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CHARACTERIZATION OF TYRE RUBBER ASH AND CRUMB AS FINE AGGREGATE RESOURCE

SHAHIRON SHAHIDAN[1,*], SAJJAD ALI MANGI[2],
MOHAMAD SYAMIR SENIN[3], SHARIFAH SALWA MOHD ZUKI[1],
MOHD HAZIMAN WAN IBRAHIM[1]

[1]Jamilus Research Center, Faculty of Civil Engineering and Built Environmental,
Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Johor, Malaysia
[2]Department of Civil Engineering, Mehran University of Engineering and Technology,
SZAB Campus Khairpur Mir's, Pakistan
[3]Construction Safety Division, Department of Occupational Safety and Health Malaysia
*Corresponding Author: shahiron@uthm.edu.my

Abstract

Concrete offers great opportunity to replace ingredients like natural sand with tyre rubber waste in the form of ash and crumb. It offers great environmental and technical benefits in terms of sustainable concrete production. This study investigated characterization-based compatibility of rubber ash and crumb as sand replacement in concrete. The physical, mineralogical, and chemical properties of rubber ash and crumb were determined such as bulk density, specific gravity, particle size distribution, morphology, element composition and compound composition and compared to that of river sand. However, it was observed that rubber crumb and rubber ash have 71% and 57% lower bulk density as compared to river sand, respectively. The specific gravity of rubber crumb and rubber ash is 46% and 18% lower compared to river sand, respectively. Further. it was also noticed that the rubber ash had finest particle size, rougher surface and its shape was rounder and smooth. Particle size distribution of rubber crumb was intermediate. Its shape was irregular and had a smooth surface. For the chemical properties, rubber crumb and rubber ash were rich with carbon while river sand was rich with silicon. It was concluded that replacement of rubber crumb and rubber ash up to 9% is suitable to be use in cement concrete.

Keywords: Ash, Crumb, Rubber, Sand, Tyre, Waste.

1. Introduction

Concrete industry is one of the most environmentally demanding industries as its productions process involved in mining of natural aggregates, use of increasingly utilization of natural resources for the sustainable concrete production [1]. However, the majority of studies were focused on the efficiency of natural resource for the structural concrete, but very limited studies were reported on resources like fine aggregate conservation by introducing industrial by-products such as fly ash and coal bottom ash [2]. Little attention has been given to the utilization tyre waste for the development of suitable substitution material for concrete production. A report presented by The National Solid Waste Management Department under the Ministry of Housing and Local Government, Malaysia, indicated that around 0.3 million tons of scrap tyres were generated annually [3]. This value was estimated to increase at about 5% every year, in line with the percentage increment of vehicle usage. It can also be estimated that by 2025, the volume of scrap tyres generated is going to be approximately 0.4 million tons. This problem may vary according to the localised as other countries such as the United States which generates around 300 million tons of scrap tyres every year, about 40% of which are used as fuel for generating energy, 26% ground into crumb rubber, 13% discarded in landfills, and only about 5.5% used in civil engineering applications [4, 5]. It was observed that the extraordinary increase in the number of vehicles worldwide and the lack of improper handling of tyre waste, leading the both technical and economic problems associated to the disposal of waste tyres which can be considered a serious pollution problem [6-8]. The best way to dispose waste tyres is to reuse them [9, 10]. However, tire rubber ash (TRA) is classified as the ash that is obtained through incinerating bulk quantities of tire rubber chips in an oven at controlled temp. of 850 °C for 72 h. In practice the TRA may be obtained from incineration of tires to generate power [4-10]. Furthermore, rubber crumb is produced by reducing tires scrap down to scopes ranging from 3/8 inches to 40 mesh particles and removing 99% or more of the steel and fabric from the scrap tires [7-10].

Besides that, the rubber is one of the industrial wastes that attracts to the many researchers to explore further. For example, Pelisser et al. [11] mixed rubber into concrete mixture to produce concrete products with increased thermal insulation, soundproofing properties, and low density. The increase in waste tyre content in concrete mixture was found to lower the density of concrete to as low as 75% of normal concrete weight [12]. Nadal Gisbert et al. [13] found that adding rubber particles to concrete mixture can produce lighter concrete. Other than specific applications, concrete containing rubber particles has the characteristic of occluding a large amount of air inside, which improves its workability. Furthermore, the increased capacity to dissipate and absorb energy, its use in many applications, including the production of sound barriers. Rubber not only has high resistance to cracking; it can also enhance the overall impact strength of concrete [14].

