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# Comparative Analysis of Asphalt Making Potentials of Bitumens from Pyrolytic Rubber Tyre and Plastic Bottle Wastes

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***Abstract—****Waste valourization is an effective means of finding solution to the twin problems of resource depletion and environmental pollution which are major challenges facing many countries in the world. The aim of this study was to determine the influence of feedstock type either as plastic bottle wastes or rubber tyre wastes on the asphalt making potential of pyrolytic bitumen from the polymeric wastes. The experiment involved bitumen extraction from condensed heavy oils produced from separate pyrolysis of 9 kg each of rubber tyre and plastic wastes. The results of quality tests indicated that asphalt concrete produced using bitumen from pyrolytic rubber tyres wastes; had only Marshall stability value of 3150 N that was not within standard limit while asphalt concrete produced using bitumen from pyrolytic plastic bottle wastes had Marshall stability value of 2950 N and void filled of 69% that were not within standard limits. Comparison of the results from the statistical analysis of the property values of the asphalt concretes produced using bitumens from the polymeric wastes indicated that their p-values were all greater than the α-level = 0.05, This implied that there was no statistical significant difference using extracted bitumen from either pyrolytic rubber or plastic wastes for asphalt concrete production*.

***Keywords—****Wastes, environmental pollution, resource depletion, bitumen, asphalt, pyrolysis*.

## I. Introduction

Huge amount of solid wastes, including plastic bottle and rubber tyre wastes, are generated daily due to the increase in demand of the polymeric products for various applications in many sectors. Plastic bottle and rubber tyre wastes could cause damaging environmental pollution and health implications if the generated solid wastes are not effectively disposed of. The polymeric wastes could provide breeding spaces for mosquitoes and other disease transmission agents. Besides, unsanitary landfilling of plastic bottle and rubber tyre wastes could cause toxic leachate pollution of surface or groundwater while open burning of the polymeric wastes could result in gaseous emission of toxic pollutants. Plastic bottles are produced for various applications including storing water, soft drinks, motor oil and milk, among others. Depending on the applications, there are different types of plastic products, including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polycarbonate (PC), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC) (1).

HDPE products are used for containers for milk, motor oil, soap bottles, and detergents; LDPE products are used for squeezable bottles, sandwich bags, grocery bags and trash bags; PET products are used for common household items such as beverage bottles, fruit juice containers, medicine jars, rope, clothing and carpet fibre(2); PC products are used for baby bottles and medical storage containers; PP products are used to make margarine containers, yogurt pots, syrup bottles, pails, flowerpot and carpet; PS products are used for items such as disposable coffee cups, plastic food boxes, plastic cutlery and packing foam; PVC products are used for pipes, wire and cable insulation, tiles, and window frames (1). Rubber tyre has natural and synthetic rubber as its main components. Typical tyre composition by weight often includes styrene-butadiene (62.1 %), carbon black (31.0 %), extruder oil (1.9 %), stearic acid (1.2 %), sulphur (1.1 %) and moderator (0.7 %) (3). Rubber tyres are used, especially, in transportation purposes including automobiles, trucks, bicycles, buses and airplanes.

Meanwhile, most of the polymeric products, including rubber tyres and plastic bottles, are produced from petroleum which is a non-renewable raw material and as a consequent, there is a continuous depletion of petroleum without replacement which makes the production of the polymers unsustainable in the long run. For sustainable development of any society, effort must be geared towards conservation of resources for future needs (4). In this context, plastic bottles and rubber tyres wastes could be used in place of petroleum as alternative sources for valuable products such as fuel gases, diesel oil, gasoline, activated carbon and bitumen, among others (5-8). Bitumen is a hydrocarbon viscous liquid that can be found as a deposit naturally or produced from fractional distillation of crude oil (9). The various applications of bitumen include road paving, roofing, waterproofing and adhesion, among others. Bitumen is used as a binder in asphalt concrete, which is a mixture of bitumen with mineral aggregates including gravel (coarse aggregate), quartz (fine aggregates) and a mineral powder (filler) (10). Quartz fills the spaces between the gravel to reduce its mobility and even out the load among the mineral aggregates. Mineral powder restricts mobility of quartz sand particles and also makes bitumen harder



