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Strength Characteristics Analysis of Crumb-Rubber Masonry Concrete

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ABSTRACT

The compressive and tensile strength of masonry concrete containing crumb-rubber (CR) particles from waste automobile tyre as partial replacement for mineral coarse aggregate (granite) was investigated with the aim of exploring its prospect for building wall applications and also proffering a permanent solution to the environmental problems constituted by waste tyres. Partial replacement was made at 5%, 10%, 15%, 20% and 25% by volume using a mix ratio of 1:1.5:3 and water-cement ratio of 0.42. The partial replacement of crumb-rubber aggregates in the masonry concrete mixes decreased the compressive and split tensile strength significantly while the flexural strength increased slightly with 10% crumb-rubber content. A compressive strength of 30.71 N/mm^2, splitting tensile strength of 3.13 N/mm^2 was obtained for the reference mixes while the compressive and splitting tensile strength of crumb-rubber masonry concrete with 25% crumb-rubber content was 16.25 N/mm^2 and 1.23 N/mm^2 after 28 days of curing and testing which indicate a loss of strength by 47% and 61% respectively. Flexural tensile strength of masonry concrete beams increased slightly with 10% crumb-rubber content; the reference sample recorded 5.12N/mm^2 while the 10% crumb-rubber content recorded 5.32 N/mm^2 indicating gain in strength of 4%. Increase in crumb-rubber content up to 25% reduced the flexural tensile strength; with strength of 4.92 N/mm^2 recorded indicating loss of strength by 4% after 28 days of standard curing. The result indicates that the potential use of such composite material for civil engineering applications is viable.

Keywords: Concrete, Crumb-Rubber, Density, Masonry and Strength

1. INTRODUCTION

The construction industry are great contributors to environmental degradation, more than automobiles and other renowned polluting activities, but engineers, architect, builders and other professionals in the built environment have in the last years made greater strides in reducing the environmental impact of the construction process. The context of a growing interest towards innovative materials recycling and sustainable buildings, particular attention is receiving the experimentation and the study of concrete products with aggregates particles and/or fibers obtained from plastic, glass, cellulose, and rubber wastes Fernado *et al.* (2011).

Several waste materials, like recycled plastics, glass, cellulose, rubber-tyres and cords, wood and carpet fibers, exhibit extreme versatility, light weight, durability, resistance to chemicals, excellent acoustic, thermal and electrical insulation properties (Fernado *et al.*, 2011). Such properties can be usefully exploited to build-up innovative and sustainable composite materials according to Aisien *et al.* (2006). Particularly relevant in this is masonry concrete with crumb rubbers from waste automobile tyres, which stands as a low-cost strengthening technique which should be able to enhance tensile strength and structural ductility of the concrete matrix.

Ebewele *et al.* (1990) reported that an estimated 5 million scrap tyres from trucks, cars and motorcycles existed in Nigeria in 1983 with an annual generation rate of 15% each year. About 37, million scrap tyres are estimated to exist in Nigeria by 2018. In Nigeria today one of the most common ways of disposing waste tyres is through open field disposal, open air combustion most especially in our abattoir and local commercial quarry where they serve as source of fire for processing slaughtered animals and mining activities. Scientists, engineers and technologists look out for using different types of solid waste as alternative for some ingredients of civil engineering materials such as asphalt and concrete Khalid *et al.* (2008). Many researchers have studied and developed various recycling methods for re-use of waste rubber-tyres in construction materials. Some of these methods are the use of waste rubber-tyres in asphalt concrete mixture, plastic and rubber products and in portland cement concrete. Also, as a visco-elastic material for vibration dampers Yunping *et al.* (2010). Eldin and Senouci (1993) discovered 85% reduction in compressive strength and 50% reduction in tensile strength when the coarse aggregate in the concrete was fully replaced by rubber chips.

