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PRODUCTION OF LIGHTWEIGHT CONCRETE FROM WASTE TIRE RUBBER CRUMB

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Abstract. A lot of research has proposed the use of alternative materials in concrete, one of such material that has gained a lot of attention is the waste tire rubber. In this research, rubber crumb was used to partially replace fine aggregate in concrete at 0, 4, 8, 12, and 16% and represented as M_0, M_4, M_8, M_{12}, and M_{16}, respectively. Sieve analysis was carried out on the rubber crumb and sand, while slump, compressive and tensile test were carried out on the concrete samples. The sieve analysis revealed that both the fine aggregate and rubber crumb are poorly graded. The slump test showed that the concrete losses it consistency as more rubber crumb was added. The 28 days compressive strength showed that there was a general reduction in strength. The work concluded that rubber crumb can be used to replace fine aggregate up to 16%, in lightweight concrete.

Keywords: building materials, concrete, rubber crumb, fine aggregate, lightweight concrete.

Introduction

The negative effect of green house gases has been a source of major concern to the world in the last few years; these gases are released to the atmosphere through the activities of man, especially through industrialization. The improper disposal of solid and industrial waste has led to part of the problem that the world is currently battling with, the burning of some of these waste such as rubber from tire has led to the release of poisonous gases such as sulphur in to the atmosphere, this gas react with oxygen in the air which eventually lead to the depletion of the ozone layers and the formation of gases like sulphur dioxide which ultimately lead to acid rain. Many researchers have worked on the effective disposal of such solid waste like used rubbers, plastics, nylon, industrial waste and even used scrap metals.

According to Sgobba *et al.* (2010). It has been estimated that more than 250 million post-consumption tires were generated annually in the 15 States of the European Union. In 1992, about 65% of the quantity produced in the then 12 member states was stored in dumps and only 35% underwent other regeneration process. In 2002, the situation was completely overturned in the 15 member states. More than 65% of post-consumption tires were prepared for reuse or exported, whereas less than 35% was stored in dumps.

The management of waste tire has been a source of major concern in many countries of the world (Khaloo *et al.* 2008). Accumulation of this waste is found to be very dangerous, not only due to a potential negative environmental impact, but also because it presents a fire hazard and provides a breeding ground for rodents. (Guneyisi *et al.* 2004; Siddique, Naik 2004; Gha-

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ly, Cahill 2005; Hernandez-Olivares *et al.* 2002; Li *et al.* 2004). The importance of recycling of waste tires have motivated a significant body of research pertaining to rubberized concrete (Khaloo *et al.* 2008). During the last few years, much research has been carried out in an attempt to reuse abandoned tires by grinding them into small particles (rubber crumb) and use in asphalt (Sukontasukkul, Chaikaew 2006). Sgbobba *et al.* (2010) concluded that the incorporation in concrete of rubber aggregates, obtained from waste tires, is a suitable solution to decrease weight in some engineering manufactures, but could not conclude on some mechanical properties of the concrete such as durability, the toughness and impact resistance of the mix. In the investigation of the shrinkage properties of rubberized concrete pavement, results obtained showed that samples prepared with 20% and 25% rubber in concrete gave a good performance at water cement ratio 0.45 and 0.40 respectively (Mohammadi, Khabbaz 2015).

The effect of carbonation and acid attack on rubberized concrete and the long term behavior was investigated (Thomas, Gupta 2015, 2016; Thomas *et al.* 2016), in the work, up to 20% of fine aggregate was replaced with waste tire rubber crumbs. The work concluded that rubberized concrete is highly resistant to the aggressive environments and can be implemented in the areas where there are chances of acid attack, the concrete shows high resistance to freeze-thaw, acid attack and chloride ion penetration, while the use of silica fume in rubberized concrete enables in to achieve high strength and high resistance to sulfate, acid and chloride environments.

There are other waste materials apart from rubber waste that have been investigated by different researchers. Aamer and Hussain (2015) investigated three types of lightweight aggregate in their study on the production of lightweight concrete. These types are red block aggregate, red ceramic aggregate and white thermostone aggregate, they carry out test on both wet and hardened concrete, it was concluded that the increase in the proportion of coarse aggregate in all types of concrete used in the study reduces the compressive strength, tensile strength, modulus of elasticity and slump flow, but the final results were within recognized standards.

