Utilizing Waste Plastic Bottles in Bituminous Asphalt Mix

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ABSTRACT

This research use Polyethylene Terephthalate as hot mix asphalt modifier. Polyethylene Terephthalate is one component of plastic material, and the research is concerned with the possibility of utilizing waste plastic bottle as an ingredient in asphalt concrete to increase the mixture engineering property and at the same time decrease cost of construction by decreasing the amount of asphalt cement (bitumen) required.

The experimental work includes all aggregate quality physical Property tests, bitumen tests and asphalt concrete mix design by using Marshall Method of mix design for both modified and unmodified mix. In this specific investigation the dry process is used for introducing the plastic in to the asphalt cement; in dry process Polyethylene Terephthalate size passing 1.18mm sieve. Overall, more than 114 Marshall Samples with, plastic content of 0%, 0.3%, 0.6%, 0.9%, 1.2%, and 1.5%, also Bitumen contents with 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% both by weight of total aggregate were prepared.

The first step of this investigation was to find the proper method of mixing and plastic size that could be effectively employed in to the asphalt cement. Due to this trial and error procedure additional 82 Marshall Specimen were prepared and tested.

This research only focuses on modifying the asphalt mix mechanical property and have not made any investigation on its environmental effect while in use.

Key Words:
Polyethylene Terephthalate ,Ethiopian Road Authority , American Society for Testing and Materials ,Optimum Bitumen Content ,Void Filled with Asphalt, Void in the Mineral Aggregate ,Void in the Mix, Bulk Specific Gravity ,HMA Hot Mix Asphalt ,AC Asphalt Concrete , Mineral Filler A fine material used in asphalt concrete to compensate very fine aggregates shortages

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1. Polymer Modification

As Ethiopia is one of the fastest growing economies in the world, road construction is being carried out in a vast range. These roads are usually a mixture of Aggregate, Bitumen, and mineral fillers. Bitumen is a byproduct of crude oil; but since Ethiopia yet doesn't produce crude oil, bitumen is not available locally. This leads to a high cost and loss of foreign currency.

Utilization of waste material as secondary construction input is being developed worldwide. One of these waste materials is plastic bottle which is produced in large amount. In food industries, plastic bottle is mostly made by Polyethylene Terephthalate (PET), and PET become very popular during the last decade because it is known as safe, durable and good material for packaging. Today, producing waste plastic becomes a main problem in many societies where it can be found almost everywhere specially in landfills. Hence, waste plastic may cause environmental pollution because it is not a biodegradable material.



Figure1. Collected and stored waste plastic bottles

Thus, it would be rewarding if waste plastics can be reused, for instance, in projects such as pavement construction as a useful material in order to improve service life of road pavement in one way and preventing from environmental pollution as well.

2. Objective

The first and main objective of our research is to Utilize Waste Plastic Bottles in Bituminous Asphalt Mix by recycling waste plastic bottles that are highly polluting our country, mostly Addis Ababa. The plastic bottles or scientifically PET, are one of the biggest potential threat for the environment and health of the community. So this research is to promot

- clean community and at the same time generate income by collecting waste plastic bottles.
- decrease the amount of bitumen used in the asphalt mix at the same time increasing the quality of the asphalt mix
- save foreign currency which is lost by importing bitumen material.
- increase engineering characteristics of the mix which leads to high quality of highways with longer life and smaller cost.

3. Methodology

The Marshall samples were prepared according to ERA 2012, Asphalt Institute, and ASTM D1559 specifications. Mixes consisting of 0%, 0.3%, 0.6%, 0.9%, 1.2%, and 1.5% PET by weight of total aggregate and different bitumen contents; 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% by weight of total aggregate has been used for this investigation. These additives can be used in two ways: wet or dry processes. In wet process the additives will be added in asphalt, modified asphalt, before mixing with aggregate particles, the hot asphalt and the plastic will be stirred at high speed until homogeneous.