Early studies on the use of waste rubber-tyres in asphalt mixes, sealants and rubber sheets were very promising. They showed that rubberized asphalt had better skid resistance, reduce fatigue cracking and achieved longer pavement life than conventional asphalt (Adams *et al*. 1985; Esch 1984; Estakhri 1990 and Khosla and Trogdon 1990). Masonry hollow concrete blocks is becoming widely accepted as a construction material for walling units in our buildings, hence the partial replacement of mineral aggregates with rubber-tyre particles in concrete blocks would be a very good and promising way to utilize the large quantities of waste rubber-tyres. The use of waste rubber-tyres particles in masonry concrete would not only make good use of such waste materials by converting a waste into a resource, but will help to enhance some masonry concrete inherent properties such as tensile strength.

2. METHODOLOGY

2.1 Materials

Crumb-rubber masonry concrete consists of cement, natural aggregate (fine and coarse), waste crumb-rubber tyre derived aggregate and water as shown in Plate 1. A general-purpose blended limestone portland cement CEM II (42.5R MPa) that conforms to BS EN 197-1:2011 with a specific gravity (*G)* of approximately 3.15 and sourced from retail outlet in Zaria was used for this study. Ordinary tap water (potable drinking water) sourced from Civil Engineering Laboratory Ahmadu Bello University, Zaria Nigeria was used for all concrete mixes and curing.

Natural sharp 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 specific gravity of 2.65 and bulk density of 1,454 kg/m^3 was used as fine aggregate. The fine aggregate (sand) as falls in zone two (medium sand) according to BS EN 12620:2002+A1:2008 specification. Natural crushed (granite) with nominal maximum sizes of 9.52-10mm as shown in Figure 1 and sourced from a local commercial quarry with specific gravity of 2.66 and bulk density of 1635kg/m^3 was used as coarse aggregate. Coarse rubber aggregate (crumb rubber) from scrap tyres with nominal maximum sizes of 4 - 8mm, specific gravity of 1.14 and bulk density of 528 kg/m^3 was used for this research. Crumb rubber surface treatment method by soaking in sodium hydroxide (NaOH) solution was adopted for this research due to its effectiveness in enhancing the hydrophilic properties of the rubber and increasing the intermolecular interaction forces between rubber and calcium silicate hydrate (C-S-H) gel which enhances strength of the composite matrix as reported by Mohammedi (2014).