Batayneh *et al.* (2007) used ground plastics and glass to replace up to 20% of fine aggregates in concrete mixes, while crushed concrete was used to replace up to 20% of coarse aggregates. The main findings of the investigation revealed that the three types of waste materials could be reused successfully as partial substitutes for sand or coarse aggregates in concrete mixtures. Sukontasukkul and Chaikaew (2006) used rubber crumb in the production of concrete blocks, and concluded that it is possible to manufacture concrete block containing rubber crumb up to about 20% by weight using a conventional plain concrete block manufacturing processes. The resulting blocks, though not as strong as plain concrete block, are lighter and seem to be more flexible with better energy absorption. The aim of the research is to further the search on the effective use of waste rubber crumb in lightweight concrete.

According to ACI 213 (1999), lightweight concrete can be classified into three, low density concrete (LDC), Moderate strength concrete (MDC), and structural lightweight concrete (SLWC) as shown in Table 1. Furthermore, EN 206 (2000) classified concrete in to three types, namely lightweight concrete (LWC), normal concrete (NC), and heavyweight concrete (HWC) as shown in Table 2. Also the code further sub-divide LWC into six classes namely: D1.0, D1.2, D1.4, D1.8 and D2.0 as shown in Table 3.

ACI 213(2003) recommended a minimum 28 days compressive strength of 7 N/mm^2 for LWC, while BS 8110 (1997) required a minimum 28 days compressive strength of 15 N/mm^2 for concrete to be used as reinforced concrete, and a minimum 7 N/mm^2 for plain concrete. Montero (2014) classified concrete into three group based on it compressive strength as, low strength concrete (LSC), moderate strength concrete (MSC), and high strength concrete (HSC) as shown in Table 4.

Table 1. Classification of lightweight concrete

Properties	Low-density	Moderate-strength	Structural concrete
Bulk density (Kg/m^3)	320–800	801–1349	1350–1920
Compressive strength (N/mm^2)	0.69–6.89	6.90–17.23	17.24–41.36

(ACI 213: 1999)

Table 2. Classification of concrete by density

Types of concrete	Density (Kg/m^3)
Lightweight concrete	800–2000
Normal–weight concrete	2001–2600
Heavy–weight concrete	>2600

(EN 206: 2000)

Table 3. Classification of lightweight concrete by density

Density class	Density range
D1.0	800–1000
D1.2	1001–1200
D1.4	1201–1400
D1.6	1401–1600
D1.8	1601–1800
D2.0	1801–2000

(EN 206: 2000)

Table 4. Classification of concrete based on compressive strength

Class	Compressive strength
Low–strength	<20
Moderate–Strength	20–40
High–strength	>40

(Montero 2014)

1. Experimental design

The rubber crumb was obtained from a recycling plant, TOSAS in Wadeville, South Africa. The rubber crumb was used to replace fine aggregate in concrete by 0, 4, 8, 12 and 16% respectively. The concrete samples were designated as M_0, M_4, M_8, M_{12}, M_{16}. Sieve analysis was carried out on the rubber crumb, and the fine aggregate in other to determine particle distribution. Test such as slump test was carried out on the wet concrete, while compressive and tensile strength tests were carried out on the hardened concrete. The distribution of the rubber particles in concrete were observed under a celestron digital microscope, this is to predict the effect of the crumb distribution on the light weight properties of the concrete. All the experiments were carried out at the structural engineering laboratory of the department of civil engineering of Tshwane University of Technology, Pretoria South Africa.

1.1. Sieve analysis and grading of fine aggregates

This test was conducted based on ASTM D 422 (2006) the sieve sizes in general used for particle size distribution of fine aggregates are 10 mm, 4.75 mm, 2.36 mm, 1.18 mm and 600 μm, 300 μm, 150 μm, and 75 μm. This test consist of dividing up and separating by means of a series of test sieves named above, a material into several particle size classifications of decreasing sizes. The mass of the particles retained on the various sieves were then related to the initial mass of the material. The cumulative percentages passing each sieve were reported in graphical form in Figures 3 and 4. The uncompacted density of the fine aggregate mixed with rubber crumb at respective percentages was also determined, in order to know the effect of the rubber crumb on the density of concrete.

