Impact of Chemical Properties Crumb Rubber with Different Waste Tire in Hot Mix Asphalt Design

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Abstract

The purpose of this research is to assess the impact of chemical properties of rubber crumbs for various types of waste tires mixed in design asphalt. This paper gives a scientific contribution of the chemical properties in relationship with the mix design asphalt. Many tires are replaced and dumped as waste in many parts of the world every year. This has created severe environmental problems such as pollution which governments of many nations spend a lot of budgets to manage every year. However, incorporating rubber crumbs as part of asphalt construction would help solve the environmental pollution problem in the world. The analysis is important because chemical properties such as Zn, Carbon, and Mg, have different characteristics that must be considered in making the best asphalt mix design. This would help to achieve alternate solutions. Furthermore, Utilizing XRD, FTIR, and TGA, the granules of several kinds of waste tire were examined. To achieve the best mix design for the asphalt, the results had many viewpoints. The TGA result demonstrated that all waste tires decomposed at the temperature of 500°C. However, the truck tire waste had the highest maximum thermal decomposition temperature of 587°C. The FTIR result showed that all the tire waste has similar chemical functional groups of polystyrene. The result of XRF showed that truck tire waste possesses the highest Zn content which is considered as dangerous element to the environment.

Keywords: Chemical Properties, XRF, FTIR, TGA, Waste Tire

1. Introduction

The petroleum asphalt chemistry at the molecular and intermolecular concentrations has been an important topic, and interesting to be discussed misunderstanding, and conjecture on how quality features in roadways can be explained by chemical information. In term of molecular rate in any specific asphalt, there are at least hundreds of thousands kinds of distinct molecular. Asphalts contain a variety of molecular species with varying polarities and molecules weights. The main goal of this part of the work is to clarify asphalt cognitive features in aspects of chemistry. To accomplish this objective, three specific parameters, including economic variables, traffic flow, and asphalt mixture, should be taken into account by developers [1].

The chemical composition in the mixed asphalt has its characteristics. So it is important to conduct research focusing on the effect of chemical properties of crumb rubber with a different waste tire in asphalt mix design. The dumping of waste tire every year is considered more damage to the environmental. This could threaten human life due to the pollution, litter, mosquitoes ,rats, snakes and many insects that are produced from the waste. Therefore, engineers and other scientist should concern the rate on recycling and granulate the waste tires into particles. This would cut down the rate of disease and infections resulting from the environmental .Tire waste mostly comes from the products of automobile industry such as truck, car, bicycle, motorcycle , which are manufactured by numerous tire companies. Roadways in our regular life are essential. Hence, the governments spend much money annually on tests road construction and servicing. Since the temperature is high during specific seasons of the year, researchers and engineers would greatly benefit the economy of the nation if they extended the lifespan of highway paving. This would be accomplished by incorporating discarded tires into the design of the asphalt mix [2].Mores, the authorities of many nations allocated much budgets for the serving o destroyed road annually .This usually result from fluctuation in temperature that weakens the asphalt and allow the roads to damage.

Table 1. The Statistic of the Tire Waste Production in World [2]

Country	The Number of Scarp Tire (Million)
USA	266(*270)
Japan	102
France	44.3
Germany	28.2
G.Britain	23.4
Canada	20.0
Australia	17.0
Italy	12.1

2. Problem Statement

Unless correctly reused and/or rejected, waste tires present important safety and environmental concerns. Over the years, scrap tires have been recycled in civil engineering applications, particularly in asphalt building mixtures [3]. The disposal tire has been one of the biggest issues in the nation. There are no significant economic issues with correctly treated scrap tires or disposal tires. However, waste tires can be a danger to the atmosphere if treated incorrectly. Tires subjected to the components can retain water and be a testing ground for disease-carrying mosquitoes. Tire stacks can also be fired by incendiary or accident. These flames are hard to carry out and generate heavy smoke and rivers toxic run-off [4].The degree and sort of rubber alteration appear to rely on the magnitude of the enhancement [5]. The increased fatigue conduct of CRM combinations was also stated by multilayer elastic assessment coupled with fatigue sample outcomes for typical Alaskan circumstances. Mixed waste is defined as waste that has both hazardous and non-hazardous components. Usually, it's important to reduce the volume of the tyres in order to create crumb rubber [6].

