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# UTILIZATION OF CERAMIC WARE WASTE AS COMPLEMENTARY AGGREGATE IN HOLLOW MASONRY UNIT PRODUCTION

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**Abstract**
Continuous increase in ceramic ware waste from construction and demolition waste without good management practice has resulted in elevated volume of this waste category. However, utilization of this waste in masonry unit production could be a plausible option to solve this menace, particularly, in its ability to enhance masonry unit compressive strength. In this study, ceramic ware waste was utilized for hollow masonry unit production and three different natural fine aggregate to ceramic aggregate mix ratios of 100:0, 90:10, 80:20 and 70:30 were examined. Furthermore, the cement to total aggregate mix ratio considered was 1:7. Sequel to the process of aggregates mixing, casting, and subsequently demoulding, the masonry units were cured for 28 days prior to inspection for compressive test parameters. Results indicated that masonry unit with natural sand to ceramic waste mix ratio of 80:20 has the highest crushing strength at peak, yield and break point which were 60.903kN, 60.493kN and 53.863kN respectively. The compressive stress at peak and break were 6.57MPa and 6.50MPa in that order and Young's modulus was 0.262GPa. Statistically, there were no significant differences at 95% confidence interval between the aggregate mix masonry units when the compressive strength indices were evaluated. Ceramics ware waste from demolition and construction waste is a suitable co-aggregate in hollow masonry unit production.

**Keywords:** Construction and demolition waste, ceramic ware waste, reuse, hollow masonry unit, compressive strength, natural fine aggregate

## 1. Introduction

Construction and demolition wastes generation are on the increase due to growth in dilapidated structures, aged structures and those threatened and affected by natural disasters, and it constitutes the largest fraction globally (Zimbili *et al.,* 2014). Usually, wastes emanate from neighbourhood where simple structures are demolished and replaced with new and gigantic ones like stories and skyscrapers that can accommodate the growing population demand. Replacement of old and dilapidated buildings with aesthetically improved ones has equally contributed to the generation. Other salient factors contributive to the waste generation are fire incident and wars (Ali and Moon, 2007). Natural disasters such as earthquake, hurricane and flood are equally inclusive in the list (ICSU, 2008, Mühr *et al.,* 2017). Hence, the waste will continue to grow in volume and pose threat to the environment except pragmatic steps are employed for its judicious utilization. Composition of construction and demolition wastes are ceramics ware, metal, wood, concrete, stone, related aggregates, glass, plastic, asphalt, plaster, rubbish, paper and others.

Among this composition, ceramic ware wastes contribute the greatest stony fraction to the waste stream; about 72% of the fraction (Zimbili *et al.,* 2014). The ware wastes are innate materials with high earth minerals subjected to dehydration, with regulated heating of about 1200˚C (Medina *et al.,* 2012). The wastes are often landfilled though this common disposal option is neither economical nor environment friendly. Recently, the non-biological wastes have found unique applications in our society beyond disposal. One important use is as storage bank for nuclear wastes (Devanathan *et al.,* 2011). Another prominent application of ceramic waste ware was as binding agent in concrete production due to the pozzolanic property (Kenna and Archbold, 2014). Other uses are as fine and coarse aggregates for construction and fillers (Amitkumar *et al.,* 2013). Production of masonry unit is another feasible area of application. Masonry units are used in places like Malaysia as noise barrier (Herni *et al.,* 2015). They are employed globally in construction industries due to the fire resistance ability, good heat insulating properties and chemical resistance compared with wood and steel (CIGR, 1999). Although, the low tensile strengths when compared with steel and wood have been the primary challenge of using this construction material especially for load bearing functions. Hence, this study intends to investigate the effect of ceramic ware waste as a partial substitution for natural sand aggregates in hollow masonry production and equally inspect the quality in terms of compressive strength. Other substances that have been utilized in masonry unit production are rice husk (Chukwudedelu *et al.,* 2015) and coconut fiber and shell (Ganiron *et al.,* 2017).

Masonry unit in Nigeria is either in the hollow or solid form. This is the major construction material for all kinds of buildings in Nigeria as compared with some part of the western world where emphasis is placed on wood. For the purpose of this study, the scale of hollow block considered to Nigerian industrial standard (NIS) 87 (2001) was 1: 3.

## 2. Materials and Methods

Natural fine aggregate was collected from the stream bed channeled through Oke-Odo, Ilorin in Kwara State in Nigeria. Visible biological materials were sifted with 2 mm diameter plastic sieve from the natural sand to ensure the aggregate was free from organic materials. Natural fine aggregate particle size considered in this study was ≤ 0.3 mm. Standard methods were employed to determine the natural fine aggregate composition, properties and sand type.

