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BEHAVIOUR OF RUBBERIZED MASONRY HOLLOW CONCRETE UNIT BLOCKS AND WALLETTE'S UNDER UNIAXIAL LOADING CONDITIONS

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ABSTRACT

This paper presents an experimental investigation into the response of modified masonry hollow concrete block units and wallette's containing crumb-rubber from end-of-life tyres. Partial replacement ratios of 0, 5, 10, 15, 20, and 25% crumb-rubber particles for coarse aggregate were investigated and presented in this paper. The unit weight, water absorption, compressive and characteristics strength were tested. The results indicated that compacting factor and unit weight of fresh masonry concrete mixes reduced by 8.3% and 10.1% respectively also density of block units decreased from 2,079Kg/m^3 to 1,686kg/m^3 indicating a 19% reduction while the compressive strength of block units decreased from 9.43N/mm^2 to 4.84N/mm^2 indicating 49% loss in strength. Furthermore, the results revealed that the water absorption coefficient (C_w) of masonry concrete blocks increased by 53%. Characteristic compressive strength of masonry hollow concrete block wallette's measured indicated a decrease with increase in crumb-rubber content with the reference masonry wallette's having a strength of 6.44N/mm^2 while 5, 10, 15, 20, and 25% crumb-rubber modified masonry concrete block wallette's have strengths of 5.30N/mm^2, 4.35N/mm^2, 3.74N/mm^2, 3.06N/mm^2 and 2.25N/mm^2 respectively indicating 65% reduction in strength. Despite the shortcomings observed in the strength reduction, load and non-load bearing masonry blocks and walls can be produced and constructed respectively with the modified masonry concrete blocks containing crumb-rubber content up to 20% and it will still meet up to the minimum strength requirement specified.

KEYWORDS: *rubberized concrete, masonry, block, wallette's, uniaxial, strength*

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INTRODUCTION

Masonry hollow concrete blocks are widely used in many parts of the world due to their numerous relative advantages such as low cost, lightweight, high bearing capacity, and efficiency in terms of energy and acoustic performance [20]. The brittle failure behavior of hollow concrete blocks in compression necessitates the utilization of alternative materials such as post-consumer tyre particles to enable it to be more ductile and also produce more sustainable concrete blocks [10].

Post-consumer tyres are always embattled with the problem of how to dispose of them. Discarded post-consumer tyre into landfills and open field pile up and create large voids under the surface and on the surface of land as the case may be which leads to the trapping of gases such as methane. The trapped gases can ignite at any given opportunity leading to uncontrollable fire [3]; such as the recent experience reported by [2] in Sesena, Spain were an uncontrollable fire rage through a pile of millions of kilograms of tyres unleashing and releasing a thick black cloud of toxic fumes into the air at the dumpsite covering 100,000 square meters. The blaze was said to have lasted for days before it was controlled as the fire continues to burn inside even though it has been extinguished from outside. Open-air combustion of waste tyre pollutes the air and poison the groundwater with the release of benzene and heavy metals that produce dioxins which are linked to various serious health problems [3]. Literature reported that around 9 billion kilograms of waste automobile tyres are discarded each year throughout the world, which was estimated to be one billion waste tyres generated annually [19], [5] and [8].

Based on 2018 statistics with a 15% annual generation rate, it is estimated that around 37 million waste tyres exist in Nigeria [16]. One of the most common ways of disposing of waste tyres is through open field disposal and combustion [15]. With this quantity, the large stockpile of waste tyres poses both environmental and health risks to its population. Waste tyres in form of chips, fibres, crumbs, and particles have been successfully incorporated into asphalt mix and used as a surface layer in a flexible pavement which is dated back to the 1980s; results reveals that the modified asphalt had better resistance to skidding, reduce fatigue cracking and prolong pavement life span compared to the conventional asphalt mix ([1], [6], [7], [12], [4] and [11]). The application of waste tyre derived aggregate in Portland cement-based materials mixes such as structural concrete and blocks have been exploded in past years using chips, fines, shreds, slit, fibres, and crumb-rubber to replace fine aggregate. Results revealed that compressive strength decreased with an increase in rubber tyre particle content however structural concrete and blocks for both load-bearing and non-load bearing structures can be produced with partial replacement of rubber particles up to 15% [14, 18 and 9].