There are three size ranges of recycled rubber tyre particles that have been used in literature to replace river sand in concrete. However, these size ranges referred by researchers in several different names. For example, according to the previous study recycled rubber with size 0.15 mm to 1.9 mm called as ground rubber used to replace either cement or fine aggregate, 0.075 mm to 4.75 mm named as crumb rubber used to substitute fine aggregate and 4.75 mm to 76 mm known as rubber chip alternative for coarse aggregate [15-20]. It was also observed from the previous research that there is great influence of particle size of supplement materials on the properties of concrete [21, 22]. Furthermore. Fattuhi and Clark [23] studied also on rubber crumb size less than 3 mm and 1-16 mm to replace fine aggregate and coarse aggregate, respectively. Khatib and Bayomy [24] stated that the rubber crumb and coarse tyre chips with size 0.3-2.5 mm and 10-50 mm to replace fine aggregate and coarse aggregate, respectively. Ganjian et al. [25] used fine chipped rubber and ground rubber with size 2-13 mm and 0.075-0.475 mm to replace coarse aggregate and cement, respectively. Aiello and Leuzzi [26] studied on rubber shreds with size 10-12.5 mm and 12.5-20 to replace coarse aggregate. Xue and Shinozuka [27] investigated on rubber crumb with size 6 mm to replace coarse aggregate. Al-Tayeb et al. [28] used fine rubber crumb with size 0.16-2.36 mm to replace fine aggregate. In 2016 Rezaifar et al. [29] studied on rubber crumb with size 1.01-1.32 mm to replace fine aggregate. Next in 2017, Mendis et al. [30] studied rubber crumb with size 0-0.6 mm, 1-3 mm and 2-4 mm to replace fine aggregate. Then in 2018, Sugapriya and Ramkrisnan [31] were studied on rubber crumb with size less than 4.75 mm to replace fine aggregate and Sugapriya et al. [32] studied on rubber crumb with size 12.75-20 mm to coarse aggregate.

Majorities of the earlier research replace either fine aggregate or coarse aggregate up to 20%. However, Xue and Shinozuka [27] found that 20% replacement ratio decrease in the compressive strength as high as 46.68% while Al-Tayeb et al. [28] discover 10% and 20% replacement ratio decrease 22% and 27% in ultimate compressive stress of the cement concrete but Rezaifar et al. [29] predicted that 3.3% sand replacement with rubber crumb and 19.5% cement replacement with metakaolin yielded the best results as the compressive strength was maximized and the water absorption was minimized. In order to avoid excessive loses beyond 20% in compressive strength of the cement concrete the replacement ratio should not more than 10%. The recommended replacement percentage would be 0-9%.

It was also noticed that the physical properties of sand vary with location of its source. Al-Akhras and Smadi [33], Al-Tayeb et al. [28], Ganjian et al. [25], Bisht and Ramana [34] and Khatib and Bayomy [24] used sand with specific gravity 2.63, 2.64, 2.65, 2.66 and 2.67 respectively, whilst Sugapriya and Ramkrishnan [31] and Sugrapiya et al. [32] used the higher specific gravity which is 2.80. However, river sand has specific gravity in the range of 2.56 to 2.70 [29, 35,36].

It was investigated that the rubber crumb, the specific gravity, and bulk density is depending on the location of its sources, tyre manufacture, tyre type and the size of the rubber crumb. The lowest specific gravity for rubber crumb was 0.54 found by Elchalakano [37]. While the highest specific gravity for the rubber crumb was 1.17 found by Noor [38]. However, Lv et al. [9] and Khaloo et al. [39] use the same specific gravity 1.16. There is some rubber crumb with several specific gravity used by Al-Tayeb et al. [28], Hernandez-Olivares and Barluenga [39], Bisht and Ramana [34], Aiello and Leuzzi [26], He et al. [35] that is 0.64, 0.84, 1.05, 1.09 and 1.10, respectively. For bulk density of rubber crumb Fattuhi and Clark [23] found that for rubber crumb size less than 3 mm and 1 mm to 16 mm is 390 kg/m^3 and 450 kg/m^3 respectively. However, Lv et al. [9, 40] and Benazzouk et al. [40] found the bulk density for rubber crumb is 365 kg/m^3 and 430 kg/m^3, respectively.