Plate 1: Material for Crumb-Rubber Masonry Concrete

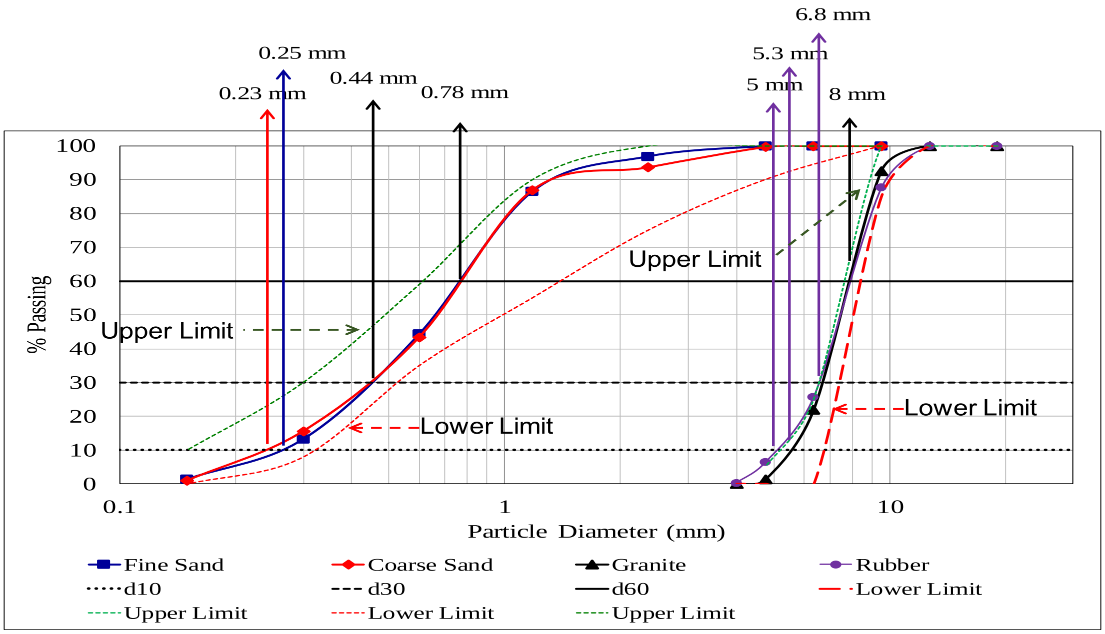


Figure 1: Grading of Natural Aggregate and Crumb Rubber

2.2 Mix Proportions

The mix design for the masonry concrete and crumb-rubber modified masonry concrete adopted was based on absolute volume method according to BS EN 206:2013+A1:2016 design, a mix ratio of 1:1.5:3, compressive strength of 30 N/mm^2 at 28 days with water/cement ratio of 0.42 and aggregate/cement ratio of 4.5:1 was used to produce a trial mix which was tested for compacting factor, strength, density and finishing properties and eventually subjected to adjustment, adopted and applied to all the concrete mixes. A total number of six (6) mixes were prepared: One control mix and five concrete mixes in which the 9.52-10 mm granite was replaced by crumb rubber aggregate at 5%, 10%, 15%, 20% and 25% by volume. The mix proportions were constant in terms of mix design ratio, water/cement ratio, sizes, type of natural and crumb rubber-tyre aggregate used for the study. The total number of specimens prepared for this study include: 72 Concrete cubes (150x150x150) mm for compressive strength test after (7, 14, 21 and 28 days) of standard curing, 36 concrete cylinders (300x150) mm for indirect tensile strength test after (14 and 28 days) of curing, 36 concrete prism beams (500x100x100) mm for flexural strength test (modulus of rupture) after (14 and 28 days) of curing.

Table 1: Quantity of Materials to a Cubic meter of Concrete (Control Mix)

Mix Ratio	W/C Ratio	A/C Ratio	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
1:1.5:3	0.42	4.5	411.29	616.94	1,233.87	179.56

2.3 Experimental Procedure

2.3.1 Compacting factor, yield and unit weight test

Tests were conducted to assess the compacting factor of the fresh (relatively dry) masonry concrete mixes; control and that of crumb-rubber modified masonry concrete mixes at the department of civil engineering concrete laboratory Ahmadu Bello University (A.B.U) Zaria in accordance with BS EN 12350-4:2009, the unit weight of the fresh masonry concrete samples was established in accordance with BS EN 12350-6:2009 using the 0.01m^3 cylinder while the yield of each concrete mix was computed from the unit weight and the sum of the weight of constituent materials based on ASTM C138-09.

2.3.2 Compressive strength test

The compressive strength tests of masonry concrete cube (150 x 150 x 150) mm samples were determined according to BS EN 12390-3:2009 after 7, 14, 21 and 28 days of standard curing in water and computed using the Equation 1:

$$f_c\left(N/mm^2\right)=\frac{P_{\max}}{A} \tag{1}$$

Where:
f_c is compressive strength
P_{max} is the maximum load that cube sustained
A = the cross-sectional area of the cube.

2.3.3 Splitting tensile strength test

The splitting tensile strength test of masonry concrete cylinders samples (300 x 150) mm were determined in accordance with BS EN 12390-6:2000 after 14 and 28 days of standard curing in water and computed using the Equation 2:

$$f_{tp}\left(N/mm^2\right)=\frac{2P}{\pi DL} \tag{2}$$

Where:
f_{tp} is the indirect tensile strength
P is the maximum load sustained by the specimen
D is the diameter of the specimen
L is the length of the specimen.

