Effect of municipal solid waste ash on comprehensive strength characteristics of an interlocking block masonry wall.

Isaac,[1] F. S., R. O. Onchiri[2] and T. Y. Tsado[3]. [1]Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya; [2]Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, P.O. Box 190-50100, Kakamega, Kenya; [3] Department of Civil Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, Nigeria.

Abstract.

Masonry is a layered composite which consists of mortar and masonry units. A good bond between the units is essential and determines how the masonry transfers and resist stresses due to applied loads. In this study interlocking blocks were used in masonry wall construction in order to introduce uniformity in the wall model by eliminating mortar as a binding media. The blocks were moulded in a CINVA-Ram machine by replacing 0%, 2%, 5% and 10% of municipal solid waste ash (MSW ash) as a stabilizing agent. The compressive strengths of individual blocks were obtained after curing for 7, 14 and 28 days. The 2%MSW ash replacement gave the highest compressive strength and was used in constructing the wall model. The wall models were loaded in compression in direction normal to bed joints. The 2%MSW ash stabilized Juja soil wall failure was generally associated with diagonal cracks and bulging of the wall from sides. A maximum crack width of 40 mm wide occurred at failure with the central deflection of the wall reaching 20 mm at an ultimate failure stress of 2.49 N/mm^2. The failure mode of un-stabilized Juja soil wall model was mainly due to vertical cracks forming below the load application point. The ultimate failure stress of un-stabilized Juja soil wall was 2.5 N/mm^2, however its central deflection was low than that of stabilized wall. Conversely, un-stabilized Murang'a soil wall failed by crushing introduced by vertical cracks. A maximum stress of 0.997 N/mm^2 was achieved with a central deflection of 12 mm. Stabilized Murang'a soil had a low failure stress of 0.85 N/mm^2 as compared to the un-stabilized soil. The wall failed due to a combination of horizontal and diagonal cracks forming on the wall. In both cases the strength of individual blocks was higher than that achieved in the wall models. The progression of failure stress cracks for 2%MSW ash stabilized wall model was corresponding to that recommended in the code of practice for masonry, thus the same code can be used in design of stabilized masonry walls.

Keywords: Compressive strength, failure mode, interlocking blocks, stabilization
Email: fsanwu@gmail.com, roocharo@gmail.com, ty.tsado@futminna.edu.ng.
Received: 2013/03/01.
Accepted: 2013/10/10

Introduction.

Earth clay as a building material is the most available and cheap material found everywhere and exists in many different compositions. It is most efficiently used in developing countries to house the greatest number of people. It is easy to work with, requires less skills and as such, it encourages and facilitates unskilled individuals and groups of people to participate in its construction. It offers high resistance to fire and provides a comfortable built living environment due to its high thermal and heat insulation value (Arumala and Gondal, 2007; Ikpenwa, 2009). However, its quick deterioration of quality has made the construction industry to show a receptive attitude towards research into new materials, like municipal solid waste, that human being constantly produce to improve its quality. Clay blocks have been used to provide shelter with the units formed from extrusion, moulding or dry-pressing and fired in a kiln at a high temperature (Adam, 2001; Ikpenwa, 2009). This gave rise to extensive use of wood fuel in firing the blocks, thus, causing environmental deterioration. By providing an alternative to the fired bricks with a sustainable cheap stabilizer could greatly reduce environmental and material demands on the construction industry. Stabilization of soil involves use of substances that aid the soil to bind together so as to modify the behaviour of soil. The use of municipal solid waste ash as a stabilizer is therefore attractive both environmentally and economically. Its consumption not only reduces waste from landfills but also provides potential profit to tipping fees for manufacturers. By eliminating the firing requirements while still maintaining block strength and durability, the energy requirements of the firing process could be reduced.

Municipal solid waste ash is obtained from incinerators after burning the waste. It consists of fine, powdery particles that are predominantly spherical in shape and mostly amorphous in nature. As a stabilizer, the ash contributes a pozollanic reaction due to its high content of calcite ($CaCO_3$) and quartz (SiO_2). In addition, replacing the ash in blocks is expected to reduce the weight of the units thus lowering the design load to be considered in structures.

