Journal of Engg. Research **Vol. 4 No. (2) June 2016** pp. 17-28

تأثير شدة الانضغاط على قدرة الكسر للطين المشوي

***نواب علي لاخو، *محمد عاشور زارداري و**فريد احمد ميمون**
*قسم الهندسة المدنية، جامعة قويض أعوام للهندسة والعلوم والتقنية، ناوابشاح، سيند 67480، باكستان
**قسم الهندسة المدنية، جامعة مهران للهندسة والتقنية، جامشورو، سيند، باكستان

الخلاصة

يمكن زيادة قوة الضغط للطين المشوي بواسطة الانضغاط في وقت الصب. تقدم هذه الورقة العلاقة بين قدرة سحق المكعب من الطين المشوي وقدرة الضغط أثناء الصب. تم صب حزم من الطين من خليط رطب من الطين وقليل من الرمل. في وقت الصب، تم لف الحزم بالكامل في بولي ورقة النسيج البر وبيلين وضغط على شدة مختلفة من الضغط. بعد التجفيف، وخبز الحزم وقطعت مكعبات لتحديد قوة الضغط. وأظهرت النتائج أن مع معدل الضغط المتزايد، وكثافة الحزم زادت أيضا، مما أدى إلى زيادة في قوة سحق مكعب من الطين المشوي المقابلة. القوة الضاغطة من مكعبات الطين المشوي كانت 50% أكثر من قوة سحق مكعب من الخرسانة المسلحة العادية. هذا اكتشاف مهم للبحث في المستقبل لتقييم مدى ملاءمة الحزم المثقبة من الطين للمنازل منخفضة التكلفة مقارنة مع تلك التي شيدت من الخرسانة الإسمنتية المسلحة.

Effect of intensity of compaction on crushing strength of indigenous baked clay

Nawab A. Lakho*, Muhammad A. Zardari* and Fareed A. Memon**

**Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, 67480, Sindh, Pakistan*

***Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan*

***Corresponding Author: muhammad.auchar@quest.edu.pk*

ABSTRACT

Compressive strength of baked clay can be increased by compaction at the time of casting. This paper presents the relationship between cube crushing strength of baked clay and the intensity of compression during casting. Clay beams were cast from a moist mixture of indigenous clay and pit sand. At the time of casting, the beams were fully enveloped in poly propylene fabric sheet and compacted at various intensities of compression. After drying, the beams were baked and cubes were cut out to determine compressive strength. The results show that with increasing rate of compaction, density of the beams also increased, which resulted in corresponding increase in the cube crushing strength of baked clay. The compressive strength of baked clay cubes obtained is 50% more than design cube crushing strength of plain cement concrete. This is an important finding for future research to evaluate suitability of pre-perforated post reinforced baked clay beams for low cost houses compared to those constructed of reinforced cement concrete.

Keywords: Baked clay; compaction of clay; cube crushing strength; density; stabilized clay.

INTRODUCTION

Human beings need shelter on mass scale that requires large amount of construction material. The structural materials such as aggregates, cement, and steel are very costly. The solution lies in the use of indigenous construction materials such as clay, the deposits of which are abundant in plain areas of Pakistan. Clay has been utilized as construction material since ancient times in structures like wonders of the world, e.g., the Ziggurats of Mesopotamia and the Hanging Garden of Babylon (Sass, 2011). Clay is generally used in the form of sun baked bricks and compressed earth blocks to construct low cost houses (Oti & Kinuthia, 2012; Oti *et al.,* 2009; Fadairo & Olotuah, 2013). But it has some drawbacks such as loss of strength on wetting, erosion due to wind and rain, and low strength (Daboucha & Hashim, 2011). These undesirable properties of clay could be improved by baking at temperature ranging from 900^0C to 1200^0C (Lee & Yeh, 2008). This implies that baked clay has a potential to be used as a construction material for buildings.

Due to lack of understanding of behaviour of baked clay, its use as a construction material was limited in the shape of bricks and compressed earth blocks only (Smeu, *et al*., 2014; Oti & Kinuthia, 2012; Miqueleiz *et al*., 2012; Muntohar, 2011; Oti *et al*., 2008; Reeves *et al*., 2006; Delgado *et al*., 2006). Therefore, baked clay has not yet got popularity as a construction material in modern buildings which are being constructed with structural elements such as footings, columns, beams, and slabs.

