CERAMIC WARE WASTE POTENTIAL AS CO-BALLAST IN DENSE MASONRY UNIT PRODUCTION

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ABSTRACT

Ceramic ware waste applicability as coarse aggregate was considered in this study for dense masonry unit production. The waste was crushed into 1.4 mm particle size and mixed with natural fine aggregate in the ratio 2:3. Portland ordinary cement, aggregate, and water mix ratio was 1:7:0.5. Masonry units produced were cured for 7, 21, and 28 days prior to compressive test. Result shows that curing age have a significant impact on all the compressive strength indices inspected except for Young's modulus. Crushing force and the compressive strength of the ceramic-natural fine aggregate blocks increased by 11.7 – 54.7 % and 11.6 – 59.2 % respectively. The highest ceramic-natural fine block compressive strength at yield and peak, 4.97 MPa, was obtained after 21 days curing age. Ceramic aggregate introduced into the dense blocks improved the suitability of the blocks for construction purposes.

Keywords: Ceramic ware waste, co-ballast, dense masonry unit, compressive strength, curing time

INTRODUCTION

Solid wastes are inevitable in today's world. Advent of modernization and development are instrumental to the volume that has resulted in global concern. Solid waste generated between 2006 and 2010 experienced upward surge by a factor of 1.58 (Akinwonmi *et al.,* 2012). This was also forecasted to be about 25 trillion kilograms by 2050 (Karak *et al.,* 2012). The increment over the years has been attributed to world's growing population among others, which calls for prompt and suitable management (Hoornweg and Bhada-Tata, 2012; Minghua *et al.,* 2009). Harmful nature of some of the wastes is similarly alarming. For instance, solid waste composed of plastic, cementitious concrete aggregate, and mortars are cancerous and hazardous in nature (Erik *et al.,* 2013; Silva *et al.,* 2013). This makes good management practice for this waste category imperative.

Generally, some of the solid wastes management methods are landfilling and incineration. A study on waste disposal and reuse by EPA (2003) shows that over 55 - 65 % of construction and

demolition waste are landfilled rather than recycled. Nevertheless, due to high competition for land, landfilling of this waste category may continue to experience constraints. Incineration, an alternate path to landfilling, is not a plausible option for construction and demolition waste like ceramic ware waste due to the waste nature. Rather, solid waste reuse and recycling are environmental-friendly approaches to effectively manage the waste, as this will reduce deposition in landfills, dumpsites and sacrificial lands.

Utilization of various demolition and construction waste streams have been documented. This includes, potential of demolition waste as land filler as reported by Hansen (1992). Mineral wool as filler in wood–polypropylene composites (Olli and Kärki, 2014). Paper waste as well has been reused as lagging material (Cline *et al.,* 2012). Plastic wastes recycling into temporary waste storage polythene bags, containers, and used in flexible pavement construction are some of the present wastes to wealth avenues for small, medium and large scale firms (Njeru, 2006; Scheinberg *et al.,* 2011; Rajasekaran *et al.,* 2013). However, waste reuse has cost reduction benefit over waste recycling. For instance, cost of paper de-inking in the processes of waste recycling poses limit to paper recycling, while paper waste reuse does not attract such cost especially in the application as lagging material. Therefore waste reuse is both environmental-friendly and economical.

Construction waste reuse is a notable and promising research area. In this study, the reuse of construction wastes from ceramic ware waste was considered. This was incorporated as aggregate in dense masonry unit construction.

METHODOLOGY

Ceramic ware waste (Plate 1) obtained from dumpsite within Ilorin metropolis, Kwara State in Nigeria was cleaned of dirt and other external materials before manual size reduction into coarse form and subsequently fine form of 1.4 mm particle size using hammer mill. The fine ceramic ware waste (Plate 2) was subjected to bulk density, moisture content, specific gravity and porosity tests using standard methods.

Natural fine aggregate was obtained from the stream bed of a flowing stream at Oke - Ode, Tanke in Ilorin, Kwara State. The choice of the source type was with respect to a number of literatures that gave credence to natural fine aggregate from flowing streams, river and sea as good construction material (Stefanidou, 2016; Subashini *et al.,* 2016). Additionally, material cost was minimized.