Studies by Prashant (2009) in utilization of screed MSW for making blocks indicated them to have encouraging strengths in the range of 3 – 6.2 N/mm^2. The increased strength was associated with the pozzolanic reactions introduced by the ash.

The compressive strength of a masonry wall has been associated with that of individual blocks (Hendry, 1990). This author indicated that compressive strength of the brick determined that of the masonry wall. On the other hand, the failure of masonry in compression has been found to depend on the interaction of block unit and mortar joint as a result of their deformation characteristics. In particular, the difference of the elastic properties of the component materials strongly influences the failure mode which can cause either tension cracks parallel to the direction of loading or a kind of shear failure along some lines of weakness (Hendry, 1998; Ogunsusi, 1995). This could occur when the mortar mechanical characteristics are similar, or greater than the unit ones.

Masonry is typically non-elastic and non-homogeneous material composed of two materials of quite different properties; stiffer blocks and relatively softer mortar (Drysdale *et. al.* 1994). Under lateral loads, masonry does not behave elastically even in the range of small deformations. Masonry is very weak in tension because it is composed of two different materials distributed at regular intervals and the bond between them is weak. Therefore, masonry is normally provided and expected to resist only the compressive forces. Apart from strength of masonry units and grade of mortar, strength of masonry depends on surface characteristics and uniformity of units (Asteris and Syrmakezis, 2005).

During compression of masonry wall constructed with stronger and stiffer blocks, mortar of the bed joint has a tendency to expand laterally more than the blocks because of lesser stiffness. However, mortar is confined laterally at the block-mortar interface by the blocks because of the bond between them; therefore, shear stresses at the block-mortar interface result in an internal state of stress which consists of triaxial compression in mortar and bilateral tension coupled with axial compression in blocks. This state of stress initiates vertical splitting cracks in blocks that can lead to the failure of the wall (McNary and Abrams, 1985). It is in this view that this study considered to use interlocking blocks in order to eliminate mortar between the block units. The intention was to eliminate the weak points and introduce uniformity in the wall model.

In this study the failure mode of Juja clayey soil stabilized with MSW ash interlocking block masonry has been examined. This failure mode has been compared to that of a masonry wall made from Murang'a soil stabilized with MSW ash. The effect of the ash has been determined by loading the wall model in direction normal to the bed joints under compression and observing the failure pattern in terms of stress-strain characteristics. Interlocking blocks were used in order to eliminate weak bonds caused by mortar and introduce uniformity in the wall model. This study, presents the experimental comparison of the failure behaviour of masonry walls constructed with natural soils stabilized with MSW ash and un-stabilized natural soils.

Experimental Details

Sample preparation

The materials used to prepare the clay for the laboratory production of blocks were Juja soil, Murang'a soil, water and Municipal solid waste ash (MSW ash). The soils were passed through a sieve analysis in accordance to the procedure outlined in BS 1377 – 1:1990. The grain size distribution of Juja and Murang'a soils were then classified according to the standards.

The chemical composition of the soil and the ash were obtained from X-ray diffractogram analysis. The mineralogical composition of the soils was determined from a depth of 0 – 20 cm and from 20 – 40 cm, categorised as top and sub soil respectively. The ash chemical composition was determined after combusting the solid waste and passing the ash through a 600 µm sieve.

Stabilizer mixing and preparation of the blocks.

Municipal solid waste ash was sieved and the percentage that passed 600 µm was used to stabilize the soil. MSW ash was added to natural soils at rates of 0%, 2%, 5% and 10% to stabilize the soils. The interlocking blocks were moulded in a CINVA-ram manually operated machine by placing the soil paste in three layers and thumping. The moulded blocks were placed under a shade and covered to allow for slow drying. The strengths of individual blocks were determined after curing for 7, 14 and 28 days. Blocks with the dimensions of 230 x 225 x 130 (mm) were tested in this study.

Wall model preparation and testing.