Ceramic aggregate was obtained from white single fired sanitary ware haphazardly discarded in dumpsites within Ilorin Metropolis, Kwara State, Nigeria (Figure 1). The sanitary ware was crushed into 0.075 mm particle sizes using 2hp hammer milling machine after collection, cleaning and manual size reduction with sledgehammer (Figure 2). Structural characterization of both natural sand and ceramic samples were inspected using a JEOL JSM-6490LV scanning electron microscope (SEM).

Ceramic and natural sand aggregate proportions were varied into three mix ratios, other than the control. The mix ratios include 100 percent natural sand without ceramic waste (M0), 90 percent natural sand with 10 percent ceramic waste (M10), 80 percent natural sand with 20 percent ceramic waste (M20) and 70 percent natural sand with 30 percent ceramic waste (M30). Physical properties of the co-ballasts such as specific gravity, moisture content, bulk density and porosity were inspected using standard methods.

Ordinary Portland cement (Dangote trade name), potable water, and aggregates were batched by weight and mixed thoroughly to ensure homogeneity in the ratio 1:7 before pouring into the 150 × 75 × 75 mm (inner dimensions) mild steel formwork. Water to cement ratio was 0.5. The choice of these ratios was based on recommendation from literatures (Afolayan *et al.,* 2017; Artêmio *et al.,* 2012; Prakash *et al.,* 2013). This formwork dimension was 1:3 of the Nigerian industrial standard sandcrete endorsed by the Nigerian Industrial standard (NIS) 87 (2001). The formwork was filled and compacted manually to avoid air spaces within the poured mixture that may reduce strength of masonry unit. Freshly formed hollow masonry units were carefully demoulded on approximately 300 × 120 mm plain pallets to avoid cracks (Figure 3). The fresh masonry units were stored temporarily in a well-ventilated shed. The blocks were cured by submerging in potable water for 28 days (Figure 4). Kaosol (2010) recommended this curing age in a study on water treatment sludge reuse for hollow concrete block production. Cured masonry units were carefully removed after each curing period, stacked to dry and stored in a well-ventilated shed. Blocks produced from each mix ratios were duplicated. Each block was labelled based on aggregate mix using oil-based paint applied with a soft brush. Densities of the masonry units were investigated using standard methods. Compressive strength indices were also inspected using Testometric (M500) universal testing machine at a test speed of 5 mm/min (Figure 5).

## 3. Results and Discussion

Aggregate Composition

Natural fine aggregate obtained from Oke-Odo contained 91.5 % sand, 2.0 % silt and 6.5 % clay. The clay content was less than 7 %, though this was expected to improve the binding process in the hollow block due to the pozzolanic property. Specific gravity of the aggregate was in line with Amitkumar *et al.,* (2013) documentation in a study on ceramic waste powder as replacement for cement in concrete production. Organic carbon and organic matter resident in the soil were less than 2.0 % each (Table 1). This is an indication of soil type suitability for construction purpose, as most organic materials decompose with time, creating pore within dried structures. Porosity of ceramic aggregate was over 200 % of the fine aggregate, though the bulk density was less by approximately 900 % (Table 1).

Figure 1: Ceramic ware waste collected from dumpsite

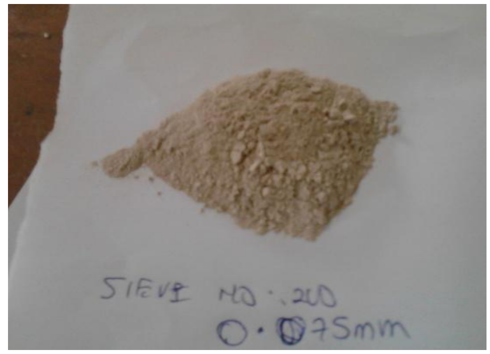


Figure 2: Granulated ceramic ware waste

Figure 3: Freshly moulded hollow block

Figure 4: Hollow masonry unit under curing


Figure 5: Masonry unit under compressive test

**Properties of Aggregate**

**Table 1:** Physical properties of natural sand and ceramic aggregates

| Properties | Natural Sand | Ceramic |
|---|---|---|
| Particle size (mm) | ≤ 0.30 | 0.075 |
| Porosity (%) | 8.16 | 20.95 |
| Specific gravity | 2.87 | 2.88 |
| Bulk density (g/cm$^3$) | 1.64 | 0.18 |
| Moisture content db (%) | 1.83 | 2.21 |
| Organic carbon (%) | 1.10 | - |
| Organic matter (%) | 1.90 | - |