This present study is aimed at introducing crumb-rubber aggregate in various proportions as a partial replacement for coarse aggregate in masonry concrete mix and also investigate the unit weight, water absorption, compressive and characteristics compressive strength of masonry hollow concrete blocks wallette’s constructed.

MATERIAL AND METHODOLOGY

Material

A general-purpose blended limestone Portland cement CEM II (42.5R MPa) NIS 444-1:2014-CEM II B-L 42.5R CB-4211 with a specific gravity *G* of approximately 3.15 and conforms to BS EN 197-1:2000 was used in this work. The natural river quartzite sand smaller than 4.76mm but larger than 75µm that is free of clay, loam, dirt, and any organic or chemical matter with average bulk specific gravity (SSD) of 2.65 was used for both fine and medium-fine aggregate. It was graded with the appropriate zone of sieves to BS EN 933-1:2012 to ensure that it conforms to BS EN 1260:2002+A1:2008 specification. Natural crushed (granite) with nominal maximum sizes of 9.52mm-10mm sourced from a local commercial quarry with average bulk specific gravity (SSD) of 2.66 was used. Tests were conducted on the coarse aggregate to ensure that it conforms to BS EN 1260:2002+A1:2008 specification. Crumb-rubber aggregate was derived from post-consumer tyres and processed to a nominal maximum size of 4 - 9mm with average bulk specific gravity (SSD) of 1.14. The surface of the crumb-rubber was treated by soaking in a sodium hydroxide (NaOH) which enhances the strength of the composite matrix [13]. Ordinary tap water which is fresh, colorless, odorless, tasteless, and free from organic matter of any kind was used for all concrete mixes and curing.

Figure 1: Crumb-Rubber Aggregate Used for Concrete Mix

Mix Design

The mix design for the masonry hollow concrete block adopted was based on absolute volume method according to BS EN 206-1:2000, "Method of specifying concrete mixes", by designing mix, where the strength testing forms an essential part of the requirements for compliance and also prescribed mix, in which proportion of the constituents to give the required strength and workability are specified. A mix ratio of 1:1.5:3 and water/cement ratio of 0.42 was adopted for all the concrete mixes due to the high strength above the required minimum standard of 30N/mm^2 attached to it also w/c of 0.42 was taken as the optimum because of the moderate compacting factor of 0.84 (low) and high strength of 30.71N/mm^2 attached to it. General-purpose masonry mortar with a strength grade of 20N/mm^2 was produced with a mix ratio of 1:3 (cement: sand) and a w/c ratio of 0.6.

Manufacture of Masonry Hollow Concrete Block Units

The masonry concrete blocks (hollow) with the size 450 x 225 x 225mm as shown in Figure 2 were produced to the requirements given in BS 771-3(2003) with the use of a vibrating machine. Six various percentages of coarse aggregate (granite) partially substituted with crumb-rubber at 0, 5, 10, 15, 20, and 25% by volume were used.

Figure 2: Manufactured Masonry Hollow Concrete Blocks

EXPERIMENTAL PROCEDURES

Tests were conducted to assess the workability of the freshly mixed concrete which includes compacting factor in accordance to BS EN 12350-4:2009 and unit weight in accordance to BS EN 12350-6:2009 while the yield was computed based on ASTM C138-09. The dry density and compressive strength of the masonry mortar were determined from the cube samples (70.6 x 70.6 x 70.6) mm according to BS EN 1015-10:1999 and BS EN1015-11:1999 respectively after 28 days of standard curing in water. The density and compressive strength of masonry hollow concrete block units were determined according to BS EN772 -13 (2000) and BS EN 772 -1:2000 respectively as shown in Figure 3 after twenty-eight (28) days of curing with water. Masonry concrete prism (160 x 40 x 40) specimens were derived from masonry hollow concrete blocks using a masonry cutting machine and used for determination of the coefficient of water absorption due to capillary action test as described in BS EN 772-11:2001 and shown in Figure 3. Equation (1) was used to compute the coefficient of water absorption $C_{w,s}$

Figure 3: Weighing and Compressive Strength Testing of Masonry Hollow Concrete Blocks

$$C_{w,s} = \frac{m_{so,s} - m_{dry,s}}{A_s \sqrt{t_{so}}} \times 10^6 \left[g / \left(m^2 \times s^{0.5} \right) \right] \tag{1}$$

Where: $C_{w,s}$ is the coefficient of water absorption due to capillary action for, aggregate concrete, natural stone, and manufacture stone masonry units, $\left[g / \left(m^2 \times s^{0.5} \right) \right]$, $m_{dry,s}$ is the mass of the specimen after drying, (g), $m_{so,s}$ is the mass of the specimen in grams after soaking for time *t,* (g), A_s is the gross area of the face of the specimen immersed in water, (mm^2) and t_{so} is the time of soaking, (s).

