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# Measurement of Hydraulic Conductivity of Crumb-Rubber Masonry Concrete Using Falling-Head Method

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**Research Article**

**Abstract**

*This paper experimentally measures the hydraulic conductivity of crumb-rubber modified masonry concrete using the falling head method. Six mix batches using a mix ratio of 1:1.5:3 and a water-cement ratio of 0.42 was used to produce masonry concrete containing 0%, 5%, 10%, 15%, 20% and 25% crumb-rubber particles partially replacing coarse granite by volume. The results reveals that the reference masonry concrete ($0\%_{CR}$) have a hydraulic conductivity of $9.88 \times 10^{-11}$ m/sec while the 5, 10, 15, 20 and 25% have hydraulic conductivity of $1.68 \times 10^{-10}$ m/sec, $2.34 \times 10^{-10}$ m/sec, $3.26 \times 10^{-10}$ m/sec, $4.03 \times 10^{-10}$ m/sec and $4.51 \times 10^{-10}$ m/sec respectively; which indicates that the hydraulic conductivity of the modified masonry concrete increased with addition of more crumb-rubber content up to 25%. The outcome of this study implies an increase in the ability of the modified masonry concrete to allow surface water to percolate through it which will be highly desirable for use as an alternative for pervious concrete in area with low surface water runoff.*



**Keywords**

Crumb-rubber; Compacting factor; Compressive strength; Hydraulic Conductivity; Masonry concrete; Unit weight.

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## 1. Introduction

Post-consumer tyres are always embattled with the problem on how to dispose. Discarded post-consumer tyre into landfills and open field piles 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 (Dinoflex, 2012); such as the recent experience reported by (AFP, 2016) in Sesena, Spain.

(Yang *et al.*, 2000), revealed that every year around 9 billion kilograms of end-of-life tyres are discarded everywhere throughout the world, which was likewise evaluated to associate with 1 billion waste tyres generated annually (Erdogan *et al.*, 2010) As well as Forrest and Rapra, (2014).

Based on 2018 statistics with 15% annual generation rate, it is estimated that around 37 million waste tyres exist in Nigeria (Ocholi *et al.*, 2018). With this quantity, the large stock pile of waste tyre poses both environmental and health risk to its population. Eldin and Piekarski (1993) reported that processing waste tyres into chips and crumb particles will make its reuse and recycling very feasible which will be an alternative to open field disposal.

Processed waste tyre is rarely used for construction application due to its low strength, compressible nature and its non-adhesion to cementitious materials.

Waste tyres in form of chips, fibres, crumbs and particles have been successfully incorporated into asphalt mix and used as surface layer in a flexible pavement which is dated back to 1980's; 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 (Adams *et al.*,1985; Esch 1984; Estakhiri 1990; Khosla and Trogdon 1990; Epps 1994 as well as Khatib and Bayomy 1999). The application of waste tyre derived aggregate in form of chips, fibres and crumb-rubber to replace coarse and fine aggregate in Portland cement-based materials mixes have exploded in past years.

### 1.1 Crumb-Rubber Modified Concrete

Masonry concrete is a type of concrete with a relatively dry mixes (low water cement ratio) but having similar ingredient and properties like normal concrete. Traditional concrete mix consists of cement binder, aggregate and water, however most modern concrete contains admixtures to enhance various properties. Dhir and Jackson (1988) reported that concrete is inherently good in compression, stiffness, low thermal and electrical conductivity while the ductility as well as the tensile strength of conventional concrete sample is low and this can be improved by the introduction of randomly orientated particles and fibres into the concrete mixes. The partial replacement of natural aggregate (coarse or fine) in masonry concrete mix with rubber particles derived from waste automobile tyre would be a welcome idea and also an alternative process of application for the large volume of waste rubber-tyres. Concrete produced with recycled waste rubber-tyres aggregate have been branded by different researchers: Chou *et al*. (2007) named it rubcrete, Olivares *et al*. (2006) used the term 'recycled tyre rubber-filled concrete'. The term 'Rubber Modified Concrete' was referred to the resulting concrete by Kumaran *et al.* (2008).

