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Characterization of Modified Crumb Rubber Concrete

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ABSTRACT

Concrete is a very important construction material used worldwide for the construction of bridges, buildings, dams, kerbs, patios, pools, roads, walkways and other civil engineering structures. The constituents of concrete are cement, coarse aggregate, fine aggregate and water. Efforts were made in this work to evaluate the suitability of crumb rubber as a partial substitute of sand in concrete mixes. This research evaluated the effects of partial substitution of sand with crumb rubber on the mechanical properties and microstructural formation of modified crumb rubber concrete. The control concrete sample and concrete samples with 1, 2, 3 and 4% sand content in the concrete substituted with crumb rubber were cured for 3, 7, 28, 90 and 120 days, respectively, and then tested. The laboratory experiments conducted on the concrete samples were workability, bulk density, compressive strength, tensile splitting strength, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Improvement in the strength and densification of the microstructure of the concrete samples occurred as the curing age increased from 3 to 7, 28, 90 and 120 days, respectively. This research further showed that marginal improvement in both the strength properties and microstructural formation of the modified crumb rubber concrete can be achieved by substituting 1% sand with crumb rubber.

1. INTRODUCTION

Waste materials, such as crumb rubber, are yet to be fully utilized for concrete works, other construction purposes or industrial applications, especially in many African countries [1]. Adequate evaluation of the crumb rubber (granulated form of waste rubber tyres) is required before it (crumb rubber) can be recommended as a material to partially replace sand in concrete [2-4].

Owing to its wide usage across the world, about 12 billion tonnes of concrete is consumed globally, on an annual basis. The rise in temperature of the earth is called global warming. Carbon dioxide (CO_2) is one of the greenhouse gases and its huge quantities is emitted in the production of cement and concrete. This leads to degradation of the ozone layer of the earth and causes global warming. It thus calls for concern to arrest the situation [2, 3].

Energy used up in the construction industry is about 30% of the total energy consumed from all human activities. Hence, it looks promising to utilize other less thermal conductive materials for construction to achieve efficient operational energy in the production of concrete [3]. The mechanical properties and microstructural formation of fine and coarse aggregates are extremely important features to achieve thermal insulation of concrete; hence, utilization of air entrainments and thermal non-conductive aggregates can enhance concrete's thermal resistance [3].

Human activities have been on the increase because the global population is constantly increasing [5] and this has resulted in astronomical increment in the volume of waste generated from activities of man. As a result, the total number of vehicles has also increased globally [6, 7]. The astronomic increase in the number of vehicles used worldwide gave rise to an increase in the quantities of waste rubber tyres used and dumped in the environment [8, 9].

It is important to ensure that the waste tyres are efficiently disposed at incinerators, landfills and other means of disposing the waste tyres have proved inefficient, owing to the non-degradable nature of the waste tyre rubber [10, 11]. Disposal of waste tyres on landfills has also led to provision of houses for pests, reptiles and rodents. These insects and reptiles are venomous, they attack human beings and domestic pets, destroy the environment and are deadly to human and destroy ecological balance in the environment [12, 13].

Crumb rubber is produced from waste tyre rubbers. The metal strings in the waste rubbers are removed and the waste rubbers are torn and ground into desired grain sizes [14-17]. Recent advances have ventured on the evaluation of crumb rubber to determine its suitability as a replacement for fine and coarse aggregates for concrete production. Literature has also shown that replacement of sand with crumb rubber reduces the strength properties of concrete [18-21].

This research was an experimental study conducted the applicability of waste crumb rubber as a partial replacement for sand in concrete. This work investigated the effects and suitability of partially substituting sand with crumb on the mechanical properties and microstructural formation of modified crumb rubber concrete.

2. MATERIALS AND METHODS

The materials used and methods adopted for the evaluation of strength properties and microstructural formation of the control concrete sample and the modified crumb rubber concrete samples (1, 2, 3 and 4% sand substituted with crumb rubber) are discussed in this section.