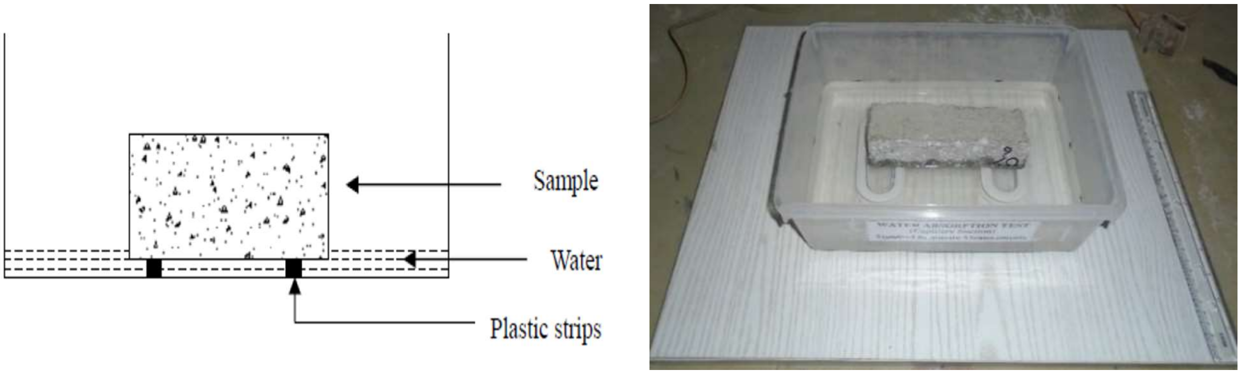

Figure 4: Water Absorption Coefficient Test

Masonry wallette's were constructed according to BS EN 1052-1:1999, wooden pallets of suitable sizes were prepared and used as a flat base upon which the masonry wallette's stand. The total dimensions of the wallette's were 690 × 720 × 230 mm (l x h x t), constructed with three courses of blocks. A total of eighteen (18) masonry wallette's (average of three per specimen) were built in the same manner to investigate the effect of crumb-rubber on its properties. The masonry mortars used for the bonding and bedding were mixed according to BS EN 196-1:2005. M20 general-purpose mortar with the mixture consisting of Portland cement (CEMII) and sand in a proportion of 1:3 by volume and water/cement ratio of 0.6 was used for the mix and kept constant for all mixes. The curing and storage of the masonry wallette's were carried out as described in Table 5 of BS EN 459-2:2001. All wallette's were covered with polythene and left for 24hrs to gain an initial set before being moved to storage. The constructed walls were cured by water sprinkling twice per day for 28 days to achieve the desired bonding strength of the mortar.

Test Set-up, Instrumentations, and Measurement

The compressive strength of masonry wallette's without the effects of loading restraint, slenderness, or eccentricity of loading was tested following EN 1052-1:1999 after 28 days of curing at room temperature**.** A testing rig as shown in Figure 5 with a maximum capacity of 1500KN was used for the experimental test. Displacement gauges (dial gauge) were set up on each wallette to record the strain values during compression. The specimens were placed centrally in the testing machine and ensured that both the top and bottom of the specimen are in full contact with the testing machine. Loading was applied uniformly to the top and bottom of the specimen at the rate of 0.15N/(mm^{2}min). The load increased steadily so that failure is reached after 15 min to 30 min from the commencement of loading. The compressive load (stress in N/mm^2) at initial cracks and final cracks i.e., the ultimate load was observed.