3. Laboratory Testing

A. Overview

This research will analyze the impact of the chemical properties of crumb rubber with different resources of tire waste in hot mix asphalt design. would know from here which type of tire is similar to crumb rubber contain, and which can be used in the mix design asphalt.The impact on the rigidity of the asphalt binder requires to be assessed, as the inclusion of nanoscale powders significantly enhances the binder, as Cr and Zn in asphalt design. The crumb rubber is produced by shredding waste tires, a specific fiber- and steel-free fabric. The particle of rubber is graded in many sizes and shapes. The rubber crumb is described or assessed during the manufacturing stage by the mesh screen or sieve magnitude it passes through [7].

There are two crumb gum production methods: atmospheric milling and cryogenic method [6]. It is possible to divide the environmental processing method into two techniques: granulation and cracker factories. The environment defines the temperature when the rubber of the disposal wheels is decreased in volume. The product is packed at ambient temperature in the chip factory or granulator. Cryogenic grinding is a slower, mildly quicker procedure. This outcome in a decent production of the mesh size. The elevated price of this method is a drawback owing to the additional expense of liquid nitrogen [8]. Figure 1 shows the different types of crumble rubber powders with different grain sizes.

Fig 1: Difference Sizes of Crumb Rubber (Xiao et al., 2007).

B. Waste Tire Rubber

By employing X-ray fluorescence to learn about the chemical characteristics of used tires, rubber granules were assessed to determine their chemical makeup. Thermo-gravimetric differential analysis was conducted to explore the connection. The temperature and mineralogical characteristics for rubber granules to assess their suitability in the asphalt mixture as an aggregate substitute [9].

C. Chemical Properties of Waste Tire Rubber

Thermo-gravimetric Analysis (TGA). Utilities the decomposition method to assess weight adjustments in samples or equipment [10]. Differential thermal analysis (DTA) detects heat adjustments and refers them to various stages of fabric or sample thermal decomposition. The TGA path modifications are depicted in the DTA by a defined maximum. The TGA and the DTA were used to check the responses and modifications that happen during the heat treatment of the samples [11]. TGA just to know mechanical properties for thermal strength.

XRF is an element analysis for chemical composition inside the particle, it's more precise than SEM-EDS/EDAX and X- ray diffraction (XRD). The chemical compositions of the rubber tires “Infra-Red Transform Fourier (FTIR) while the PerkinElmer Spectrum 100 FT-IR characterized the samples before the screening. The FTIR assessment was performed with 32 images per sample (1 mg test per 100 mg KBr) on a spectrometer using the magnesium bromide (KBr) pellet method) gathered at 32 cm^{-1}sizes from 4000 to 650 cm^{-1} [12].FTIR influences the chemical interaction between an anion and a cation.

SEM uses EDS/EDAX to establish the surface shape, pore, structure, and chemical composition of the particle.

4. Results and Discussion

A. TGA Analysis

As shown in Figure 2, the calculated weight (%) was dropping while more samples' temperatures were rising. It was reduced after the temperature reached 400°C, and it was again reduced after the temperature rose once more to 1000°C. So, it can be observed that the derivative weight (%) decreases along with the temperature of number samples, and the lowest was at the temperature of 580.59 °C was the maximum degradation temperature of the sample with the residue of 34.23%.

The plastic rubber asphalt (PRA) and asphalt styrene-butadiene (SBS) has comparable performance in high temperatures, low temperatures, and water durability. Plastic Rubber Asphalt (PRA) mixture is more environmentally-friendly. However, mixtures containing these binders are more prone to cracking at low temperatures comparing the described technologies and providing justifications and suggestions for the widespread use of Recycled Tire Rubber Modified Bitumen (RTR-MBs) [9]. Changed crumb rubber binders and crumb rubber features are more widely recognized. It is, therefore, possible to estimate the ground effectiveness of crumb rubber modifier pavements more properly. Crumb rubber modifier performance was revealed to depend on multiple factors such as crumb rubber, mixing circumstances, mixing variables, overall gradation, and compaction method used [13].