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(10). The composition of asphalt concrete is such that the mineral aggregates and bitumen constitute 90 – 95 wt % and 5 – 10 wt%, respectively. The aggregates provide the required load supporting capacity of asphalt concrete while bitumen influences greatly the performance of the asphalt concrete since the bituminous binder is the only deformable component of the asphalt concrete (11). The quality and performance of asphalt concrete depend on the aggregates, as well as, bitumen quality and composition. The asphalt concrete must have the right proportions of all the components since the performance of the concrete depends on the quality and composition of the aggregates and bitumen.

There are many publications on the usage of polymeric wastes as bitumen modifier, as well as, aggregates for asphalt concrete (9, 12) but much work has not been done on using bitumen extracted from condensed heavy oil from pyrolytic polymeric wastes, as binder in asphalt concrete production. Akinbomi et al. (13) only worked on the asphalt making potential of bitumen from pyrolytic rubber tyre wastes; other polymeric wastes were not considered. This study, therefore, focused on the comparison of asphalt making potentials of bitumens from plastic bottle and rubber tyre wastes, to determine the suitability of using the bitumen from pyrolysed plastic wastes for asphalt concrete production.

## II. Materials and Methods

The feedstock materials used for the pyrolysis process were rubber tyre and plastics bottles wastes. The wastes were collected from dumpsites in communities around Lagos State University, Lagos, Nigeria. Reinforced steel was removed from the waste tyres before the tyres were shredded manually into chips, washed with clean water, and then spread under the sun for drying. Plastics bottles wastes were also washed, dried and shredded. Chemical balance, measuring cylinder, stop clock and empty containers were used during the pyrolysis experiment for measuring feedstock weight, cooling water volume, progressing reaction time and collection of condensed liquid oil and char, respectively. Gas-fired furnace, pyrolysis reactor, heavy oil condenser, two cyclones for light oil condensation, scrubber for gas purification, and gas storage bag made up the pyrolysis system (Figure 1). The pyrolysis reactor was a cylindrical steel cylinder with a thickness of 12 mm, an internal diameter of 250 mm, and a capacity of 25 kg of shredded polymer. Two pairs of flanges were used to close the reactor vessel (top and bottom). The reactor vessel had a hole at the centre that served as a gas escape. The gas-fired furnace was built in such a way that the pyrolysis reactor would get consistent heat. To measure the temperature in the pyrolysis reactor, a solar-powered temperature sensor was installed inside the reactor vessel (Figure 2).

During the pyrolysis experiment, the main reactor containing 9 kg each of the dried shredded tyres and plastic bottle wastes at separate times was placed inside liquefied petroleum (LPG) gas-fired furnace for batch pyrolysis process. Before starting the pyrolysis process, about 20 litres of clean water was measured into each of the two cyclones used for light oil condensation. The 9 kg of shredded tyres was pyrolyzed at a temperature range between 236 ºC and 488 ºC. The temperature was maintained for about 5 hours (residence time) at 488 ºC. At the end of the pyrolysis experiment, the non-condensable gas was collected in a gas storage bag and utilized for lighting of 80 Watt electric bulb. The condensable liquid oil was collected in two containers: one for heavy oil collection and the other for light oil collection. The furnace was left to cool down to room temperature (25 ºC) before the char left in the reactor vessel was removed (12).

After the experiment, bitumens were extracted from the heavy oils obtained from pyrolytic plastic bottle and rubber tyre wastes. The extraction of bitumens from the pyrolytic heavy oil was made possible by the addition of concentrated sulfuric acid (25 cl) to the heavy oil (2 l). The acid was required to heat up the heavy oil and speed up the rate of the chemical reaction so that bitumen could settle down from the oil, making filtration possible. The mixture was then left for about 48 hours to allow the reaction to take place. The obtained bitumen was separated into two parts; the first part was used for quality test while the second part was used in the asphalt concrete production. The quality and physicochemical tests of light oils, bitumens and asphalt concrete produced were carried out at MEDSON Nigeria Limited, Ebute Meta, Lagos and Master Control Service Limited, Dopemu, Agege, Lagos, Nigeria.