Unconfined masonry wall models of 840 mm height and 1100 mm length were constructed using the stabilized blocks dried for 28 days in accordance with EN 1052-1:1999. The block units were laid to interlock one another without using cement mortar to join them (Figure 1). The maximum deflection of the wall was measured by a transducer placed at the point of load application and the stresses determined from a portable data logger. White wash was applied at the surface of the wall to aid in visual inspection of the cracks as they developed. The wall was then subjected to uniform compression in direction normal to the bed joints. The compression loading was applied by jacking system connected to a 50 tonne weight load cell on a steel plate. The steel plate enabled to uniformly distribute the load over the wall model.

The effect of MSW ash was determined by observing the failure mode of the wall models and establishing the maximum deflection at load application points at ultimate failure load. Furthermore, the stress-strain curves of stabilized and un-stabilized masonry have been compared in order to determine the elasticity of the wall models.

Figure 1: General arrangement of wall model for testing

Results and Discussions.

Physical and chemical characteristics of experimental soils.

The grain size distribution of Juja soil can be categorised as being uniformly graded while Murang'a soil as well graded (Figure 2). Juja and Murang'a soil can be characterised as having coefficient of uniformity, C_u of 5.0 and 7.1, respectively; and coefficient of curvature, C_c of 1.3 and 2.7 respectively. Murang'a soil was found to have low content of clay particles as compared to Juja soil. Therefore the pozzolanic reactivity of Murang'a soil was expected to be lower than that of Juja soil since clay is the major contributor to the pozzolanic reaction (AASHTO, 1986). The particle distribution of Murang'a soil depicts it to have a gap of particles between 0.2 and 0.5 mm (Figure 2). It is therefore expected that blocks from Murang'a soil will have lower strength in compression because the particles can easily be compressed to occupy the voids.

The chemical composition of Juja soil at a depth between 20 – 40 cm, depicted it to contain more minerals of clinocore, microcline, montmorillonite and goethite as compared to Murang'a soil at the same depth. Murang'a soil at 20 – 40 cm deep had more of quartz and kaolinite minerals (Table 1). The soil between 20 – 40 cm deep was considered in preparation of the blocks because the topsoil (0 – 20 cm deep) contained large amounts of humus materials. On the other hand, the main constituent of MSW ash was calcite (57.6%) and quartz (14.1%). Studies by De Silva and Glasser indicated that addition of a stabilizer containing calcium carbonate helps to cement the clay particles together creating a cementatious gel that enhances plasticity to the soil paste (De Silva and Glasser, 1992). The presence of calcium carbonate in MSW ash was therefore expected to help in cementing the clay particles of the natural soils. The chemical composition indicated that MSW ash can be assigned as class F pozzolana, as prescribed in ASTM C 618, because the total amount of SiO_2, Al_2O_3, and Fe_2O_3 (17.7%) was less than 70%.

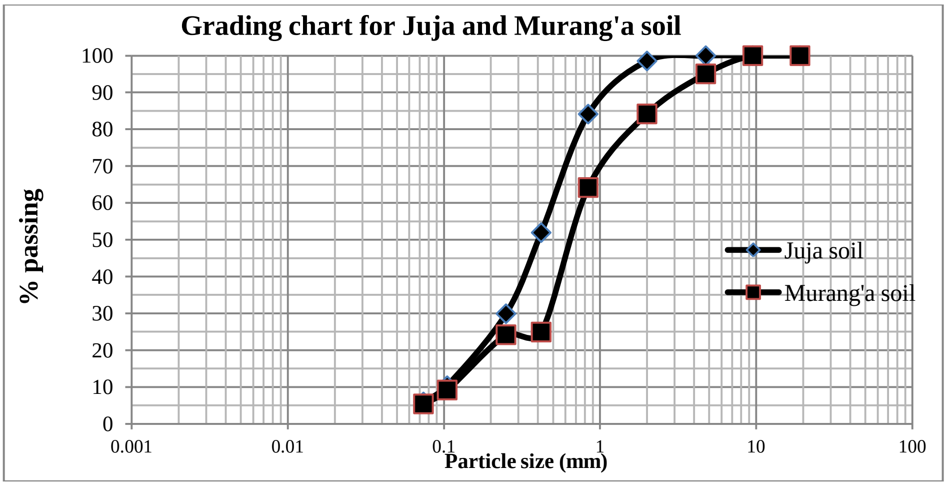

Figure 2: Particle size distribution curves for Juja and Murang'a soils.