In order to widen the use of baked clay as major construction material for low cost housing in developing countries like Pakistan, an extensive systematic research program is planned. The idea is to manufacture reinforced baked clay panels of beams, columns and slabs. Reinforcement will be provided later by grouting in pre-perforations made in the panels at the time of casting. Structural properties of reinforced baked clay panels will be determined experimentally and compared with those of reinforced cement concrete.

This study is a part of the above mentioned systematic research program. Initially, it was planned to manufacture reinforced baked clay beams and to investigate their structural behaviour. For this purpose, it was necessary to first investigate the compressive strength of baked clay. The objective of the present study is to gradually increase the compactive pressure during casting of the beams, so that after baking, the compressive strength of baked clay could be comparable to that of plain cement concrete. Since the compressive strength of compressed earth blocks increases with increase in density using compaction (Heathcote, 1991; Walker, 1995; Riza *et al.,* 2011; Khan *et al.*, 2014). Increase in the achieved density of clay depends upon optimum moisture content and energy used in process of compaction (Purushothama, 2005; Terzaghi *et al.*, 1996).

In previous study, the baked clay beams were compacted with manual compacting system that was not capable of compressing the beams to the desired degree (Ansari *et al.,* 2013; Ansari *et al.,* 2011; Ansari, 2008). Therefore, it was not possible to squeeze water out from the moist clay beams up to optimum moisture content. Maximum dry density and maximum compressive strength could be achieved at optimum moisture content in moist clay beams during casting process. Hence, in this study, a mechanized system of casting and compacting of clay beams was designed and fabricated in order to compress the clay beam sufficiently so that maximum compressive strength of baked clay could be obtained.

MATERIALS AND METHOD

Indigenous clay was mixed with 30% of pit sand by weight and hence after be referred to as moist clay. Twenty percent of water was added in the mixture. A preliminary study was conducted using gradual increments of pit sand in indigenous clay (Ansari, 2008). This study showed that maximum cube crushing strength was obtained using 30% of pit sand (Ansari, 2008). The addition of pit sand helped in reduction of shrinkage and cracks and it increased compressive strength. In case of less than 20% of water, no proper bond developed in layers of clay beams after casting (Ansari, 2008). In order to achieve more workable and monolithic beams, 20 to 22% of water was needed depending upon the type of soil and pan mixer used for mixing. Index properties of the indigenous clay are mentioned in Table 1. The moisture content of pit sand was about 8% and it was non-liquid and non-plastic in nature.

Beams of size 150 mm width, 300 mm depth, and 2000 mm length were cast using this moist clay. A mechanized system was designed and fabricated for casting and compacting of clay beams (Figure1a). The moist clay was filled in the mould of the mechanized system and compacted with the help of wooden plunger. The plunger was connected flexibly to an assembly of four hydraulic jacks powered by hydraulic pump as shown in Figure 1b. The clay beams were compacted in this mechanized system at intensity of compaction of 1.94, 3, 4, 5, 6, and 7.2 MPa.

Table 1. Average index properties of indigenous clay (Ansari, 2008).

Moisture content (%)	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index	Density of wet soil (g/cm^3)	Density of dry soil (g/cm^3)
12	2.5	44	23	21	1.5	1.3

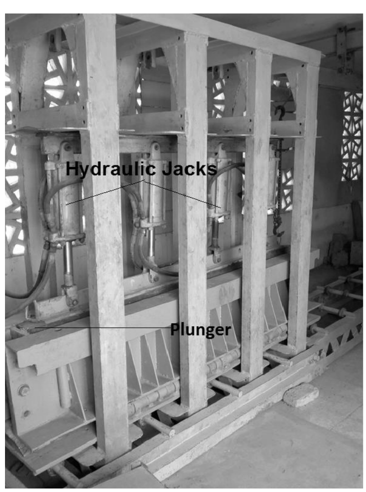

Fig. 1a. Mechanized system for casting and compacting beams.