There are limited studies on rubber ash, only two researchers found which is Al-Akras and Smadi [33] and Gupta el al. [36], who found the specific gravity for rubber ash as 2.21 and 1.33, respectively. There is no bulk density established by both researchers. Consequently, it was concluded that the specific gravity and bulk density for rubber crumb, are depended on the location of its sources, tyre manufacture, tyre type and the size of the rubber crumb. For example, Aiello and Leuzzi [41] reported that the discrepancies in properties of the materials may be probably due to the origin as well as the type of the tyre namely car, lorry, or motorcycle tyres. Therefore, this study aims to evaluate the physical and mineralogical and chemical properties of tyre rubber ash and crumb as these characteristics predominantly affect the mechanical and durability properties of concrete.

2.Materials and Methodology

This study investigated three materials: tyre rubber ash, recycled tyre rubber crumb and river sand. The river sand was transported from Kampung Sungai Batu Badak River, Johor, Malaysia and then passed through sieve 5 mm. Moreover, characterization was evaluated based on bulk density, specific gravity, particle size distribution, scanning electronic scope with energy dispersive x-ray (EDX) and x-ray fluorescence (XRF) tests.

2.1. Recycle Tyre Rubber Ash

The recycle tyre rubber ash was collected from the recycled tyre factory located at Gopeng Perak, Malaysia. The size of rubber ash particles was ranged between 0.1 mm to 1.0 mm, produced by pyrolysis technique as shown in Fig. 1. Pyrolysis is a process of converting waste tyres into fuel oil at temperature higher than 400 ºC [42]. The waste tyres were shredded, and then burned in the pyrolysis furnace or incinerator. This process produced gas, fuel oil and rubber ash. The gas produced is known as hydrocarbon gas that would be directly feed back to the pyrolysis plant as fuel. The fuel oil will be used for either fuelling power generators for electricity or lubricants for machineries depending on the grade. The rubber ash is a by-product of the tyre recycling process and has low demands. It is normally thrown away, either in legal or illegal ways. Thus, the rubber ash produced from this process was used as raw material for this study.

Fig. 1. Pyrolysis process of waste tyre and its by-products (Recycled tyre factory located at Gopeng, Perak, Malaysia).

2.2. Rubber Crumb

The rubber crumb was collected from Recycle Tyre factory located at Bakri, Muar, Johor, Malaysia. The factory produces 3 different sizes of rubber crumb graded as 40 (0.425 mm), 20 (0.850 mm) and 16 (1.18 mm). Figure 2 illustrates the rubber crumb process, from the waste tyre been cut into chipped tyre using cutting machine then been shredded using ground machine then been sieve using sieve machine and separated between rubber crumb and steel wire. In this research, rubber crumb with size of 0.425 mm (sieve # 40) was used because rubber crumb 40 was the finest and have similar size to the rubber ash compare to others size. It is noteworthy that although the rubber tyre is separated from its metal component during the process, it is possible that remnant of metallic element can still be present in crumb rubber and ground rubber.