1.2. Preparations of test samples

The specimens were cast in iron moulds of 100×100×100 mm cubes, while 150 mm diameter by 300mm height cylinders was also cast for the tensile splitting test. This conforms to the specifications of BS 1881(1983). The inside surface of the moulds was cleaned and lubricated before usage, to prevent sticking of concrete to the formwork surface. The moulds were then assembled tightened using bolts and nuts to prevent leakage of the rubber crumb concrete mix. The Mix design for the concrete was ratio 1:2:3, for Ordinary Portland Cement (OPC, CEM I, 32.5N), fine aggregate and coarse aggregate respectively with a water–cement ratio of 0.5, all based on BS 1881 (1983) standard method, the fine aggregate was partially replaced with the rubber crumb at 0, 4, 8, 12, and 16% mix proportion. Upon preparation of trial mixes, the moulds were filled with concrete in three layers, each layer being compacted using an iron rod to remove as much entrapped air as possible and to produce full compaction of concrete without segregation.

The specimens were removed from the moulds after about 24 hours of casting and marked with details of the type of mix, date of casting using a water proof marker, duration for curing and the determined crushing date was recorded in a note book. The samples were cured for 7, 14, 21, and 28 days at 20±2 °C. The distribution of the rubber crumb in hardened concrete was investigated using a celestron digital microscope.

1.3. Slump test

The slump test is used to determine variations in the uniformity of mix of given proportions. The objective of the test is to determine slump of fresh concrete mix. The procedure of the test involved cleaning and oiling the inside surfaces of the cone mould to prevent sticking of fresh concrete on the surfaces of the mould. The mould is then filled with fresh concrete in three layers with each layer compacted with 25 strokes of the tamping rod. When filled, the top surface was struck off using a straight blade, and the cone slowly lifted and removed, leaving the molded concrete unsupported. Then its height duly measured. The difference between that height and that of the cone was therefore recorded as the slump.

1.4 Hardened concrete

1.4.1. Density of concrete

In line with BS 1881 (1983), the test was carried out to determine the density of hardened concrete on each test days for all the mixes. The procedure involves measuring the weight of the cubes after their curing period. The dry cured specimens were placed on a weighing machine and their masses accurately recorded. The volume of the cubes is already known, since the standard 100×100×100 mm cubes was used and that of the cylinder is 150 mm diameter by 300mm high. The density of the concrete for each plastic replacement was calculated.

1.4.2. Compressive strength

The compressive strength for all the concrete cubes was determined in accordance with South African standard, SANS 5863 (2006) and BS 12390 parts 3 (2009). Each concrete was prepared in accordance with the percentage mixes been investigated in this work. Three samples for each curing age and for the percentage replacement were replicated, a total of 70 cubes were cast. The compressive strength of each cube was determined from a compressive testing machine at a load rate of 180 kN/min. All the samples were tested to failure by crushing and the maximum load recorded, the maximum load divided by the area of each cube gives the compressive strength of the samples. The average compressive strength for each specimen was taken from three results as the resultant strength. Figure 1 showed a sample under the compressive testing machine.

1.4.3. Tensile split strength

Testing for split tensile strength of concrete is done as per ASTM C 496–96 (2004). The test is conducted on compression testing machine of capacity 2000 kN as shown in Figure 2. The cylinder is placed horizontally between the loading surfaces of compression testing machine and the load is applied at the rate of 100 kN/minute until the failure of the cylinder, during the test the platens of the testing machine should not be allowed to rotate in a plane perpendicular to the axis of cylinder, the splitting tensile test equation is shown below.

$$\frac{2P}{\pi LD}, \tag{1}$$

where P – load at failure; L – length of the cylinder and D – diameter of the cylinder.