2.1 Materials

Cement, sand, granite, crumb rubber and water were the materials used for concrete production. The materials are discussed as follows:

2.1.1 Cement

Sephaku 32 CEM IV/B (V) 32.5N conforming to ref. [22] and having specific gravity (SG) of 2.48 was used for the study. Cement sample is presented in Figure 1a.

2.1.2 Sand

River sand having maximum size of 4.75 mm was used for the study. Sand sample is presented in Figure 1b.

2.1.3 Granite

Granite sample having maximum size of 19 mm was used for the study. Granite sample is presented in Figure 1c. Aggregates used were donated by Raumix Aggregates, Centurion, Pretoria, South Africa.

2.1.4 Crumb rubber

Crumb rubber having specific gravity (SG) of 1.14, donated by TOSAS recycling plant, Gemiston, Gauteng Province, South Africa was used for the study. Crumb rubber sample is presented in Figure 1d.

2.1.5 Water

Potable water obtained from the Civil Engineering laboratory of Tshwane University of Technology, Pretoria, South Africa was used for the study. Water sample is presented in Figure 1e.

Figure 1. Samples of (a) cement, (b) sand, (c) granite, (d) crumb; and (e) water used for concrete

2.2 Methods

Experimental investigations were carried out to evaluate the mechanical properties and microstructural formation of the control sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber. The laboratory tests conducted were slump, bulk density, compressive strength, tensile splitting strength, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

2.2.1 Slump

The workability of fresh concrete was determined by obtaining the reduction or subsidence in the height of concrete with the aid of slump test. Concrete cylinders having top diameter of 100 mm, base diameter of 300 mm and height of 200 mm in line with specification [23] were used.

2.2.2 Bulk density

The bulk density of hardened concrete was carried out by weighing 150 x 150 x 150 mm concrete cubes at different curing ages with the aid of electronic weighing balance in conformity to specification [24].

2.2.3 Compressive strength

The compressive strength of hardened concrete was carried out to determine the maximum load required to crush 150 x 150 x 150 mm concrete cubes with the aid of compression testing machine in conformity to specification [25].

2.2.4 Tensile splitting strength

The tensile splitting strength of hardened concrete was carried out to determine the indirect tensile load required to crush concrete cylinders having diameter of 150 mm and height of 300 mm in conformity to specification [26].

2.2.5 Scanning electron microscopy

The microstructural formation of the control sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber was determined using the scanning electron microscope (SEM). About 15 mm long and 5 mm thick specimen was cut from the central portion of the concrete cubes for the SEM analysis.

2.2.6 Energy dispersive spectroscopy

The elemental composition of the control sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber was determined using the energy dispersive spectroscope (EDS). The collection of sample was similar to that of SEM.

2.3 Concrete mix design and preparation

2.3.1 Mix design

Control concrete sample and concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber are represented with samples B_0, B_1, B_2, B_3 and B_4 respectively. The mix proportion for 25 MPa concrete samples prepared in line with specifications [27, 28] is presented in Table 1.

2.3.2 Concrete preparation

Different concrete samples (B_0, B_1, B_2, B_3 and B_4) used for the study were prepared with the electronic concrete mixer in conformity to specifications [27]. Loss of concrete portion (part) was prevented during mixing. Homogeneity of the different concrete mixes was carefully maintained. Testing of the different concrete cubes for compressive strength and cylinders for tensile splitting strength was done at curing ages of 3, 7, 28, 90 and 120 days, respectively.

Table 1. Mix proportioning for the partial substitution of sand with crumb rubber in concrete

Materials	Proportions of Crumb rubber Substituted				
	Control	1% crumb rubber	2% crumb rubber	3% crumb rubber	4% crumb rubber
Cement (gm)	4410	4410	4410	4410	4410
Sand (gm)	7973	7893.3	7813.5	7733.8	7654.1
Granite (gm)	12201	12201	12201	12201	12201
Water (ml)	2416	2416	2416	2416	2416
Crumb rubber (gm)	0	79.7	159.5	239.2	318.9

3. RESULTS AND DISCUSSION

This section elaborates on the results of the experimental setup presented in section 2.