According to Figure 2, it can be said that the maximum decomposition temperature (Td) of car waste tires were at 507.59°C which was indicated by the highest weight reduction rate of 5.23 wt. % in DTA. There were 32.5 wt. % residues at the end of the heating process.

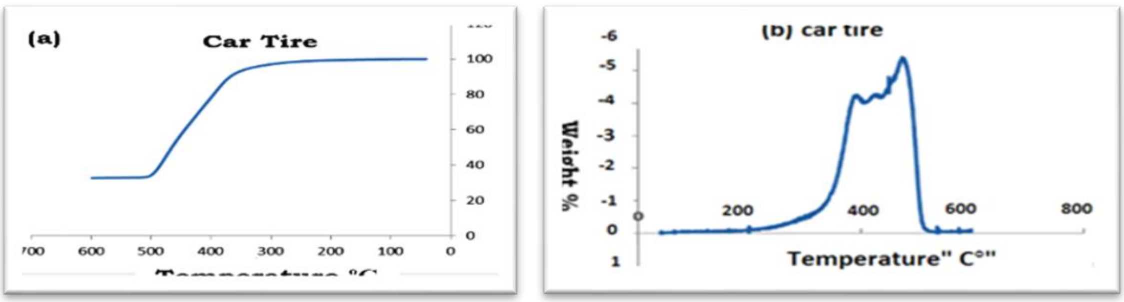

Fig 2: TGA (a) and DTA (b) Curves of Car Waste Tires Co. (Dunlop 2016).

Figure 3 illustrates the TGA and DTA of truck waste tires. It can be said that the maximum decomposition temperature (Td) of waste Truck tire was at 507.98°C which was indicated by the highest weight reduction rate of 7.02 wt. % in DTA. There were 31.17 wt. % residues at the end of the heating process.

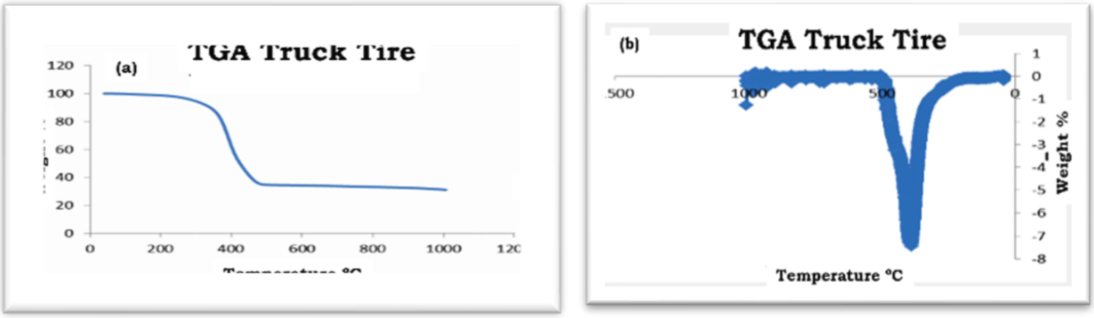

Figure 3: TGA (a) and DTA (b) Curve of Truck Waste Tires Co. (Gajah Tunggal 2016).

Figure 4 illustrates the TGA and DTA of motorcycle waste tires. It can be said that the maximum decomposition temperature (Td) of motorcycle waste tire was at 507.98°C. This was indicated by the highest weight reduction rate of 4.72 wt. % (mg/min) in DTA. There were 32.11 wt. % (mg/min) residues at the end of the heating process.