Physical properties of the aggregates were examined using standard methods. Furthermore, scanning electron microscope JEOL JSM-6490LV model was employed to investigate the structural characteristics and pattern of the aggregates.

Mould of 105 x 105 x 105 mm volume was constructed using a galvanized steel of 3 mm thickness. The sides were joined by arc-welding.

Aggregates to ordinary Portland cement to potable water mix ratio for this experiment was 7:1:0.5 in that order. Natural fine aggregate to fine ceramic ware aggregate mix ratio was 60:40 % by weight. Natural fine and ceramic aggregates were thoroughly mixed together before the

introduction of ordinary Portland cement. This was homogeneously mixed until uniform colouration of mix was attained and quantified water added. The paste was placed in the formwork, compacted and demoulded on plain pallet. Green dense masonry units produced were placed in a cool and well ventilated shed for a period of 24 hours. The masonry units were submerged in drinkable tap water for 7, 21, and 28 days and thereafter stacked (Plates 3 & 4). Two samples were produced for each curing age. Densities of the blocks after curing and before crushing were examined.

Dense masonry unit produced from natural fine aggregate only and cured for 7 days was denoted with M0C7. Masonry unit produced from mixture of natural fine and ceramic ware waste aggregates at 60 % and 40 % of aggregate weight and cured for 14 days was represented with M40C14 in this study. Similar trend were used to define M40C7 and M40C28. The M0 series (M0C7, M0C21 and M0C28) were used as control in this study.

Evaluation index employed to examine the suitability of the dense blocks was compressive strength test using Testometric (M500) universal testing machine. Operating speed of the machine was 5 mm/min without preload force (Plate 5).



Plate 1: Ceramic ware waste

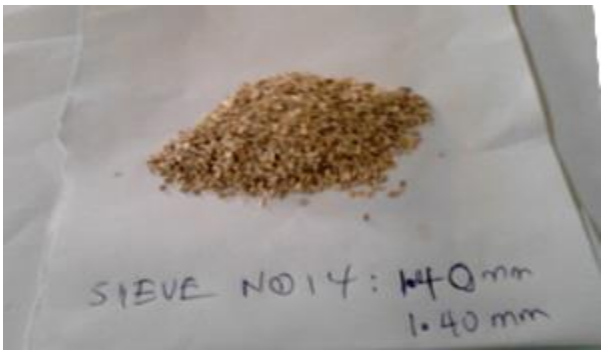


Plate 2: Granulated ceramic ware waste



Plate 3: Dense masonry units under curing



Plate 4: Masonry units stacked



Plate 5: Compressive test on dense masonry unit

RESULTS AND DISCUSSION

Properties of Aggregate

Porosity of the aggregates increased with particle size though bulk density followed contrary trend (Table 1). Specific gravity of the ceramic aggregate obtained in this study was higher than the value documented by Correia *et al.*, (2005) in a study on recycled ceramic aggregates. Natural fine aggregate bulk density was about 2.4 times the ceramic aggregate (Table 1).

Table 1: Physical properties of natural fine and ceramic aggregates

	Natural fine	Ceramic
Particle size (mm)	≤ 0.30	1.40
Porosity (%)	10.20	13.20
Specific gravity	2.46	2.10
Bulk density (g/cm^3)	1.61	0.67
Moisture content db (%)	1.91	2.17

Aggregage Morphological Pattern

The surface morphology of the natural fine aggregate revealed a smooth surface with no evident pore spaces at 10µm and 1000 magnification. On the contrary, crushed ceramic ware waste shows evidence of pore spaces on the matrix at similar magnification and size (Figures 1 & 2).