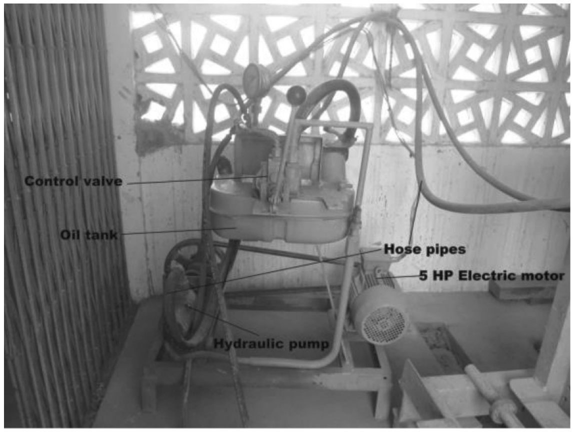

Fig. 1b. Hydraulic pump and control unit.

Moist clay was filled in the mould in five equal layers and each layer was tamped manually and a slight spray of water was applied before putting the next one. After filling all the five layers of moist clay in the mould, compression was applied through wooden plunger driven by hydraulic jacks (Figure 1a). The compacting load was applied, in small increments on the beam, with plunger and when compacting load reached 1.94 MPa, the clay oozed out of the openings and crevices of the mould and intensity of compaction could not be increased. In order to curtail the possibility of oozing out of the moist clay from the mould, the beam was fully enveloped, on all sides, with poly propylene fabric sheet before application of compacting load (Figure 2). With this application, the water present in the clay oozed out instead of moist clay and degree of compaction could be increased accordingly. Moisture content was determined for each beam specimen after compaction.

Fig. 2. Clay beam enveloped with Propylene fabric sheet during casting.

After casting of clay beams, it was necessary to keep them moist for a sufficient time in order to obtain maximum compressive strength and to reduce possibility of surface cracks. This process of keeping the clay beams moist for adequate time is similar to that of curing of concrete. Initially, the compacted clay beams were kept in shade at room temperature of 35^0C and humidity of 66%. A number of vertical drying shrinkage cracks occurred due to uncontrolled evaporation of moisture from the surface of beams (Figure 3). In order to decrease rate of evaporation of moisture from surface, the beams were fully covered with plastic sheet (Figure 4). The plastic sheet was effective in controlling the rate of evaporation, subsequently the drying shrinkage cracks were minimized and no drying shrinkage crack was observed in any beam during drying process (Figure 5). This curing process of clay beams was completed in about three months.

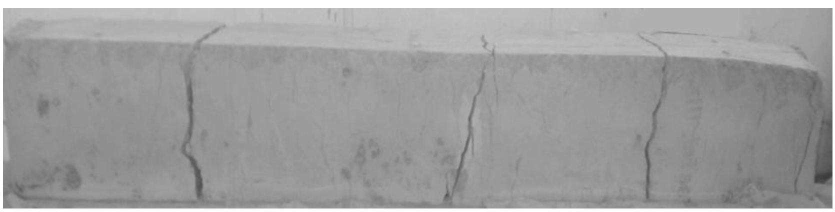

Fig. 3. Occurrence of drying shrinkage cracks in the beam due to evaporation of moisture.

Fig. 4. The beams were covered with plastic sheet in order to decrease evaporation of moisture. The circles in the bottom portion of the beams indicate perforations that are made for tensile reinforcement to be provided after drying and baking.

Fig. 5. The beam without drying shrinkage cracks.

TESTING PROCEDURE

The dried clay beams were baked at temperature of 960-1000^{0}C (Karaman *et al.,* 2006). This is consistent with average firing temperature range of 870 - 1200^{0}C for baking clay bricks (ASTM C62). Three beams were cast and compacted at each compactive pressure of 1.94, 3, 4, 5, 6 and 7.2 MPa, respectively. In total, eighteen beams were cast. Five cubes, each of 150 mm, were cut from each beam with the help of disk cutter, and tested for compressive strength in Universal Testing Machine (UTM). Average values of the compressive strength are described in this paper. The baked clay cubes were tested according to British Standard (BS EN 12390-3:2002). The reason for choosing cube testing is that it is the objective of the study to check compressive strength of baked clay and compare it with that of plain cement concrete.

RESULTS AND DISCUSSION

Optimum moisture content

Optimum moisture content of the moist clay was determined by Standard Proctor Test (ASTM D698) and is shown in Figure 6. It can be observed that the optimum moisture content of this moist clay is about 12% and the corresponding value of maximum dry density is 2000 kg/m^3.

