

Original research paper

UTILIZATION OF PLASTIC WASTES IN ASPHALT DESIGN FOR ROAD CONSTRUCTION

ABSTRACT

THE USE OF SYNTHETIC POLYMERS (PLASTICS) HAS BECOME PART OF OUR EVERYDAY LIFE SINCE THEIR INTRODUCTION OVER 100 YEARS AGO. EVERY VITAL SECTION OF THE ECONOMY RANGING FROM CLOTHING, AGRICULTURE, PACKAGING, AUTOMOBILE, MEDICINE, ELECTRICAL AND ELECTRONICS HAVE BEEN VIRTUALLY REVOLUTIONIZED BY APPLICATION OF PLASTICS. THE CHALLENGE OF THE DISPOSAL OF THESE PLASTICS AFTER USE IS WHAT THIS STUDY SEEKS TO ADDRESS IN PART. LOW DENSITY POLYETHYLENE (LDPE) AND POLYETHYLENE TEREPHTHALATE (PET) PLASTIC WASTES WERE BLENDED WITH BITUMEN AS BINDER FOR ROAD CONSTRUCTION AS AN EFFECTIVE AND VALUABLE MEANS OF DISPOSING THESE WASTES, EMPLOYING MARSHALL HOT-MIX DESIGN. 15% AND 30% W/W LDPE AND PET WASTES OF TOTAL BINDER REQUIRED FOR THE ASPHALT DESIGN WERE INCORPORATED AT 6% OPTIMUM BINDER CONTENT. THE POLYMER MODIFIED ASPHALTS (PMA) WERE TESTED FOR MARSHALL STABILITY AND FLOW. AT 15% W/W LDPE, THE STABILITY AND FLOW VALUES ARE 819KG AND 3.6MM, RESPECTIVELY, WHILE AT 30% W/W LDPE, THE STABILITY AND FLOW VALUES ARE 643KG AND 4.1MM, RESPECTIVELY. SIMILARLY, AT 15% W/W PET, THE STABILITY AND FLOW VALUES ARE 737KG AND 3.3MM, RESPECTIVELY, WHILE AT 30% W/W PET, THE STABILITY AND FLOW VALUES ARE 707KG AND 3.5MM, RESPECTIVELY. THESE RESULTS ARE IN AGREEMENT WITH THE "GENERAL SPECIFICATION FOR ROADS AND BRIDGES, VOL. II (1997)" OF THE FEDERAL GOVERNMENT OF NIGERIA, WHICH ARE 350KG MINIMUM AND 2-4MM FOR STABILITY AND FLOW, RESPECTIVELY. HOWEVER, THE 15% LDPE AND PET PLASTIC WASTES INCORPORATION GIVES BETTER RESULTS THAN THAT OF THE 30% INCORPORATION.

Keywords: plastic wastes, Marshal Stability, pollution, asphalt, binder

1. INTRODUCTION (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

MUNICIPAL SOLID WASTE MANAGEMENT HAS BECOME A THREAT TO THE ENVIRONMENT AND THE GREATEST PROBLEM FACING MANY URBAN AND SEMI-URBAN AREAS IN NIGERIA AND WORLDWIDE. AN AVERAGE NIGERIAN IS ESTIMATED TO GENERATE ABOUT 0.49KG OF SOLID WASTES PER DAY WITH HOUSEHOLD AND COMMERCIAL CENTERS CONTRIBUTING ABOUT 90% OF THE TOTAL URBAN WASTE BURDEN [1]. IN NIGERIA, PLASTICS CONSTITUTE BETWEEN 40% AND 60% OF THE VOLUME OF SOLID WASTES. IT WAS ESTIMATED THAT, KANO METROPOLIS GENERATED ABOUT 3085 TONNES OF SOLID WASTES PER DAY AND MORE THAN HALF OF THESE SOLID WASTES ARE PLASTICS [2]. THE MENACE OF PLASTIC WASTES IN NIGERIA CAN BE ATTRIBUTED TO A NUMBER OF ROOT CAUSES: FIRST AND FOREMOST IS THE FACT THAT, NO ONE IS PAYING FOR THE ADVERSE IMPACT THAT PLASTIC WASTES ARE CAUSING TO THE ENVIRONMENT; SECONDLY, PROPER COLLECTION AND DISPOSAL OF THE PLASTIC WASTES ARE NOT FACTORED IN THE PRODUCT COST OF THE MATERIALS, AS A RESULT, PLASTIC PACKAGES HAVE BECOME OVERLY SO CHEAP THAT THEY ARE GIVEN AWAY “FOR FREE” AT SUPERMARKETS AND KIOSKS [3].

