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Waste to Wealth; The Utilization of Scrap Tyre as Aggregate in Bituminous Mixes for Road Construction

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ABSTRACT
The problem associated with solid waste management is on the increase both in the industries, urban cities and in the rural areas. In the United States of America, Asia and Europe, there are over hundreds of waste to wealth combustion plants from where solid wastes are incinerated. In Nigeria, amidst the increasing importation of vehicle tyre such plants are scarcely in existence to enhance generation of revenue from waste through the extraction of raw material for the production of light weight aggregates, printing ink, paints, shoe polish, dry cell and battery heads. This research paper seeks to utilize vehicle scrap tyre (VST) as aggregates in asphaltic mixture by adopting the dry process to evaluate the effect of rubber-bitumen interaction on asphaltic concrete properties; laboratory investigation using 4.75mm, 2.36mm and 0.600mm chunk tyre particle size modified asphalt mixture containing 2%, 4%, 6%, 8% and 10% scrap tyre and 0% tyre content as control mixture. The mixtures were subjected to Marshall Tests where the stability, flow, percentage air void, unit weight, void mineral aggregate, height of specimen and specific gravity were determined. The results obtained shows that as tyre percentage increase the stability, unit weight and specific gravity value decreases. On the other hand, as the tyre content increases, the flow and height of specimen increases while as the tyre content increases the percentage air void and VMA increased for 4.75mm Tyre Particle Size (TPS) and 2.36mm TPS while for 0.600mm TPS, reverse is the case. In summary and in comparism with standard specification for road construction material, the Marshall tests conducted on the tyre modified specimens remained intact and by interpretation; material possessing such property indicates good impact resistance when use as surface course in flexible pavement. Conclusively, the use of 10% 4.75mm, 4% 2.36mm or 4% 0.600mm TPS by weight of aggregate in asphaltic concrete is recommended for medium traffic volume pavement which in turn leads to a considerable percentage of sanitation in our cities in terms of reduction in scrap tyre waste management and waste to wealth generation.
Keywords: Waste, Scrap Tyre, Aggregate, Management, Nigeria.

I. INTRODUCTION

Ground Scrap Tyre Rubber (GSTR) can be used in the secondary application as asphalt mixtures either as binder modifier (wet process) or as fine and/or coarse aggregate replacement (dry process). As the volume of waste material generated from scrap tyre in our society and cost of disposal continue to increase. Records show that every year an estimated eight hundred and fifty thousand (850,000) scrap tyres generated in Nigeria are carelessly discarded, resulting in serious waste disposal problem [1]. In essence, the introduction of scrap tyre rubber into asphalt concrete pavement has the potential to solve this waste problem. In the united state, it has been estimated that if only 10% of all asphalt pavement laid each year contain 3% of rubber, all scrap tyres produced for the year which is estimated to be approximately 225 million would be consumed [2]. This fact which informed the work contain herein is also applicable in Nigeria as the use of scrap tyre rubber as additive in asphalt concrete has been developing for over thirty years in developed and most developing countries. Rubberized asphalt formula consumes 8,000 to 12,000 scrap tyres per mile of two-lane road construction [3]. Most importantly, the rubberized asphaltic pavement lasts longer, it is more resilient, less prone to cracking, provides better traction, allows for quieter rides and de-ice more rapidly than conventional pavement [4]. However, rubberized asphaltic pavement tends to be more expensive, its property benefits as stated above outweighs that of the conventional asphalt pavement especially on some roads with peculiar problems [5]. Basically, Ground Scrap Tyre Rubber (GSTR) has been extensively used in surface treatment, inter-layers, joint sealer and cold mix asphalt but the research contained herein is centered on the use of Ground Tyre Scrap (GTS) in hot mix asphalt adopting the dry process. A control mix of 0% rubber was adopted upon which the Marshall method of mix design was used to obtain the optimum bitumen content. A total of 103 samples were prepared using one aggregate source and 6 GSTR percentages for 3 different rubber particle sizes.

Dry process was originally developed in 1967 in Sweden. In this process, ground rubber or crumb rubber is used as a portion of the aggregate. The crumb rubber is sometimes referred to as a crumb rubber modifier (CRM) because it modifiers the properties of the resultant hot mix asphaltic concrete [4]. This process can be used for hot mix asphaltic concrete in dense-graded, open-graded or gap-graded mixture but it is not applicable on cold mix and surface treatment and it is used as substitute for a small portion of fine aggregate usually 1- 3% by weight of the total aggregate prior to the addition of the asphalt binder. On the other hand, wet process; is one of the processes of by which GSTR can be incorporated into asphaltic concrete. The process was first developed in 1962 by Charles McDonald; the process uses the GSTR as an additive in the asphalt cement in percentages ranging between 10 – 25% by weight by introducing it into the cement at high temperature and allowing the rubber to react with the binder before the mixture is added to the aggregate. The reaction in this process involves the absorption of aromatic oils from the asphalt cement into the polymer chains that compresses of the major structural components of natural and synthetic rubber in crumb rubber [6].