2.3.4 Flexural tensile strength test

Flexural tensile strength of masonry concrete prism beam (500 x 150 x 150) mm samples were prepared and determined in accordance with BS EN 12390-1:2000 and BS EN 12390-5:2000 under two-point loading (also called four points loading including the reactions) after 14 and 28 days of standard curing in water. The flexural strength of each beam is expressed as the modulus of rupture f_b and calculated to the nearest 0.05(N/mm^2) as follows:

$$f_b\left(N/mm^2\right)=\frac{PL}{bd^2} \tag{3}$$

Where:
f_b is the flexural tensile strength
P is the ultimate load (N)
L is the supporting roller distance (mm)
b is width of the beam (mm)
d is depth of the beam (mm).

3. RESULTS AND DISCUSSION

3.1 Compacting Factor, Yield and Unit Weight

The compacting factor (C.F) as shown in Figure 2 was observed to decrease significantly. Control masonry concrete mixes had C.F of 0.84 (low workability) while the 25% crumb rubber mix had C.F of 0.77 (very low workability) indicating 8.3% reduction. The modified masonry concrete mixes exhibited lower unit weight than the reference mix, it was deducted that unit weight of fresh masonry concrete mixes reduces by 10.1% and this was expected, as the specific gravity of crumb-rubber, at 1.14, is less than that of natural coarse aggregate (granite), at 2.66. Yield value of fresh masonry concrete mix in Figure 2 was observed to increase slightly from 0.0186 m^3 for control masonry concrete mix to 0.0207 m^3 for mix with 25% crumb-rubber content, which indicates an increase by 10.2% and this can be attributed to low bulk specific gravity of crumb-rubber 1.14 and the increase in crumb-rubber volume.

3.2 Density (unit weight)

The density of reference and modified hardened concrete samples is presented in Figure 3. it can be seen that the modified concrete mixes exhibited lower densities than the reference mix for all ages of the test samples, it can be deducted from the graph that density reduces by 12.4%.This was expected, as the specific gravity of crumb-rubber, at 1.14, is less than that of natural coarse aggregate (granite), at 2.66.

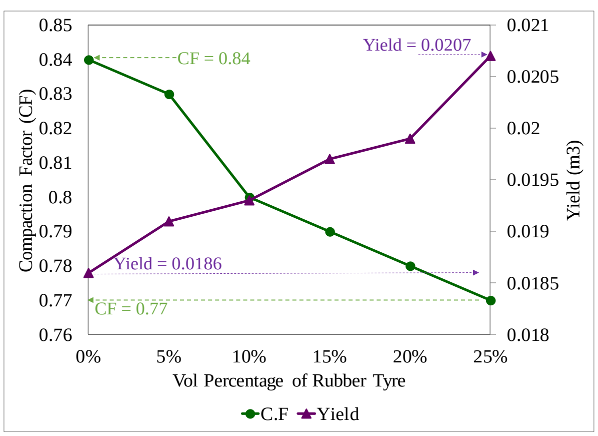


Figure 2: Compacting factor and Yield Vs Crumb-Rubber Content (%)

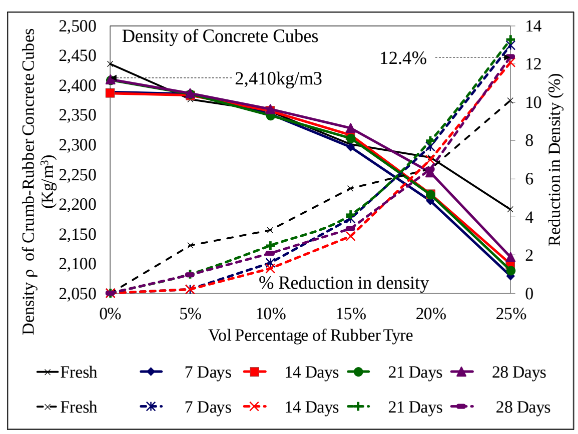


Figure 3: Density of Concrete Vs Rubber Content (%)