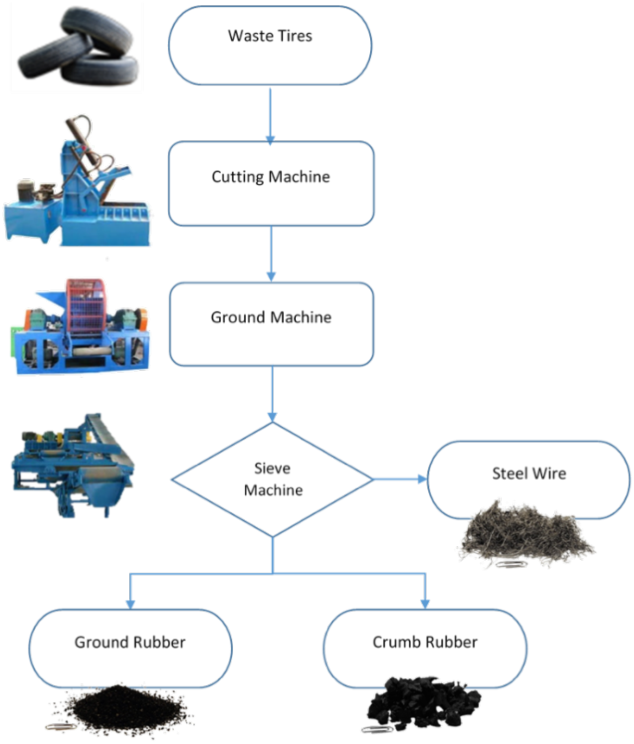


Fig. 2. Grounding process of waste tyre and its by-products (Recycled tyre factory located at Gopeng, Perak, Malaysia)

2.3. River Sand

The river sand was transported from Kampung Sungai Batu Badak River, Johor, Malaysia then it was passed through 5 mm sieve to use in this study.

2.4. Experimental setup

This study involves five different tests: namely bulk density, specific gravity, particle size distribution, scanning electron microscope with energy dispersive x-ray and x-ray fluorescence.

2.4.1. Bulk density

The bulk density test was conducted for three materials namely, river sand, rubber ash and rubber crumb according to the BS EN 1097-3 [43]. First rubber ash was dried in an oven for 24 hours at 110±5 °C. The empty, clean, and dry container was weighted and recorded as mass A. Then the rubber ash was fully filled in the container and weighted and recorded as mass B. Then the volume of the container was measured and indicated with volume A. The bulk density was calculated by formulae indicated in Eq. 1. This procedure was repeated for the natural sand and rubber crumb. The bulk density was taken as the average of the bulk densities of three specimens for each material.

$$Bulk\ density = \frac{(mass\ A - mass\ B)}{volume\ A} \quad (1)$$

where:
mass A = is the mass of dry material + container, in gr;
mass B = is the mass of empty container, in gr;
volume A = is the volume of the container, in mm^3.

2.4.2. Specific gravity

In this research, specific gravity test has been conducted for river sand, rubber ash and rubber crumb complied to BS EN 15326 [44]. First the empty pycnometer has been weighted (M1). Then the rubber ash was filled in the pycnometer (M2). After that distilled water was half filled in the pycnometer. Then the pycnometer was put in the vacuum desiccator and been vacuumed. After that the pycnometer was taken out from the vacuum desiccator and fully filled with the distilled water. Next the pycnometer was put in the vacuum desiccator and been vacuumed again. After vacuumed finished the pycnometer was taken out and been weighted (M3). Using the same pycnometer fully filled with only distilled water repeated the procedure to get the reference mass (M4). All the procedure has been repeated for river sand and rubber crumb. The specific gravity of the material has been calculated using formula Eq. 2.

$$Specific\ gravity = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} \quad (2)$$

where:
M1: mass of empty pycnometer, g
M2: mass of pycnometer with material, g
M3: mass of pycnometer with material and distilled water, g
M4: mass of pycnometer with distilled water, g

2.4.3. Particle size distribution

The sieve analysis for river sand, rubber ash and rubber crumb have been conducted in the laboratory according to BS EN 933-1 [45]. First the rubber ash was weighted, then all empty sieves was weighted. The sieves were placed from the bottom is small opening and larger opening on the top. Next the rubber ash was filled in the sieve and vibrated using a shaker. After that, all the sieves with retained rubber ash were weighted. This procedure was repeated for river sand, rubber crumb, river sand mixed with 9% rubber ash replacement and river sand mixed with 9% rubber crumb replacement.

2.4.4. Scanning Electron Microscopy

The scanning electron microscopy (SEM) with energy dispersive x-ray (EDX) was conducted on the natural sand, rubber ash and rubber crumb as shown in Fig. 3. Firstly, the materials were packed in the small plastic bag to bring to the laboratory. Next the materials were stick on the mounting using a tape. After that the materials were gold coated using fold splutter coater machine. Then the materials were placed in the chamber. The images of the materials were observed by using SEM-EDX instrument. This analytical technique is integrated SEM and EDX. However, SEM provides images and EDX provides element composition of the materials.

Fig. 3. Scanning electron microscopy test setup.