II. MATERIALS AND METHOD

The aggregates used for this research consist of 9.5mm granite chipping, 0.5mm quarry sand obtained from Crush Rock Nigeria Limited Depot in Rivers State with main quarry source in Cross River State. Scrap tyre rubber was collected from Anozie Street in Port Harcourt. The tyres were washed thoroughly, dried and shredded into sections to free it from steel breeds or strands and further cut into smaller pieces before grinding using mechanical means thereby producing rubber particles and synthetic fibre mixture which was sieved to enable for the extraction of retained particles on sieve 4.75mm, 2.36mm and 0.600mm. The bitumen used was gotten from the building material market at mile III in Port Harcourt.

Sieve analysis was conducted in accordance with [7] methods of test for soils for civil engineering purposes as shown in Table 1 and 2 for granite chipping and quarry sand respectively while Particle Size Distribution (PSD) is as shown in Figure 1 and 2 for both respective materials as stated above. Specific gravity test was carried out in accordance with [7] methods of test for soils for civil engineering purposes and its results are as shown in Table 3 and 4 for granite chipping/quarry sand and GSTR. Table 5 represents results for bitumen specific gravity and penetration. Los Angeles abrasion test was conducted on the granite in accordance with [8] with its results presented in Table 3. Aggregate crushing test was conducted in accordance with [7] and results presents in table 3 while penetration test was carried out on the bitumen in accordance with [8]. Mix gradation, the mix adopted in this research was designed as dense graded with 100% passing 12.5mm sieve using Asphalt Institute IV(a) specification, Rothfuch's method was used in the aggregate blending [9]. The control mix with no chunk or crumb rubber was designed and the amount of rubber used in the mixes varied from 2%-10% by weight of granite chippings for scrap tyre rubber particles retained on sieves 4.75mm and 2.36mm as well as quarry sand for rubber particles retained on sieve 0.600mm sieve. The results obtained are shown in Table 1 and 2 and their respective particle size distribution graph in figure 1 and 2 while figure 3 shows the gradation curves of the blend aggregate in the specification envelop.

Specimen preparation, the method adopted in preparing the test specimen was the method recommended for Marshall Test by [10] in accordance with [11]. In this research, the total weight of mixture required for one specimen was 1200g; the aggregates were thoroughly heated and mixed to an average temperature of 140^{o}C, bitumen was also heated at an average temperature of 160^{o}C and added to the aggregate where it was mixed thoroughly for about 3 minutes before the mixture was transferred into the steel cylindrical mould placed on a base plate. The steel cylindrical mould was positioned on manually operated compaction equipment from where 50 blows (corresponding to medium traffic category on wearing course) were applied on each face of the specimen. The specimen 10.16cm in diameter and height 6.35cm-7.5cm were removed from the mould and allowed to cool for one day before testing.

Marshall Stability test was carried out on the specimen in accordance with [11]. The results are presented in Table 6.

III. RESULTS AND DISCUSSION

Table 1: Result of Sieve Analyses on Granite Chippings

Sieve Size (mm)	Weight of Sample Retained (g)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
12.500	-	-	-	100
9.520	14.0	1.4	1.4	98.60
4.750	855.0	85.5	86.9	13.10
2.360	105.0	10.5	97.4	2.60
0.600	5.0	0.5	97.9	2.10
0.300	4.0	0.4	98.3	1.70
0.150	3.0	0.3	98.6	1.40
0.075	3.0	0.3	98.9	1.10
pan	11.0	1.1	100	0.00

Table 2: Result of Sieve Analyses on Quarry Sand

Sieve size (mm)	Weight of sample Retained (g)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
12.500	-	-	-	100.0
9.520	-	-	-	100.0
4.750	13.0	2.17	2.17	97.83
2.360	82.0	13.67	15.84	84.16
0.600	214	35.67	51.51	48.49
0.300	83	13.83	65.34	34.66
0.150	83	13.83	79.17	20.83
0.075	62	10.33	89.50	10.50
pan	63	10.50	100.0	0.00