3.3 Compressive strength

Compressive strength of crumb-rubber modified concrete results is plotted and shown in the Figure 4 and 5. From the results obtained in general, it can be seen that the addition of crumb-rubber aggregates in concrete mixes decreased the compressive strength significantly with percentage increase in the crumb-rubber tyre particles. A compressive strength of 30.71N/mm^2 was obtained for the control concrete mixes after 28 days of standard curing and testing while the strength of crumb-rubber concrete with 25% by volume of the coarse aggregate replaced with crumb-rubber aggregate is 16.25N/mm^2, which indicate a percentage loss of strength by 47%. Eldin and Senouci (1993) in their investigation observed a reduction of up to 85% in concrete, Toutanji (1996) discovered that the incorporation of the rubber aggregates in concrete produced a reduction in compressive strength of up to 75%.

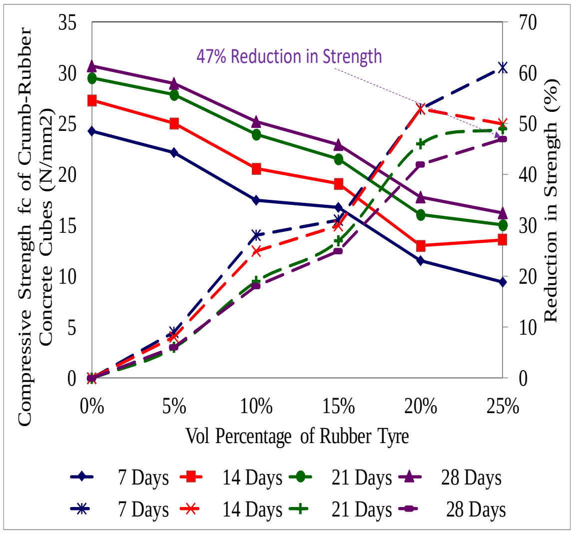


Figure 4: Compressive Strength of Masonry Concrete Cubes with increase in Crumb-Rubber (%)

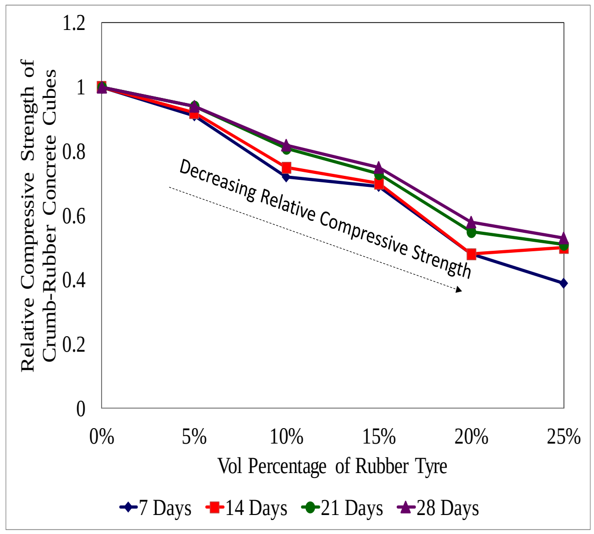
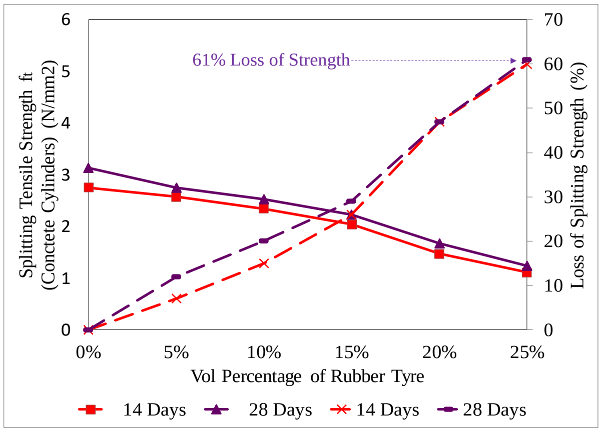