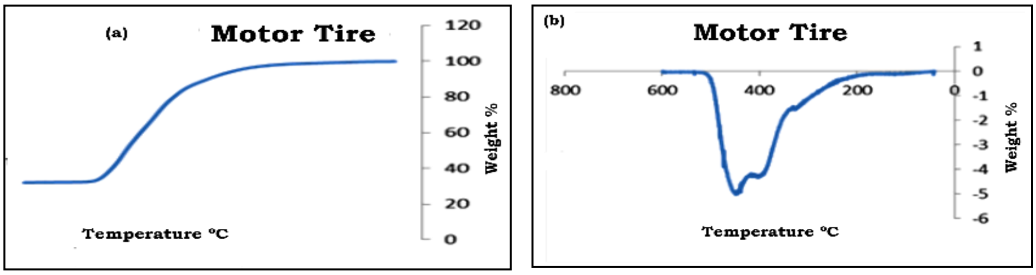

Fig 4: TGA and DTA Curves of Motor Waste Tires Co. (IRC2017).

Figure 5 illustrates the TGA and DTA of bicycle waste tires. It can be observed that the maximum decomposition temperature (Td) of bicycle waste tires were at 507.92°C. This was indicated by the highest weight reduction rate of 4.22 wt. % in DTA. There were 39.19 wt. % residues at the end of the heating process.

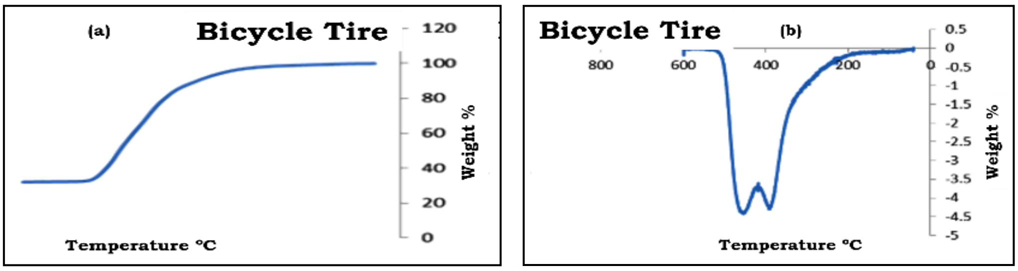

Fig 5: TGA and DTA Curve of Bicycle Waste Tires Co. (Dend 201).

Based on the TGA study, it was revealed that truck and motorcycle exhibit the highest decomposition temperature as compared to other waste tire with Td of 507.98 ºC. This was followed by the bicycle waste with Td of 507.92 ºC. On the other hand, bicycle had the highest residue of 39.19 wt.%. It was therefore concluded that the bicycle waste tires consists of high metal content. Thus, bicycle waste tires are suitable to be used as asphalt additive to improve the thermal resistance due to high degradation temperature and residue.

B. FTIR Analysis

The specimens were described in the Perkin Elmer 100 FT-IR spectrum before they were evaluated. The samples were prepared in powder form. The FTIR analysis was performed on a spectrometer using the potassium bromide (KBr) pellet method (1 mg sample per 100 mg KBr) with 32 scans per sample collected at 32 cm^{-1} resolutions from 4000 to 650 cm^{-1}.

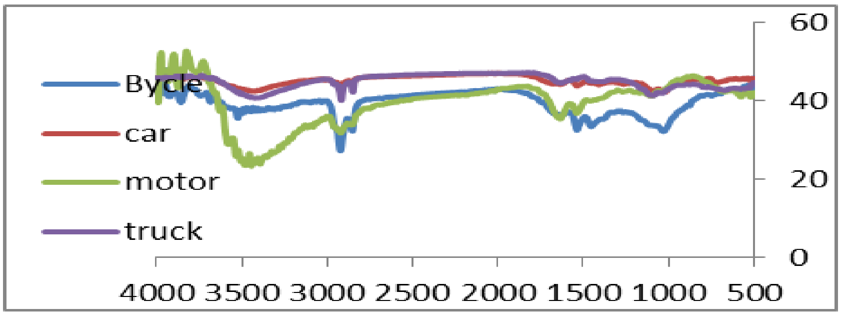

Fig 6: FTIR with Different Types of Waste Tire.

As can be seen on the graph above,(i) the entire sample showing the similar FTIR spectra; (ii), the peak at 1000 cm^{-1} corresponds to conjugated C-H from vinyl groups; (iii) . The peak at 1600 cm^{-1} corresponds to conjugated C=C; (iv) The peak at 1500 cm^{-1} corresponds to conjugated C=C aromatic groups; (v) The peak at 2900 cm^{-1} corresponds to conjugated C-H methylene groups; (vi). The peak at 2850 cm^{-1} corresponds to conjugated C-H methylene groups.