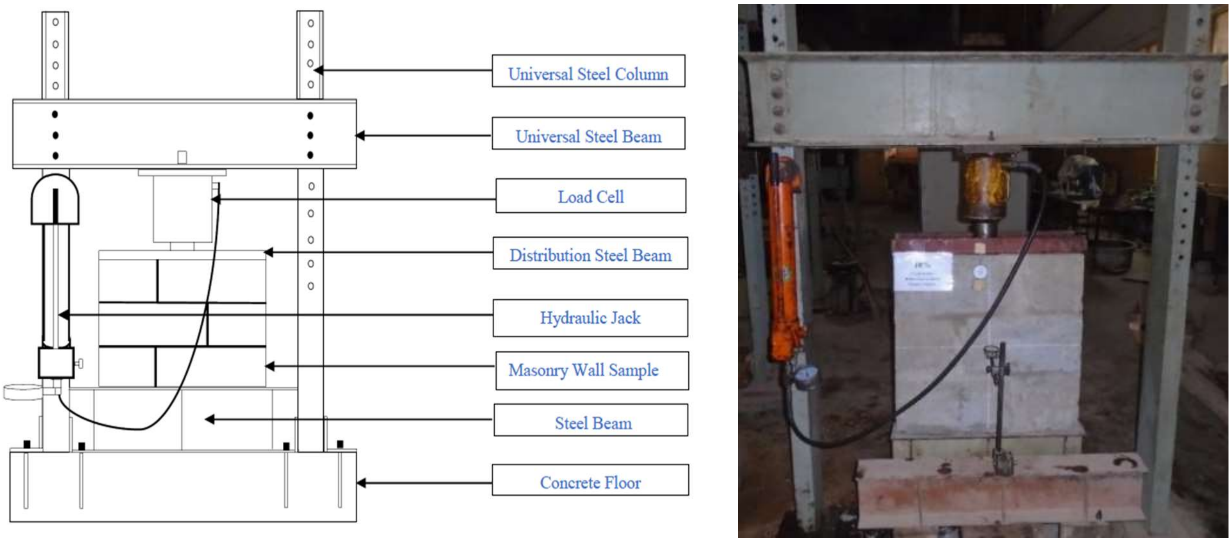

Figure 5: Details of Testing Rig for Compressive Strength Test of Masonry Wallette's

Equation 2 was used to determine the compressive strength of each wallette

$$f_i = \frac{f_{i\max}}{A_i}(N/mm^2) \tag{2}$$

Where f_i is the compressive strength (N/mm^2); $f_{i\max}$ is the maximum load (N) and A_i is the loaded Area (mm^2). The characteristic compressive strength was determined using Equation 3.

$$f_k = \frac{f}{1.2} \text{ or } f_k = f_{i\min}(N/mm^2) \text{ whichever is smaller} \tag{3}$$

RESULTS AND DISCUSSION

The compacting factor (C.F) was observed to decrease significantly, control masonry concrete mixes had a C.F of 0.84 (low workability) while the 25% rubberized mix had a C.F of 0.77 (very low workability) as shown in Figure 6 indicating an 8.3% reduction. Incorporation of crumb-rubber tyre aggregate decreased the unit weight of fresh concrete mix from 2,436Kg/m^3 to 2,191Kg/m^3 with crumb-rubber content up to 25% which indicates a 10.1% reduction. The density of control and rubberized masonry hollow concrete block samples is presented in Figure 7. It can be seen that the rubberized masonry hollow concrete blocks exhibited lower densities than the control mixes, also it can be deduced from the graph that density reduces by 19%, with the reference concrete block units having an average net density of 2079 kg/m^3 while 25% rubberized masonry hollow concrete block units have an average of 1686 kg/m^3. According to the requirement of ASTM C90 (ASTM, 2004c) and C129 (ASTM, 2004b) as shown in Figure 7, the test result revealed that the density of rubberized masonry hollow concrete block units (R-MHCBU) ranges from medium weight to normal weight depending on the percentage of crumb-rubber content.

Compressive strength of rubberized masonry hollow concrete blocks results in Figure 8, indicates a decrease in compressive strength with increase in crumb-rubber content also a percentage loss of strength by 49% was observed with the reference units having a strength of 9.43N/mm^2 while 5, 10, 15, 20 and 25% crumb-rubber modified masonry concrete block units having a strength of 8.29N/mm^2, 7.20N/mm^2, 7.02N/mm^2, 6.61N/mm^2 and 4.84N/mm^2 respectively.