2.4.5. X-ray fluorescence

The x-ray fluorescence (XRF) was conducted for the natural sand, rubber ash and rubber crumb to examine the materials chemical composition. This test was performed in accordance with ASTM C114 [46]. Initially, rubber ash was sieved through 63 μm sieve. The rubber ash was mixed with wax at a proportion of 2:8 (wax to ash). After that the material was compacted to form a pallet by using compacting machine as shown in Fig. 4. The specimens were keeping in the vacuum desiccator. The XRF analyser was used to analyses the compound composition of the specimens.

Fig. 4. Hydraulic compacting machine.

3. Results and Discussion

3.1. Bulk density

The experimental results of bulk density of the rubber ash, rubber crumb and river sand are presented in Table 1. However, three tests were conducted for each sample and recorded as T1, T2 and T3. The average of the results was also calculated and presented in the average column. Rubber crumb has the lowest bulk density and 71% lower compared to river sand. While rubber ash is in the middle and is about 57% lower compared to river sand. According to Neville and Brooks [47] it is necessary to identify the bulk density of the materials which is the actual mass that would fill a container of unit volume and this density is used to convert quantity by volume to quantity by mass. Since there is a major different of the bulk density between river sand and both rubbers, therefore the suitable method of the sand replacement is by volume.

Table 1. Bulk density for the raw materials.

Material	Bulk Density (kg/m^3)			
	T1	**T2**	**T3**	**Average**
Rubber Ash	640.23	642.87	641.34	641.48
Rubber Crumb	435.78	430.15	431.84	432.59
River Sand	1507.47	1509.33	1507.63	1508.15

3.2. Specific gravity

The specific gravity of rubber ash, rubber crumb and river sand as provided in Table 2. There were three tests for each material represent as T1, T2 and T3. Average of the result considered as the result. The ranges of the results are like the bulk density whereby rubber crumb has the lowest specific gravity while rubber ash in the middle and the river sand had the highest specific gravity. The specific gravity of rubber crumb and rubber ash is 46% and 18% lower compared to river sand, respectively.

Table 2. Specific gravity for the raw materials.

Material	Specific Gravity			
	T1	**T2**	**T3**	**Average**
Rubber Ash	2.17	2.15	2.20	2.17
Rubber Crumb	1.43	1.39	1.44	1.42
River Sand	2.62	2.65	2.68	2.65

3.3. Particle size distribution

The particle size distribution of the rubber ash, river sand, and rubber crumb is illustrated in Fig. 5. While another two dotted line ASTM Min and Max represent the envelope of the minimum and maximum size of fine aggregate recommended by ASTM C33 [48]. According to the Superpave Mix Design Manual the nominal maximum aggregate size is one sieve size larger than the first to retain more than 10% of the aggregate [49]. Thus, the nominal maximum aggregate size for rubber ash, rubber crumb and river sand are 1.18 mm, 1.20 mm, and 2.36 mm, respectively. It was observed that rubber ash has the finer particle size while rubber crumb in the middle and river sand has the coarser particle size. For the individual particle size distribution of rubber ash and rubber crumb, it -does not meet the requirement as recommended by ASTM C33 [48] while river sand meet the requirement.

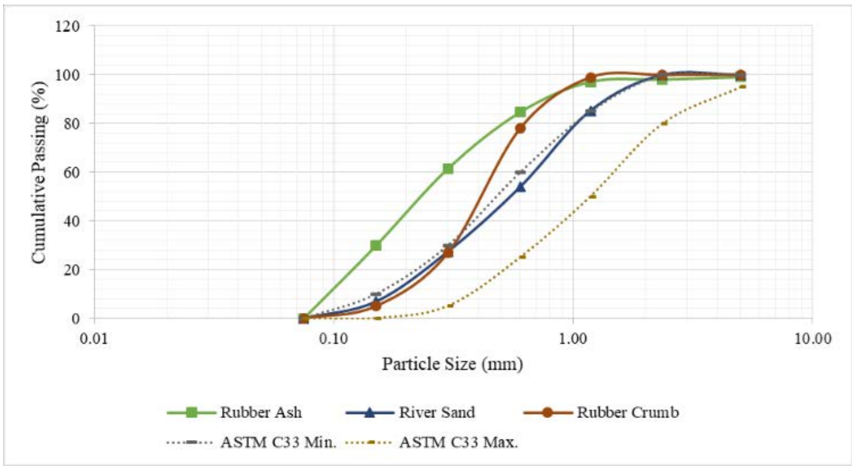


Fig. 5. Particle size distributions of rubber ash, river sand, and rubber crumb.