C. FNS Analysis

The technology of flicker noise spectroscopy (FNS) enables the analysis of the noise spectrum; decompose it into elementary components (spikes, steps, kinks, etc.). Therefore, it is a sort of spectroscopy capable of evaluating not only medium-amplitude noisy signals, but also the structure of the noise [14].

The FNS analysis was done at a temperature of 22.6°C and 55% humidity. The results showed that the bicycle waste tires type have the highest Cr element content, while in the truck waste tires type the Cu element content was the highest. Meanwhile, the highest element content in the vehicle waste tires types were the Cr and Zn. Finally, the highest chemical elements content was found in the motorcycle waste tires, whose types were Cr and Ba. Figure 6 showing results of the FNS analysis.

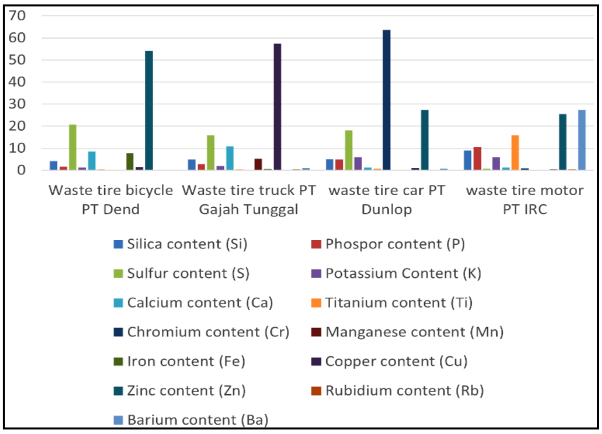

Fig 7: The FNS Results

D. XRF Analysis

The result of X-Ray Fluorescence Analysis (XRF). Figure 7 indicates that the components of bicycle waste tires: Based on Figure 7, it can be observed that the sulfur content (S) is higher than the Calcium content (Ca) with 15.9% while Ca with 10.9%. Both sulfur and calcium have higher contents meanwhile iron content (Fe) is higher than silica with 5.23%. The lowest is rubidium (Rb) with 0.06 %, while Mn with 0.1 the highest chemical content was the Zn with 57.4% of the sample weight.

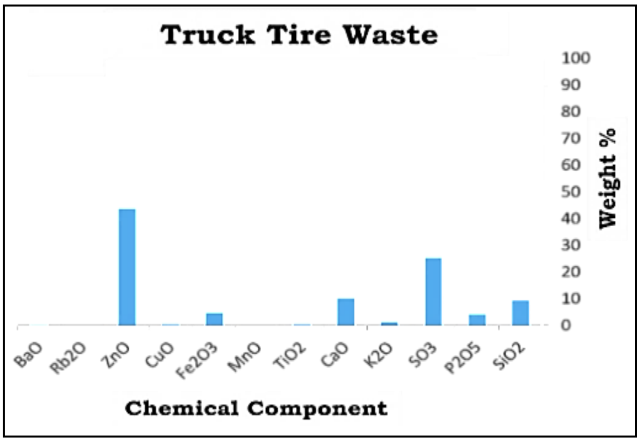

Fig 8: Truck Waste Tires from CO. (Gajah Tunggal Years 2016).

Based on the results in Figure 9, it can be indicated that the higher chemical component in the motorcycle tire waste is the zinc content (Zn) with about 27% wt., followed by iron content with about 25%. The third is calcium with about 16% wt. % (mg/min) meanwhile, the other chemical components contents including silica (Si), aluminum (Al), sulfur (S), copper (Cu), potassium (K), titanium (Ti), vanadium (V), chromium (Cr), nickel (Ni) bromide (Br) and barium (Ba) are less than 11 % wt.