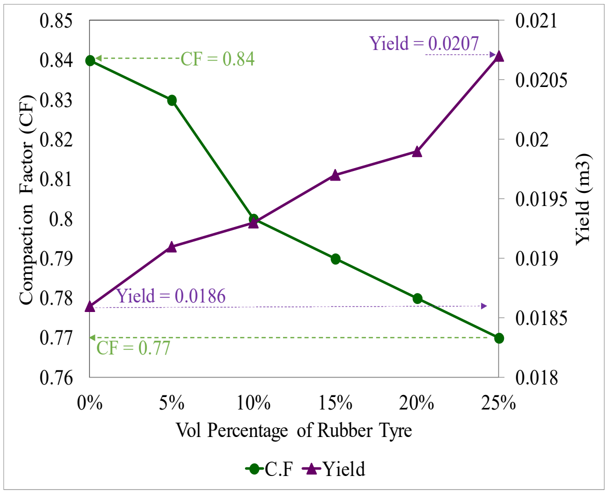

Figure 6: C.F and Yield of Rubberized Concrete Against % CR Content

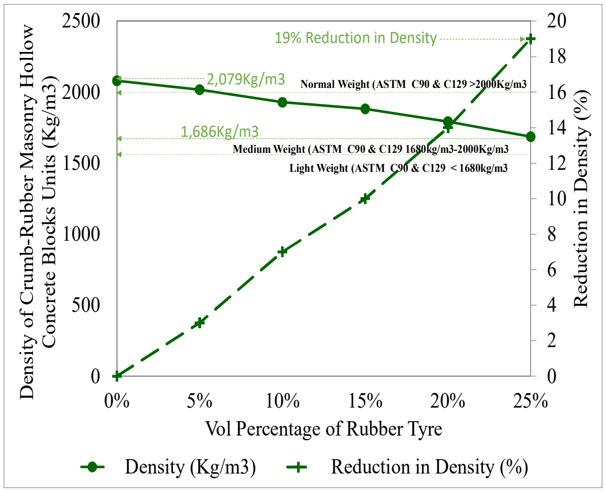

Figure 7: Net Dry Density of Rubberized Block Against % CR Content

It can be seen from Figure 8 that a load-bearing rubberized block can be produced with 15% (CR) content which is above the minimum requirement specified following the requirement of the BS EN 771-3 which specified a strength greater than or equal to 7N/mm^2. Also, a Non-load bearing rubberized block with strength above the minimum specified in BS EN 771-3 (>3N/mm^2) can be produced with crumb rubber content ranging from 16% - 25%.

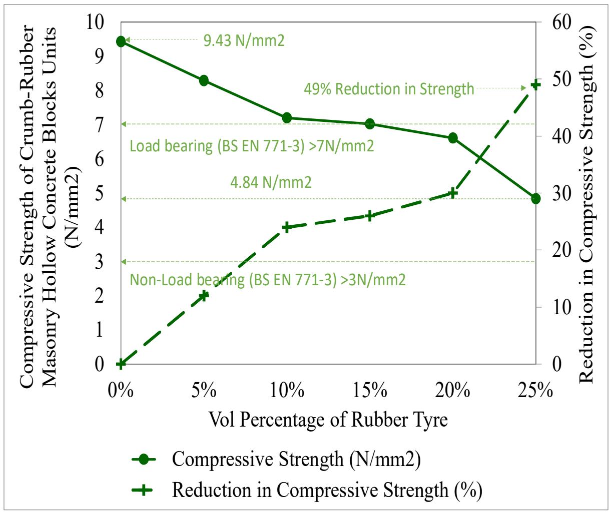

Figure 8: Compressive Strength of Rubberized Block Against % CR Content

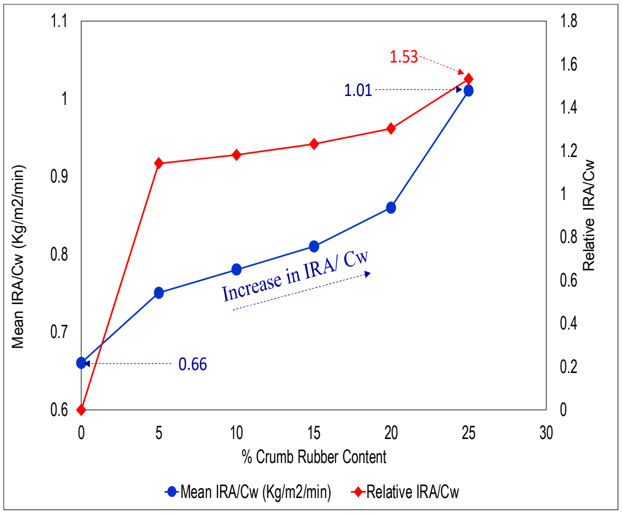

Figure 9: Coefficient of Water Absorption (C_W) of Rubberized Concrete Against % CR Content