3.1 Influence of partial replacement of sand with crumb rubber on the slump of concrete

The results of the slump test for the control sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber was 45, 40, 35, 30 and 30 mm respectively, as presented in Figure 2. There was reduction in the slump value of the concrete sample upon substitution of 1, 2 and 3% sand with crumb rubber but the slump values remained 30 mm with the substitution of 4% sand with crumb rubber. Crumb rubber drew water from the concrete because it had affinity for water. Though substitution of sand with crumb rubber caused decrease in the concrete slump, however, the concrete samples remained workable. The modified crumb rubber concrete had slump values, between 30 and 40 mm, which complied with recommendation for concrete which has stone sample with maximum size of 19 mm and was vibrated moderately to range from 25 to 100 mm by literature [28]. The results obtained compares favourably with that obtained by Batayneh [18] which show that increase in the quantity of sand substituted with crumb rubber in the concrete mixes from the 0% (control sample) to 20, 40, 60, 80 and 100% reduced the slump from 75 to 61, 36, 18 10 and 5 mm, respectively. Nevertheless, the workability or slump of the modified crumb rubber concrete mixes was not affected or compromised.

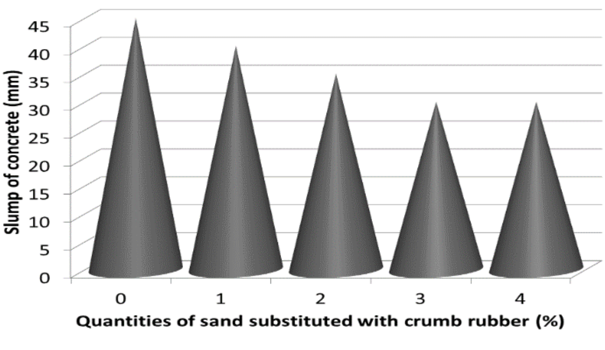

Figure 2. Slump of concrete samples with sand substituted with crumb rubber

3.2 Influence of partial replacement of sand with crumb rubber on the bulk density of concrete

The results of the bulk densities of the control concrete sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber is presented in Figure 3. The control concrete sample and 1% sand substituted with crumb rubber had the same bulk density value (2320 kg/m^3) at 3 and 7 days curing. Concrete sample with 2% sand substituted with crumb rubber had bulk density value of 2310 kg/m^3 when cured for 3 and 7 days. Concrete samples with 3 and 4% sand substituted with crumb rubber had the same bulk density value (2300 kg/m^3) at 3 and 7 days curing. It can be observed that slight reduction occurred in the bulk density of the concrete samples at 3 and 7 days curing with increase in the quantity of sand substituted with crumb rubber. The values of the bulk densities of the control concrete sample and concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber at 28 days curing were 2330, 2320, 2310, 2300 and 2300 kg/m^3 respectively.

The control concrete sample had bulk density of 2330 and 2340 kg/m^3 at 90 and 120 days curing respectively. However, concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber had bulk densities of 2330, 2320, 2310 and 2310 respectively at both 90 and 120 days curing. There was minimal reduction in the values of the bulk density of the different modified crumb rubber concrete samples as the crumb rubber content increased. Finally, the bulk density results obtained in this study for the control concrete sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber were within specified limits, as all the results ranged between 2300 and 2340 kg/m^3 which fell within the specified range of between 2001 and 2600 kg/m^3 specified by EN 12390-7 [24].