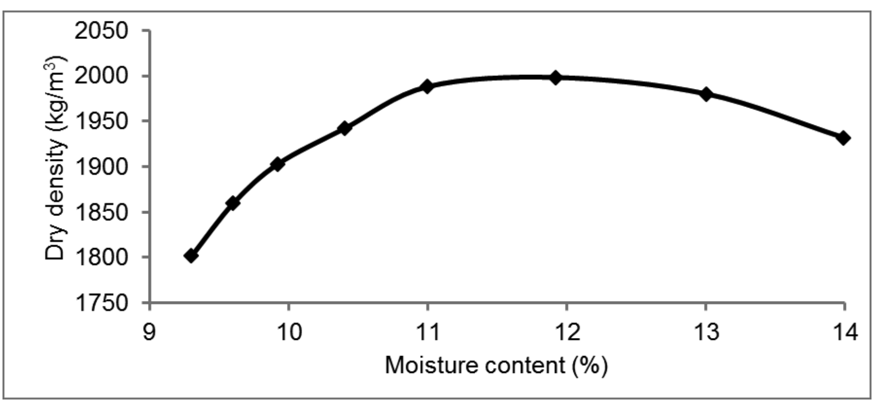

Fig. 6. Moisture content and dry density curve by Standard Proctor Test.

Reduction of moisture content using compression with mechanized system

It is to be noted that for proper workability and homogeneity of clay beams, 20% of water was added to the clay-pit sand mixture. This amount of moisture needs to be decreased to the value of optimum moisture content in order to achieve maximum dry density. For this purpose, the beams were compacted with the help of the mechanized system. Therefore, the beams were compacted at 1.94, 3, 4, 5, 6, and 7.2 MPa, and corresponding values of moisture content were determined. The results of moisture content versus intensity of loading were plotted as shown in Figure 7.

It can be seen that, when the beams were compacted, no oozing out of water from the mould was observed till the compressive load reached 1.94 MPa. Water started to ooze out from the clay in the mould once the pressure exceeded 1.94 MPa. The beam was then compacted up to 7.2 MPa in various increments. It can also be observed that (Figure 7), with the help of this casting and compacting system, the water content of the beam could be reduced to the value of 13.4% which is close to the value of optimum moisture content (i.e., 12%) obtained by Standard Proctor Test.

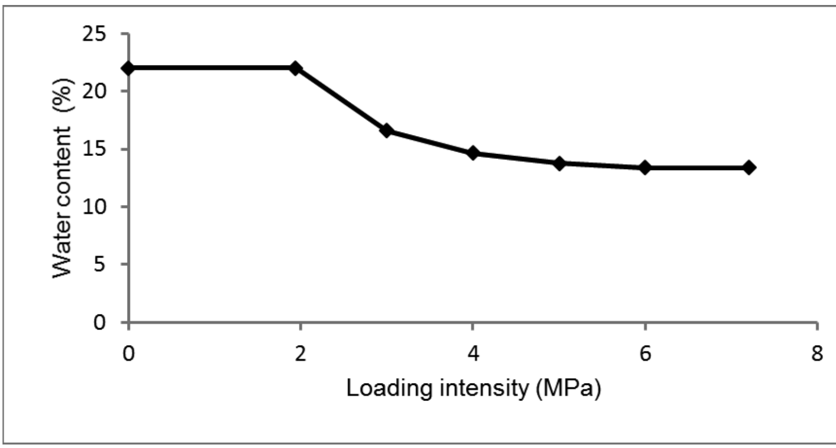

Fig. 7. Loading intensity on clay beam versus water content.

Effect of loading intensity during casting of clay beams on dry density

The beams were cast and compacted at 1.94, 3, 4, 5, 6, and 7.2 MPa in order to observe the effect of compressive loads during casting on dry density of beams (Figure 8). It can be seen that the dry density of beams increased with increase of loading intensity.

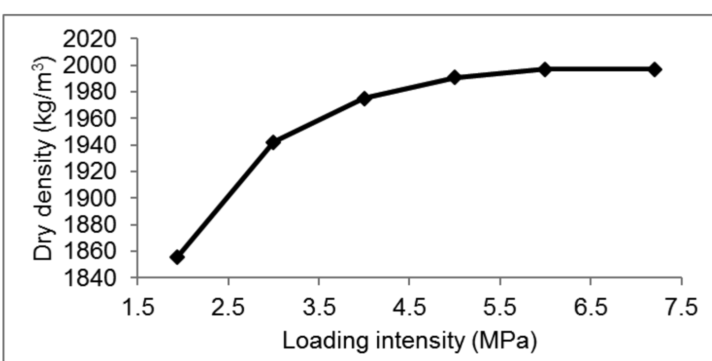

Fig. 8. Relationship between loading intensity during casting of beams on dry density.