### 3.1 Density

The least density after moulding and before crushing was observed for M0 and M30 respectively (Table 2). Density after moulding increased between 1.47 – 5.08 % for the entire masonry unit category. Reduction in density prior to crushing could be because of handling. Decrease in weight could also be attributed to the curing process that ensures the complete hydration of the masonry unit and water loss. Solely natural sand aggregate block had the least density. This is an indication that hydration process influences the density of ceramic-based masonry unit than purely natural sand block. Furthermore, these densities were within the range for Type A hollow sandcrete block (NIS, 2001). The densities after moulding was higher than the values obtained for concrete hollow block with the inclusion of coconut fiber cum shell and commercial concrete hollow block documented by Ganiron *et. al.,* (2017).

**Table 2:** Mean masonry unit density

| Block | Density after moulding (kg/m$^3$) | Density before crushing (kg/m$^3$) |
|---|---|---|
| M0 | 1635.5 | 1422.2 |
| M10 | 1718.5 | 1214.8 |
| M20 | 1718.5 | 1333.3 |
| M30 | 1659.3 | 1185.2 |

### 3.2 Scanning Electron Microscopy

Pore spaces were noticed in the ceramic ware waste morphological structure while natural sand had rough and crystal–like surface at 50µm and 500 magnification (Figures 6 & 7). The pore and rough surface will possibly enhance adhesion of the mix.

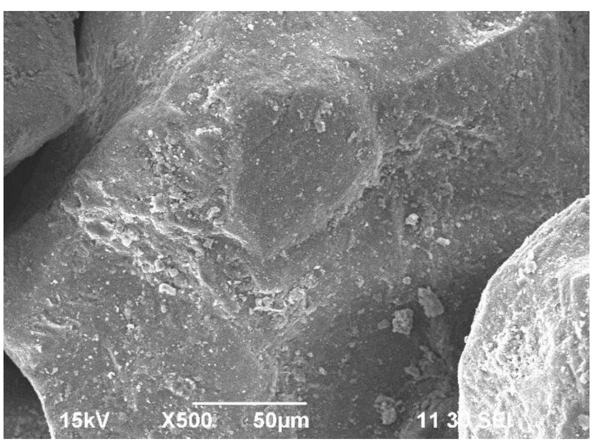


Figure 6: Natural sand

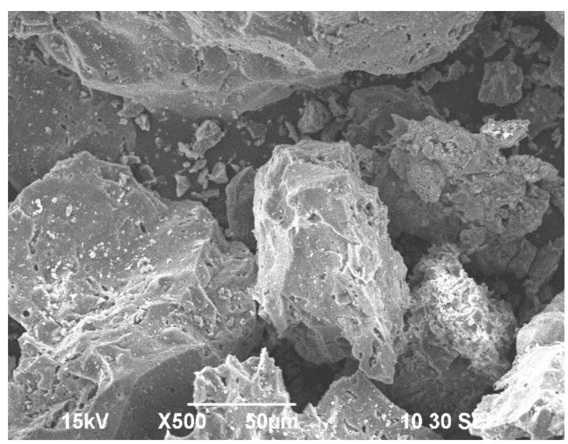


Figure 7: Ceramics ware waste

### 3.3 Compressive Strength Test

Results show that energies and forces required to crush the modified aggregates masonry units at 5 mm/min speed were greater than the pure natural sand aggregate hollow blocks (M0) by 57.5 – 467.45 % and 17.7 - 54.1 % in that order irrespective of the mix ratios considered (Table 3). This suggests that hollow masonry unit produced from ceramic-sand aggregates might have higher compressive strength and possibly be a better product than solely natural sand aggregate blocks. The three levels of energies (peak, yield and break) increased with ceramic aggregate increase. Similar trend was observed for the compressive force exerted to crush the blocks except for hollow blocks with 30% ceramic aggregate (M30). Block produced with mix ratio of 20 % ceramic to 80 % natural sand aggregate required the highest crushing force (60.903kN) as shown in Table 3. There was no significant difference among the three ceramic-sand masonry units (M10, M20 and M30) with respect to energies and forces ($P > 0.05$). The crushing force was higher than the value documented by Maroliya (2012) despite the mix ratios of 1:3:6 used in the study. This was also greater than the values reported for commercialized concrete hollow blocks reported by Ganiron *et. al.,* (2017). However, it is very close to the force required to crush commercialized hollow bock concrete with the addition of fiber and coconut shell. Other possible reason for the difference was the block dimension. Crushing energies in this study were greater than values observed by Chukwudedelu *et. al.,* (2015). The author obtained crushing energy between 7.55 and 12.80 Nm in a study on hollow and dense block production from mixture of rice husk and slaked lime. Biological material introduced by the author seems to be the major constituent that might have affected the crushing energy. However, higher energy required in this study to crush the ceramic-sand aggregate blocks shows that ceramic aggregate is a better option than rice husk in terms of strength in hollow masonry unit production, though rice husk block evidently has light weight advantage.