Hydraulic conductivity (water permeation) is described as the behavioural property of a medium to permeate fluid through it as a result of the pressure differential. The steady-state flow rate through a medium is directly proportional to its hydraulic gradient as stated by Darcy, i.e.

$$\upsilon = Q/A = -K\left(dh/dL\right) \quad (1)$$

$\upsilon$ is the apparent velocity of flow, which is the ratio of flow rate (Q) to its cross-sectional area (A), hydraulic gradient is given by equation 1 which is the ratio of head loss (dh) across a path flow length given by dL. The coefficient of permeability is given by *K.* Generalization of Darcy's law can be applied to the flow of a viscous fluid in any direction in a given medium (porous material) which can be represented by the equation:

$$\upsilon = Q/A = -\left(k/\mu\right)\left(dP/dL\right) \quad (2)$$

The loss in pressure is given as dP while the path flow is dL, fluid viscosity is given as μ, while intrinsic permeability of the porous medium is given by k which does not depend on the fluid property (viscosity) governing the flow.

Basheer *et al.* (2001) reported that hydraulic conductivity of cementitious materials such as concrete and mortar are very important with respect to their long-term performance under certain conditions such as environment (durability). Han *et al.* (2019) also reported that liquids, vapour, air, gases, chloride and ions can penetrate structures through numerous mechanical and chemical processes. This process is also referred to as penetration which occur as a result of combination of pressure difference in water or air, difference in humidity and concentration or difference in temperature of solution. Nilsson *et al.* (1996).

The permeated substance will interact with the constituent materials or the porewater which can affect the integrity of the cementitious materials leading to the progressive degeneration of the structures where it's used as reported by Basheer *et al.* (2001) and Han *et al.* (2019).

Wong *et al.* (2012) reported a strong correlation between microstructural properties of cementitious composite materials (aggregate, cement binder paste, and the area of the cement paste surrounded by the aggregate particles) and permeability while Halamickova *et al.* (1995) and Shane *et al.* (2010) also revealed an increase in permeability with rise in aggregate fraction.

Various non-destructive experimental methods for evaluation of hydraulic conductivity (permeability) of cement-based material exists which includes: Back scattered electron micro-graphing (BEM), water-spray test Wong *et al.* (2012), water penetration depth BS EN 12390-8:2009, permeability test cell designed and built by Hearn and Mills (1991), falling head and constant head method adopted from geotechnical investigation.

This present study is aimed at introducing crumb-rubber, in various percentages, as partial replacement for coarse aggregate in masonry concrete mix and also investigate the water permeability properties of the reference masonry concrete compared to the modified crumb-rubber masonry concrete using falling head method to see if there are any changes in the permeability. Crumb-rubber particles was use to partially substitute the coarse aggregate (granite) by volume at six designated percentages with 0%, 5%, 10%, 15%, 20% and 25% of coarse aggregate. Totally, 18 masonry concrete samples (average of three per mix) were cast and tested for hydraulic conductivity. Masonry concrete in form of concrete blocks is becoming widely accepted as a construction material for walling units and other applications in our buildings, hence the partial substitution of granite aggregates with crumb-rubber particles having low water absorption (high resistance to water/moisture transfer) in concrete blocks and related products could enhance the rate at which water permeate through it and also would be an excellent and welcome approach to utilize the large volume of waste tyres constituting nuisance in our environment.

The utilization of waste tyres aggregates in masonry concrete blocks would not just utilize such waste materials by converting a waste into a resource, but will help to enhance some inherent properties of the composite.

## 2. Methodology

### 2.1 Materials

Cement used for this study is a general-purpose blended limestone Portland cement CEM II (42.5RMPa) that conforms to BS EN 197-1:2011, having specific gravity of approximately 3.15 and sourced from a retail outlet in Zaria, Nigeria. Clean water sourced from the department of civil engineering laboratory was utilized for preparing concrete mix.

Aggregate used for the study include:

i. Natural fine aggregate (sharp river quartzite sand) with size 75μm-4.76mm, relative density of 2.65 and bulk density of 1,454 $Kg/m^3$.
ii. Natural coarse aggregate with size ranging between 9.52 - 10mm, relative density of 2.66 and bulk density of 1,635 $Kg/m^3$.
iii. Crumb-rubber aggregate of particle size ranging between 4 - 8mm, relative density of 1.14 and bulk density of 528$Kg/m^3$.