AS A RESULT OF THE VAST APPLICATIONS (CONSUMPTION) OF PLASTICS ESPECIALLY LDPE AND PET, THE PRESSING QUESTION THAT NEEDS TO BE ADDRESSED IS, “*WHAT HAPPENS TO ALL THE PLASTICS AFTER USE?*” IN 2012, NIGERIA WAS FACED WITH A SERIOUS PROBLEM OF FLOOD, WHICH CLAIMED MANY LIVES AND PROPERTIES. MANY SEE PLASTIC AS THE NUMBER ONE CULPRIT IN THE 2012 FLOOD.

ACCORDING TO THE AMERICAN PLASTIC COUNCIL (APC), ONLY ABOUT 8% OF PLASTICS CONSUMED ARE RECYCLED. MOST END UP IN LAND FILLING AND INCINERATORS WHICH DOES NOT SOLVE THE PROBLEM OF POLLUTION. THEREFORE, THE ONLY WAY OF ADDRESSING THE PROBLEM OF DISPOSAL OF POST-INDUSTRIAL AND POST-CONSUMER PLASTIC WASTES IS THROUGH RECYCLING [4]. FOR THE PAST TWO DECADES RESEARCH HAS BEEN CONDUCTED ON THE USE OF POLYMER SUCH AS PET AND PE WASTE FOR PLASTIC MODIFIED ASPHALT (PMA) MIXTURE. THIS CAN SUCCESSFULLY IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENT AT LOW, INTERMEDIATE AND HIGH TEMPERATURE BY INCREASING MIXTURE RESISTANCE TO FATIGUE, CRACKING, THERMAL CRACKING AND PERMANENT DEFORMATION [5].

IN A REPORT BASED ON EXPERIMENT, ASPHALT MIXTURE WITH WASTE PE MODIFIER UP TO 10% AND WASTE PVC MODIFIER OF 7% CAN BE USED FOR FLEXIBLE PAVEMENT CONSTRUCTION IN WARMER REGION FROM STAND POINT OF STABILITY, STIFFNESS AND VOIDS CHARACTERISTICS. THE RESULTS OBTAINED INDICATE THAT, THE UNIT WEIGHT AND STABILITY OF THE COMPACTED SPECIMEN SHOWS AN APPRECIABLE INCREASING BEHAVIOR INITIALLY WITH AN INCREASE OF PE AND PVC CONTENT IN BITUMEN. AFTER REACHING TO AN OPTIMUM CONTENT OF PE AND PVC, IT SHOWS A DECLINING BEHAVIOR WITH THE INCREMENT OF PE AND PVC ON BINDER [6]. THIS STUDY SEEKS TO INCORPORATE UP TO 30% W/W LDPE AND PET PLASTIC WASTES OF TOTAL BINDER REQUIRED FOR THE ASPHALT DESIGN INTO BITUMEN FOR ROAD PAVEMENT. THIS WILL HELP TO SECURE AN ENVIRONMENT FRIENDLY WAY OF PLASTIC WASTES DISPOSAL, IMPROVE SOIL COMPOST FOR AGRICULTURE, REDUCE THE DEMAND OF BITUMEN, REDUCE THE COST OF ROAD CONSTRUCTION AND CREATE JOB OPPORTUNITIES.

2. MATERIAL AND METHODS

Sample Collection The Polyethylene Terephthalate (PET) and Polyethylene (PE) wastes were collected from a wastes dump-site in Mista Ali, Zaria road, Bassa LGA, Plateau State. The 60/70 Bitumen and aggregates (14mm, 10mm and stone dust) were graciously obtained from P.W Nigeria Limited, Vom Quarry, Plateau State.

Sample Treatment

The plastic waste types were washed in a warm solution of detergent and bleach to remove dirt and to disinfect, after which they were sundried and sorted according to the SPI code. This was followed by shredding into sizes between 2 and 4mm with a pair of shear (scissors).