In order to understand the heavy element composition of all waste tires, The FNS analysis was carried out at a humidity level of 55% and a temperature of 22.6°C. (Figure 8). As can be seen, almost identical heavy components, such as silica, sulphur, chromium, and zinc, are present in all of the discarded tires. Those elements are dominant in all tire types used in this research. Initially, the bicycle tires have the highest Zn and S contents which are to be considered environmentally as a toxic material [15]. On the other hand, discarded tires from cars and trucks have the highest concentrations of precious metals like chromium and copper. The motorcycle waste tires type was found to have the greatest silica content.

The FNS analysis was done at a temperature of 22.6°C and 55% humidity. The results showed that the bicycle waste tires type have the largest Cr element content, while in the truck waste tires type, the Cu element content was the highest. Cr and Zn were the elements with the highest content in the different types of vehicle waste tyres. Finally, the highest element content was in the motorcycle waste tires type with Cr and Ba.

According to the resulted data of the X-ray fluorescence analysis which was carried out on the particles of different types of waste tires, the highest element contents in the bicycle waste tires were the Cr and Ba, the highest element contents in the truck waste tires were Cr and Cu. Meanwhile, the highest element contents in the car waste tires were the Cr and Zn. Finally, The motorcycle waste tires pneumatics has the largest element contents of Cr and Ba element.

Table 2 is based on the chemical elements available in the crumb rubber using XRF analysis. According to the resulted data, the highest chemical element in the crumb rubber was Zn with 60.1 wt. %, the S, Fe, Ca and Si have wt. % contents 12.8, 9.40, 9.09 and 5.80 wt.% respectively. Some other chemical elements were also available in the crumb rubber with low contents less 0.88 wt. % including Br, K, Ti, Cu, Mn, and V, the (Figure 9) showing the relationship between the chemical elements available in the crumb rubber and their weight percentage.

Table 2: Chemical Element and their wt. % of Crumb Rubber Using XRF.

Chemical Element	Percentage wt. [%]
Si	5.8
S	12.8
K	0.82
Ca	9.09
Ti	0.62
V	0.02
Mn	0.16
Fe	9.40
Cu	0.39
Zn	60.1
Br	0.88

It is recommended that the bicycle, car, and truck tires waste is the most applicable candidates as an asphalt additive due to high Zn content. The chemical composition of these tire wastes similar elements on the crumb rubber, thus they very promising to be used as an asphalt additive. Moreover, all of the tire waste exhibits similar thermal degradation at ~507°C.

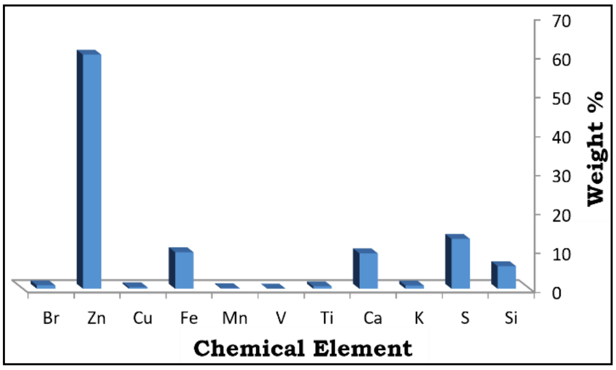

Fig 9: XRF for Crumb Rubber Contents.

5. Conclusions

There are several measurable chemical properties that are believed to be associated with the mechanical or organizational resistance of a pavement. According to the results, the comparative outputs of the elastic and viscous behaviour differed with the structure. Following are the findings' conclusions:

1. The results of the TGA shows that the truck waste tires have the highest thermal resistance up to maximum degradation temperature, because it's related to the chemical composition, while the lowest one was the bicycle waste tires, because they have the lowest amount of Cr/Zn. A
2. FTIR results indicated that all the waste tire types were consisting of the same chemical group's composition. The only differences are that the amount of chemical group's presence there. For instance, the motor waste tires type have the highest amount of water content, while the lowest content was found in car and truck waste tire types.
3. The XRF outcome suggests that the entire waste tire consist of the same elements. The only the difference was that the concentration. Car waste tires have the highest Zn element content comparing to the other waste tire types, on the other hand, motor waste tires type have the highest Si, Fe and Ti, contents and bicycle waste tires type has the highest S content.

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