Table 1: Mineralogical composition of ash and soil

	Mineral Composition (%)				
Mineral	**Juja (0 – 20 cm)**	**Juja (20 – 40 cm)**	**Muranga (0 – 20 cm)**	**Muranga (20 – 40 cm)**	**MSWA**
Quartz (SiO_2)	39.7	19.7	33.0	29.2	14.1
Microcline ($KAlSi_3O_8$)	31.7	17.3	21.7	-	13.2
Montmorillonite	9.4	16.8	-	16.5	-
Geothite ($Fe_3O(OH)$)	19.2	11.3	-	6.3	-
Clinocore	-	26.5	-	-	-
Illite	-	8.4	-	-	-
Kaolinite	-	-	29.4	48.0	-
Muscovite	-	-	5.5	-	-
Albite	-	-	10.4	-	-
Calcite ($CaCO_3$)	-	-	-	-	57.6
Hematite (Fe_2O_3)	-	-	-	-	1.6
Corrundum (Al_2O_3)	-	-	-	-	2.0
$SiO_2 + Al_2O_3 + Fe_2O_3$					17.7

sample (Source: XRD data from ICRAF).

Compressive strength characteristics of experimental blocks.

The properties of individual blocks indicated that the un-stabilized blocks shrunk most compared to the stabilized blocks (Table 2). However, as the percentage of MSW ash was increased in Juja soil, the average weight of the block reduced. This was expected because the density of the ash is low than that of Juja soil. The design standard of bricks for construction (KS 02-300, 1983) provides that the minimum compressive strength of internal walls be 3 N/mm^2 on the 28th day. The interlocking blocks from Juja soil stabilized with 2%MSW ash were the only ones that achieved strength above the minimum requirement. The strength of blocks from Murang'a soil was far below the minimum requirement as required by the design code even after stabilization. The low strength of Murang'a soil blocks can be associated with the absence of clay minerals responsible for pozzolanic reaction in soil.

Table 2: Properties of interlocking blocks used in the study

	Properties of blocks used in the study		
Treatment	28 day strength (N/mm^2)	Average weight (kg)	Average shrinkage (%)
Juja soil	2.633±0.34	9508.75±202.3	2.80±0.2
Juja soil + 2%MSWA	3.696±0.09	10083.60±110.8	1.86±0.05
Juja soil + 5%MSWA	2.447±0.14	9622.00±210.8	2.10±0.16
Juja soil + 10%MSWA	1.159±0.22	8825.38±154.1	2.62±0.25
Murang'a soil	0.411±0.12	9480.38±534.3	3.0±0.5
Murang'a soil + 2%MSWA	0.484±0.16	8953.5±224.8	2.5±0.12

The strength of individual blocks was determined and their strength plotted against time (Figure 3). The gain of strength after 28 days indicated blocks from Juja soil stabilized with 2%MSW ash had higher strength as compared to those moulded from Murang'a soil (Figure 3). The gain of strength in Juja stabilized blocks can be associated with the pozzolanic activity introduced by the ash and presence of clay minerals in the soil. This was as expected findings of Okunade, 2008. On the other hand, un-stabilized Juja soil blocks were stronger on the 7th day and their strength reduced with age (Figure 3). This early strength of Juja un-stabilized blocks was introduced by hardening of the soil encouraged by fusion of the clay minerals (mainly clinocore and microcline). However with time the strength of Juja un-stabilized blocks reduced due to weakening of the fusion bond caused by drying of the block. In their study of chemical stabilization of sandy-silty illite clay, Ninov *et. al*, 2006 found out that clay minerals can bond together but in the absence of pozzolanic material there will be no hardening of the amorphous hydrosillicates in the soil for a long time, as it was realised in this study (Ninov *et. al.*,2006).