**Table 3:** Average force and energy values for compressive test

| Class | Compressive force (kN) | | | Energy (Nm) | | |
|---|---|---|---|---|---|---|
| | Peak | Yield | Break | Peak | Yield | Break |
| M0 | 30.435 | 27.755 | 27.469 | 30.42 | 19.89 | 41.70 |
| M10 | 51.449 | 43.643 | 39.123 | 74.77 | 46.80 | 88.41 |
| M20 | 60.903 | 60.493 | 53.863 | 94.08 | 69.42 | 124.08 |
| M30 | 56.999 | 45.730 | 54.400 | 172.62 | 44.06 | 186.13 |

There was no significant difference among the three ceramic-sand masonry units (M10, M20 and M30) with respect to stresses and strains ($P > 0.05$). Stress result followed the same trend with density. The stress at peak, yield and break for the ceramic-sand aggregate blocks were greater than that of natural sand aggregate blocks by 19.3 - 56.2 %. The greatest yield stress increment based on mix ratio occurred at M20 about 56.2 %. Stress at peak for this mix ratio was the highest produced. Masonry units with aggregate mix of M20 has highest stress value (6.57 MPa) and lowest strain value (3.72 %). This confirms that M20 masonry unit was stronger and therefore more suitable for construction than other mix ratio and particularly pure natural sand masonry unit. The stresses obtained (compressive strength) were lower than the values obtained by Barbosa and Hanai (2009) in a study on strength and deformation of hollow block with dimension 140 x 390 x 190 mm. However, it was greater than the values obtained for pure concrete hollow block and concrete hollow block with the addition of coconut fiber and shell (Ganiron *et al.,* 2017). Difference in block size was the obvious explanation for the disparity. Despite this, the compressive strength for the ceramic masonry units met the British and Nigerian standard (3.5 Mpa and 3.45 Mpa respectively). It equally met the A(3.5) and A(4.5) hollow load bearing unit specified for Indian standard (2005).

**Table 4:** Average stress and strain values for compressive test

| Class | Stress (MPa) | | | Strain (%) | | |
|---|---|---|---|---|---|---|
| | Peak | Yield | Break | Peak | Yield | Break |
| M0 | 3.10 | 2.85 | 2.83 | 5.22 | 4.59 | 5.83 |
| M10 | 5.30 | 4.70 | 4.14 | 5.54 | 3.79 | 5.90 |
| M20 | 6.57 | 6.50 | 5.86 | 4.07 | 3.72 | 5.06 |
| M30 | 5.81 | 4.66 | 5.45 | 7.70 | 3.98 | 8.05 |

Young's modulus value was highest with masonry unit produced from 80 % natural sand and 20 % ceramics aggregate mix ratio (0.262GPa). This almost doubled the value for pure natural sand aggregate blocks. This stated elastic modulus is the only value in Table 5 greater than the one reported by Ganiron *et al.,* (2017) for concrete hollow block with coconut and fiber inclusion. Though with respect to deflection from these masonry unit category, the least deflection was observed for M20 (Table 5). The high Young's modulus value indicates the suitability of M20 masonry unit compared with the other block categories in this study. There was no significant difference among the three ceramic-sand masonry units (M10, M20 and M30) with respect to deflection ($P > 0.05$). Deflection during compression test was highest for M10 at break, 10 % ceramic- sand aggregate mix ratio (Table 5).

**Table 5:** Average deflection and Young's modulus values for compressive test

| Class | Deflection (mm) | | | Young's modulus (GPa) |
|---|---|---|---|---|
| | Peak | Yield | Break | |
| M0 | 3.65 | 3.21 | 4.08 | 0.139 |
| M10 | 3.88 | 3.04 | 4.13 | 0.147 |
| M20 | 2.85 | 2.62 | 3.54 | 0.262 |
| M30 | 4.43 | 2.79 | 5.63 | 0.213 |

### 3.4 Stress-Strain Pattern

The three stress strain curves in Figures 8 - 10 followed the same trend. Hemant *et al.,* (2007), reported these overall non-linear shaped stress-strain curves. Non-linearity in the blocks were more obvious and pronounced when ultimate failure loads were reached (Figures 8 – 10).

