Analysis of Physical Properties and Mineralogical of Pyrolysis Tires Rubber Ash Compared Natural Sand in Concrete material

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Abstract. Waste tires pose significant health and environmental concerns if not recycled or discarded properly. At the same time, natural sand is becoming scarcer and costlier due to its non-availability. Waste tires as fine aggregate can be an economical and sustainable alternative to the natural sand. Recent years, the interest on recycling waste tires into civil engineering applications by the researchers has increased. In this research, the chemical and physical properties of the tires rubber ash and the natural sand have been analysed. The densities of the rubber ash are lower than the natural sand. Rubber ash had finer particle size compared to the natural sand. Almost all chemical in the natural sand had in rubber ash, with the additional sulphur trioxide and zinc oxide in the rubber ash, made the rubber ash better than natural sand. Rubber ash seems to be a suitable material to use in concrete as sand replacement.

1. Introduction
Road authorities manage a large population of ageing bridges, a substantial number that fail to meet the current requirement either due to deterioration and due to other structural deficiencies or as result of the escalating demands imposed by increased traffic intensity and higher axle loads. As a result, the maintenance, upgrading and replacement of existing bridges have become a very challenging task for the construction industry. Existing concrete is a brittle material with low cracking resistant. Therefore, new technology of concrete ought to develop in order to replace the existing concrete.

Portland cement concrete is one of the most versatile construction materials on earth and has facilitated industrial growth in the last century, it also one if the biggest in term of environmental impact [1][2]. Between the production of cement, mining of natural aggregate, use of increasingly scare fresh water resources and development of new chemical admixture, the concrete industry is consistently one of the most environmentally demanding industries [3-5]. Most of the research today and the current state-of-practice pertaining to resource productivity in structural concrete is limited to cement or natural aggregate conservation through the partial replacement of cement or natural aggregate with industrial waste-product (e.g., fly ash, granulated blast slag, coal bottom ash, recycle aggregate, recycle rubber and etc.) [6-9]. Engineer need to find suitable materials that have resistance to impact or blast or vibration or damping such as rubber material. The economical and sustainable way to get rubber is from recycle tires. The car or passenger tire consist of 41-48% rubber, 22-28% carbon black, 13-16% metal, 4-6% textile and 10-12% additives as shown in Table 1.

Table 1
Table 1. Material composition in tire manufacturing

| Type of tire  | Car/passenger | Truck   |
|--------------|---------------|---------|
| Rubber/elastomer | 41-48         | 41-45   |
| Carbon Black  | 22-28         | 20-28   |
| Metal/steel   | 13-16         | 20-27   |
| Textile       | 4-6           | 0-10    |
| Additives     | 10-12         | 7-10    |

The United State generates approximately 300 million scrap tires annually [10]. The rate of scrap tires generation is expected to continue growing as the world population and vehicle usage increases [11]. There were still 128 million tires remain stockpiled throughout the United State [12]. Figure 1 shows the 9 million tyres stockpiled at the Stawell, Australia. The site is believed to receive as many as 5000 tyres per week but has the capacity to process only about 2000. Stockpiling is dangerous, not only due to potential negative environment impact, but also because it present a fire hazard and provides a breeding for rats, mice, vermin, and mosquitoes [13]. Figure 2 shows plumes of smoke from the massive fire at a recycling plant in Sherburn, North Yorkshire captured from space by a NASA satellite. Accumulations of discarded waste tires have been a major concern because the waste tires are not easily biodegradable even after a long period landfill treatment. However, the waste tire postulate to become an alternative material and energy [14]. The new technologies that have been introduced to recycle waste tires is by pyrolysis.