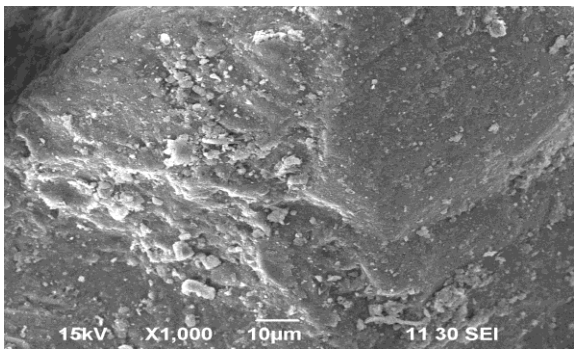


Figure 1: Fine sand aggregate SEM pattern

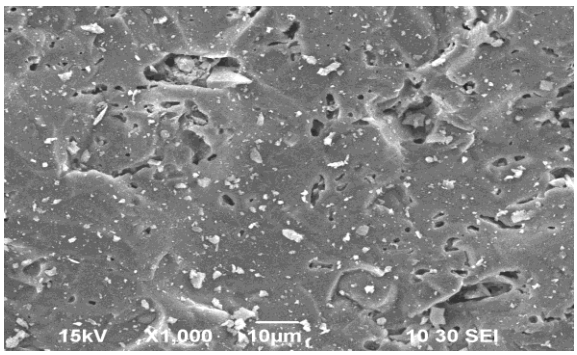


Figure 2: Ceramics SEM Pattern

Block density

The non-uniform variation in the densities after curing and before crushing was as a result of curing effect and weight loss during handling. Furthermore, densities after curing was higher than those before crushing for all categories considered in this study (Table 2). Both densities were higher than the values documented in a study on commercial hollow sandcrete blocks assessment by Mohammed and Anwar (2014). There was significant difference between pure and modified masonry unit with respect to the two densities considered.

Table 2: Mean block density

Dense Block	Density after curing (kg/m^3)	Density before crushing (kg/m^3)
M0C7	1683.94	1660.91
M0C21	1727.12	1640.78
M0C28	1694.73	1651.55
M40C7	1791.88	1705.53
M40C21	1791.88	1727.12
M40C28	1813.47	1705.53

Compressive Strength Test

Results show that energies and forces required to crush the modified aggregates dense masonry units at 5mm/min speed were greater than the pure natural fine aggregate blocks by 23 – 50 and 27 – 54 % respectively irrespective of the curing times (Table 3). This indicates that dense masonry units produced from ceramic-natural fine aggregates are stronger than solely natural fine aggregate blocks. Silva *et al.*, 2013 attributed this result to unhydrated cementitious substance inherent in the ceramic waste ware aggregate and the improved binding potential due to greater coarseness of the ceramic ware waste aggregate. Furthermore, modified aggregates dense masonry units cured for 21 days required the highest crushing energy and force. Crushing force and energy increase with curing age till 21 days curing time followed by a decline. This indicates that 21 days curing time is most suitable age for strong dense masonry blocks with 60 % natural fine and 40 % ceramic ware waste aggregate mix ratio (Table 3). There was significant difference between forces required to crush the pure and modified masonry unit at 95 % confidence interval. This means that increasing the mix ratio within the stated range for this study has significant effect on the force required to crush the masonry units. Curing time similarly has significant impact on the crushing force.

Table 3: Force and energy

Class	Force (kN)			Energy (Nm)		
	Peak	Yield	Break	Peak	Yield	Break
M0C7	24.829	24.830	19.356	23.24	23.24	35.55
M0C21	31.486	29.860	27.910	34.64	26.86	53.46
M0C28	32.082	30.200	25.223	46.18	30.96	70.35
M40C7	47.250	34.224	42.320	46.40	30.30	68.60
M40C21	54.820	54.820	47.860	51.05	51.05	77.77
M40C28	49.100	49.100	42.400	50.50	50.50	72.03