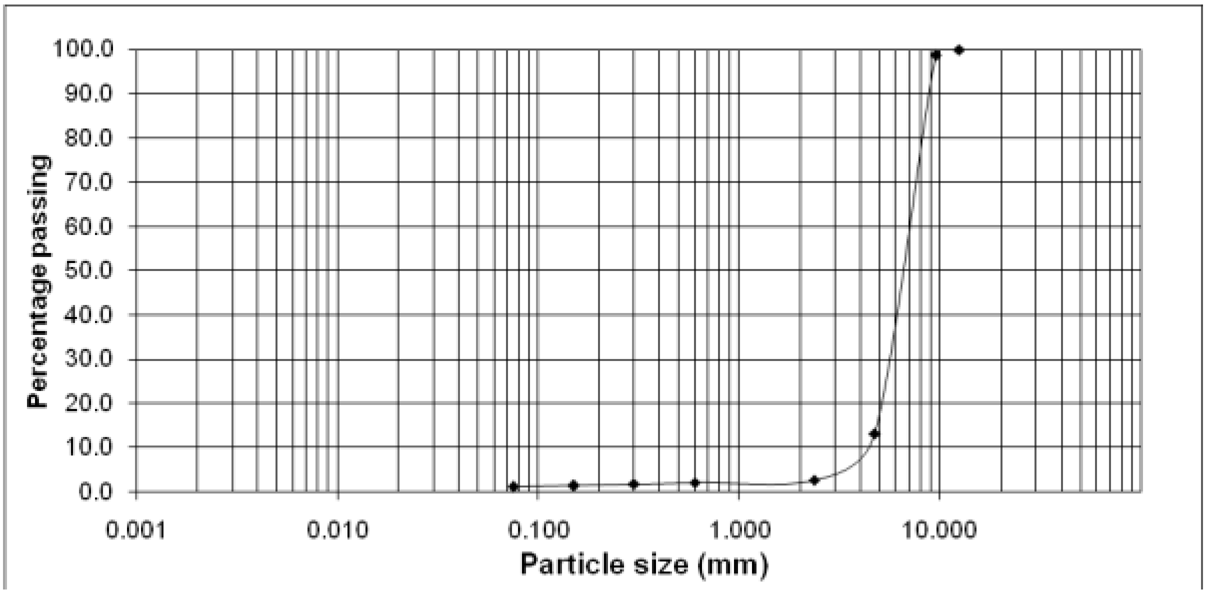

Figure 1: Particle Size Distribution for Granite Chippings

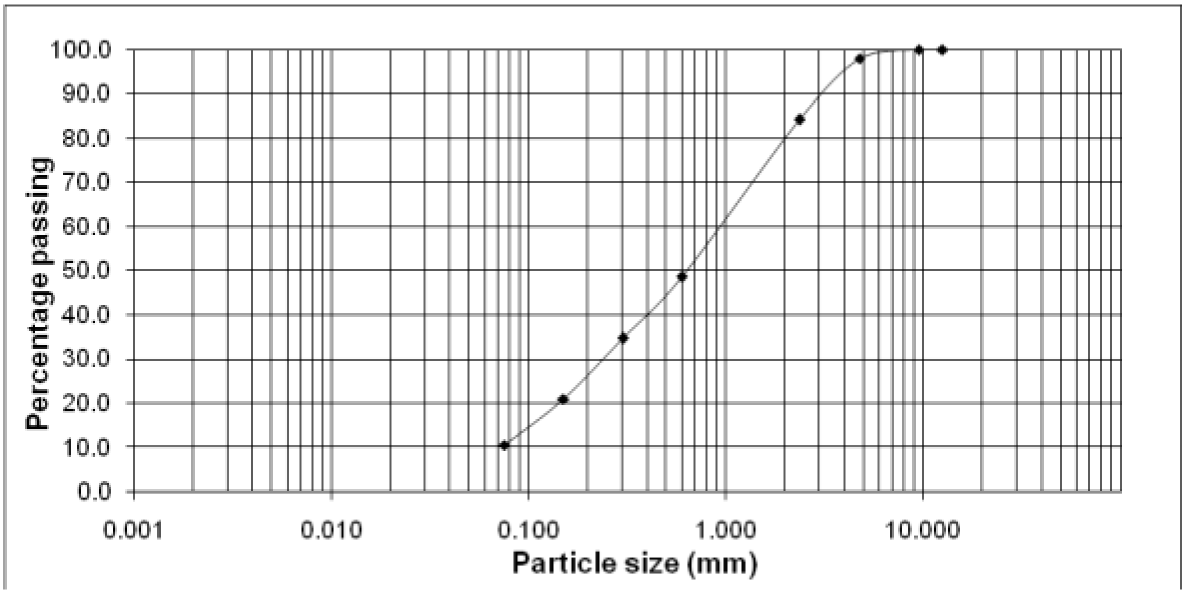

Figure 2: Particle Size Distribution for Quarry Sand

Table 3: Summary of Physical Properties of Aggregates used

Materials	Specific gravity	Los Angeles abrasion (%)	Aggregate Crushing (%)
Granite chippings	2.66	31.19	36.80
Quarrysand	2.55	-	-

Table 4: Summary of Ground Scrap Tyre Rubber (GSRT) used

Materials	Specific gravity
4.74mm	1.11
2.36mm	1.16
0.600mm	0.96

Table 5: Summary of Bitumen Used

Material	Specific gravity	penetration
Bitumen	1.03	63

Table 6: Results of Marshall Tests.