Many studies in the literature have proven that there is weak bonding between crumb-rubber and cementitious materials which could be improved by modifying the surface of the crumb-rubber aggregate in NaoH solution (Mohammedi, 2014). The rubber particles were immersed into the NaoH solution for 60 min at room temperature after which it was washed with tap water until the pH of the water used in washing crumb-rubber is very close to neutral. The crumb-rubber were dried in the open air at ambient temperature. The gradation curve of the various aggregate used for this study are shown in Figure 1.

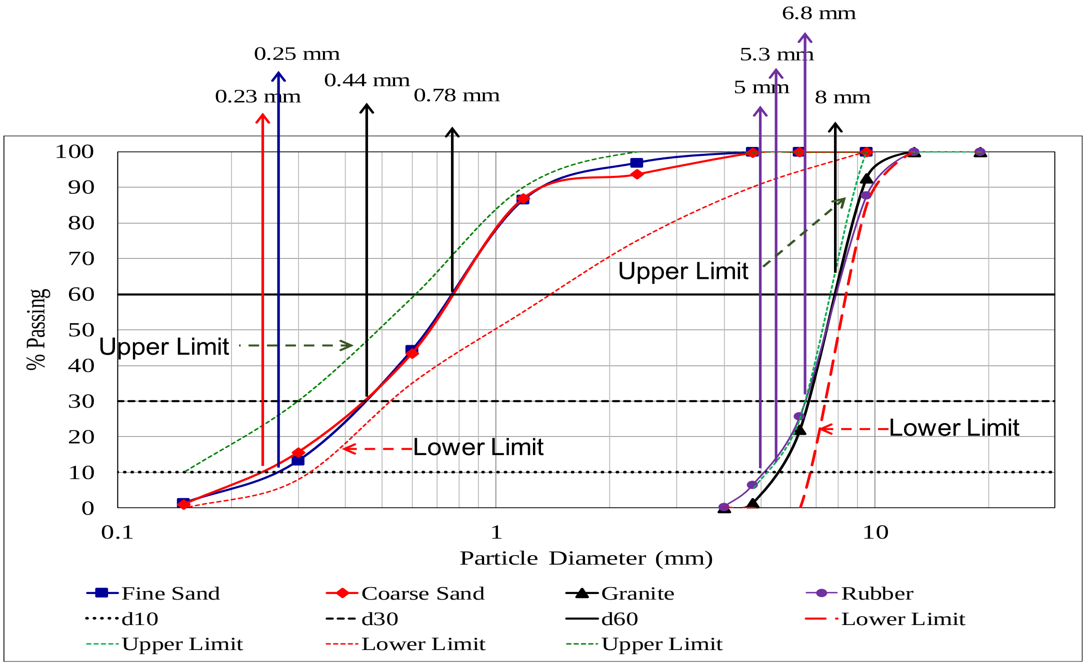


Figure 1: Grading of Natural Aggregate and Crumb-Rubber

## 2.2 Experimental Procedures

### *2.2.1 Mix Design*

Absolute volume method stated by BS EN 206:2013+A1:2016 was adopted for the mix design method for the concrete and modified concrete. A mix ratio of 1:1.5:3 water/cement ratio of 0.42 was applied to produce a trial mx which was adjusted and eventually adopted for the production of all the concrete mixes. Six (6) mixes having one control and five mixes whereby granite was partially substituted with crumb-rubber aggregate at (0-25%) by volume.

Figure 2: Material for Crumb-Rubber Masonry Concrete

The mix ratio, type and size of aggregate (crumb-rubber and granite) and water-cement ratio, used for the experimental work were kept constant. Eighteen (18) concrete samples (average of three sample per mix) were used to determine the hydraulic conductivity using the falling head method.