Figure 1. 9 million tyre stockpiled in Stawell, Australia. (The Sydney Morning Herald)
2. Waste Tyre Pyrolysis

Pyrolysis Plan (shown in Figure 3) is the one of the tyre-refining device decomposes waste tires through high temperature process into kinds of useful resources, such as fuel oil, carbon black, steel wires and fuel gas. Figure 4 illustrate the percentage of the useful resources produced through the pyrolysis process. Pyrolysis is referred as a reverse polymerisation thermal depolymerisation of polymer cracking. From the recycling point of view, the main advantage of the process is that it can deal with waste, which are otherwise difficult to recycle and consequently, can create reusable product. The pyrolysis plant designed based on the green technology to achieving the environmentally friendly process, which is the excellent waste tire management solution for tyre recycling [14].

The resources such as fuel gas, fuel oil and steel have higher demand. The tyre rubber ash also known as carbon black has low demand. Therefore, this research mainly focuses in maximising the utilisation of the rubber ash in concrete for building construction. In this research, the tyre rubber ash has been analysed and compared to the natural sand.

Figure 2. Stockpiled tyres on fire in Sherburn, North Yorkshire, UK. (Express UK)

Figure 3. Pyrolysis Plan
3. Experimental Work

3.1. Raw Material
In this research only two raw materials were used which are rubber ash and natural sand.

3.1.1. Rubber Ash. The rubber ash were collected from the pyrolysis plant located at Gopeng, Perak. Figure 5 shows the picture of the rubber ash.

![Figure 5. Rubber Ash](image)

3.1.2. Natural Sand. The natural sand was bought from the Hardware located at Parit Raja, Johor. As presented in Figure 6.
3.2. Result and Discussion

3.2.1. Material Properties. The bulk density and specific gravity had been carried out followed to the ASTM C29 and ASTM C128 respectively[15][16]. Table 1 shows the different physical properties between sand and rubber ash in term of colour, density and specific density.

Table 2. Material Properties

| Material            | Rubber Ash | Natural Sand |
|---------------------|------------|--------------|
| Bulk Density (Kg/M³)| 641.48     | 1508.15      |
| Specific Gravity    | 2.17       | 2.65         |
| Colour              | Black      | Light Brown  |

Table 2 shows the bulk density of rubber ash and natural sand was 641.48 Kg/m³ and 1508.15 Kg/m³ respectively. The specific gravity of the rubber ash was 2.17 and natural sand was 2.65. Rubber ash has lower bulk density and specific gravity compared to the natural sand. The material with low density if apply in concrete, it will reduce the density of the concrete. Therefore, lightweight concrete can be produce. The colour of the rubber ash was black in colour while the natural sand is light brown in colour. The black colour of the rubber ash may change the colour of the concrete to be a bit dark not as usual.

3.2.2. Particle Size Distribution. In this research sieve analysis has been conducted according to the ASTM C33 [17]. Figure 7 shows the different particle size distribution between rubber ash and natural sand.
From the Figure 7, rubber ash had finer particle than natural sand. The finer particle is good for concrete because the finer particle will fill the entire gap or void in the concrete. Therefore, rubber ash suitable to be a filler material for concrete and the concrete made of rubber ash will improve the quality of the concrete in term of strength.

3.2.3. **Scanning Electron Microscopy.** The scanning electron microscopy (SEM) had been conducted using an electron microscope. Figure 7, 8 and 9 shows the comparison image come from the microscope between rubber ash and natural sand at 100x, 500x and 1000x magnificent respectively.

![Figure 8. Rubber ash and natural sand at 100x magnification](image)
Figure 9. Rubber ash and natural sand at 500x magnification

Figure 10. Rubber ash and natural sand at 1000x magnification

Figure 11. Rubber ash at 100,000x magnification

Figure 8a show the image of the rubber ash while Figure 8b show the image of the natural sand at 100x magnificent. Rubber ash has irregular round shape but natural sand has irregular shape. Round shape is good for workability for concrete while irregular share is good for binding in concrete.
Therefore, the irregular round shape of the rubber ash will improve the workability of the concrete without loss the binding ability.

Figure 9a and Figure 9b indicate the comparison between the rubber ash and natural sand at 500x magnificent respectively. The rubber ash seems like a solid material while the natural sand seems like porous material. Figure 10a and Figure 10b shows the images for the rubber ash and natural sand at 1000x magnificent respectively. By observing using the naked eye, the rubber ash looks like one big particle. Hence rubber ash element are arranged as aciniform (grape-like cluster) particulate. Rubber ash is a group of small particle bind together and form larger particle.