However, the use of rubber ash and rubber crumb is to partially replace river sand. The particle size distribution of the river sand mix with rubber ash and river sand mix with rubber crumb demonstrate in Fig. 6.

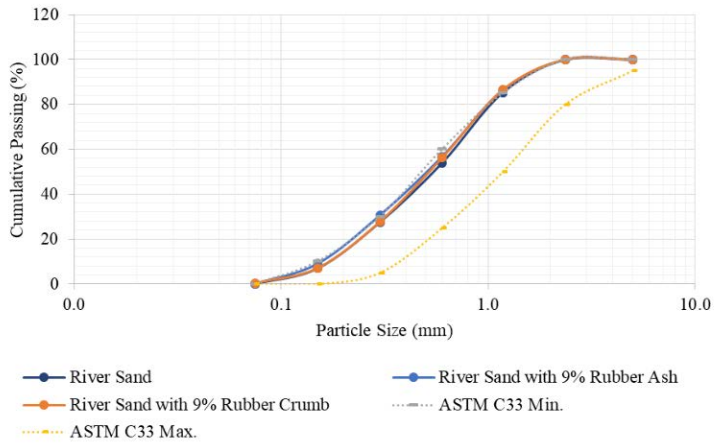


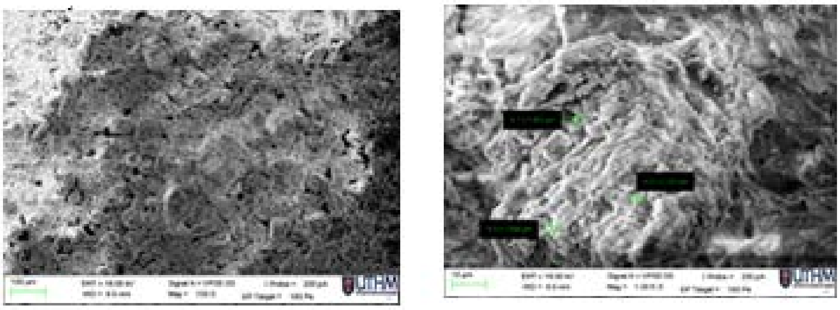
Fig. 6. Particle size distributions of river sand, river sand with 9% rubber ash and river sand with 9% rubber crumb.

Figure 6 presents the particle size distribution of the river sand, river sand mix with 9% replacement rubber ash and river sand mix with 9% replacement of rubber crumb. Two dotted line marked as minimum and maximum limits of the fine aggregate recommended by ASTM C33 [48] respectively. However, 9% replacement was selected because 9% is the maximum replacement used in this study. River sand mixed with 9% replacement of rubber ash and river sand mixed with 9% rubber crumb is in the envelope therefore both fine aggregate are meet the requirement recommended by

ASTM C33 [48]. Therefore, the replacement up to 9% sand replacement with rubber ash and rubber crumb suitable to be used for this study.