### *2.2.2 Sample Preparations*

All samples were prepared as cylindrical specimens with same size of mould used for all specimens; the diameter of these samples is 10.16 cm and the height are 10cm. The specimens were compacted in the mould based on ASTM C192.The fresh (relatively dry) concrete mix was placed into the mould in three (3) lifts according to Table 1 of ASTM C192. To provide uniform compaction in all cylinders, each lift was rodded 25 times as shown in Figure 3 with an appropriately sized tamping rod according to Table 2 of ASTM C192. Specimens used for the water permeability test were cured by soaking in water tank for a period of 28 days, to achieve high strength and maximum saturation as shown in Figure 4. The samples were then stored in open air at approximately 21$^{o}$C until the time of testing.

Table 1: Volume of Materials to 1m$^3$ of Concrete

| Ingredients | Crumb-Rubber Modified Concrete Mixes (CR-MC Mixes) Per Cubic Meter (m$^3$) | | | | | |
|---|---|---|---|---|---|---|
| | Mix Ratio (1:1.5:3), Water-Cement Ratio (w/c): 0.42 | | | | | |
| | Reference Concrete Mix (Kg/m$^3$) | 5% CR-MC Mix (Kg/m$^3$) | 10% CR-MC Mix (Kg/m$^3$) | 15% CR-MC Mix(Kg/m$^3$) | 20% CR-MC Mix (Kg/m$^3$) | 25% CR-MC Mix (Kg/m$^3$) |
| CEM II | 411.29 | 411.29 | 411.29 | 411.29 | 411.29 | 411.29 |
| Fine Aggregate (Natural Sand) | 616.94 | 616.94 | 616.94 | 616.94 | 616.94 | 616.94 |
| Coarse Aggregate (Granite) | 1,233.87 | 1,172.18 | 1,110.48 | 1,048.79 | 987.10 | 925.40 |
| Crumb-Rubber (CR) | 0.00 | 61.69 | 123.39 | 185.08 | 246.77 | 308.47 |
| Effective Water | 172.74 | 172.74 | 172.74 | 172.74 | 172.74 | 172.74 |
| Water Due to Absorption | 6.823 | 6.823 | 6.823 | 6.823 | 6.823 | 6.823 |
| Total Water | 179.56 | 179.56 | 179.56 | 179.56 | 179.56 | 179.56 |
| Water Cement Ratio (w/c) | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 |

Table 2: Coefficient of Permeability of Saturated Crumb-Rubber Masonry Concrete Samples

| Sample No | Length L (mm) | Diameter D (mm) | Area A ($mm^2$) | Average Permeability K (mm/min) | Average Permeability K (m/sec) | Quality According to CSTR Report No.31 (1988) |
|---|---|---|---|---|---|---|
| $0\%_{CR-MC}$ | 100 | 100 | 7855 | $5.93 \times 10^{-6}$ | $9.88 \times 10^{-11}$ | Average to Good |
| $5\ \%_{CR-MC}$ | 100 | 100 | 7855 | $1.01 \times 10^{-5}$ | $1.68 \times 10^{-10}$ | Average to Poor |
| $10\%_{CR-MC}$ | 100 | 100 | 7855 | $1.41 \times 10^{-5}$ | $2.34 \times 10^{-10}$ | Average to Poor |
| $15\%_{CR-MC}$ | 100 | 100 | 7855 | $1.96 \times 10^{-5}$ | $3.26 \times 10^{-10}$ | Average to Poor |
| $20\%_{CR-MC}$ | 100 | 100 | 7855 | $2.42 \times 10^{-5}$ | $4.03 \times 10^{-10}$ | Average to Poor |
| $25\%_{CR-MC}$ | 100 | 100 | 7855 | $2.71 \times 10^{-5}$ | $4.51 \times 10^{-10}$ | Average to Poor |

Figure 3: Sample Preparation of Fresh Masonry Concrete

Figure 4: Masonry Concrete Samples for Water Permeability Test

***2.2.3 Compacting factor, Yield and Unit Weight Test:***

Test were conducted to determine compacting factor of the fresh concrete mixes (control and modified) mixes in accordance with BS EN 12350-4:2009 while the unit weight was determined using the 0.01m3 cylinder as stated in BS EN 12350-6:2009. Yield of the fresh concrete mix was calculated in accordance with ASTM C138-09 using the unit weight and the total sum of the weight of the constituent materials.