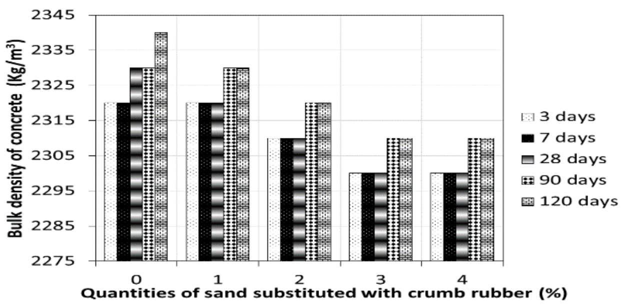

Figure 3. Bulk density of concrete samples with sand partially substituted with crumb rubber

3.3 Influence of partial replacement of sand with crumb rubber on the compressive strength of concrete

Results of the compressive strength of the control concrete sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber is presented in Figure 4. The values of the compressive strength of sample B_0 was 16.0, 18.5, 27.0, 36.5 and 37.5 MPa while those of sample B_1 were 18.5, 21.0, 28.5, 41.0 and 42.5 MPa at 3, 7, 28, 90 and 120 days of curing, respectively. The compressive strength of the concrete improved from the control concrete sample to the concrete sample with 1% sand substituted with crumb rubber. Conversely, the compressive strength of the concrete samples reduced progressively from samples B_1 to B_2, from sample B_2 to B_3 and from sample B_3 to B_4. The values of the compressive strength of concrete samples with 2% sand substituted with crumb rubber (sample B_2) was 16.0, 19.0, 25.0, 37.0 and 39.0 MPa, the compressive strength of concrete samples with 3% sand substituted with crumb rubber (sample B_3) was 14.0, 18.5, 23.0, 35.0 and 36.5 MPa; and the compressive strength of the concrete samples with 4% sand substituted with crumb rubber (sample B_4) was 12.0, 18.0, 21.5, 32.0 and 34.5 at 3, 7, 28, 90 and 120 days curing, respectively.

At 28 days curing, the compressive strength of the concrete samples showed 5.6% improvement (from sample B_0 to B_1) with the substitution of 1% sand with crumb rubber, 7.4% reduction (from sample B_1 to B_2) with the 2% substitution of sand with crumb rubber, 14.8% reduction (from sample B_2 to B_3) with the substitution of 3% sand with crumb rubber and 20.4% reduction (from sample B_3 to B_4) with the substitution of 4% sand with crumb rubber. The distinction between this work and related literature is the improvement in the compressive strength between the control concrete sample and the sample with substitution of 1% sand substituted with crumb rubber. This development shows that crumb rubber can be used as a supplementary construction material in place of sand to improve the compressive strength of concrete. This advance differentiates this work from existing literature [19, 21, 29] which showed drastic reduction in the compressive strength of concrete with the increase in quantity of sand replaced with crumb rubber. This distinction or contrast can be attributed to the quantities of sand substituted with crumb rubber. The existing literature used variation of 5% while this work utilized variation of 1%. The very small proportion examined in previous work was not considered [19, 21, 29] in the existing literature.

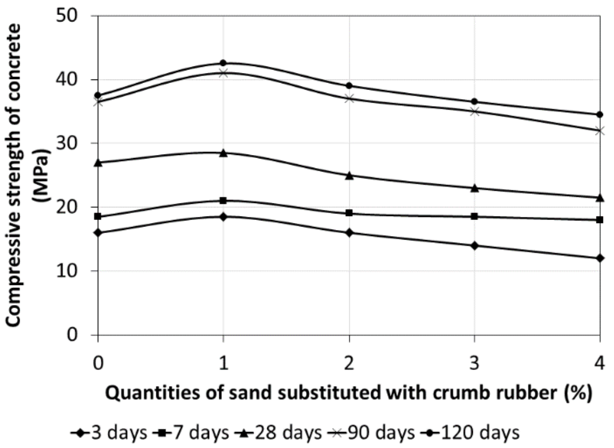

Figure 4. Compressive strength of concrete with sand partially substituted with crumb rubber