The coefficient of water absorption (C_W) and the relative coefficient of water absorption of crumb-rubber masonry hollow concrete block as shown in Figure 9 was found to increase by 53% with a percentage increase in rubber content up to 25%.

The result of density and dry-weight of rubberized masonry hollow concrete block wallette is presented in Figure 10 which indicates a reduction in both density and dry-weight with increase in crumb-rubber content. Characteristic compressive strength (f_k) result of rubberized masonry hollow concrete block wallette's shown in Figure 11 indicates a loss of strength by 65% with the reference wallette having a strength of 6.44N/mm^2 while 5, 10, 15, 20 and 25% crumb-rubber modified masonry concrete block wallette having a strength of 5.30N/mm^2, 4.35N/mm^2, 3.74N/mm^2, 3.06N/mm^2 and 2.25N/mm^2 respectively.

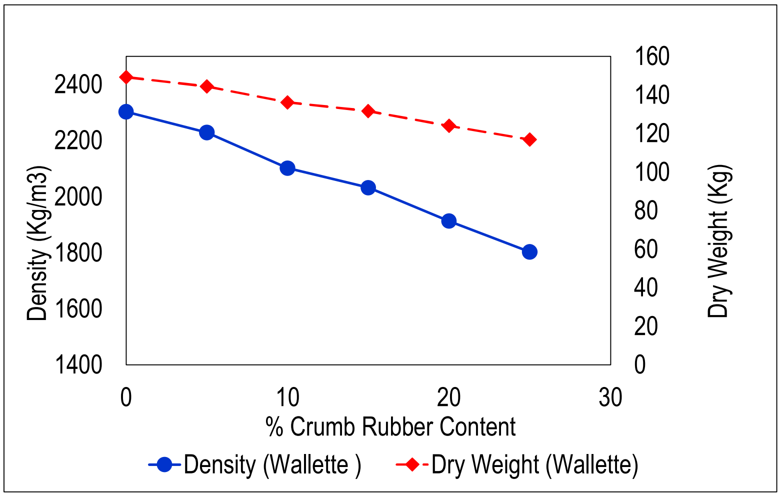

Figure 10: Density (Kg/m^3) & Dry-Weight of Rubberized Wallette's Against % CR Content

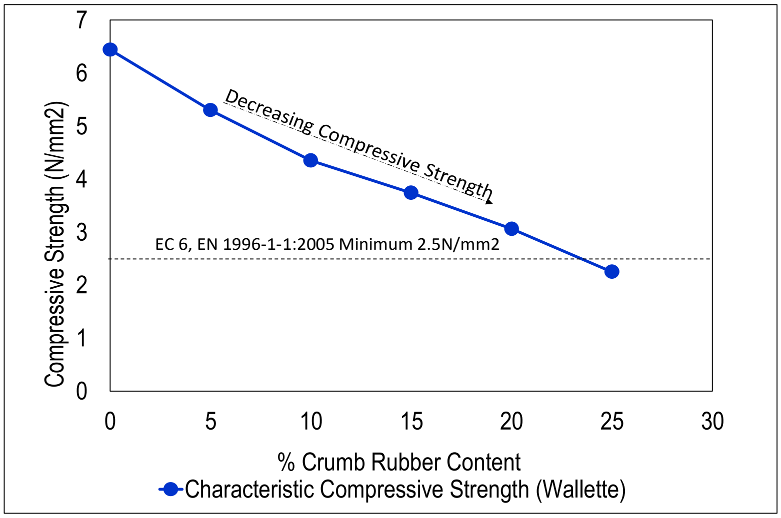

Figure 11: Characteristic Compressive Strength of Rubberized Wallette's Against % CR Content