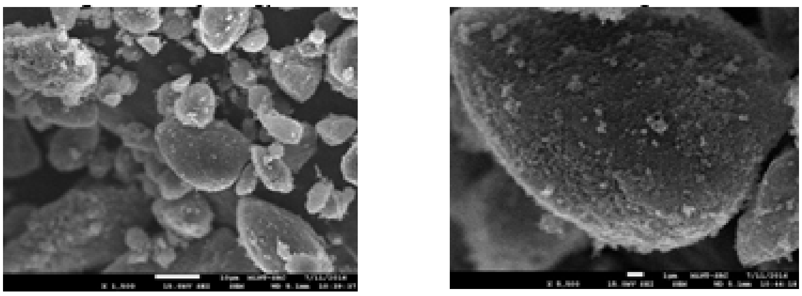
3.4. Morphology

The morphology of the river sand, rubber ash and rubber crumb were evaluated and analysis images are presented in Figs. 7(a) and (b), which illustrated the morphology of river sand at 100x and 1,000x magnifications respectively while Figs. 8(a) and (b) demonstrated the morphology of rubber ash at 1,500x and 5,500x magnification respectively and Figs. 9(a) and (b) reveal the morphological of rubber crumb at 100x and 1,000x magnification, respectively. River sand has irregular shape while rubber ash rounded shape, but rubber crumb has angular shape. Irregular aggregates may result 35% to 37% voids and these will give lesser workability when compared to rounded aggregate while rounded aggregate have 33% to 35% voids and gives more workability with less require amount of water-cement ratio but cannot considered for high strength concrete because of poor interlocking behaviour due to weak bond strength meanwhile angular aggregate have 38% to 41% voids, give less workability and give 10% to 20% more compressive strength due to development of stronger aggregate-mortar bond [50] however, the strength of the concrete also depended on the type of the aggregate not only the shape of the aggregate. Surface texture of river sand is high roughness while rubber ash is low roughness, but rubber crumb is polished. Surface texture is one of the factors that effecting workability and the strength of the cement concrete. The higher the roughness of the aggregate the stronger the cement concrete but the higher the roughness of the aggregate the lower the workability of the cement concrete.



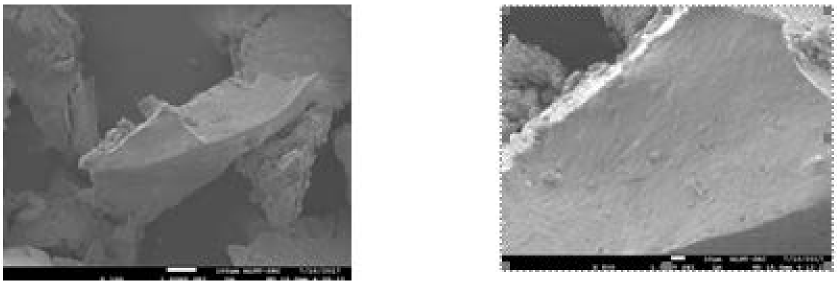
(a) (b)

Fig. 7. Morphology of river sand at (a) 100x and (b) 1,000x magnification.



(a) (b)

Fig. 8. Morphology of rubber ash at (a) 1,500x and (b) 5,500x magnification.



(a) (b)

Fig. 9. Morphology of rubber crumb at (a) 100x and (b) 500x magnification.

3.5. Chemical composition

The element composition for the river sand, rubber ash and rubber crumb as provided in Table 3. The EDS analysis technique only analyses single element for each specimen. For example, if the specimens containing silicon dioxide the result only report the silicon content and the oxygen content not the silicon dioxide content. Due to EDS analysis technique is done in vacuum condition there is no gas was present. The oxygen reported in Table 3 is not oxygen gas. Oxygen normally compounds with other element such as aluminium, silicon, carbon, and Sulphur in form of aluminium oxide, silicon dioxide, carbon dioxide, Sulphur trioxide, respectively. Therefore, oxygen is not considered for this analysis. River sand is highly content of silicon. Based in the periodic table of element, silicon is in metalloid group. Metalloid is an element with both metallic and non-metallic properties. However, rubber ash and rubber crumb have high carbon content compared to river sand. Carbon is in non-metal group in periodic table of element.

Table 3. Elements Composition for the raw materials

Elements Composition	River Sand (%)	Rubber Ash (%)	Rubber Crumb (%)
Carbon, C	0.73	54.87	50.30
Oxygen, O	50.89	18.34	16.76
Magnesium, Mg	-	-	0.06
Aluminium, Al	10.03	5.05	0.44
Silicon, Si	35.65	2.04	0.37
Sulphur, S	-	6.20	8.37
Chlorine, CI	0.09	0.19	-
Potassium, K	0.30	0.15	0.19
Calcium, Ca	0.32	0.67	0.24
Titanium, Ti	0.29	0.26	0.33
Iron, Fe	0.93	0.13	2.74
Cobalt, Co	0.20	0.33	-
Copper, Cu	0.56	1.37	1.00
Zinc, Zn	-	10.38	19.20