Furthermore, this study established that the modified crumb rubber concrete possessed substantial early strength at 3 days of curing, which could be attributed to fly ash composition of the Sephaku 32.5 cement used. However, there was slight improvement in the strength of concrete from 3 to 7 days curing. Great improvement in the compressive strength of the modified crumb rubber concrete was also obtained between 7 and 28 days curing and from 28 to 90 days curing. There was however a slight and unnoticeable improvement in the compressive strength of the concrete between 90 and 120 days, which is suggestive of nearing the peak of the compressive strength of the concrete at 120 days curing. Conclusively, there was improvement in all the concrete samples as the age of curing increased as suggested by literature [30]. However, Adeboje et al. [31] gave a prelude to the increment or improvement in the compressive strength of concrete with the joint substitution of 0.5% cement with bentonite clay and 0.5% sand with crumb rubber.

3.4 Influence of partial replacement of sand with crumb rubber on the tensile splitting strength of concrete

The result of the tensile splitting strength of the control concrete sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber is presented in Figure 5. The control concrete sample (sample B_0) had tensile splitting strength of 1.60, 1.90, 2.65, 3.70 and 3.75 MPa at 3, 7, 28, 90 and 120 days curing. Sample B_1 (1% sand substituted with crumb rubber) had tensile splitting strength of 1.85, 2.10, 2.80, 4.15 and 4.30 MPa while sample B_2 had tensile splitting strength of 1.55, 1.90, 2.50, 3.65 and 3.90 MPa at 3, 7, 28, 90 and 120 days of curing respectively. Sample B_3 (3% sand substituted with crumb rubber) had tensile splitting strength of 1.35, 1.85, 2.35, 3.50 and 3.65 MPa while sample B_4 (4% sand substituted with crumb rubber) had tensile splitting strength of 1.20, 1.85, 2.20, 3.20 and 3.45 MPa at 3, 7, 28, 90 and 120 days of curing respectively.

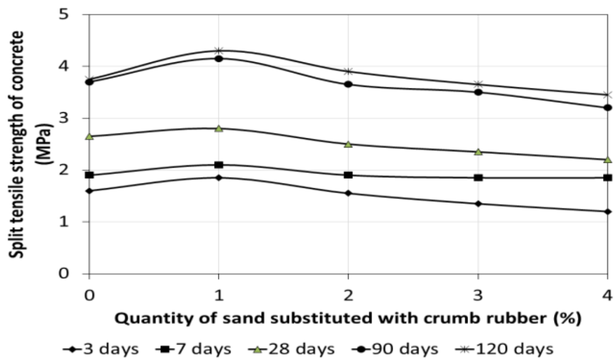

Figure 5. Tensile splitting strength of concrete with sand partially substituted with crumb rubber

The tensile splitting strength result at 28 days curing shows 5.7% improvement (from sample B_0 to B_1) with the substitution of 1% sand with crumb rubber, 5.7% reduction (from sample B_1 to B_2) with the substitution of 2% sand with crumb rubber, 11.3% reduction (from B_2 to B_3) with the substitution of 3% sand with crumb rubber and 17% reduction (from B_3 to B_4) with the substitution of 4% sand with crumb rubber. Similar to the compressive strength result, the tensile splitting strength of the concrete improved with substitution of 1% sand with crumb rubber. The tensile splitting strength however reduce with further substitution of 2, 3 and 4% sand with crumb rubber at curing ages 3, 7, 28, 90 and 120 days respectively. This work contrasts the result reported in by El-Gammal et al. [19], Aravind et al. [21], Akinyele et al. [29], which showed drastic reduction in the tensile strength of concrete without any evidence of achieving improvement in the strength properties of concrete. However, improvement in the tensile splitting strength of concrete with the joint substitution of 0.5% cement with bentonite clay and 0.5% sand with crumb rubber was recently documented by Adeboje et al. [31].