These curves trend seem to be specific for hollow masonry units, as prism masonry units had linear stress strain curve (Prakash *et al.,* 2013). Therefore, stress-strain pattern is subjective to the type of masonry unit under consideration. Block produced with mix ratio of 20 % ceramic to 80 % fine aggregate had the best stress-strain curve pattern.

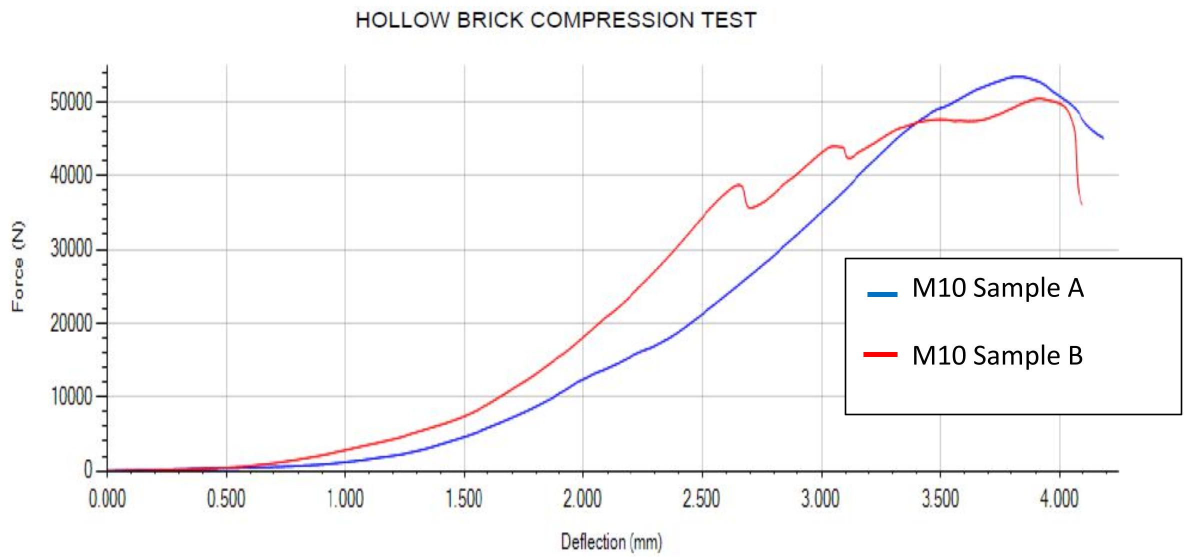


Figure 8: Stress strain curve for hollow block with10% ceramic ware waste hollow block

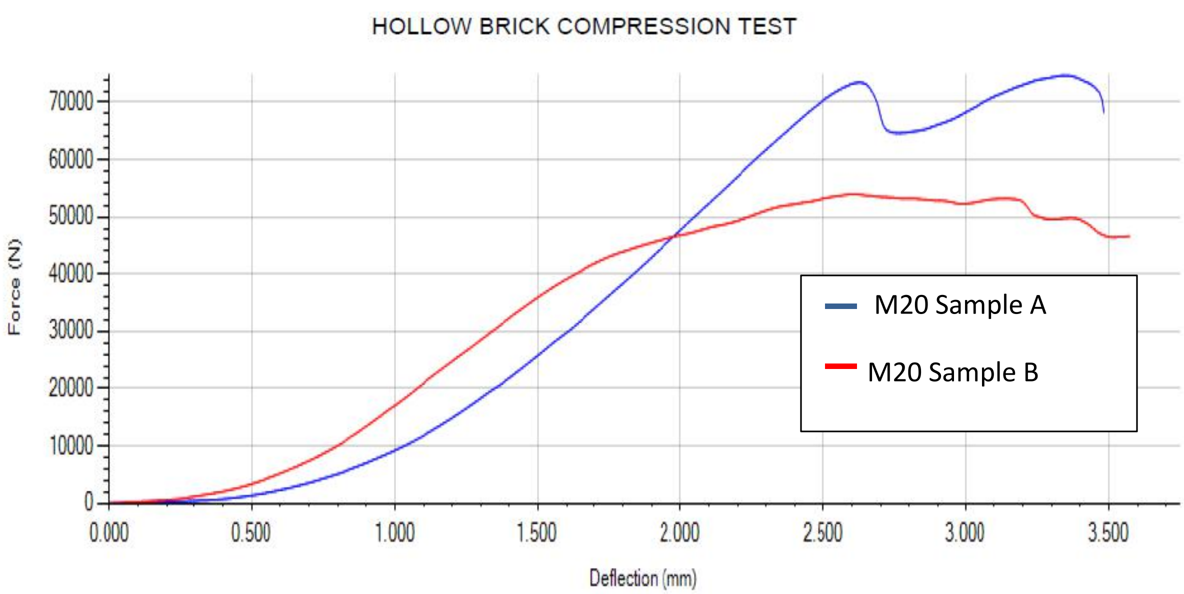


Figure 9: Stress strain curve for hollow block with 20% ceramic ware waste hollow block