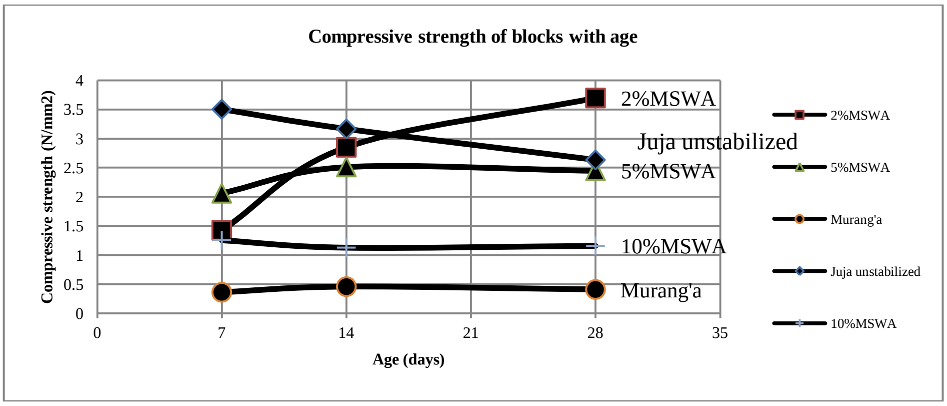

Figure 3: Compressive strength of individual blocks.

From Figure 3, the maximum compressive strength of 2%MSW ash stabilized Juja soil masonry wall model was achieved at 2.49 N/mm^2, while for the un-stabilized Juja soil masonry wall was achieved at 2.5 N/mm^2 A comparison between the results of an individual block compressive strength and the wall model indicated that the compressive strength of wall model was much lower than the compressive strength of the blocks (3.6 N/mm^2). On the other hand, un-stabilized Muranga soil wall model had a maximum compressive stress of 0.997 N/mm^2. The stress was slightly higher than for stabilized Murang'a soil (0.85 N/mm^2). Results presented by Hemant *et. al*, 2007 clearly showed a relationship between masonry prism compressive strength and brick units. The wall prisms had low strength due to non linearity and composite behaviour of masonry walls introducing weak points at the joints (Hemant *et. al*, 2007).

Stress-strain characteristics of the wall models.

Three stages of the failure behaviour were identified in terms of stress-stain pattern for the Juja soil. The ascending part of the 2%MSW ash stabilized masonry wall stress-strain curve (Figure 4) was found to be behaving linearly (section OA) up to about two-third of the ultimate load after which a parabolic curve was depicted (section ABC). The first crack was observed at stage A accompanied by a fall of stress value. As the stress increased beyond stage A, the cracks begun to increase in length, width and number, thereby causing non-linearity of the stress-stain curve. There was also excessive cracking and bulging of the wall sides. At stage B ultimate load was reached; although the wall did not completely collapse, it could not support more stress.

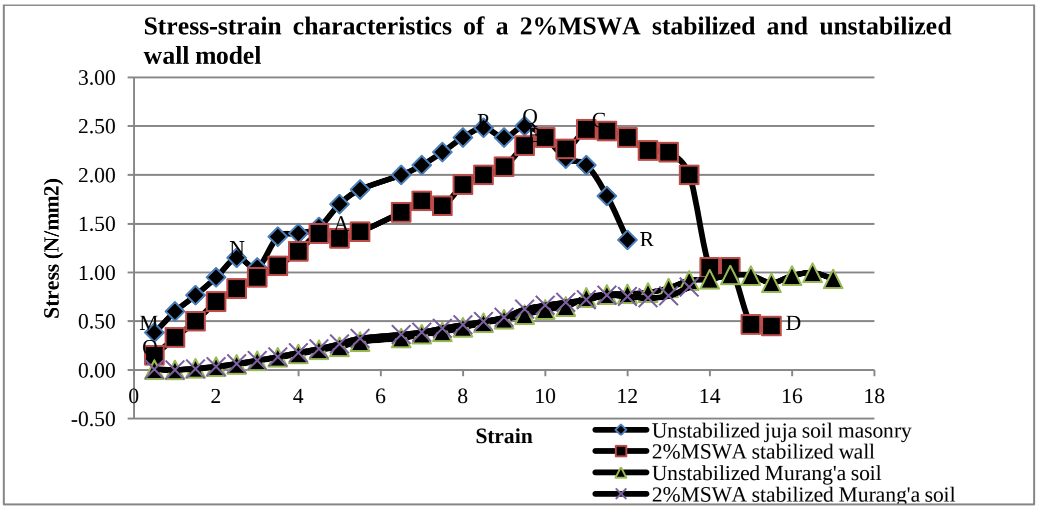

Figure 4: Stress-strain behaviour of a 2%MSW ash stabilized and un-stabilized model walls