Aggregate Testing:

The aggregates were tested (analyzed) according to the British Standard for testing aggregates (BS 812) to employ a job-mix and to ensure the aggregates are of standard and sound quality to for use in the asphalt design.

a) Sieve analysis of aggregate

The practical combination of wearing coarse is expected not more than 1200g. A representative sample of each of the aggregates was riffled using riffle box. 75% by weight of the total mix (1200g) was assigned for stone dust, 5% for 10mm aggregate and 20% for 14mm aggregate. It was then poured into the vertically arranged sieve of the following seizes 20mm, 14mm, 10mm, 6.3mm, 1.18mm, 600µm, 150µm, 75µm and the base. The weight retained at each sieve after sieving was noted so as to get the percentage retained,

$$\% \text{ Retained} = \frac{\text{weight retained}}{1200} \times 100 \quad \text{----- (1)}$$

b) Determination of Specific Gravity of Aggregates

First, an empty Picnometer was weighed and the weight labeled A. Next, the aggregates (14mm) were added to the picnometer and weighed, which was labeled B. The picnometer containing the aggregate was then filled with water to the brim and weighed (C). Again, the picnometer filled to the brim with water only was weighed and labeled D.

The specific gravity was calculated using the formula

$$\text{Specific gravity (SG)} = \frac{(B-A)}{(D-A) - (C-B)} \text{ mg/m}^3 \quad \text{----- (2)}$$

Note that, the above was repeated for 10mm aggregates and stone dust.

The specific gravity of the mixed aggregate (SGMA) is calculated using the formula below:

$$\text{SGMA} = \frac{100}{(20/\text{S.G of 14mm}) + (5/\text{S.G of 10mm}) + (75/\text{S.G of dust})} \quad \text{----- (3)}$$

c) Determination of elongation index of aggregates.

The Aggregates that passed through sieve 14mm and were retained in 10mm during sieve analysis were weighed and then passed one after another through the "14 to 10mm" space on the elongation index test instrument. The aggregates which passed successfully were weighed and the percentage retained was calculated using the formula below

$$\% \text{ Retained} = \frac{\text{weight retained}}{1200} \times 100 \quad \text{----- (4)}$$

d) Determination of Flakiness Index of Aggregates

The Aggregates that passed through sieve 14mm and were retained in 10mm during sieve analysis were weighed and then passed one after another through the "14 to 10mm" space on the flakiness index test instrument. The aggregates which passed successfully were weighed and the percentage passing was calculated using the formula below

$$\% \text{ Passed} = \frac{\text{weight passed}}{1200} \times 100 \quad \text{----- (5)}$$

e) Determination of Impact Value of Aggregates

The sample of 14mm aggregates were collected and riffled in the riffle box. The mould of the impact value machine was filled with the riffled sample and then compacted using tamping rod with 15 strokes. The mould was taken back into the machine and the sample was then rammed with 15 blows. The rammed sample was weighed and then passed through the BS sieve of mesh size 2.36mm and the percentage passed was calculated using the formula below

$$\% \text{ Passed} = \frac{\text{weight passed}}{1200} \times 100 \quad \text{----- (6)}$$

Asphalt Hot Mix Design with Polyethylene (PE) and Polyethylene Terephthalate (PET) Plastic Wastes

The asphaltic design of 6% optimum binder content was done for three different percentages of PET and PE waste in the total mix. The design was done for

- Asphalt free of plastic wastes.
- 85% bitumen and 15% plastic wastes.
- 70% bitumen and 30% plastic wastes.

a) Job Mix for 100% Bitumen with 0% Plastic Wastes

$$\text{I. 6\% Bitumen} = \frac{6}{100} \times 1200 = 72\text{gms} \quad \text{----- (7)}$$

$$\text{II. 94\% Aggregates combination} = \frac{94}{100} \times 1200 = 1128\text{gms} \quad \text{----- (8)}$$