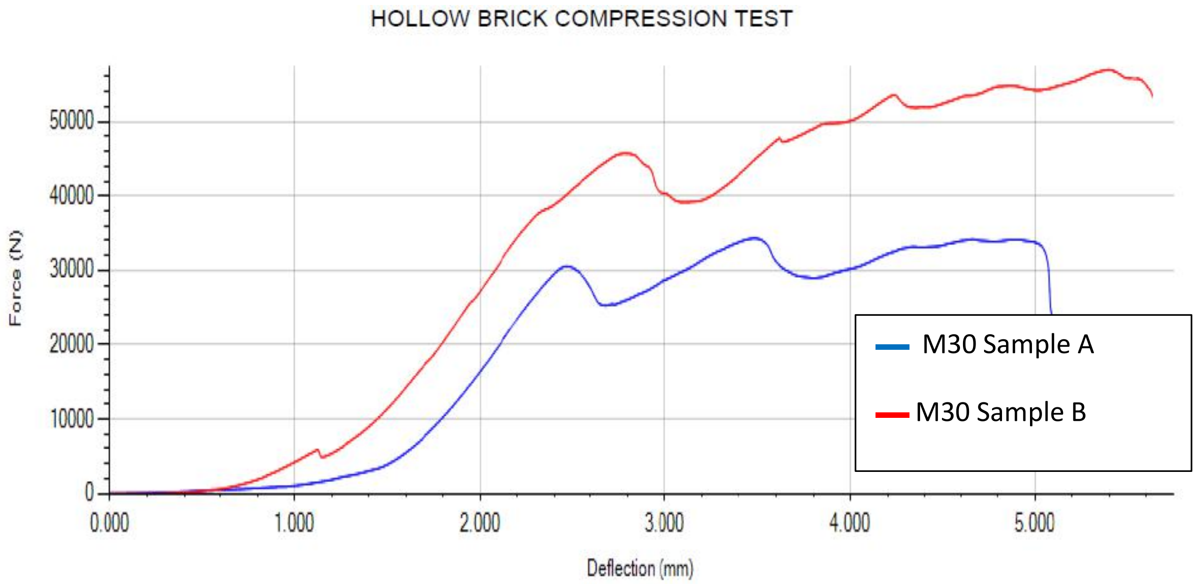


Figure 10: Stress strain curve for hollow block with 30% ceramic ware waste hollow block

### 3.5 Intra-Relationship between Mix Ratio and Compressive Test Output

Masonry unit with 30% ceramic waste mix ratio was exempted from the intra-relationship between mix ratio and compressive test output. This was due to inconsistent pattern observed as compared with other mix ratios. Graphs for M10 were equally not presented. Strong nexus exits between the various natural sand-ceramic mix ratio and the compressive test outputs such as compressive force and energy required to crush masonry units. The correlation coefficients ($R^2$) were more than 0.95. This is an indication that crushing energy and force values under this mix ratio conditions can be predicted. On the contrary, relationships for the other compressive test parameters such as compressive strength, strain, deflection and Young's modulus investigated in this study were inconsistent and mostly below 0.81 (Figures 11-16).