Figure 5: Relative Compressive Strength of Masonry Concrete Against Crumb-Rubber Content (%)

3.4 Splitting tensile strength

The splitting tensile strength test results are shown in Figure 6 and 7, which indicates a reduction in the splitting tensile strength with increase in percentage of coarse (crumb-rubber) aggregate content. But the losses in the splitting tensile strength are not has high as that obtained in compressive strength. The splitting tensile strength result of control concrete mixes for 14 and 28 days is 2.75N/mm^2 and 3.13N/mm^2, respectively while for 25% rubber mix; the 14 and 28days strength is 1.11N/mm^2 and 1.23N/mm^2. This indicates a percentage loss of strength by 60% and 61% for 14 and 28 days respectively.

The reduction in strength could be attributed on the effect of rubber aggregate on the microstructure of concrete matrices and the transition zone between the aggregate and the cement past Najim *et al.* (2008) also Christos *et al.* (2006) related the phenomenon to the non-polarity of the rubber attracting air to the surface and therefore reduces the bond with cementitious matrix.
In a similar investigation conducted by Najim *et al*. (2008), he reported a percentage decrease in splitting tensile strength at 7 days to be 11.6% and 54.2% for concrete with 20% and 30% fibre worn-out tyre (rubber aggregate) partial replacement ratio by volume of coarse aggregate respectively while at 28 days the percentage decreased in splitting tensile strength were 18.2% and 41.9% for concrete with 20 and 30% respectively.



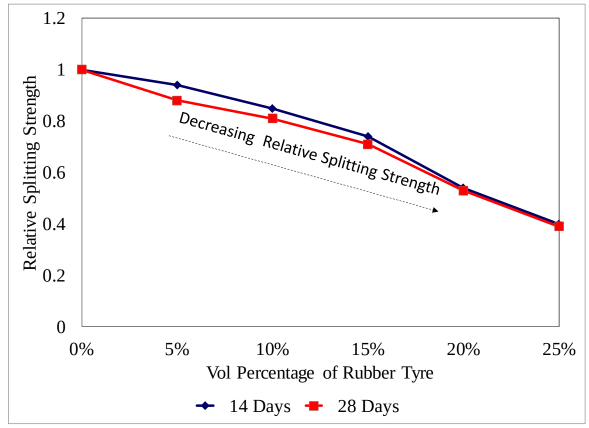
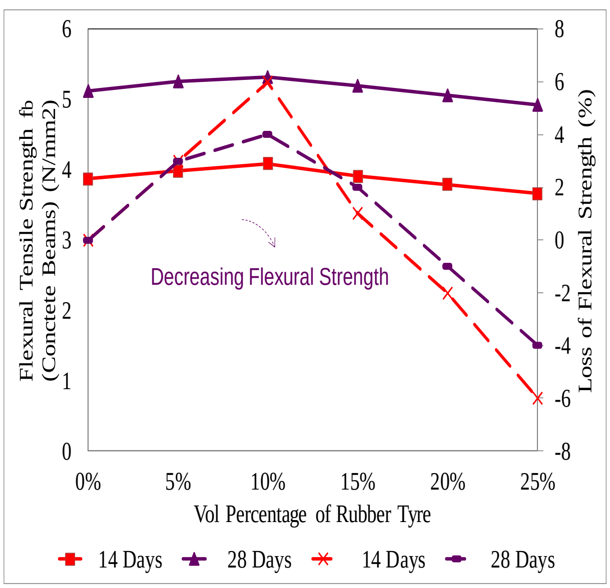


Figure 6: Splitting Tensile Strength of Masonry Concrete Cubes with increase in Crumb-Rubber (%)

Figure 7: Relative Splitting Tensile Strength of Masonry Concrete Against Crumb-Rubber Content (%)