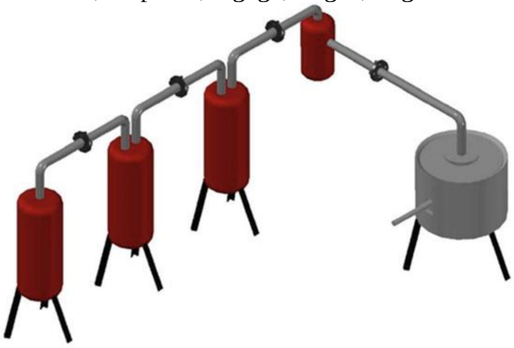

Fig. 1. Pyrolysis system setup

Fig. 2. Gas-fired furnace with attached solar-powered temperature sensor

## III. Results and Discussion

The results obtained from the quality tests and physicochemical analyses performed on the light oils, extracted bitumen and the asphalt concretes from pyrolytic plastic bottle and rubber tyres wastes are presented in Tables 1 to 3. Table 1 indicated that the property values of oils from pyrolytic rubber tyre wastes that were within the limits of standard diesel oil included centane number and kinematic viscosity while property values of pyrolytic plastic bottle wastes that were within the limits of standard diesel oil included sulphur content, in addition to, centane number and kinematic viscosity. Comparison of results for the property values of the extracted bitumen from pyrolytic rubber tyre and plastic bottle wastes (Table 2) showed that all the property values of bitumen from the rubber tyres were within the limits of standard bitumen. Regarding plastic bottle wastes; only values of flash point and ductility properties of the bitumen were not within the limits of standard bitumen. For the asphalt concrete produced from pyrolytic rubber tyre wastes; only Marshall Stability value was not within standard limits while in the case of asphalt concrete produced from pyrolytic plastic bottle wastes; both values of Marshall Stability and voids filled, were not within the standard limits (Table 3). The poor arrangement of mineral matter or aggregates during the production of the asphalt concretes might be responsible for the low stability values of asphalt concretes produced from pyrolytic rubber tyre and plastic bottle wastes. This is because coarse aggregates are responsible for stability in asphalt concrete while fine aggregates enhance adequate flow by filling the pores within coarse aggregates which results in the reduction in the amounts of voids in the asphalt oncrete.

Meanwhile, statistical analysis of the values of the properties in Table 1 to 3 was done using Minitab 17 paired t-tests, and the results obtained are presented in Table 4. Comparison of the results showed that the p-values for property values for light oils, bitumen and Asphalt concrete from rubber tyre wastes and plastic bottle wastes; were all greater than the α-level = 0.05, which was the criterion p-value. As the p-values were greater than 0.05, it could be inferred that there were no statistical significant differences in terms of the quality of light oil, bitumen and asphalt concrete produced when rubber tyre wastes or plastic bottle wastes are used as feedstock for the pyrolysis process., as well as, when comparing the quality of light oil, pyrolytic bitumen and asphalt concrete with the standard values.

TABLE 1. Comparative analysis of physicochemical analysis of pyrolytic oils from rubber tyres wastes and plastic bottle wastes

| Property of extracted light oil | | | | | |
|---|---|---|---|---|---|
| **S/N** | **Property** | **Unit** | **Rubber tyre wastes (13)** | **Plastic bottle wastes (this study)** | **Standard diesel oil limits (14-19)** |
| 1 | Density at 20 ºC | Kg/m$^3$ | 936 | 785 | 806 – 855 |
| 2 | Kinetic viscosity at 40 ºC | mm$^2$ /sec | 3.6 | 5.76 | 1.6 – 5.5 |
| 3 | Flash point | ºC | 52 | 43 | ≥ 55 ºC |
| 4 | Diesel index | | 42.8 | 42.8 | ≥ 47 |
| 5 | Gross Calorific Value | MJ/kg | 43.22 | 37.46 | ≥ 45.15 |
| 6 | Sulfur content | % | 0.904 | 0.026 | ≤ 0.05 |
| 7 | Centane number | | 45 | 47 | ≥ 40.0 |