Rubber Content (%)	Rubber Particle Size (mm)	Marshall Stability (KN)	Flow (MM)	Air Void by Total Mixture (%)	Unit Weight (Kg)	Voids Filled with Bitumen (VMA) (%)	Height of Specimen (mm)	Specific Gravity
0		7.24	4.04	3.23	2.354	81.19	63.70	2.385
2	4.75	4.63	3.68	3.09	2.275	81.11	67.50	2.355
	2.36	5.47	3.71	3.05	2.288	81.92	67.30	2.360
	0.600	6.20	3.74	3.02	2.300	81.79	65.40	2.316
4	4.75	3.61	3.25	3.40	2.230	80.16	70.40	2.332
	2.36	4.95	4.05	3.53	2.276	79.45	67.90	2.335
	0.600	4.97	4.22	2.28	2.246	85.52	67.20	2.216
6	4.75	3.49	3.61	4.30	2.206	75.19	71.50	2.306
	2.36	4.90	4.52	4.46	2.268	74.56	70.40	2.311
	0.600	4.33	4.48	2.13	2.231	86.70	67.50	2.283
8	4.75	3.14	4.21	4.34	2.191	75.43	72.60	2.267
	2.36	4.85	4.97	4.76	2.177	73.63	71.60	2.289
	0.600	3.84	4.69	2.04	2.205	86.72	68.40	2.251
10	4.75	2.69	4.52	4.37	2.158	75.51	73.10	2.255
	2.36	4.28	5.54	4.89	2.164	72.89	72.00	2.265
	0.600	3.61	5.43	1.35	2.190	90.74	69.10	2.220

IV. Discussion

Table 6 show the results obtained from the various percentages of rubber content; however the marshal stability decreases with increased rubber content it will be seen on the basis of the benefits of rubberized asphaltic pavement as stated by [4] that rubberized asphaltic pavement lasts longer compared to traditional aggregate asphaltic pavement, it is more resilient, less prone to cracking, provides better traction, allows for quieter rides and de-ice more rapidly, considering these in consonance with the works of [12], [13] and [14] where the marshal stability results of three different rubber particle sizes followed the same trend as arrived at and presented in this research and summarizing same on the work of [10] where he arrived at adopting 2.0 as the minimum stability for medium volume traffic roads it will be concluded that hence all specimen tested for in this research indicated results above this minimum value, the work contain herein can be of high recommendation in terms of (MVTR). From the column indicating results of flow from the various percentages of rubber particles, it will be observed that the flow increases with increased rubber content which by interpretation mean better flexibility of the asphaltic material, basically the percentage air voids for medium volume roads ranges between 3%-5%, according to standard specification, [10]. It will be seen that only specimens produced with 4.75mm, 2.36mm and 2% of 0.600mm RPS meet these specification. Hence in as much as this research encourages the use of RPS in asphaltic pavement, certain percentages must be adhered to in order to meet standard specifications. The least height of specimen was recorded for 2% rubber content at 0.600mm particle size with result of 65.40mm against 0% rubber content with 63.70mm thereby enhancing considerable pavement thickness when laid at economic quantity. From table 6, it will be seen that the weight of the specimen is a product of the particle size of rubber, that is, the larger the particle size, the lesser the weight of the mixture. In terms of Voids Filled with Bitumen (VMA), 81.19% gotten from the 0% rubber content meets the Asphalt Institute Specification and it will be observed from table 6 that for all the various percentages of rubber content, rubber particle size 0.600mm gave result above 81.19% implying standard attainment but with consideration for particle size irrespective of percentage application. On the aspect of specific gravity, other than the 0% specific gravity, for all the percentages of rubber content ranging from 2% to 10%, rubber content particle size of 2.36mm gave the highest value of specific gravity.

V. CONCLUSION

Based on the results obtained from the Marshall tests conducted where it was noticed that the rubber modified specimens remained intact after failure it can be concluded that material possessing such engineering property indicates good impact resistance when used as pavement construction material hence, the use of 10% 4.75mm, 4% 2.36mm or 4% 0.600mm RPS by weight of aggregate in asphaltic concrete is highly recommended for medium traffic volume pavements.

VI. RECOMMENDATIONS

The adoption of 10% of 4.75mm RPS, 4% of 2.36mm and 0.600mm RPS is recommended for flexible road construction as it meets design criteria for medium volume pavements.

0.600mm rps modified asphalt is recommended for intersections (high volume and slow moving traffic) pavements.

For the purpose of environmental sanitation, economic material procurement and generation of wealth from waste, recycling activities should be encouraged by government and non-government institutions.

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