rota, M., Manzini, C. F., Da Porto, F. & Magenes, G. (2014). Performance of masonry buildings during the Emilia 2012 earthquake. Bulletin of Earthquake Engineering, 12, 2255-2273.

Rao, K. V. M., Reddy, B. V. V., & Jagadish, K. D. (1996). Flexural bond strength of masonry using various blocks and mortars. Materials and Structures, 29, 119-124.

Rashid, K., Haq, E. U., Kamran, M. S., Munir, N., Shahid, A., & Hanif, I. (2019). Experimental and finite element analysis on thermal conductivity of burnt clay bricks reinforced with fibers. Construction and Building Materials, 221, 190-199.

Santhosh, V., Padmalal, D., Baijulal, B., & Maya, K. (2013). Brick and tile clay mining from the paddy lands of Central Kerala (southwest coast of India) and emerging environmental issues. Environmental Earth Sciences, 68, 2111-2121.

Slevin, R., & Whalen, E. (1998). Turning a lump of clay into a brick. 148. Available: http://dut.summon.serialssolutions.com/.

South African Bureau Of Standards (1980). The structural use of masonry Part 1: Unreinforced masonry walling. SABS 0164. Pretoria: The South African Bureau of Standards.

South African National Standard (2007). Burnt clay masonry units. SANS 227. Pretoria: Standards South Africa.

The Clay Brick Association Of Southern Africa. (2021). The voice of the clay brick industry [Online]. Building 2, Unit 6, Ground Floor, Bedfordview Office Park, 3 Riley Road, Bedfordview 2007: The Clay Brick Association of Southern Africa. Available: https://www.claybrick.org/ [Accessed 12 June 2021 2021].

Tosti, F., Patriarca, C., Slob, E., Benedetto, A. & Lambot, S. (2013). Clay content evaluation in soils through GPR signal processing. Journal of Applied Geophysics, 97, 69-80.

Wu, F., Li, G., Li, H.-N. & Jia, J.-Q. (2013). Strength and stress-strain characteristics of traditional adobe block and masonry. Materials and Structures, 46, 1449.

Yang, Y., Yu, S. Y., Zhu, Y. & Shao, J. (2014). The Making of Fired Clay Bricks in China Some 5000 Years Ago. Archaeometry, 56, 220-227.

Zhang, L. 2013. Production of bricks from waste materials – A review. Construction and Building Materials, 47, 643-655.

Zhang, Z., Wong, Y. C., Arulrajah, A. & Horpibulsuk, S. (2018). A review of studies on bricks using alternative materials and approaches. Construction and Building Materials, 188, 1101-1118.

Zohreh Heydariha, J., Das, S., & Banting, B. (2017). Effect of grout strength and block size on the performance of masonry beam. Construction and Building Materials, 157, 685-69