TABLE 2. Comparative analysis of properties of extracted bitumens from pyrolytic rubber tyre wastes and plastic bottle wastes

| S/N | Property of extracted bitumen | Test method | Unit | Rubber tyres | Plastic bottle wastes | Standard Bitumen limits (FMW*)(20) |
|---|---|---|---|---|---|---|
| 1 | Specific gravity at 15 ºC and 25 ºC | ASTMD70 | | 1.02 | 1.06 | 1.00 – 1.05 |
| 2 | Penetration at 15 ºC | ASTMD5 | mm | 93 | 80 | 80 -100 grade |
| 3 | Flash point | ASTMD92 | ºC | 235 | 176 | ≥ 225 |
| 4 | Softening point | ASTMD36 | ºC | 47 | 52 | 42 -52 |
| 5 | Ductility at 25 ºC | ASTMD113 | cm | 150 | 75 | ≥ 100 |
| 6 | Loss of heating | ASTMD6 | % | 0.5 | 1 | 0.5 |
| 7 | Solubility in trichloroethylene | ASTMD2042 | % | 99 | 99 | 99 |

*Federal Ministry of Works and Housing in Nigeria (FMW 2007)

TABLE 3. Comparative analysis of properties of asphalt concrete using pyrolytic bitumens from rubber tyres wastes and plastic bottle wastes

| S/N | Property of asphalt made | Unit | rubber tyre wastes | Plastic bottle wastes | FMW* Limits (20) | Remarks | |
|---|---|---|---|---|---|---|---|
| | | | | | | **Rubber tyres wastes** | **Plastic bottle wastes** |
| 1 | Marshall stability | N | 3150 | 2950 | ≥ 3500 | Failed | Failed |
| 2 | Flow value | mm | 2.55 | 2.31 | 2mm – 4mm | Passed | Passed |
| 3 | Percent air voids in the mix | % | 3.1 | 3.4 | 3% - 5% | Passed | Passed |
| 4 | Voids filled | % | 77.4 | 69.8 | 75% - 82% | Passed | Failed |

*Federal Ministry of Works and Housing in Nigeria (FMW 2007)

TABLE 4. P-values of statistical analysis of property values of light oil, bitumen and asphalt concrete from asphalt pyrolytic rubber tyre and plastic bottle wastes

| S/N | P-values | Light oil | Bitumen | Asphalt |
|---|---|---|---|---|
| 1 | P-values between property values for rubber tyre and plastic bottle wastes | 0.319 | 0.154 | 0.371 |
| 2 | P-values between property values of rubber tyre wastes and standard values | 0.245 | 0.244 | 0.387 |
| 3 | P-values between property values of plastic bottle wastes and standard values | 0.241 | 0.178 | 0.381 |



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## IV. Conclusion

The aim of this study was to determine the influence of type of polymeric waste feedstock either as a plastic bottle wastes or rubber tyre wastes on the asphalt making potential of bitumen extracted from the polymeric wastes. Quality tests were performed on the asphalt concretes produced to determine the viability of using the extracted bitumens from pyrolytic plastic bottle and rubber tyre wastes for making road asphalt design. Comparison of the results from the statistical analysis of the property values of the asphalt concretes produced using bitumens from the polymeric wastes indicated that their p-values were all greater than the α-level = 0.05, This implied that there was no statistical significant difference using extracted bitumen from either pyrolytic rubber or plastic wastes for asphalt concrete production. The study was able to establish the possibility of using polymeric wastes including rubber tyre and plastic bottle wastes as alternate sources to petroleum for bitumen extraction. The importance of this study could be related to the associated benefit of mitigation against twin problems of resource depletion and environmental pollution through the production of bitumen from rubber tyre and plastic bottle wastes.

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