Job mix formula for each aggregates type

$$\begin{aligned} 14\text{mm aggregates} &= 20\% \text{ of } 1128 = 226\text{gms} \\ 10\text{mm aggregates} &= 5\% \text{ of } 1128 = 56\text{gms} \\ \text{Stone dust} &= 75\% \text{ of } 1128 = 846\text{gms} \\ \text{Total} &= 1128 \end{aligned} \quad \text{----- (9)}$$

b) Job Mix for 85 % Bitumen with 15 % Plastic Wastes

$$\text{Plastic waste} = 15\% \text{ by weight of total binder} = \frac{15}{100} \times 72 = 11\text{g}$$

141 ----- (10)

142 Bitumen = 85% by weight of total binder = $\frac{85}{100} \times 72 = 61g$

143 The Job mix of each aggregate type is maintained.

144 **c) Job-Mix for 70 % Bitumen with 30% Plastic Wastes**

145 Plastic waste = 30% by weight of total binder = $\frac{30}{100} \times 72 = 22g$

146 ----- (11)

147 Bitumen = 70% by weight of total binder = $\frac{70}{100} \times 72 = 50g$

148 The Job mix of each aggregate type is maintained.

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150 Design Procedure

151 The design was done in duplicate for each job-mix. First, the aggregates of different sizes were
152 collected and sun dried to remove moisture. The different aggregate sizes were heated on a sample
153 tray to a temperature of 150°C in the oven. The plastic wastes were melted separately (PET wastes
154 was melted at 250°C while LDPE wastes was melted at 110°C) and the bitumen also, was heated to
155 150°C.

156 The aggregates and binder (bitumen or bitumen and plastic wastes, as the case may be) were mixed
157 according to the job-mix, for the three different cases. The mixture was then properly mixed on a
158 source of heat with temperature maintained at 150°C. The hot mixture was poured into a warm
159 standard Marshall Compaction mould and compacted with 75 blows given at both sides (150 blows
160 altogether).

161 On cooling, a protruding jack was used to remove the compacted asphalt from the mould. The asphalt
162 was then left to set for at least 24 hours, after which it was tested for Marshall stability and flow.

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164 3. RESULTS AND DISCUSSION

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166 Results of Sieve Analysis for Wearing Course Practical Combination Mix

167 The result on table 1 below shows the size distribution of the mixed aggregates (practical
168 combination) which shows the quality of the aggregate and also serve as a guide to obtain the
169 percentage job-mix of the aggregate types. The percentage passing fall within the specification (BS
170 812) which is also in line with the "General Specification for Roads and Bridges, Vol. II"(1997), of the
171 Federal Government of Nigeria, therefore, 20%, 5% and 75% by weight were chosen for 14mm, 10mm
172 aggregates and the dust, respectively, for the job-mix.

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178 **Table 1: Results of Sieve Analysis for Wearing Course Practical Combination Mix**

Sieve Size	Weight Retained	% Retained	% Passed	BS 812 Specification
20mm			100	100
14mm	21	1.8	98.2	85 – 100
10mm	177	14.8	83.4	75 – 92
6.3mm	128	10.7	72.7	65 – 82
2.36mm	215	17.9	54.8	50 – 65
1.18mm	133	11.1	43.7	36 – 51
600µm	110	9.2	34.5	26 – 40
300µm	102	8.5	26.0	18 – 30
150µm	138	11.5	14.5	13 – 24
75µm	77	6.4	8.1	7 – 14
Passing 75µm	99	8.2		
TOTAL	1200			

179 **Results of Specific Gravity for Mixed Aggregates**

180 Specific gravity is a measure of a material's density (mass per unit volume) as compared to the
 181 density of water at 23°C. Correct and accurate material specific gravity determinations are vital to
 182 proper mix design. An incorrect specific gravity value will result in incorrect calculated volumes and
 183 ultimately result in an incorrect mix design. It can also indicate possible material contamination. Again,
 184 specific gravity differences can be used to indicate a possible material change. A change in aggregate
 185 mineral or physical properties can result in a change in specific gravity. The specific gravity of the
 186 mixed aggregates determined was found to be 2.63 as shown below, which meet the specification of
 187 2.5 to 3.0 as given in BS 812. Therefore the aggregates are fit to be used for the design.