Stress values for the modified aggregate dense masonry units almost double the pure natural fine aggregate ones (Table 4). This could be linked to the higher coarseness of the ceramic ware waste compared to fine natural fine aggregate which improves inter-particle friction thereby resulting in uniform load distribution (Silva *et al.,* 2013). Compressive strength values increased from curing age 7 to 21 days with a decline at further curing age (28 days). Most compressive strength values for the natural fine aggregate dense masonry units cured for 7 days satisfied the minimum industrial standard for some developing and underdeveloped countries. For instance, minimum standard for countries such as Nigeria, Ireland, and Philippine are 2.5 MPa, 1.73 MPa, and 2.42 MPa respectively (Amistad, 2008; e-SIB, 2017). All compressive strength values for the dense masonry units made from ceramic ware waste and natural fine aggregates met British standard (3.5 MPa) except for compressive strength at yield for M40C7. Highest compressive strength for modified aggregate masonry unit was obtained at 21 days curing age (4.31 – 4.97 MPa). The quantity of ceramic ware waste and curing days influenced masonry compressive strength as observed by Murdock *et al*., (1991). Despite the difference in aggregate mix and curing time, strain values were closely related. The values range between 1.67 – 4.06 % (Table 4). Statistically, there was significant difference between the curing ages for stress and strain values obtained at 95% confidence interval. Furthermore, mix ratios considered were equally statistically different. This further substantiate the observation noted about effect of ceramic waste on force required to crush masonry unit in this study.

Table 4: Stress and strain

Class	Stress (MPa)			Strain (%)		
	Peak	Yield	Break	Peak	Yield	Break
M0C7	2.25	2.25	1.76	2.16	2.16	2.75
M0C21	2.86	2.71	2.53	2.74	2.46	3.34
M0C28	2.91	2.74	2.29	3.18	2.64	4.05
M40C7	4.29	3.10	3.84	2.21	1.68	2.70
M40C21	4.97	4.97	4.31	2.79	2.79	3.29
M40C28	4.45	4.45	3.85	2.45	2.45	2.85

Aggregate modified masonry units had higher Young's modulus values (Table 5). Modulus of aggregate modified masonry units were 33 – 45 % greater than the pure natural fine aggregate masonry units. Deflection for modified masonry units followed sinusoidal path. On the contrary, deflection in pure natural fine aggregate masonry units were directly proportional to curing time. Deflection increased with curing time (Table 5). There was significant difference in dependent variable (deflection) obtained with respect to curing time.

Table 5: Deflection and Young's modulus

Class	Deflection (mm)			Young's modulus (GPa)
	Peak	Yield	Break	
M0C7	2.26	2.26	2.88	0.170
M0C21	2.87	2.58	3.51	0.200
M0C28	3.33	2.77	4.25	0.157
M40C7	2.32	1.77	2.83	0.278
M40C21	2.93	2.94	3.45	0.300
M40C28	2.56	2.57	2.99	0.285

Stress-Strain Nexus

Force applied to crush the blocks was directly proportion to the deflection obtained until it reached the peak and declination set in (Figures 3-5).



Figure 3:Stress-strain curve for modified solid masonry unit after 7-day curing



Figure 4:Stress-strain curve for modified solid masonry unit after 21-day curing



Figure 5:Stress-strain curve for modified solid masonry unit after 28-day curing

Effect of curing time on compressive parameters

Nexus between mix ratio and curing time was examined on compressive dependent variables such as energy, force, stress, strain, deflection, and Young's modulus. There exist strong relationship between crushing force and curing time for unmodified masonry unit. Correlation coefficients were greater than 0.9 for force at yield and peak (Figure 6). These might suggest that modification of masonry unit with 40% ceramic waste influenced the relationship between mix ratio and curing time. The trend for modified masonry unit shows that after 21 days curing, relationship between these compressive parameters and curing times were not closely fit. The correlation coefficients were less than 0.88 (Figures 6 - 11). Visual inspection of the closely fitted correlations shows that crushing force increased with curing time (Figure 6). Similar trend was observed for energy exerted on unmodified solid blocks, correlation coefficient were above 0.9 (Figure 7). This further substantiate the hypothesis that modification of masonry unit with 40% ceramics waste altered the nexus between energy required to crush solid masonry units and curing time. Particle size of ceramic waste might be responsible for this result as modified masonry unit obviously have more void spaces compared with pure masonry unit. Though thorough investigation on this was not carried out in this study.