The stress-strain relationship of rubberized masonry hollow concrete block wallette can be seen in Figure 12. The behavior indicates a convergent strength level and deformation criterion under compression loads for these concrete mixes. There was a linear increase in the stress of the reference and rubberized masonry hollow concrete block wallette's until reaching the maximum stress before releasing the energy by fracture. The stress-strain curves, in this case, are "sharp peaks" therefore the stress-strain relationships were considered to be quasi-linear. Furthermore, it can be noticed that increasing the crumb-rubber content has a significant effect on the maximum stress and strain of the masonry wallette's. Nevertheless, a remarkable variation in stress and deformation was observed between the reference mix and the modified mixes. This variation reached about 65% at the maximum stress with crumb-rubber content up to 25% as shown in Figure 12. The rubberized wallette's also revealed an increase in lateral and vertical (axial) strain up to 9.4% and 32% respectively at the maximum stress with respect to the reference wallette's and crumb-rubber content up to 25%. This increase in the plastic strain translates into an increase in toughness with a gradual failure and high-energy absorption capability [17].

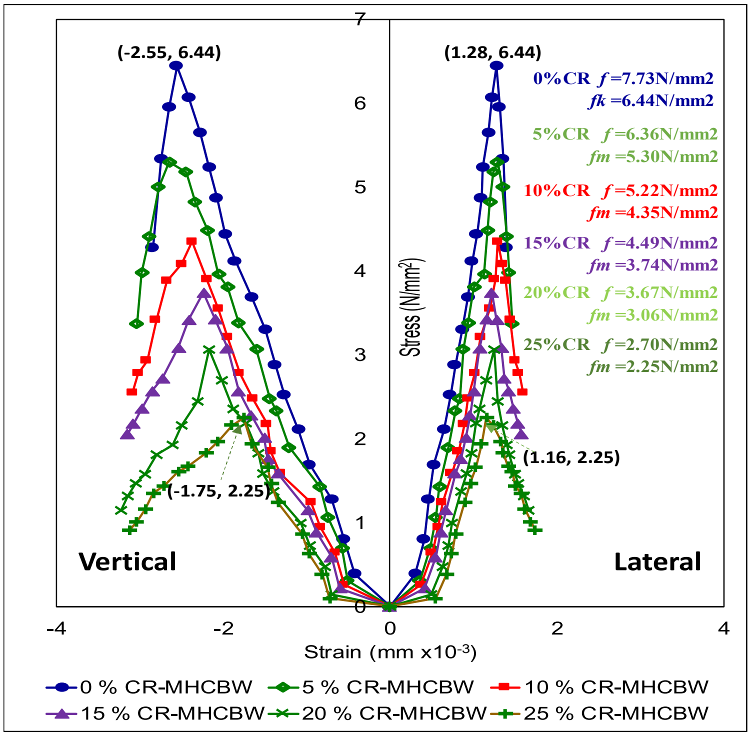

Figure 12: Stress-Strain Relationship for Rubberized Masonry Concrete Wallette's

The displacement-load relationship of the rubberized masonry concrete block wallette's as shown in Figure 13 revealed that the maximum axial loads at failure were 696kN for the reference wallette's implying a corresponding vertical (axial) displacement of 0.00255 and lateral displacement of 0.00128. while the 5, 10, 15, 20, and 25% rubberized wallette's recorded maximum axial loads of 572kN, 470kN, 405kN, 331kN, and 243kN respectively with a corresponding ultimate displacement of 0.00175 for vertical and 0.00116 for lateral respectively with 25% crumb-rubber replacement which indicates a percentage loss in the vertical strain of 31.4% and lateral strain of 9.4%. It can also be observed that the displacement-load relationships were quasi-linear.