***2.2.4 Compressive Strength Test:***

Compressive strength test was carried out on the hardened concrete cubes (150x150 x 150) mm as stated by BS EN 12390-3:2009 for a curing duration of 7, 14, 21 and 28 in water. The strength in compression was computed using Equation 3:

$$f_c\left(N/mm^2\right) = \frac{P_{\max}}{A} \tag{3}$$

Compressive strength is given by $f_c$ while the load (maximum) the cube can sustain is given by $P_{max}$ and the area of the cube is given as A.

***2.2.5 Hydraulic Conductivity Measurement:***

The saturated hydraulic conductivity of masonry concrete samples was determined using the falling head apparatus adapted from soil testing method. After saturation of the samples, silicon glue adhesive was applied at the edge of the permeability cell cap and sample to prevent sidewall leakage. The samples were then assembled on the falling head permeameter and permeated with tap water under average hydraulic gradient of 10 as shown in Figure 5. The coefficient of permeability *K*, was calculated from Equation 4 and the results presented in Table 2 while Table 3 present the typical coefficient permeability values associated with concrete quality as stated in Concrete Society Technical Report No.31 (1998):

$$K = \frac{aL}{At}\ln\frac{h_o}{h_1} \tag{4}$$

Coefficient of Permeability is given as *K* (mm/min), Area of the standing burette is *a* ($mm^2$), sample column length is L (mm), A area of sample column (mm) is A, $h_o$ = water initial height (mm), $h_1$ = water final height (mm) and t = head drop time for $\Delta h$ (min).

.

Figure 5: Permeability Test of Samples Permeated with Water

Table 3: Water Permeability and Concrete Quality
(Source: Concrete Society Technical Report No.31 (1998)

| Water Permeability (m/s) | Quality |
|---|---|
| $< 10^{-12}$ | Good |
| $10^{-12} – 10^{-10}$ | Average |
| $> 10^{-10}$ | Poor |

3.

## 3. Results and Discussion

### 3.1 Compacting factor, Yield and Unit weight

Compacting factor (C.F) result presented in Figure 6 reveals a significant decrease with increase in rubber particles. Control mix had C.F of 0.84 which signify low workability while the mix with 25% crumb-rubber aggregate recorded C.F of 0.77 which implies very low workability. The result further indicate reduction in C.F by 8.3%. Lower unit weight was observed for the modified concrete mix as shown in Figure 6 compared to the reference mixes. Unit weight of the fresh concrete mixes declines by 10.1% which can be related to low relative density of rubber particles (1.14) against that of granite (2.66). Figure 3.1 also reveals that the yield of the fresh concrete mix increased slightly from $0.0186m^3$ to $0.0207m^3$ with 25% crumb-rubber aggregate content which indicates 10.2% rise which can be attributed to low relative density (1.14) and the rise in rubber particles volume compared to that of granite for which it is replacing.

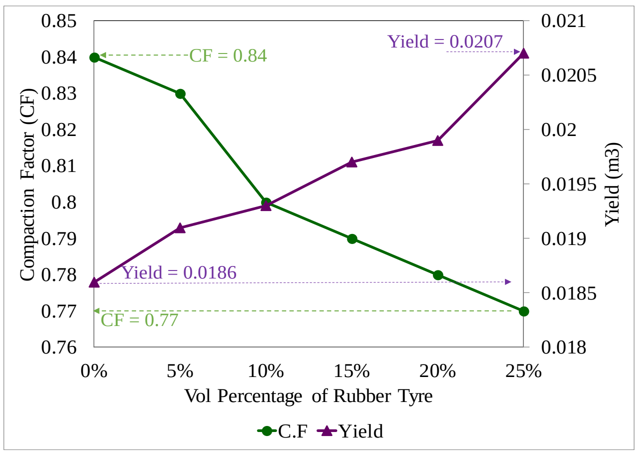


Figure 6: Compacting factor and Yield Vs % Crumb-Rubber Content

### 3.2 Compressive Strength of Crumb-Rubber Masonry Concrete

Strength result of the hardened masonry concrete (control and modified) in compression is presented in Figure 7. the result reveals that the incorporation of rubber particles in the concrete mixes reduced the strength in compression tremendously by 49% with 25% rise in rubber aggregate.