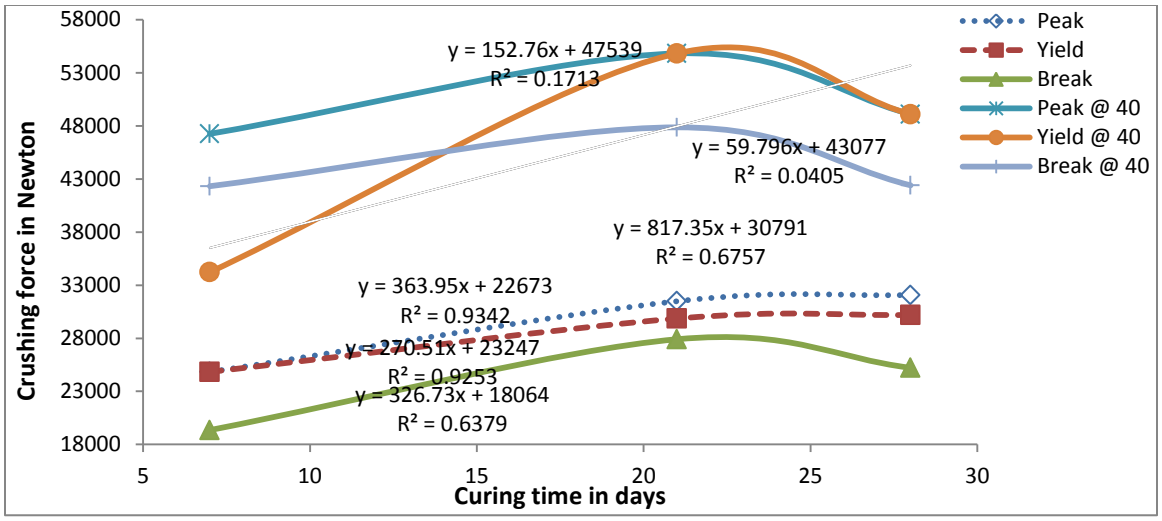


Figure 6: Effect of curing time on masonry unit crushing force

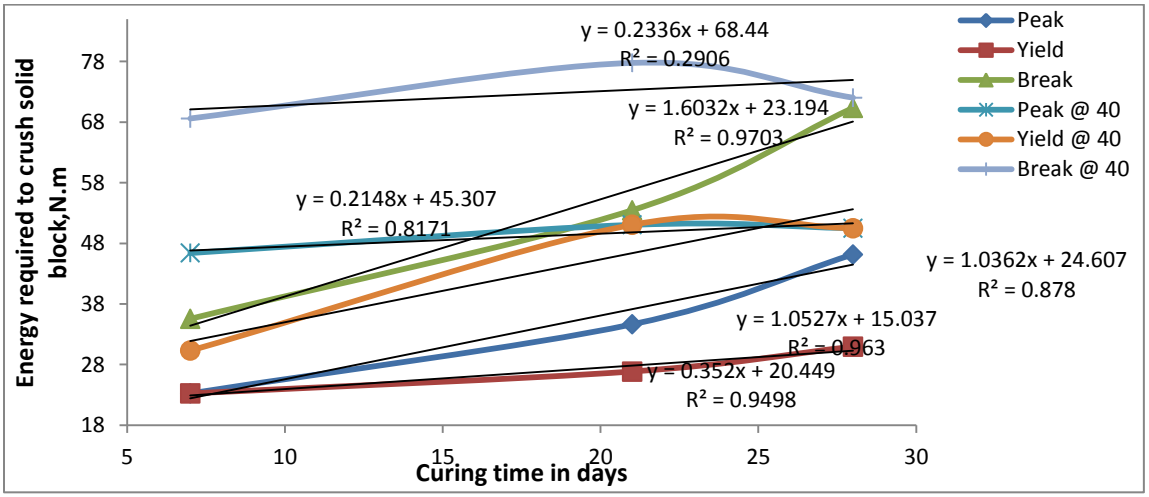


Figure 7: Effect of curing time on energy required to crush masonry unit

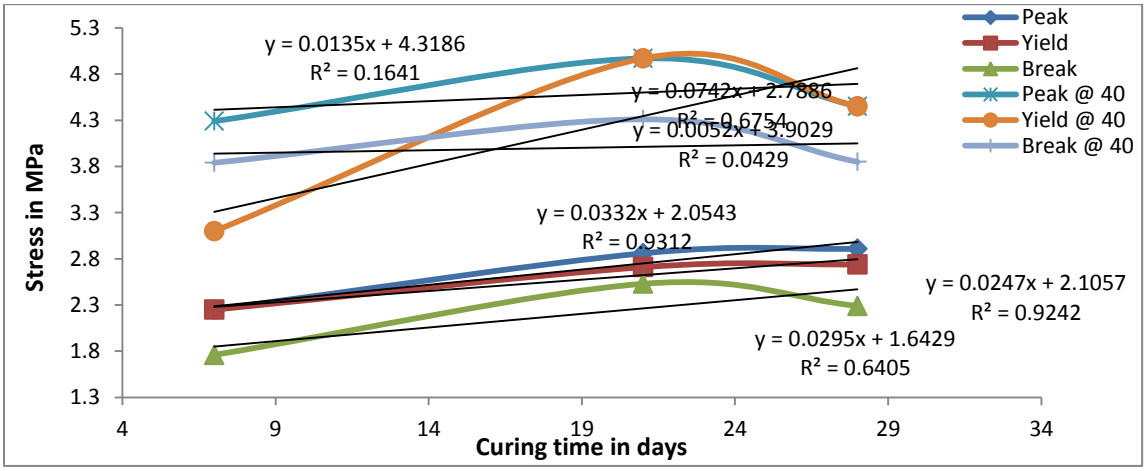


Figure 8: Effect of curing time on stress

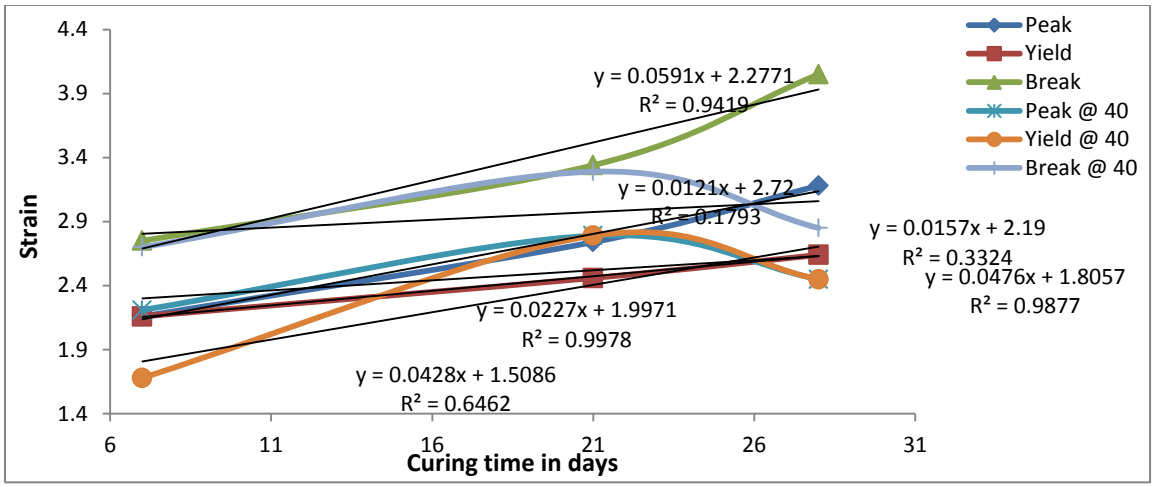


Figure 9: Strain relationship with curing time

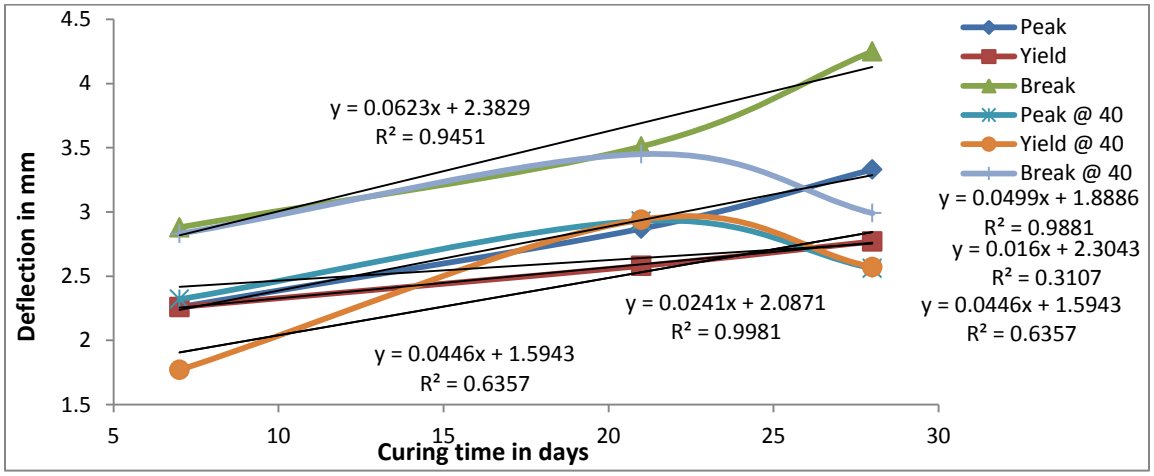


Figure 10: Deflection relationship with curing time