3.4 Flexural tensile strength

Flexural tensile strength test results are shown in Figure 8 and 9, which shows that the strength of masonry concrete mix with crumb-rubber aggregate content up to 10% at 14 and 28 days of standard curing increased to a maximum of 4.09N/mm^2 and 5.32N/mm^2 respectively gaining up to 6% and 4% compared to the control mixes (0%) with 3.87N/mm^2 and 5.12N/mm^2. The result further shows a decline in flexural strength with increase in crumb-rubber aggregate, for 15%, 20% and 25% with a flexural strength of 3.91N/mm^2 and 5.19N/mm^2, 3.79N/mm^2 and 5.06N/mm^2, 3.66N/mm^2 and 4.92N/mm^2 obtained for 14 and 28 days testing periods respectively. This result indicates that the improvements in flexural strength are limited to a relatively small amount of crumb-rubber aggregate content and the percentage losses of strength is very low compared to other mechanical properties tested.



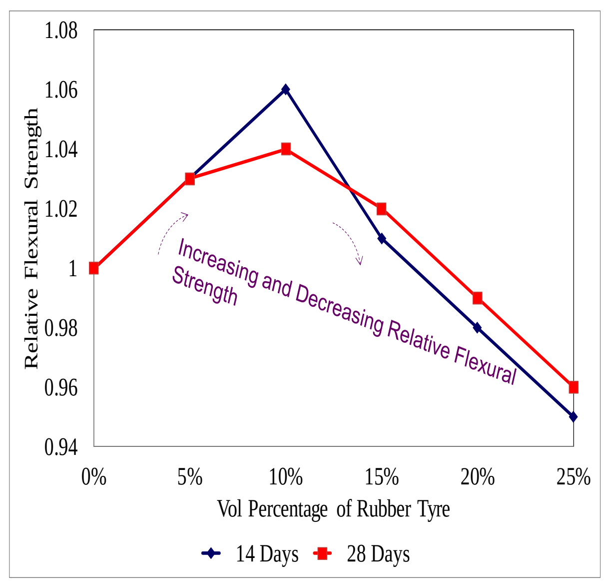


Figure 8: Flexural Tensile Strength of Masonry Concrete Cubes with increase in Crumb-Rubber (%)

Figure 9: Relative Flexural Tensile Strength of Masonry Concrete against Crumb-Rubber Content (%)

4. CONCLUSION

The following conclusions are drawn on the physical and compressive strength of masonry concrete containing crumb-rubber particles from waste automobile tyre as partial replacement for coarse granite by volume.

i. The compacting factor and unit weight of fresh (relatively dry) masonry concrete mixes reduce by 8.3% and 10.1% respectively with percentage increase in crumb-rubber aggregates content up to 25%.
ii. Yield of fresh concrete mix increased slightly by 10.2% with percentage increase in crumb-rubber aggregate content up to 25% which can be attributed to low specific gravity (SSD) of crumb-rubber aggregate (1.14) and increase in volume of crumb-rubber in-terms of weight compared to the same weight of aggregate replaced with.
iii. Density of masonry concrete cubes decreased from 2,410Kg/m^3 to 2,111Kg/m^3 indicating 12.4% reduction with 25% crumb-rubber content after 28 days of standard curing in water.
iv. Compressive strength of masonry concrete cubes decreased from 30.71N/mm^2 to 16.25N/mm^2 indicating 47% loss in strength with 25% crumb-rubber content after 28 days of standard curing with water.
v. Splitting tensile strength of masonry concrete was reduced from 3.13N/mm^2 to 1.23N/mm^2 with 25% crumb-rubber content after 28 days of curing in water indicating 61% loss in strength.
vi. Flexural tensile strength of masonry concrete increased slightly with 10% crumb-rubber content. The reference mix recorded 5.12N/mm^2 while the 10% crumb-rubber content recorded 5.32N/mm^2 indicating gain in strength of 4%. Increase in crumb-rubber content up to 25% reduced the flexural strength; with a strength of 4.92N/mm^2 recorded indicating loss of strength by 4% and 4.7% after 28 days of standard curing.

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