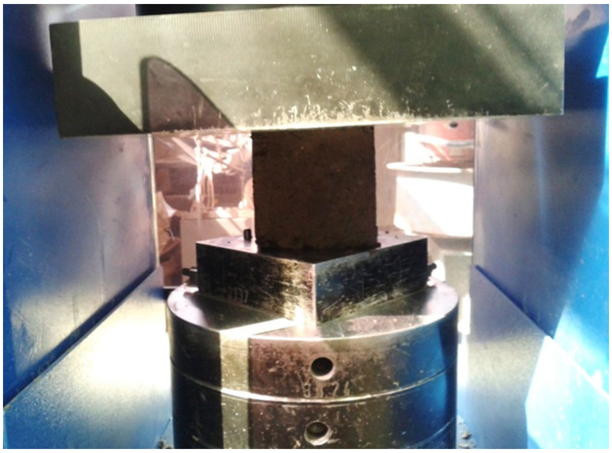

Fig. 1. Test sample under compression

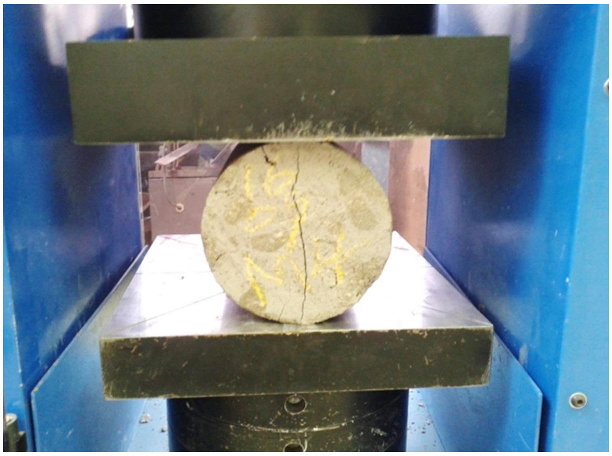

Fig. 2. Tensile splitting test

2. Experimental results and discussion

2.1. Particle size distribution

The particle size distribution for both the rubber crumb and sand were carried out, and the results are shown in Figures 3 and 4 respectively.

The particle size distribution curve for the recycled rubber crumb has a steep curve, indicating a type of aggregate containing particles of almost the same size. According to ASTM D2487 (2006), any clean aggregate with less than 5% fines, with grading requirements of C_u (coefficient of uniformity) greater than 6 and C_c (coefficient of curvature) greater than 1 but less than 3 is a well or uniformly graded aggregate. From Equation (2),

$$C_U = \frac{D_{60}}{D_{10}}. \tag{2}$$

From equation (3)

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}. \tag{3}$$

From the result obtained above, the recycled rubber crumb has C_u of 4.5 and a C_c of 2.0, the C_c value is within the recommended range, but the C_u is less than the recommended value of 6. Hence, it can be concluded that the recycled rubber particles are poorly graded.

The sieve analysis in Figure 4 showed that the natural river sand has a coefficient of uniformity (C_u) of 2.13, and the curvature (C_c) was 1.96, the C_c value is within the range of $1 \leq C_c < 3$ recommended for sand but below the C_u value of ≥6 recommended for sand according to ASTM D2487 (2006). Hence it is classified as poorly graded, but the microscopic analysis in Figure 5 showed that the soil particle are cubical or round with smooth surface texture which gave it a good advantage of good workability in concrete.