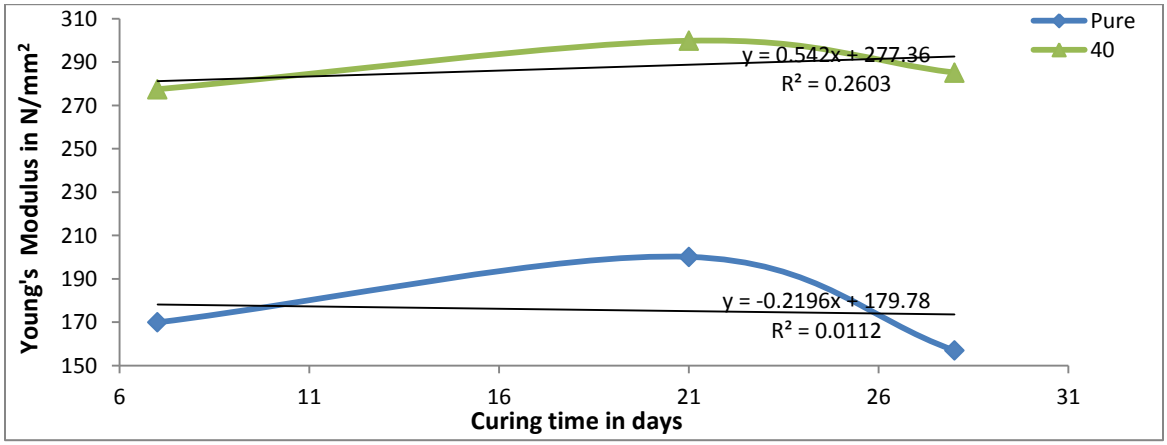


Figure 11: Young's modulus relationship with curing time

CONCLUSION

Ceramic ware waste as co-ballast was investigated in this study for masonry unit production. There was no significant difference between the compressive stresses obtained based on the two different mix ratio of 0% and 40% ceramic aggregate, though force and energy required to crush the different mix ratios were significantly different. This greater values of force and energy required to crush the solid masonry unit compared to the solid masonry unit are indicators of the improved strength of the ceramic-natural fine solid masonry units. The best curing time for the solid masonry units was 21 days for all category. Thorough inspection of the effect of ceramic ware waste particle size on masonry unit compressive parameters should be studied. Suitability of ceramic ware waste as complementary aggregate in solid masonry unit production was ascertained in this study.