This method requires substantial additional funds including fuel, and asphalt mixer at high speed; however, in a different procedure, the dry process will be considered by adding the additive directly into the aggregate rather than asphalt, this method offers easier way to insert the plastic into the hot aggregate, without requiring any other equipment of mixture. In this case, using waste materials as additives in dry process would be a better solution in order to prevent additional costs. Hence, this paper completes its investigation using only dry process.

According to ERA 2012 manual and other specifications a minimum of three trial specimens of Marshall should be prepared for same asphalt

contents, in this investigation over 114 Marshall samples were prepared and tested. In these processes, PET size < 1.18mm sieve size were effective; other sizes 4.75mm - 0.075 mm, 4.75 – 2.36, and 2.36mm - 1.18mm were also used but their effect is very low, and in some cases, they even decrease the Marshall stability, this is due to high melting point of PET (typically >250°$_C$.

4. Experimental Works

Prior to the experimental works, aggregate tests such as; Specific gravity, water absorption, gradation, Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Sodium Sulphate Soundness, Los Angeles Abrasion (LAA), Coating and Stripping, Flakiness Index, Sand equivalence, and 10% Fine Value were obtained. Also, Bitumen tests; Penetration, Softening Point, Ductility, Flash & Fire Point, and Solubility in Trichloroethylene was obtained according to ERA 2012 Manual Specifications. After a lot of observations and considerations the following processes were used in all 114 Marshal samples prepared to determine the optimum asphalt and PET content.

The overall process is;

- The aggregate which are obtained from the batch plat was thoroughly washed and dried at 110°$_C$ for a minimum of 12hrs.
- After taking out the aggregate from the oven and allow them to cool the materials are sieved with serious of sieves compiling with ERA 2012 Pavement Design Manual. And transferred in to plastic bags and marked.
- Required quantity of Coarse aggregate, Fine Aggregate, and mineral filler in this case 1150g were taken in to an iron pan and kept in an oven at a temperature of 165°$_C$ (only the Coarse & Fine Aggregates) for a minimum of 24hours. The iron pan containing the mineral filler is kept in different oven at a temperature of 70°$_C$ in order to avoid over burning. Preheating is required because the aggregates, PET, and bitumen are to be mixed in heated state, and to remove moisture in the aggregate completely.
- The heated aggregate is then transferred in to asphalt mixing machine and the required amount of shredded PET was weighed and applied in to the aggregate. Mixing time is between 120 sec - 180 sec.
- After the aggregate and PET has been thoroughly mixed in a dry process, the required amount of bitumen is applied to the mixture and mixed for 120 seconds. While mixing the temperature should be in a range of 160°$_C$ - 165°$_C$.
- Then the mix was transferred in to a casting mold, 75 blows were given each side of the sample. Then each sample were marked and kept separately, and allowed to cool overnight so that no deformation will result when removed from the mold by extrusion jack.

5. Results and Discussion

The following results are based on a laboratory evaluation done in CRBC - Addis. In which the aggregate gradation was kept constant and different percentage of asphalt and PET contents applied. The weight of the aggregate used to create each specimen was 1150g to which a calculated amount of 80/100 penetration grade bitumen and PET both by weight of total aggregate was added to individual specimen. For each of these variations three specimens were prepared and tested. The final result of the tests conducted on bituminous asphalt mixture with and without PET is presented in the tables below.

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.254	6.2	15.6	60.1	7.57	2.06
4.50%	2.262	5.5	15.7	65.0	8.10	1.91
5.00%	2.266	4.8	16.2	70.3	9.67	2.22
5.50%	2.293	4.1	15.4	73.5	9.95	2.21
6.00%	2.282	3.6	16.2	78.0	9.12	2.63
6.50%	2.276	3.2	16.8	81.2	9.18	2.40

Table 1. 0% PET (Conventional Mix, Without PET)

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.256	6.2	15.8	61.0	8.53	2.31
4.50%	2.265	5.5	15.8	65.4	9.97	2.39
5.00%	2.284	4.9	15.6	68.5	11.68	2.57
5.50%	2.287	4.2	15.9	73.3	11.46	2.96
6.00%	2.277	3.7	16.6	77.4	10.73	3.41
6.50%	2.250	3.4	18.0	81.1	10.24	3.06