Figure 11 shows the image of the rubber ash at 100,000x magnificent. Rubber ash can consider as a nano material because the particle is smaller than 100nm as shown in Figure 11 [13][14]. Therefore, the nano particle of the rubber ash can fill up all the gap and void in the concrete and the quality of the concrete can be improved.

3.2.4. X-Ray Fluorescence. X-ray fluorescence has been conducted in the laboratory. The purpose of this test is to determined the chemical properties of the rubber ash and natural sand. Table 3 show the different chemical properties between rubber ash and the natural sand.

| MATERIAL                     | RUBBER ASH | NATURAL SAND |
|------------------------------|------------|--------------|
| Carbon Dioxide, CO2 (%)      | 0.10       |              |
| Sulfur Trioxide, SO3 (%)     | 16.90      |              |
| Zinc Oxide, ZnO (%)          | 14.60      |              |
| Silicon Dioxide, SiO2 (%)    | 12.70      | 51.00        |
| Calcium Oxide, CaO (%)       | 3.54       | 0.48         |
| Iron(III) Oxide Fe2O3 (%)    | 1.38       | 0.32         |
| Aluminium Oxide, Al2O3 (%)   | 0.51       | 6.83         |
| Potassium Oxide, K2O (%)     | 0.36       | 0.40         |
| Bromine, Br (%)              | 0.34       | -            |
| Copper(II) Oxide, CuO (%)    | 0.21       | -            |
| Chlorine, Cl (%)             | 0.19       | -            |
| Cobalt(II) Oxide, CoO (%)    | 0.14       | -            |
| Carbon, C (%)                | -          | 0.10         |
| Titanium Dioxide, TiO2 (%)   | -          | 0.58         |
| Zirconium Dioxide, ZrO2 (%)  | -          | 0.43         |

The rubber ash highly contains sulphur trioxide, zinc oxide and silicon dioxide while natural sand highly contains silicon dioxide and aluminium oxide. Based on the ASTM C618 the chemical requirement of natural sand is in class C but the rubber ash almost meet the chemical requirement. Almost all chemical in natural sand had in rubber ash, however the percentage in not similar.

The sulfur trioxide in the rubber ash is 16.90%. Sulfur trioxide is one of the factor that induced the volumetric expansion of concrete. The uses up to 10% rubber ash in concrete only increase 1-2% of sulfur trioxide. Concrete with less than 5.16% sulfur trioxide, its duration of effect was approximately 3-56 days. However, when the sulfur trioxide content more than 5.16%, its duration can effect up to 91 days [18].

From the Table 3, shows 14.6% zinc oxide were recorded in the rubber ash. Zinc oxide will increase the setting time of the concrete. However, the zinc oxide enhances the mechanical and physical properties of concrete [19]. Therefore, the substitution of rubber ash in concrete will produce high quality concrete.

4. Conclusion
The density and the specific gravity of the rubber ash are lower than natural sand, therefore, rubber ash suitable to produce lightweight concrete. The rubber ash was black in colour and it will change the colour of the concrete but the colour of the concrete is not indicative of the concrete strength. Rubber ash has finer size compared to natural sand. Therefore, rubber ash has features that can be filler for the concrete. Rubber ash has irregular round shape. Irregular round shape is good for both workability and binding. Rubber ash can consider, as the nano material due to the particle size is smaller than 100nm. Almost all chemical in natural sand has in the rubber ash. Sulphur trioxide and zinc oxide contains in rubber ash may enhance the physical and the mechanical properties of the concrete such as density and compressive test. Therefore, rubber ash postulates to be a good sand replacement for concrete.

Acknowledgement

The authors would like to thank UTHM fellowship and Grant Vot U523 and U572. This paper was partly sponsored by the Centre for Graduate Studies, UTHM.

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