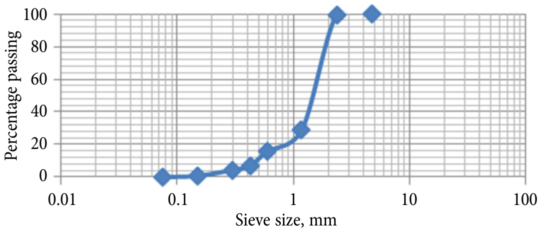

Fig. 3. particle size distribution of rubber crumb

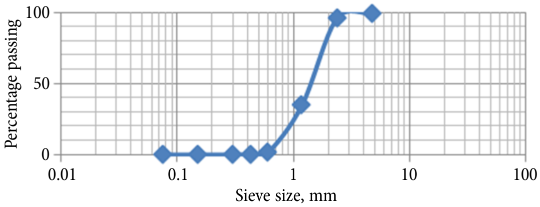

Fig. 4. Particle size distribution of fine aggregate

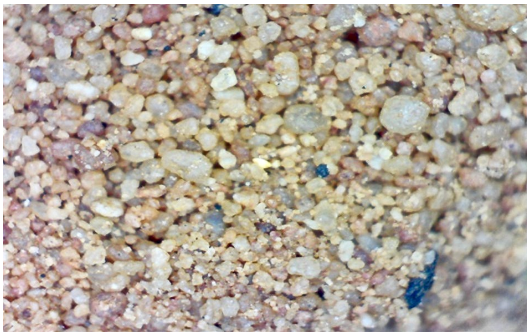

Fig. 5. Microstructure properties of fine aggregate

2.2. Uncompacted particle density

The uncompacted density of the sand and rubber mixture from Figure 6 showed that the more rubber added to the sand the less the density of the fine aggregate. The initial uncompacted fine aggregate density was 1458 kg/m^3, while that of rubber crumb was 473 kg/m^3, but when the fine aggregate was replaced and mix with rubber crumb at 4, 8, 12, and 16%, the new uncompacted densities were 1323, 1275, 1171 and 1082 kg/m^3 respectively. This showed that the light weight rubber crumb, and it unevenly distributed particle create larger void within the aggregate structure, this eventually have effect on the weight of the concrete under investigation.

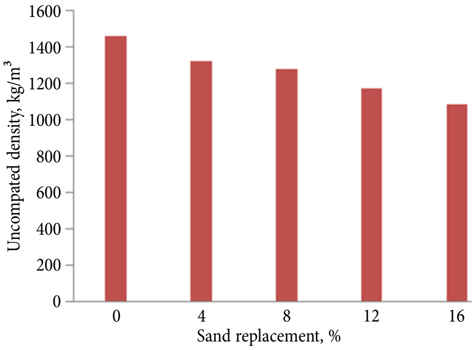

Fig. 6. Uncompacted densities of fine aggregate

2.3. Slump test result

The slump test is the most commonly used method of measuring the consistency or workability of concrete which can be employed either in the laboratory or on site. It was observed that all the concrete sample slumps evenly, which can also be referred to as a true slump during the test period and this can be said that the entire sample have good consistency properties. But from Figure 7, the slump value decreases as the percentage of rubber increases in the concrete mix, the M_0 and M_4 specimens both give a slump of 25 mm, the M_8 specimen has 20 mm slump value while the M_{12} and M_{16} specimens have 15 mm and 10 mm slump respectively. The implication of this is that if the concrete is to be transported to a distance site, the water cement ratio will have to be increased in order to increase its slump and workability before pouring, but in general, the rubberized concrete specimens have acceptable workability in terms of ease of handling, placement, and finishing. The very low slump especially in all the rubberized samples can be attributed to the absorption of water by the rubber particles in the concrete mixture; since the rubber crumb was dry, it affinity with water was high within the concrete environment hence the almost dry concrete obtained, Figure 8 showed a sample of the wet concrete mix with16% rubber crumb.