3.5 Influence of partial replacement of sand with crumb rubber on the microstructure of concrete

The morphology of the control concrete sample and the concrete samples with 1, 2, 3 and 4% sand substituted with crumb rubber (samples B_0, B_1, B_2, B_3 and B_4) is presented in Figure 6a, b, c, d and e, respectively. The denser or closely-packed the microstructure of the concrete sample, the more improved the mechanical properties and the strength properties of the concrete. Sample B_0 (Figure 6a) looks dense but pores are visible on its micrograph which indicates that the voids need to be filled to attain a perfect and dense microstructure. Sample B_1 (Figure 6b) indicates a more compact and closely-packed microstructure compared to sample B_0 (Figure 6a) which conformed to the improved strength discussed in sections 3.3 and 3.4. Conversely, the microstructural formation of the other concrete samples (B_2, B_3 and B_4) became looser, less compact, less dense and weaker from sample B_2 (Figure 6c) to B_3 (Figure 6d) and from sample B_3 (Figure 6d) to B_4 Figure 6e).

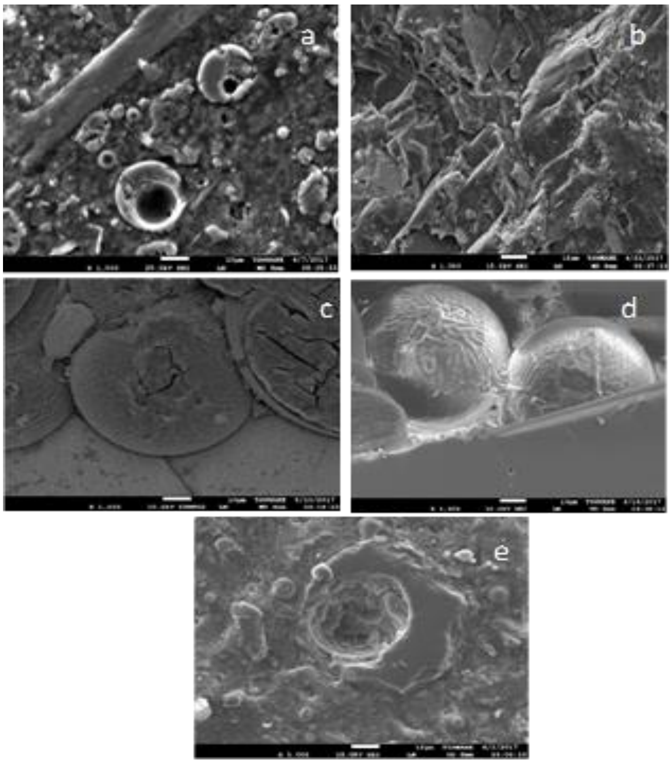

Figure 6. SEM micrographs for the Partial Substitution of sand with crumb rubber by (a) 0%, (b) 1%, (c) 2%, (d) 3%; and (e) 4% in concrete at 28 days

Therefore, the concrete sample became loose, less dense, less compact and that made the strength properties lesser and the concrete samples become weaker from sample B_2 to B_3 and from sample B_3 to B_4. Hence, the microstructural formation of concrete samples has direct impact on the strength parameters and mechanical properties of the modified crumb rubber concrete. This study suggests that substitution of sand with crumb rubber to achieve improved strength and microstructure should be limited to and not exceeding 1%. This is because further substitution of sand with crumb rubber can lead to appearance of (or clustering of) crumb rubber around cement particles which can weaken the bond between cement and water, thus slowing down cement hydration and also mitigate against firm bonding between aggregates and cement paste. This phenomenon is similar to the situation where crumb rubber created voids in concrete which led to reduction in the strength of rubberized concrete [19, 29].

3.6 Influence of partial replacement of sand with crumb rubber on the composition of concrete

The EDS experiment gave the elemental composition for the control concrete sample and the concrete samples of 1, 2, 3 and 4% sand substituted with crumb rubber as presented in Table 2. Cement is the material which enhances hydration and strength development in concrete and also binds aggregates [32]. The major components of cement are oxides of calcium (CaO), silicon (SiO2), aluminium (Al_2O_3) and iron (Fe_2O_3) [32].