Furthermore, Table 4 presents the compound composition for river sand and rubber ash. However, XRF have their limitation which is it cannot analyses or detect light elements that listed in first two row and one element in third row of periodic table of the elements which is hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen fluorine, neon and sodium [51]. There is no result reported for rubber crumb because by referring to Table 3 rubber crumb is highly content with light element which is carbon. Rubber crumb are made from 25% rubber hydrocarbon and 35% carbon black makes the major components in rubber crumb is carbon [52]. The compound composition of river sand, silicon dioxide was the higher content which is 51% and followed by aluminium oxide which is 6.83% however the loss in ignition or light element content was 39.86% might be the carbon or oxygen content. For rubber ash the higher compound composition recorded was Sulphur trioxide is about 16.90% followed by zinc oxide 14.60% and silicon dioxide 12.70%. One of the factors is Sulphur trioxide (SO_3) that generates volumetric expansion in concrete. However, incorporation of 10% rubber ash in concrete increase the proportion of SO_3. Concrete having less than 5.16% SO3, its duration of effect was approximately 3-56 days. However, when SO3 content more than 5.16%, its duration can effect up to 91 days [53].

Table 4. Compounds composition for the raw materials

Compounds Composition	**River Sand (%)**	**Rubber Ash (%)**	**Class of Ash as per ASTM C618 [54]**		
			N	F	C
Silicon Dioxide, SiO_2	51.00	12.70	Min 70	Min 70.00	Min 50.00
Aluminium Oxide, Al_2O_3	6.83	0.51			
Ferric Oxide, Fe_2O_3	0.32	1.38			
Sulphur Trioxide, SO_3	-	16.90	Max 4	Max 5.00	Max 5.00
Zinc Oxide, ZnO	-	14.60	-	-	-
Calcium Oxide, CaO	0.48	3.54	-	-	-
Potassium Oxide, K_2O	0.40	0.36	-	-	-
Bromine, Br	-	0.34	-	-	-
Copper (II) Oxide, CuO	-	0.21	-	-	-
Chlorine, CI	-	0.19	-	-	-
Titanium Dioxide, TiO_2	0.58	-	-	-	-
Zirconium Dioxide, ZrO_2	0.43	-	-	-	-
Loss on Ignition	39.86	49.03	Max 10.00	Max 6.00	Max 6.00

Zinc oxide (ZnO) rises the setting time of cement. However, ZnO enhances the physical and mechanical properties of concrete [55]. Rubber ash has 25% SO2 compared to river sand. There are 49.03% loss in ignition or light element in rubber ash. It was observed that the rubber ash has 54.87% carbon. Nonetheless, the light element that invisible in the rubber ash result is carbon. In tyre manufacturing, carbon was used as reinforcing filler and light stabilizer in rubber compounds [56-58]. It was previously reported by Yilmaz and Degirmenci [59] that the composite materials containing 10% Portland cement, 20%-30% tire rubber particles and 70%-60% fly ash found to have sufficient strength for masonry applications. Therefore, this study suggested that the substitution of rubber ash and crumb as fine aggregate in concrete will produce high quality concrete.

4. Conclusions

Based on the experimental results, following conclusions have been made:

- The rubber crumb and rubber ash have 71% and 57% lower bulk density as compared to river sand, respectively.
- The specific gravity of rubber crumb and rubber ash is 46% and 18% lower compared to river sand, respectively. Therefore, the suitable method to replace sand is by volume not by weight. The replacement of the sand with rubber crumb and rubber ash can reduce the bulk density of the cement concrete.
- All three materials have different particle shape and surface texture. River sand has irregular shape while rubber ash rounded shape, but rubber crumb has angular shape. Surface texture of river sand is high roughness while rubber ash is low roughness, but rubber crumb is polished.
- The highest element composition for river sand is silicon, while rubber ash and rubber crumb are carbon. While the highest compound composition for river sand is silicon dioxide and rubber ash are Sulphur trioxide.
- Rubber ash has finest particle size distribution compared to rubber crumb and river sand while rubber crumb is intermediate between rubber ash and river sand. For individual particle size distribution rubber crumb and rubber ash.
- However, river sand mixed with 9% replacement rubber ash and river sand mixed with 9% replacement of rubber crumb is suitable to be use in concrete.

Moreover, this study suggested that rubber ash and rubber crumb can be utilized as sand replacement. The end-product termed as modified concrete produced through tyre rubber ash and rubber crumb can be used for the building construction. However, future studies can be carried out on these materials incorporated in concrete or mortar.

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Abbreviations

ASTM	American Society for Testing and Materials
BS	British Standard
EDX	Energy Dispersive X-ray
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscopy
XRF	X-ray Fluorescence

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