REFERENCE

Akinwonmi, A. S., Adzimah, S. K. and C. M. Karikari (2012) Assessment of solid waste management in Tarkwa municipality Ghana: Time series approach. Journal of environment and earth science, 2(10):139-147.

Amistad, F. T. (2008) Mechanical Test of Concrete with Aggregates Hauled from Strategic Quarry Sites in Ilocos Sur. UNP Research Journal, 25:112 - 124.

British Standards (BS) 3921 (1969) Specification for brick and block of fired brick earth, clay and shale.

Cline, J., Domingue, E., Fournier, E. and M. Villar (2012) Sustainable paper insulation for Kambashus in informal settlements of Namibia: An assessment of thermal resisitanvce¸flammability and efficiency of recycled waste material for insulating shacks in Katutura. Worcester polytechnic institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

Correia J. R., de Brito, J. and A. S. Pereira (2006) Effects on concrete durability of using recycled ceramic aggregates. Materials and Structures, 38:169-177.

EPA (2003), Estimating 2003 Building Related Construction and Demolition Materials Amount, URL http://www.epa.gov/osw/conserve/rrr/imr/cdm/pubs/cd-meas.pdf

Erik S., Tostar S., Boldizar, A., Foreman M. R.StJ. and K. Möller (2013) An analysis of the composition and metal contamination of plastics from waste electrical and electronic equipment (WEEE). Waste Management, 33(4):915-922.

e-ISB (2017) No. 50/1953 - Standard Specification (Hollow Concrete Building Blocks Made With Natural Aggregate) Order, 1953. electronic Irish Statute Book. Government of Ireland. http://www.irishstatutebook.ie/eli/1953/si/50/made/en/print. Accessed on 22nd June 2017.

Hansen, T.C. (1992). Recycling of demolished concrete and masonry. E & FN Spon, London (UK).

Hoornweg D. and P. Bhada-Tata (2012) What a waste – A Global Review of Solid Waste Management. World Bank, Washington DC, USA.

Karak, T., Bhagat, R. M. and P. Bhattacharyya (2012) Municipal solid waste generation, composition, and management: the world scenario. Critical Reviews in Environmental Science and Technology, 42:1509-1630.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A. and L. Yi (2009) Municipal solid waste management in Pudong New Area, China. Journal of Waste Management, 29:1227-1233.

Mohammed M. and A. R. Anwar (2014) Assessment of structural strength of commercial sandcrete blocks in Kano State. Nigerian Journal of Technological Development, 11(2): 39-43.

Murdock, L. J., Brook, K. M. and J. D. Dewar (1991) Concrete materials and practice 6th Ed., Edward Arnold, London, 83:382-391.

Nigerian Industrial Standard (NIS) 87. 2000 Standard for sandcrete bricks, ICS, 91 10.20, NIS, Abuja Nigeria.

Njeru, J. (2006) The urban political ecology of plastic bag waste problem in Nairobi, Kenya. Geoforum, 37:1046-1058.

Rajasekaran, S., Vasudevan, R. and S. Paulraj (2013) Reuse of Waste Plastics Coated Aggregates Bitumen Mix Composite For Road Application –Green Method. American Journal of Engineering Research, 2(1):1-13.

Scheinberg, A., Spies, S., Simpson, M. H. and A. P. J. Mol (2011) Assessing urban recycling in low- and middle-income countries: building on modernized mixtures. Habitat International, 35 (2):188-198.

Silva, R. V., de Brito, J. and R. K. Dhir (2014) Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production, Construction and Building Materials, 65: 201-217.

Stefanidou M. (2016) Crushed and River-Origin Natural fines Used as Aggregates in Repair Mortars, Geosciences, 6(23):1-6.

Subashini, B., Sivaranjani, G., Dhanalakshmi, G., Gayathri, K., Kumar, A. A. Srimathi, A. and C. Revathi (2016) Experimental Investigation of Sea Natural fine for Construction Purposes, Indian Journal of Science and Technology, 9(11):1-5

Väntsi O. and T. Kärki (2014) Utilization of recycled mineral wool as filler in wood–polypropylene composites. Construction and Building Materials, 55:220-226.