Effect of loading intensity during casting of clay beams on cube crushing strength

The cubes of 150 mm were cut from the baked clay beams and were tested in the directions both parallel and vertical to the layers by which the beams were cast. It is to be noted that the average compressive strength of the cubes tested in both the directions showed almost similar values. This is because the beams behaved like a homogenous material under the application of compressive loads. Therefore, anisotropic behaviour of the baked clay, presented in this study, does not have significant influence on the compressive strength.

The effect of compressive load during casting process of clay beams on cube crushing strength of baked clay is shown in Figure 9. It can be seen that compressive strength of baked clay cubes is directly related to the compacting load at which the beams were compacted at the time of casting. The compressive strength of baked clay specimen compacted at 1.94 MPa was found to be 18.5 MPa, which increased to 33.5, and 38.2 MPa at the compaction of 6 and 7.2 MPa, respectively. The specimens which were compacted at less intensity of compaction showed moisture content greater than the optimum one. When the beams were dried, this amount of moisture was evaporated. Consequently, there were voids in the clay beams. Due to presence of such voids, the compressive strength of the cubes was reduced compared to the ones compacted at high compactive load.

The design compressive strength of plain concrete is 20 MPa (Neville, 2011). This implies that baked clay beams compacted at the intensity of 6 MPa at the time of casting could be used instead of plain cement concrete. Here the compressive strength of baked clay was compared with that of plain cement concrete. The reason is that concrete is widely used as material of construction and many researchers are familiar with structural properties of concrete. Therefore, this comparison gives direct idea of how good baked clay could be considered as material of construction in relation to plain cement concrete.

It is to be noted that this study has provided an important base for future research, in which plain baked clay beams will be post reinforced through perforations made at the time of casting (Figure 4). Tensile reinforcement will be inserted through the perforations and grouting will be done for proper bonding between baked clay beams and reinforcing bars. Flexural behaviour of reinforced baked clay beams will be tested and compared with that of beams made of reinforced cement concrete.

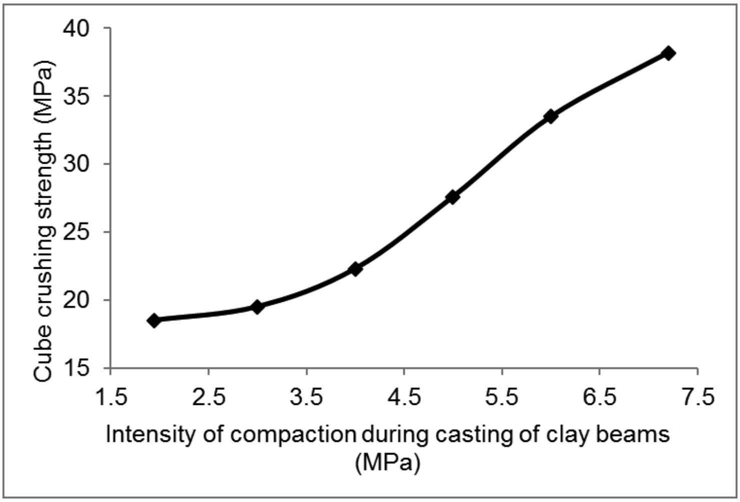

Fig. 9. Relationship between cube crushing strength of baked clay specimen and intensity of compaction at the time of casting.

CONCLUSIONS

The paper presented the effect of compactive load during casting of clay beams on the compressive strength of baked clay cubes. Following conclusions were drawn from this study:

1. Compressive strength of cubes cut from baked clay beams depends upon both the intensity of compaction and moisture content during casting.
2. With the help of the developed mechanized system, using compression, the moisture present in the moist clay beams could be reduced close to the value of optimum moisture content.
3. Dry density of the baked clay beams, compacted with this system, increased as the compactive load increased.
4. Drying shrinkage cracks of the moist clay beams could be eliminated by covering them with plastic sheet.

ACKNOWLEDGEMENTS

The authors would like to thank Quaid-e-Awam University of Engineering Science and Technology, Nawabshah for financial support to develop the mechanized system for casting and compacting of clay beams.