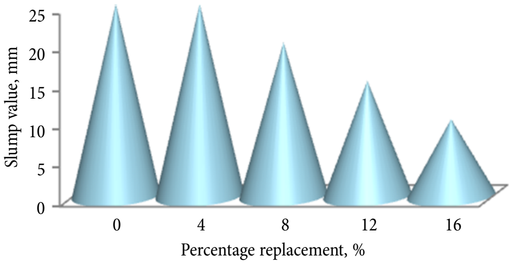

Fig. 7. Slump test result of wet concrete

Fig. 8. Concrete sample mix with 16% rubber crumb

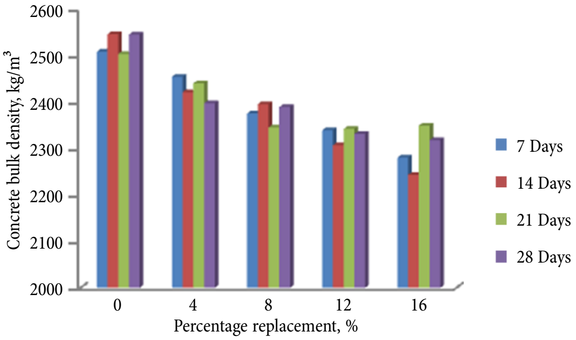

Fig. 9. Bulk density of concrete cubes

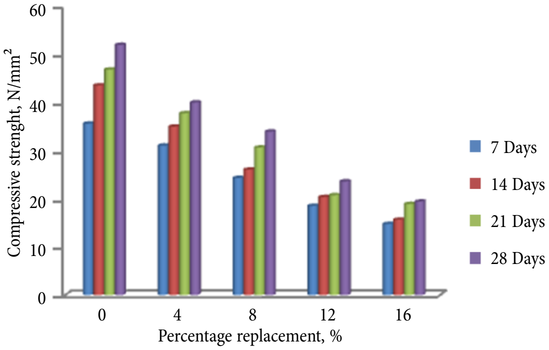

Fig. 10. Compressive strength test

2.4. Bulk density of concrete samples

The bulk densities of each concrete mix were determined on each day of compressive strength test, Figure 9 showed the variation in concrete densities. All the concrete samples showed a decrease in bulk density with increase in the amount of rubber crumbs; all the concrete samples maintain an average density of between 2200–2500 kg/m^3 which qualifies it as normal weight concrete as described in Table 2. This showed that the addition of rubber crumb to concrete up to 16% will not have serious effect on the concrete density, although the density of concrete also depends on the degree of compaction of the samples during casting.

2.5. Compressive strength test result

The compressive strength test results are showed in Figure 10, the general trend is that the compressive strength reduces as the percentage of rubber crumb increases in the concrete mix. The ultimate strength for Control specimen (M_0) is more than that of M_2 specimens by over 23%, while the M_8 is lower than the control by 35%; however for total rubber concentrations greater than M_{12}, the ultimate strength results are very low than the half of the control samples. The systematic reduction of ultimate strength in tire rubber concrete might restrict the use of tire–rubber concrete, with tire–rubber concentrations exceeding 8%, in structural applications. The reduction in compressive strength can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste. Since the aim of this work is to use rubber crumb in lightweight concrete, ACI 213 (2003) recommended a minimum 28 days compressive strength of 7 N/mm^2 for light weight concrete (LWC), while BS 8110 (1997) required a minimum 28 days compressive strength of 15 N/mm^2 for concrete to be used as reinforced concrete, and a minimum 7 N/mm^2 for plain concrete. The results from the entire test specimen showed that rubber crumb can be used to replace fine aggregate in light weight concrete up to 16%, since the least 28 days compressive strength obtained for M_{16} was 19.40 N/mm^2, which is greater than the recommended values.

2.6. Tensile test

The 14 and 28 days tensile test result for all the samples are showed in Figure 11. As more rubber crumbs were added to the concrete samples, the tensile strength also reduces. The results showed the tensile strength for the control M_0 to be 2.76 and 3.11 N/mm^2 for the 14 and 28 days test respectively. These reduced by 39 and 41% at 14 and 28 days respectively for the M_4 sample. The phenomenon continued for the entire concrete samples as M_{16} gave1.15 and 1.33 N/mm^2 at 14 and 28

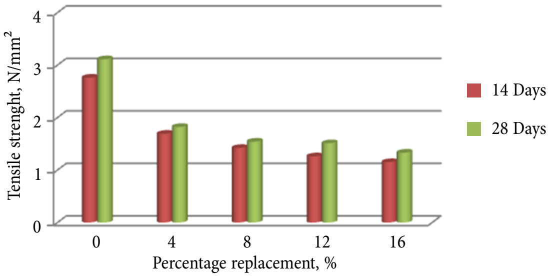

Fig. 11. Splitting tensile strength result

days respectively. The reduction in tensile strength can also be attributed to the weak interfacial adhesive force between the cement paste and the elongated surface of the rubber crumb which encourages micro voids within the concrete material; these voids are potential weak points for the tensile stresses generated during the application of tensile forces on the concrete samples, the more voids within the concrete samples the less the compressive strength.