The development of first crack in 2%MSW ash stabilized Juja soil wall models occurred after a considerable strain value in the wall. This meant there was a delay in development of the cracks. This failure mode compares well with walls constructed with weaker mortars (Type N or O), that behave elastically in their failure (McNary and Abrams, 1985). The stress-strain curve for the un-stabilized Juja masonry wall block depicted a fall at point N (Figure 4) indicating the development of first cracks. The first crack was observed at a low bearing stress (1.2 N/mm^2) as compared to that achieved by 2%MSW ash stabilized masonry wall (1.4 N/mm^2). After the occurrence of the crack at point P (Figure 4) the wall model could not sustain any load higher than the achieved and an ultimate load of (2.5 N/mm^2) was recorded at point Q. A maximum central deflection of 14 mm was recorded at ultimate failure of the wall model with a maximum crack width of 50 mm (Table 3). On reaching the ultimate failure load, the un-stabilized wall could not accommodate any load making the curve to have a short-sharp fall (QR) as compared to that of stabilized wall that had a longer fall even after maximum load was attained (CD).

The stress-strain curves for Murang'a soil did not show a well defined yield stress though the curves for both stabilized and un-stabilized soil increased exponentially with increase in loading. The un-stabilized Murang'a soil wall achieved a higher ultimate failure stress as compared to the stabilized soil. This factor was contributed due to the presence of ash in the soil; since Murang'a soil does not contain clay minerals in adequate quantity, the ash could not contribute to pozzolanic reaction thereby reducing the density of the block and ultimately the strength. The un-stabilized Murang'a soil wall model achieved a vertical deflection of 12 mm while the stabilized wall had a deflection of 10 mm.

Wall model failure mode.

The failure of 2%MSW ash stabilized wall model was preceded by cracks starting at the block directly below the first loaded block (Figure 5a). The cracks then propagated diagonally with minor vertical splitting cracks occurring below the load application point accompanied by spalling of the block materials on the surface. The failure of the wall was generally associated with diagonal cracks and bulging of the wall from sides (Figure 5a). This failure was governed by the tensile damage of the blocks thereby the resulting failure mode was tensile splitting on the vertical plane of the wall model. This failure is similar to the normal mode of failure reported by Berto et al for masonry constructed using weaker mortar (Berto *et. al.*, 2005). The maximum crack width at failure was 40 mm wide occurring diagonally to the load application and the central deflection of the wall reached 20 mm (Table 3) at the ultimate failure stress of 2.49 N/mm^2.

Table 3: Properties of the experimental model walls

Wall model type	Maximum deflection (mm)	Maximum crack width (mm)	Crack propagation
2%MSW ash + juja soil	20	40	Diagonal
Unstabilized Juja soil	14	50	Vertical
2%MSW ash + Murang'a soil	10	15	Horizontal and diagonal
Unstabilized murang'a soil	12	13	Horizontal

Figure 5 (a): Failure of a 2%MSWA stabilized wall.

5(b): Failure of un-stabilized wall

Contrary to the stabilized wall model, failure of un-stabilized Juja soil masonry wall was initiated by vertical cracks directly below the load application point (Figure 5b). As the ultimate failure load was reached, the wall bulged from the edges and created disjoints in the interlocking blocks. The first crack occurred earlier than it had occurred in the stabilized masonry wall. Cracks did not propagate diagonally as it was observed in 2%MSW ash stabilized masonry wall, rather they occurred vertically down the wall face. This was because of high stiffness of the un-stabilized block units tending to reduce the lateral strains in the wall model leading to a state of triaxial compression in the wall. This lead to a significant vertical splitting of the blocks as observed in the case where mortar is stronger than block units (Berto *et. al,* 2005). Such failure can be attributed to the phenomenon of shear failure which can be found in compression of brittle materials (Vonk, 1992). This failure mode indicated that the un-stabilized blocks are brittle and when utilised in masonry, their crack development is faster than for the MSW ash stabilized blocks. The failure of un-stabilized Murang'a soil wall was mainly due to vertical cracks developing in the face of the wall model (Figure 6 a). Cracks developed randomly and rapidly to cover the whole wall face. The wall failed by crushing of the block units but the crack did not increase in width as was observed in stabilized Juja soil. This mode of failure was caused by low strength of the blocks resulting from lack of bondage of Murang'a soil. The blocks easily disintegrated when loaded and caused failure by crushing. However, the development of failure cracks of this wall compared well with those of un-stabilized Juja soil. Stabilized Murang'a soil wall model had its failure initiated by nearly diagonal and horizontal cracks (Figure 6b). The stabilized wall failed at a lower compressive strength than the un-stabilized wall due to the inactivity of the ash caused by absence of active clay minerals to initiate pozzolanic reaction. The wall failed by buckling when the block units split along the horizontal axis, with a maximum stress of 0.85 N/mm^2 being achieved.