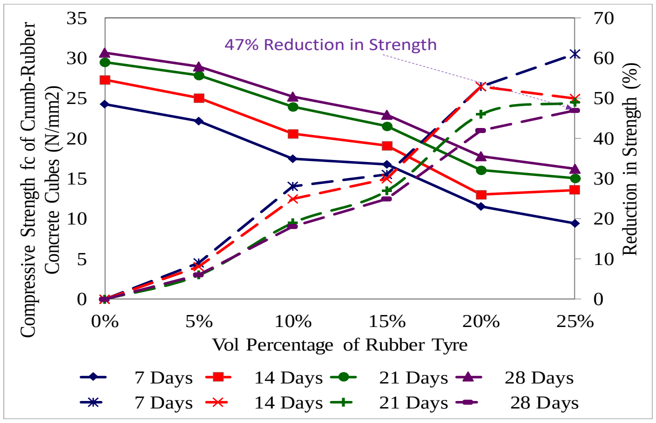


Figure 7: Compressive Strength of Masonry Concrete Cubes with % Rubber Particle Content

### 3.3 Measured Hydraulic Conductivity

Hydraulic Conductivity of masonry concrete specimens measured employing falling head test method is presented in Figure 8. The results which show that the reference masonry concrete sample (0%CR) have a permeability of $9.88 \times 10^{-11}$ m/sec while the 5, 10, 15, 20 and 25% have permeability of $1.68 \times 10^{-10}$ m/sec, $2.34 \times 10^{-10}$ m/sec, $3.26 \times 10^{-10}$ m/sec, $4.03 \times 10^{-10}$ m/sec and $4.51 \times 10^{-10}$ m/sec respectively. Furthermore, the results indicate that the rise in rubber particle increases coefficient of permeability of masonry concrete samples with over 300% for 25% crumb-rubber replaced in coarse granite aggregate by volume. Classifying coefficient of permeability of the reference masonry concrete and crumb-rubber masonry concrete based on quality according to CSTR report No.31 (1988); the reference masonry concrete will be classified as average to good while the crumb-rubber masonry concrete in general will be classified as average to poor.

The rise in hydraulic conductivity can also be associated to voids created as a result of poor bonding between rubber particles with the concrete composite matrix, which in general can be linked to the increase in porosity as a result of rise in crumb-rubber content in the concrete composite.