188 **Table 2: Results of Specific Gravity for Mixed Aggregates**

Material	14mm aggregate	10mm aggregate	Stone dust
Mass of picnometer (A)	340.5	340.5	340.5
Mass of picnometer + sample (B)	965.2	935.2	903.3

Mass of picnometer + sample + water (C)	1579.4	1576.8	1559.9
mass of picnometer + water only (D)	1210.3	1210.3	1210.3
Specific gravity = $\frac{B-A}{(D-A)-(C-B)}$	2.63	2.61	2.64

189 The specific gravity of the mixed aggregates (SGMA) is calculated to be = 2.63

190 Results of Elongation Index and Flakiness Index Tests

191 Table 3 shown the elongation index and flakiness tests results. The elongation index is a
 192 characterization used in the super-pave specification to identify aggregates that may have a tendency
 193 to impede compaction. The elongation index value must be less than 30% according to the "General
 194 Specification for Roads and Bridges, Vol.II" (1997), of the Federal Government of Nigeria and also
 195 according to BS812. The result obtained as shown on Table 3 shows that the aggregates fall within
 196 the specification, having a value of 22.9%. Therefore, the aggregate is suitable for use in asphalt
 197 design.

198 Flakiness index shows the percentage of particles in a coarse aggregate that have a thickness
 199 (smallest dimension) of less than one-half of the nominal size. This too, must have a value of less
 200 than 30%, to be seen fit for use in road pavement as given on the "General Specification for Roads
 201 and Bridges, Vol. II" (1997), of the Federal Government of Nigeria and also on BS812. The result as
 202 given on the table above shows that the aggregates meet the standard, having a value of 22.2%.

203 **Table 3: Results of Elongation Index and Flakiness Index Tests**

	Elongation Index	Flakiness Index
Total weight of sample, A (g)	177	177
Weight retained, B (g)	40.5	39.2*
Elongation index $\frac{B}{A} \times 100$	22.9%	22.2%
BS 812 Specification	<30%	<30%

204 Where 39.2*= weight passing.

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206 Results of Aggregate Impact Value (AIV) Test

207 Aggregate impact value shows the resistance of the aggregate to sudden shock or impact. The
 208 classification of aggregates based on AIV is as below:

209 <10% - Exceptionally strong 10-20% - Strong

210 20-30% - Satisfactory for road surfacing

211 >35% - Weak or not suitable for road surfacing

212 In essence, it must have a value less than 30% to be fit for use in road pavement. The value as
213 shown on table 4 indicates that the toughness or resistance of the aggregate to impact is good, as it
214 falls within specification given (BS 812) and on the "General Specification for Roads and Bridges, Vol.
215 II" (1997), of the Federal Government of Nigeria. The value of 13.39% shows it to be a strong
216 aggregate.

217 **Table 4: Results of Aggregate Impact Value (AIV) Test**

	1 st Run	2 nd Run
Weight of material, A (g)	680	683
Weight of material passing sieve No.7 (2.36mm), B (g)	91	95
Aggregate impact value $\frac{B}{A} \times 100$	13.38	13.39
Aggregate impact value (AIV)	13.39%	
BS 812 Specification	<30%	

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220 **Results of Voids in the Hot Mix Design**

221 Table 5 below shows results of voids. The voids show the gap or opening in the mixed aggregates
222 and total mix. The voids filled with binder (bitumen alone or bitumen with LDPE and PET wastes), is
223 the inter-granular space occupied by the binder. Whereas, voids in total mix is the percentage of
224 space filled by air.

225 The voids as given on the table shows that, both the voids in total mix and the voids filled with
226 aggregates are slightly out of the specification as given by the Federal Ministry of Works and Housing,
227 Nigeria (1997). This can be attributed to the fact that, both the aggregates elongation and flakiness
228 index values are high even though within the specification, as even the mix without the plastic wastes
229 is also out of specification. This also agrees with the work reported by Rahman *et al* (2012) and
230 Mohammad and Lina (2007) that, after reaching an optimum PE waste incorporation of 12% and 10%
231 by weight of total binder, respectively, a declining behavior was observed [6-7]. This however,
232 suggests that, the life span of the plastic modified road in areas with high rainfall may be shorter than
233 that in warmer area

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239 **Table 5: Results of Voids in the Hot Mix Design**