REFERENCES

Ansari, A.A., Bhatti, N.K. & Bhutto, A. 2013. Suitability of pre-perforated post-reinforced baked clay beam panels for low cost housing. American Journal of Civil Engineering, **1**(1):6-15.

Ansari, A.A., Memon, M. & Khaskheli, G.B. 2011. Pre-perforated post-reinforced structural panels of baked clay as cheaper alternative of RCC construction. Procedia Engineering, **14**: 2635–2641.

Ansari, A.A. 2008. Experimental study of the behaviour of pre-perforated post-reinforced baked clay panels of beams, Ph.D. Thesis, Quaid-e-Awam University of Engineering Science and Technology, Nawabshah.

ASTM C62-13a. 2013. Standard specification for building brick (Solid masonry units made from clay or shale). ASTM International, West Conshohocken.

ASTM D698-12e2. 2012. Standard test methods for laboratory compaction characteristics of soil using standard effort (12400 ft-lb_f/ft^3 (600 kN-m/m^3)). ASTM International, West Conshohocken.

BS EN 12390-3:2002. Testing hardened concrete - Part 3: Compressive strength of test specimens.

Deboucha, S. & Hashim, R. 2011. A review on bricks and stabilized compressed earth blocks. Scientific Research and Essays, **6**(3):499-506.

Delgado, M.C.J. & Guerrero, I.C. 2006. Earth building in Spain. Construction and building materials. **20**(9):679-690.

Fadairo, G. & Olotuah, A.O. 2013. Low-cost housing for the urban poor in Akure, Nigeria: Materials and techniques of construction. Journal of Environment and Earth Science, **3**(9):135-142.

Heathcote, K. 1991. Compressive strength of cement stabilized pressed earth blocks: Strength of cement stabilized pressed earth blocks depends on cement content and compacted density- simple formula presented to predict strength based on variables. Building Research and Information, **19**(2):101-105.

Karaman, S., Ersahin, S. & Gunal, H. 2006. Firing temperature and firing time influence on mechanical and physical properties of clay bricks. Journal of scientific and industrial research, **65**(2):153-159.

Khan, F.S., Azam, S., Raghunandan, M.E. & Clark, R. 2014. Compressive Strength of compacted clay-sand mixes. Advances in Materials Science and Engineering, **2014**:1-6.

Lee, V. G. & Yeh, T. H. 2008. Sintering effects on the development of mechanical properties of fired clay ceramics. Materials Science and Engineering, **485**(1):5-13.

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.

Muntohar, A.S. 2011. Engineering characteristics of the compressed-stabilized earth brick. Construction and Building Materials. **25**(11):4215-4220.

Oti, J.E. & Kinuthia, J.M. 2012. Stabilised unfired clay bricks for environmental and sustainable use. Applied Clay Science, **58**: 52-59.

Oti, J.E., Kinuthia, J.M. & Bai, J. 2009. Engineering properties of unfired clay masonry bricks. Engineering Geology **107**(3):130-139.

Oti J.E., Kinuthia, J.M. & Bai, J. 2008. Developing unfired stabilised building materials in the UK. Proceedings of the Institution of Civil Engineers, Engineering Sustainability. **161**(4): 211–218.

Neville, A.M. 2011. Properties of Concrete, Prentice Hall.

Purushothama, R. 2005. Ground Improvement Techniques, Laxmi Publications.

Reeves, G.M., Sims, I. & Cripps, J.C. 2006. Clay materials used in construction. Geological Society of London.

Riza, F.V., Rahman, I.A. & Zaidi, A.M.A. 2011. Preliminary study of compressed stabilized earth brick (CSEB). Australian Journal of Basic and Applied Sciences, **5**(9):6-12.

Sass, S. L. 2011. The substance of civilization: Materials and human history from the stone age to the age of silicon. Arcade Publishing.

Smeu, S., Gal, A. & Badea, C. 2014. Environmental friendly building materials: Unfired Clay Bricks. Journal of Environment, **3**(3):47-50.

Terzaghi, K., Peck, R.B. & Mesri, G. 1996. Soil mechanics in engineering practice. Third Edition. John Wiley & Sons.

Walker, P.J. 1995. Strength, durability and shrinkage characteristics of cement stabilised soil blocks. Cement and Concrete Composites, **17**(4):301-310.

Submitted: 4/4/2015
Revised: 5/9/2015
Accepted: 30/9/2015