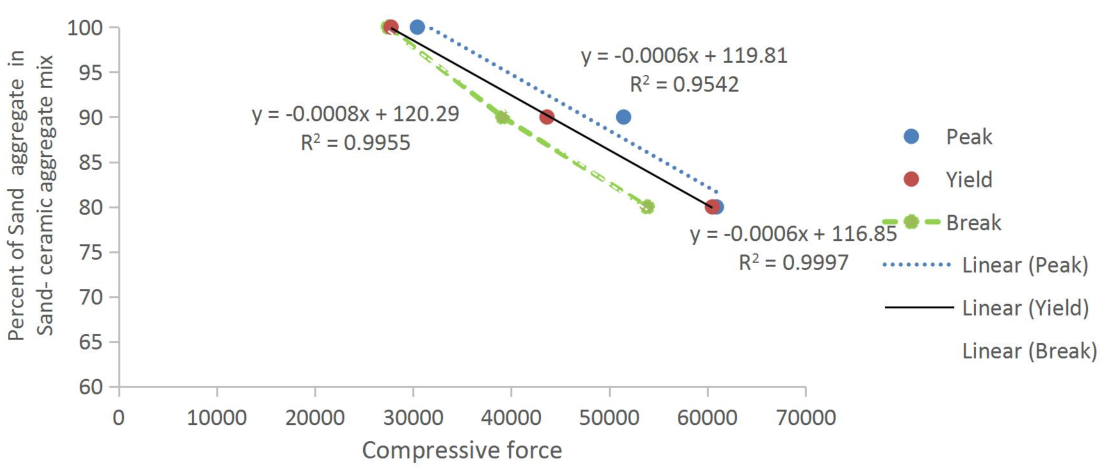


Figure 11: Aggregate mix ratio and compressive force nexus

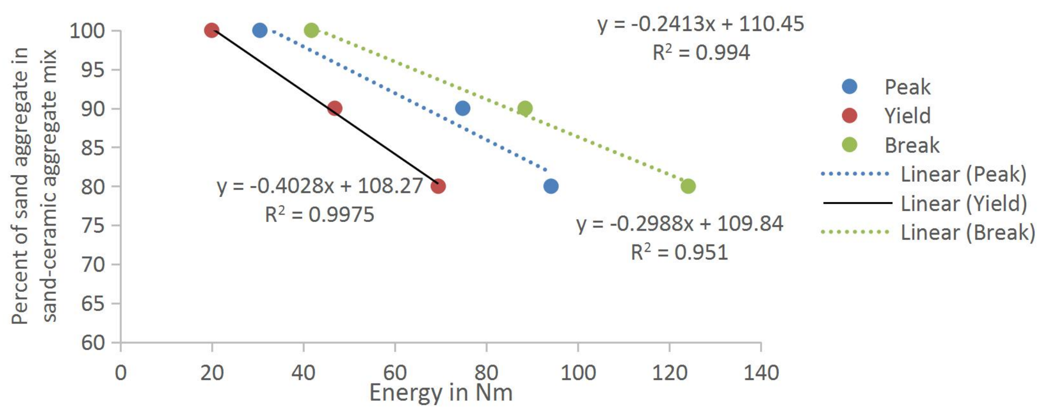


Figure 12: Aggregate mix ratio and energy applied nexus

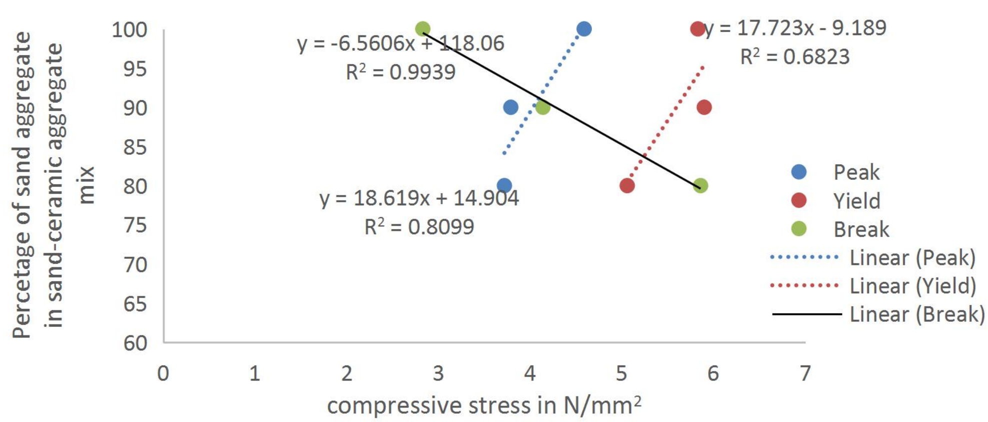


Figure 13: Aggregate mix ratio and compressive stress nexus

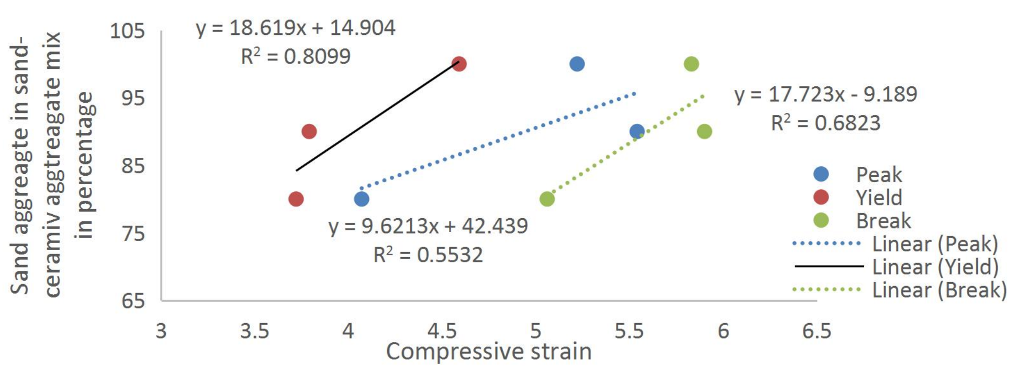


Figure 14: Aggregate mix ratio and strain nexus

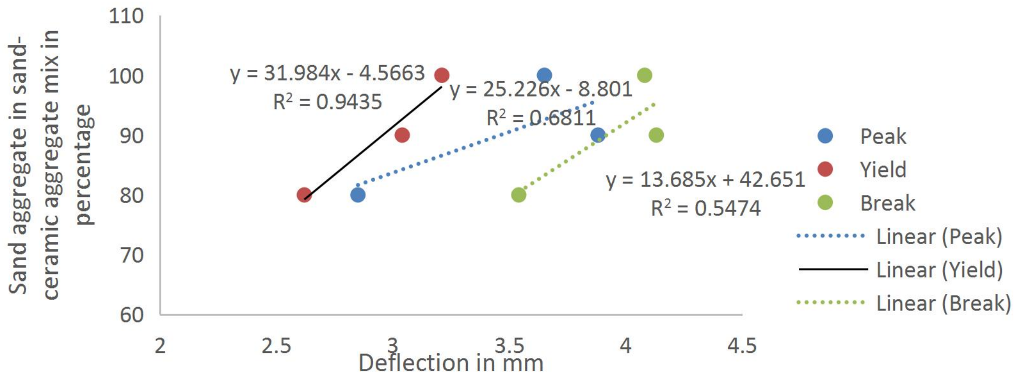


Figure 15: Aggregate mix ratio and deflection nexus

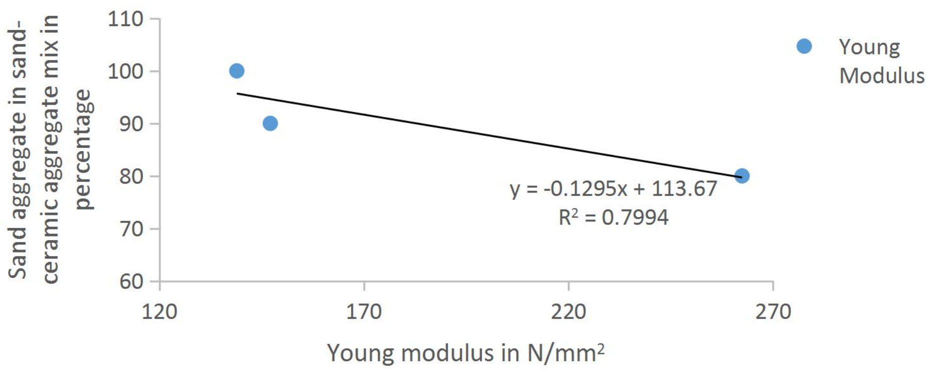


Figure 16: Aggregate mix ratio and Young's modulus nexus

## 4. Conclusion

Quest for strength in masonry units in order to meet present day demands in construction has fostered the utilization of various materials, especially solid waste introduction into aggregate mix. This study considered the 10, 20 and 30 % fractional replacement of natural sand aggregate with single fired sanitary ware waste. Hollow masonry units from ceramics and fine aggregates have more suitable compressive strength than pure natural sand ballast blocks. However, M30 did not follow the same trend as other modified hollow blocks from the compressive strength indices investigated. Block from 80:20 percent ceramic to fine aggregates mix ratio was the best under the study, the compressive strength ranges from 5.86 - 6.57 MPa and as such suitable for load bearing structures. Stress-strain curves followed overall non-linear pattern. There was no significant difference among the three ceramic-natural sand mix ratios utilized in this study, however M20 masonry unit has the highest potential of being utilized than other grades considered in this study. Modification of aggregate composition in masonry unit production with ceramic ware waste enhanced masonry unit quality and this will reduce environmental nuisance resulting from poor management practices of construction and demolition waste. Ceramic wares from demolition and construction wastes are feasible co-ballast in hollow masonry unit construction.

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