S/No.	Samples	Void in Total Mix (VTM), %	Voids in Mineral Aggregate (VMA), %	Voids filled with Bitumen, %
1	100% Bitumen with 0% LDPE waste(100:0)	6.12	17.79	67.95
	100% Bitumen with 0% PET waste(100:0)	6.12	17.79	68.63
2	85% Bitumen with 15% LDPE (85:15)	7.35	18.87	63.86
	85% Bitumen with 15% PET waste(85:15)	7.35	18.87	63.86
3	70% Bitumen with 30% LDPE (70:30)	8.16	19.58	61.03
	70% Bitumen with 30% PET waste(70:30)	10.61	21.73	53.52
Specification as given by the Federal Ministry of Works and Housing, Nigeria (1997).		3 – 5 %	16 - 19%	63 – 72%

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241 **Results of Marshall Stability and Flow Tests**

242 The Marshall Stability and flow tests provide the performance prediction measure for the Marshall
 243 designed asphalt. The stability portion of the test measures the maximum load supported by the
 244 specimen at loading rate of 50.8mm/min at standard temperature of 60°C. During the loading, an
 245 attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading.
 246 The flow value is the deformation the Marshall Test specimen undergoes during the loading, up to the
 247 maximum load, 0.25mm units.

248 The results for the Marshall stability and flow as shown on table 6, falls within the specification given
 249 on the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of
 250 Nigeria.

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255 **Table 6: Results of Marshall Stability and Flow Tests**

S/No.	Samples	Marshall Stability (kg)	Marshall Flow (mm)
1	100% Bitumen with 0% LDPE waste(100:0)	1406	3.0
	100% Bitumen with 0% PET waste(100:0)	753	3.0
2	85% Bitumen with 15% LDPE (85:15)	819	3.6
	85% Bitumen with 15% PET waste(85:15)	737	3.3
3	70% Bitumen with 30% LDPE (70:30)	643	4.1
	70% Bitumen with 30% PET waste(70:30)	707	3.5
Specification as given by the Federal Ministry of Works and Housing, Nigeria (1997).		350kg minimum	2-4mm

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4. CONCLUSION AND RECOMMENDATION

Conclusion

261 The results obtained from the research indicate that, Low-Density Polyethylene (LDPE) And
262 Polyethylene Terephthalate (PET) Wastes can be used to contribute to the binder content in asphalt
263 concrete for wearing course by the Marshall hot mix design method. That is, some percentage by
264 weight of bitumen required for asphaltic concrete can be replaced with plastic wastes. The results also
265 points to the fact that, LDPE and PET incorporation of 15% w/w of binder required, gives better result
266 than that of the 30% w/w LDPE and PET wastes incorporation in terms of the Marshall stability, flow,
267 and voids.

268 This is an environmental friendly way of disposing plastic wastes and will go a long way in addressing
269 the menace of streets, towns, cities and ocean littering by plastic wastes. Soil fertility degradation as a
270 result of the poor aeration and poor water penetration caused by these plastics can be checked,
271 thereby improving compost for agriculture by separation of the plastic from other municipal solid
272 wastes which are biodegradable.

273 Economic wise, the cost of road construction will be reduced by 11g per every 72g of bitumen
274 required for asphalt concreting is saved. That is, about 15% of the cost of bitumen required for road

275 pavement is cut down of which the cost of collection, sorting, cleaning and shredding of the plastic
 276 wastes cannot account for this cost. Also, the service of people for the collection, sorting and cleaning
 277 of the wastes will be needed and as such, job opportunities will be created.

278 **Recommendations**

- 279 1. The incorporation of Low-Density Polyethylene (LDEP) And Polyethylene Terephthalate (PET
 280) plastic wastes of 15% by weight of binder content required in asphalt for road pavement
 281 should be imbibe by the government of Nigeria.
- 282 2. There should be a workable policy by the Nigerian government on plastic wastes disposal and
 283 proper labeling of plastic product according to the SPI code by manufacturers, so as to help in
 284 the sorting of plastic wastes.
- 285 3. The blending of two different polymer types with bitumen for road pavement should be
 286 research on to checked for it performance. For instance, blending Polyethylene Terephthalate
 287 and polyethylene together, with the bitumen and checked for performance.
- 288 4. Production of shredding machine for plastic sizing to specified sizes (2-4mm)

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