2.7. Rubber crumb distribution in concrete

The distributions of the rubber crumb in concrete are showed in Figures 12–16. The specimen M_0 showed that there was no rubber crumb in the sample, while other specimen from the figures revealed how the rubber crumbs were dispersed in each sample, the red arrows in the figures pointed to the rubber crumbs. As the percentage of rubber crumb increased in the concrete samples so were the amounts of rubber crumbs seen from the micrographs. The presence of rubber crumbs in concrete allowed for the formation of voids or spacing between the interface of the cement paste and the rubber crumbs, these voids accommodate water molecules when the concrete was wet, but by the time the concrete becomes hardened, these voids are left behind and it eventually contributed to the reduction in compressive strength of the concrete. The more rubber crumb present in a sample, the more voids formed and hence the increases in weak adhesive force (van der Waals forces of attraction). Naturally, capillary and air voids are present in concrete cement paste; Capillary voids represent the space not filled by the solid components of the hydrated cement paste, but the presence of external impurities like the rubber crumb increases the amount of these voids in concrete and hence the low density and compressive strength experienced from the samples where fine aggregates were replaced by rubber crumbs.

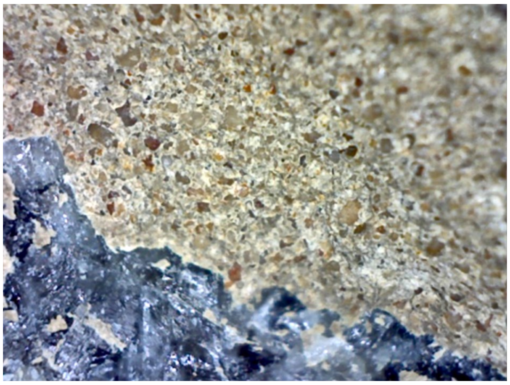

Fig. 12. Microstructure of M_0 sample

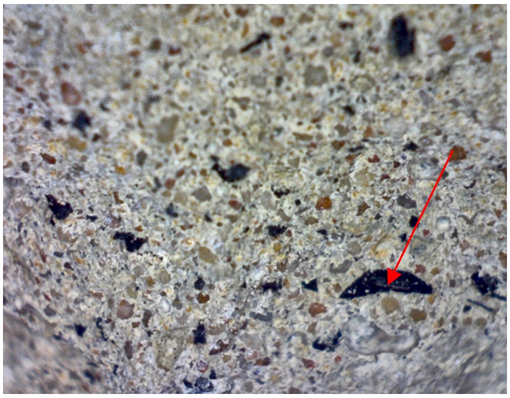

Fig. 13. Microstructure of M_4 sample

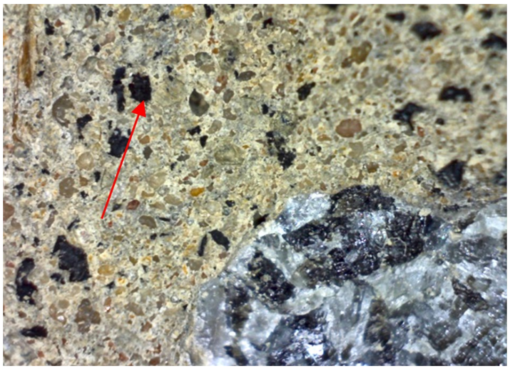

Fig. 14. Microstructure of M_8 sample

Fig. 15. Microstructure of M_{12} sample

Fig. 16. Microstructure of M_{16} sample

Conclusions

From the investigation carried out on the use of rubber crumb in lightweight concrete, it can be concluded that:

(a) Although the presence of rubber crumb reduces both compressive and tensile strengths of concrete, this is because the rubber crumb allowed the increase in water demand, reduction in bond between aggregate and cement paste, leading to increase in drying shrinkage and lower strength.

(b) The uncompacted density of the fine aggregates mix with concrete reduced as more rubber crumb replaced fine aggregate in concrete and these was due to the low density of the rubber crumb.

(c) The result obtained for the compressive strength gave a positive side of the research work because the 28 days compressive strength for the M_{16} concrete mix is higher than the recommended compressive strength of 15 N/mm^2 for reinforced light weight concrete. Hence rubber crumb can conveniently replace fine aggregate in concrete up to 16% for light weight concrete.

(d) The rubber crumbs in concrete encourage the formation of voids within the concrete interface and thus lead to the lightweight characteristics of the rubberized concrete.

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