Fig 6**(a):** Un-stabilized Murang'a soil wall

Fig 6(b): 2%MSW ash stabilized Murang'a soil

The concentrated loads applied in the wall models were assumed to be uniformly distributed over the bearing area since a suitable spreader was used and the spreader was not located at the end of the wall as provided in BS 5628-1:2005. In understanding the effect of MSW ash on the compressive behaviour of masonry wall it requires an understanding of the pozzolanic reaction. This is a process that allows gradual development of strength by cementing the clay particles together by calcium carbonate ($CaCO_3$). The reaction then will occur between calcium oxide (CaO), silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3) to produce a stable calcium silicate and calcium aluminate hydrate (National Lime association, 2007). The activity of adding MSW ash as a stabilizer had two properties that covered the chemical activity and micro-filler effect. Addition of MSW ash enabled formation of solid skeleton from calcium silicate hydrate and formed a cementitious matrix in reacting with active clay minerals. This matrix allowed strain ductility in the masonry wall thus delaying the development and propagation of shear cracks. This enabled the stabilized Juja soil wall model to behave more elastically as compared to the un-stabilized ones. In the absence of clay minerals in Murang'a soil, the ash reduced the density of the block and ultimately made it to have low compressive capability in the wall model. In general the elimination of mortar in interlocking blocks made the failure not to depend on the weak bonds but on the characteristic of individual blocks. However, in both wall models the ultimate failure load was low than for the individual stabilized blocks. Since the bed joints, because of their continuous nature, divide the media into layers of equal thickness, this gave the masonry the appearance of a laminated composite material (Asteris and Syrmakezis, 2005). Therefore during transfer of the load, the bearing capacity of the wall was reduced as compared to that of an individual block.

Conclusion.

The effect of MSW ash on the compressive strength and failure characteristic of a masonry wall has been discussed. Two percent replacement of the ash was carried out on the wall model and the following conclusions were drawn:

Addition of MSW ash as a stabilizer enables a pozzolanic reaction which cements and hardens the clay particles together forming an elastic soil matrix which reduces formation of early cracks in stabilized soil.

The ultimate compressive strength of 2%MSW ash stabilized masonry wall is almost equal to that of un-stabilized masonry although the compressive strength of individual block units is higher than for the walls. A 2%MSW ash stabilized masonry wall model failure is more ductile and allows a higher deflection to be attained than un-stabilized Juja soil masonry wall. The failure stress lines propagation in 2%MSW ash corresponds well with the recommendation of the code of practice for masonry design; the code can therefore be used in design of masonry units stabilized using municipal solid waste ash.

The 2%MSW ash stabilized masonry wall can carry almost half its ultimate failure load even after development of first crack and allow a higher deflection than un-stabilized Juja soil wall. In the design consideration of un-reinforced masonry wall the code of practice for use of masonry recommends the stress loads to be dispersed extending downwards at 45° from the edges of the loaded area. This was well depicted in the failure mode of 2%MSW ash stabilized masonry wall as compared to that of un-stabilized Juja soil blocks. The failure of the wall models indicated that elasticity of masonry increases when the soil is stabilized and mortar is not used in joining the units. Murang'a soil does not contain active clay minerals, therefore MSW ash should not be used to stabilize it because it will lower the bearing strength of the block units in a wall.