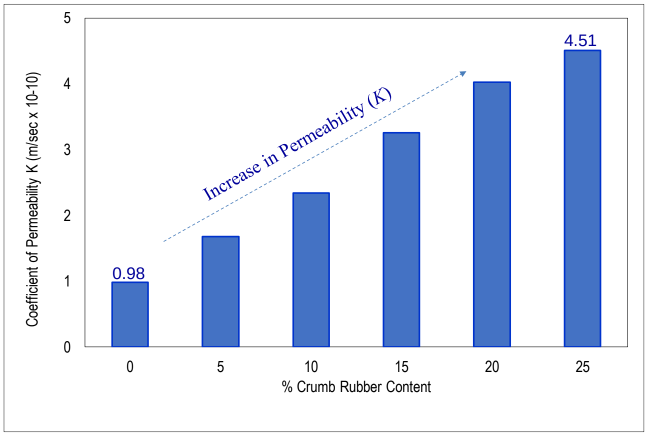


Figure 8: Coefficient of Permeability (k) of CR-MHC Vs % Crumb-Rubber Content

Similar result was also reported by other researchers: Adenan and Kamaruddin (2015) reported that hydraulic conductivity of concrete increased with increment in rubber particles when partially replaced for fine aggregate by volume in the concrete mix. Be that as it may, with substitution of 30% for fine aggregate in concrete mix, the hydraulic conductivity can be classified as average which falls between the range of $10^{-9}$ mm/s to $10^{-6}$ mm/s as stated in Concrete Society, Technical Report 31. Thus, the long-term behavior or performance (durability) with respect to water penetrability of the concrete reduced with rise in quantity of rubber particles in the modified concrete mix. Hence, the flow of the water under hydraulic head increased likewise. Subsequently, durability of the concrete diminished as the protection from the infiltration by the aggressive agents diminished. Adenan and Kamaruddin (2015) additionally detailed that all the mixes recorded lower hydraulic conductivity compared to the control mix which demonstrated that crumb-rubber modified concrete samples has higher permeability compared to the control mix. Adenan and Kamaruddin (2015) proceeded to uncover that hydraulic conductivity measured after 28 days curing is higher compared to that measured after 60 days which suggests that fluid penetrability in concrete specimen diminished with curing age since gel bit by bit fills the pore space occupied with water. Besides, with adequate curing, concrete samples will become more stronger and also increasingly becomes impermeable. In this manner, durability behavior of concrete is enhanced with increment in curing age.

Su *et al.* (2015) in similar research conducted, reported that the permeability of modified concrete with rubber tyre particles of same and varying sizes, that the increment in the permeability index for CR-A20, CR-B20, CR-C20 and CC-SR20 were 3.09, 1.42, 1.39 and 1.25 times the penetrability index of control mix. This implies the water penetrability resistance of concrete is reduced when rubber particles are introduced. Moreover, he revealed that this behavior is like that explained by Bravo and Brito (2012); Ganjian *et al.* (2009); Bignozzi and Sandrolini, (2006). He ascribed the increment in permeability to the increase in void fraction of modified concrete. Since crumb-rubber particles has lightweight and tends to float in the wet mix combined with the elastic properties due to its compact nature has led to poorly compacted concrete with more voids as suggested by Onuaguluchi and Panesar, (2014).

Anwar *et al.* (2010) revealed that it is apparent that permeability increased with progressive increment in rubber particles substance for all test series of modified concrete mix they tested. Anwar *et al.* (2010) ascribed it to non-bonding nature between the crumb-rubber aggregate and concrete materials; also, to the increase in porosity with increase in rubber particles.

They further mentioned that the non-compliance of particle size grading of rubber aggregate compared to sand could likewise be an explanation as clarified by Bignozzi and Sandrolini (2006). Güneyisi and Mehmet (2011) outlined the causes of increase in the permeability of rubberized concrete to: i. non-attraction between crumb-rubber aggregate and other constituent in the concrete mix, ii. High porosity due to percentage increase in rubber aggregate replacement and iii. Surface morphology of rubber particles, low attraction between rubber particles and concrete matrix, which is responsible for high porosities. These porosities in tested concrete results in high permeability characteristic (increase in porosity increases the water permeability).

## 4. Conclusion

1. Compacting factor and unit weight of fresh concrete mixes was reduced by 8.3% and 10.1% with 25% crumb-rubber content respectively.
2. Fresh masonry concrete mixes have its yield (volume) increased by 10.2% with 25% rubber particles content which can be linked to low specific gravity of rubber (1.14) compared to that of granite (2.66) and also the increase in volume of the rubber content against that of granite for which it is partially replacing in the concrete matrix.
3. Hardened masonry concrete samples have its compressive strength reduced from 30.71N/mm2 to 16.25N/mm2 signifying 47% strength lost with rubber content up to 25% after 28 days curing in water under room temperature.
4. Coefficient of permeability of masonry concrete increased with addition of more crumb-rubber content; the results which shows that the reference masonry concrete (0%CR) has a permeability of $9.88 \times 10^{-11}$ m/sec while the 5, 10, 15, 20 and 25% have permeability of $1.68 \times 10^{-10}$ m/sec, $2.34 \times 10^{-10}$ m/sec, $3.26 \times 10^{-10}$ m/sec, $4.03 \times 10^{-10}$ m/sec and $4.51 \times 10^{-10}$ m/sec respectively. The results reveal that increase in crumb-rubber content increased the permeability of masonry concrete with over 300% for 25% crumb-rubber replaced in coarse granite aggregate by volume.
5. The outcome of this studies indicates that the modified concrete has increased its capacity to absorb water from the surface compared to the control which implies that its resistance to flow of water have also been decreased.
6. Finally, outcome from the study suggest the possible application of this modified concrete as an alternative to pervious concrete in areas with low surface water runoff due to its increase in permeability compared to the control specimen.

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