Oxygen plays important part in the microstructure of compounds [33] and strength improvement in concrete [34] which has abundant oxygen content. Similarly, compactness of the microstructure and strength improvement are also dependent on the abundance of oxygen in the concrete sample [33, 34]. This work shows that concrete sample with 1% sand substituted with crumb rubber (sample B_1) possessed the highest oxygen content (31.45%) and also possessed high iron content (48.62 %) by weight. The abundance of both oxygen and iron enhanced improved strength improvement and the densest microstructure of the concrete sample (sample B1).

The amount of oxygen in the concrete samples after sample B_1 is as follows: control concrete sample (sample B_0), samples with 2% (sample B_2), 3% (sample B_3) and 4% sand (sample B_4) replaced with crumb rubber which yielded 30.71, 29.49, 25.31 and 23.97% oxygen contents respectively. Furthermore, crumb rubber has huge carbon content which reduces the strength and weakens the microstructure of concrete. The increment in the carbon content of concrete from 39.97 to 64.00 and 73.95% for the control sample (sample B_0) to the concrete samples with 2% (sample B_2) and 3% sand (sample B_3) replaced with crumb rubber, is suggestive of the rate of reduction in the strength and weakness in the microstructure of the concrete samples.

Materials with huge carbon content, such as crumb rubber, are chemically unreactive in the presence of heat or high temperature [35]. This can be responsible for the lack of compactness of carbon based materials, such as crumb rubber with loose or weak microstructure and reduced strength, when used in concrete [36, 37]. The reduction in the strength and loose microstructure, especially when more than 1% sand is substituted with crumb rubber is established and becomes the emphasis of this work. This is comparable with literature [38], where enhancement of the microstructural and mechanical properties of 30 MPa concrete were achieved with the substitution of small proportion of sand with crumb rubber; and also corroborates [31] that 0.5% cement and 0.5% sand can jointly be replaced with bentonite clay and crumb rubber in modified bentonite clay-crumb rubber concrete.

Table 2. Elemental composition of concrete with sand partially substituted with crumb rubber by EDS

Elements	Sample B_0		Sample B_1		Sample B_2		Sample B_3		Sample B_4	
	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %
C	39.97	54.70	-	-	64.00	72.22	73.95	79.29	4.00	8.77
O	30.71	31.55	31.45	57.84	29.49	24.99	25.31	20.37	23.97	39.40
Mg	0.35	0.24	-	-	-	-	-	-	-	-
Al	1.20	0.73	-	-	0.54	0.27	-	-	3.74	3.65
Si	6.11	3.57	-	-	0.96	0.46	0.75	0.34	11.83	11.07
P	2.28	1.21	-	-	3.65	1.60	-	-	-	-
Ca	17.71	7.26	-	-	1.36	0.46	-	-	52.79	34.64
Fe	-	-	48.62	25.62	-	-	-	-	-	-
K	0.70	0.29	-	-	-	-	-	-	3.67	2.47
Cl	0.97	0.45	19.93	16.54	-	-	-	-	-	-

4. CONCLUSIONS

The microstructural and mechanical properties of modified crumb rubber concrete have been investigated. The conclusions are as follow:

(1) The slump of the control concrete sample was 45 mm while those of samples with 1, 2, 3 and 4% sand substituted with crumb rubber ranged between 40 and 30 mm. The use of crumb rubber did not affect the workability of concrete.

(2) The bulk density of the control and modified crumb rubber concrete samples ranged between 2300 and 2340 kg/m3 and can all be classified as normal weight concrete.

(3) Substitution of 1% sand with crumb rubber is the optimal proportion that can produce improved modified crumb rubber concrete.

(4) Substitution of 1% sand with crumb rubber is the optimal proportion that can produce the densest microstructure and improved strength of modified crumb rubber concrete.

(5) Substitution of 1% sand with crumb rubber can give mechanically improved and microstructurally enhanced modified crumb rubber concrete.

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