Acknowledgements

The authors would like to thank the resources provided by Jomo Kenyatta University of Agriculture and Technology in carrying out the practical of the research. The authors would also like to acknowledge the staffing resources provide by the Department of Civil and Environmental Engineering in Jomo Kenyattta University of Agriculture and Technology, and Department of Civil Engineering in Federal University of Technology, Minna.

References.

AASHTO, (1986). *Standard for Transportation Materials and Methods of Sampling and Testing*, 14th Ed. Washington DC

Adam, E. A. (2001). *Compressed Stabilized Earth Block Manufacture in Sudan*. United Nations Education, Scientific and Cultural Organization. France.

Arumala, J. O. and T. Gondal (2007). *Compressed Earth Building Blocks for Affordable Housing.* Proc. of the construction and building research conference of the Royal Institute of Charted Surveyors. Atlanta USA.

Asteris, P. G. and C. A. Syrmakezis (2005). *Strength of Unreinforced Masonry Walls under Concentrated Compression Loads*. **DOI:** 10.1061 / (ASCE) 1084-0680 10:2(133).

ASTM C 618, (2001). *Standard Specification for Coal Fly Ash and raw or Calcined Natural Pozzolana for use as a Mineral admixture in Concrete*, Annual Book of ASTM Standards. 4(2): 149-155.

Berto, L., Saetta, A., Scotta, R., and R. Vitaliani (2005). *Failure Mechanism of Masonry Prism Loaded in Axial Compression: Computational Aspects*. Journal of Materials and Structures, 38: 249-256.

BSI, BS 1377-1(1990). Soils for Civil Engineering Purposes – Part 1: General Requirements and Sample Preparation.

BSI, BS 5628-1 (2005). Code of Practice for the Use of Masonry – Part 1: Structural Use of Un-reinforced Masonry.

De Silva, P. S. and F. P. Glasser (1992). *Pozzolanic Activation of Metakaolin*. Journal of Advanced Cement Research, pp 167-178.

Drysdale, R. G., Hamid, A. A., and L. R. Baker (1994). *Masonry Structures: Behaviour and Design.* Prentice-Hall, Englewood

EN 1052-1. (1999). Method of Test Masonry, Part 1 – Determination of Compressive Strength.

Hemant, B. K., Durgesh, C. R. and K. J. Sudhir (2007). *Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression*. Journal of Materials in Civil Engineering. 19(9): 728-739.

Hendry, A.W. (1990). *Structural Design of Masonry Buildings*. ISBN 0333497481.

Hendry, A.W. (1998). *Structural Masonry, 2nd Edition*. Macmillan Press ltd, London.

Ikpenwa P.E. (2009). Effect of Firing Temperature on the Structural Properties of Fired Clay Bricks, Federal University of Technology. Minna, Niger State, Nigeria, pp.99.

Kenya Standard, KS 02-300:1983: *Specification for Burnt Building Bricks*.

McNary, W.S., and D. P. Abrams (1985). *Mechanics of Masonry in Compression*. Journal of Structural Engineering. 111 (4): 857–870.

National Lime Associational, (2007). 200N, Glebe Road, Suite 800, Virginia.

Ninov, J., Donchev, I., Lenchev, A. and I. Grancharov (2006). *Chemical Stabilization of Sandy-illite Clay*. Journal of the University of Chemical Technology and Metallurgy. 42 (1): 67-72.

Ogunsusi V. (1995). Compressed earth bricks masonry hand book pts 1, 2,3, Jos, National Commission for museuns and Conuments.

Okigbo, S. N. (1999). Earth (Laterite) as a Building Material, Federal University of Technology. Minna, Niger State, Nigeria, pp.45.

Okunade, E. A. (2008). *The Effect of Wood ash and Sawdust Admixtures on the Engineering Properties of a Burnt Laterite-clay Brick*. Journal of Applied Science. 8: 1042-1048.

Prashant, B. (2009). *Municipal Solid Waste (MSW) as a Construction Material*. Master thesis presented to Civil Engineering Department. Mumbai.

Vonk, R. A. (1992). *Softening of Concrete Loading in Compression*. Dissertation Eindhoven University of Technology, Eindhoven, The Netherlands.