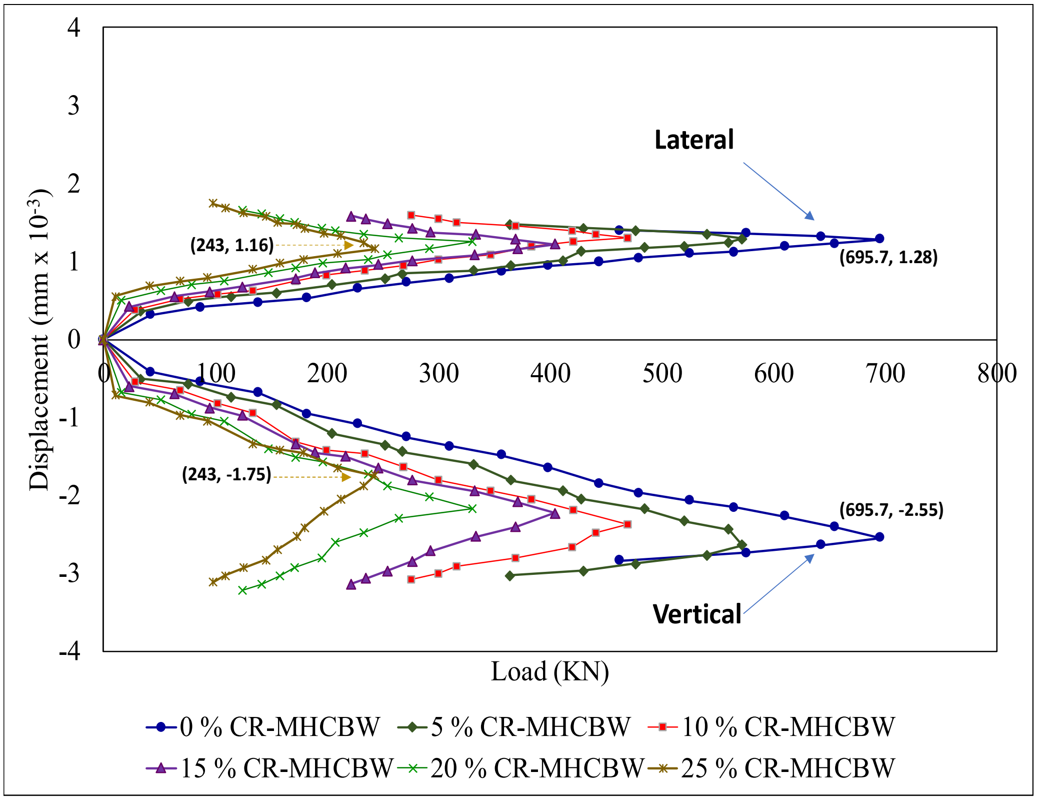

Figure 13: Displacement-Load Relationship for Rubberized Masonry Concrete Wallette's

CONCLUSIONS

The following conclusions are drawn on the behaviour of rubberized masonry hollow concrete block units and wallette's under uniaxial loading conditions.

i. The compacting factor (C.F) of masonry concrete was observed to decrease significantly by 8.3%, the yield of fresh concrete mix increased slightly by 10.2%, and the density of masonry hollow concrete block unit reduced by 19% with 25% crumb-rubber content.

ii. Compressive strength of $9.43N/mm^2$ was obtained for the control mixes while the compressive strength of rubberized masonry hollow concrete block with 25% crumb-rubber content is $4.84N/mm^2$ indicating a loss of strength by 49%. Despite the strength reduction, load-bearing rubberized masonry hollow concrete blocks can be produced with 15% crumb-rubber content which is above the minimum ($7N/mm^2$) requirement specified in BS EN 771-3. Also, Non-load bearing rubberized masonry hollow concrete blocks with strength above the minimum

(>3N/mm^2) specified in BS EN 771-3 can be produced with crumb-rubber content ranging from 16% to 25% which makes the material viable for building fabric or envelope applications.

iii. The coefficient of water absorption (C_w) of masonry concrete block increased by 53% with a percentage increase in crumb-rubber content up to 25%. From the result, the application of such material will be suitable for indoor building elements with low and moderate air humidity and also outdoor building walls sheltered from the rain with finishing layers to enhance durability.

iv. The characteristic compressive strength of masonry concrete block wallette decreased by 65% with an increase in crumb-rubber content up to 25%. This results when compared with the minimum characteristic compressive strength (f_k) for masonry concrete wall (EC 6, EN 1996-1-1:2005) = 2.5N/mm^2, implies that crumb-rubber masonry hollow concrete wall with crumb-rubber content up to 20% can be used to produce masonry wall that will meet up with the minimum requirement.

v. The stress-strain relationship of rubberized masonry concrete block wallette's shows a quasi-linear relationship with an increase in the crumb-rubber content which has a significant effect on the maximum stress and maximum strain.

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