Table 2. 0.3% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.258	6.5	15.9	58.9	10.30	2.40
4.50%	2.267	5.6	16.0	65.0	11.67	2.50
5.00%	2.287	5.1	15.7	67.5	12.09	2.94
5.50%	2.287	4.3	16.0	73.1	11.55	3.52
6.00%	2.275	3.8	16.9	77.5	10.89	3.91
6.50%	2.262	3.4	17.7	80.8	10.93	3.12

Table 3. 0.6% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.247	6.8	16.6	59.1	12.54	2.92
4.50%	2.265	5.5	16.3	66.2	13.28	3.01
5.00%	2.278	4.7	16.3	71.2	13.41	3.19
5.50%	2.259	3.8	17.3	78.3	13.24	3.19
6.00%	2.245	4.0	18.3	78.3	12.26	3.26
6.50%	2.234	3.4	19.0	82.1	11.45	3.22

Table 4. 0.9% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.239	7.2	17.1	57.8	10.98	3.17
4.50%	2.253	6.6	17.0	61.4	10.90	3.26
5.00%	2.268	5.2	16.8	69.2	12.47	3.29
5.50%	2.245	4.2	18.1	76.9	11.57	3.29
6.00%	2.242	3.9	18.5	79.2	11.42	3.36
6.50%	2.232	3.8	19.3	80.5	10.13	3.42

Table 5. 1.2% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.249	7.6	17.0	55.4	10.16	3.56
4.50%	2.248	7.0	17.5	60.2	10.25	3.47
5.00%	2.261	5.7	17.3	67.0	11.36	3.59
5.50%	2.251	4.8	18.0	73.5	10.98	3.62
6.00%	2.236	4.0	19.0	79.0	10.82	3.75
6.50%	2.229	3.6	19.6	81.7	10.40	3.81

Table 6. 1.5& PET by Weight of Aggregate

From the trend of Fig. 2. it is observed that the Bulk Specific Gravity of the compacted specimen slightly increased for PET content 0.3% and 0.6%. But the value of BSG decreased for PET content of 0.9%, 1.2%, and 1.5% from the conventional mix value. In ERA 2012 Pavement Design Manual, there is no specified minimum or maximum value of specific gravity, but the value of the specific gravity is controlled by keeping the value of VIM between 3 - 5% as specified in ERA 2012 Pavement Design Manual. This is due to, the presence of non-molten PET even after mixing the aggregate and the PET for at least two minutes. Hence, this PET's will result in a decrease of the density as the weight of the PET is smaller than that of bitumen and at the same time results in the increment of the VIM. The Value of BSG for the conventional mix is 2.281 and for the PET content of 1.5% the BSG reduced to 2.247; and the percentage reduction is 1.49%. It has been mentioned that the first aim of this research is to increase the engineering properties of bituminous asphalt mix and also decrease the cost of construction. From fig. 3, it is shown that the stability value has drastically increase when the content of PET increased up to some level, but passing that level the stability decrease. ERA 2012 Pavement Design Manual gives a minimum value of 8000N for (1 - 5) * 106 ESA.

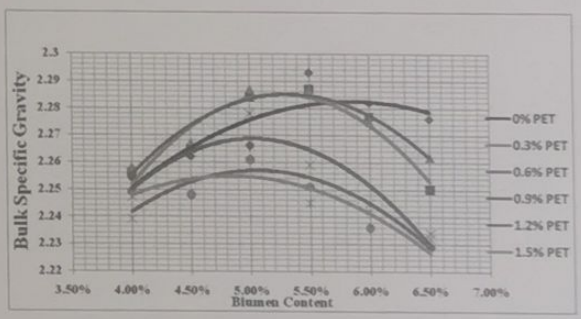


Figure 2. Bulk Specific Gravity Vs Bitumen Content

It is also possible to observe that not only the increment of the stability but also the max value of each PET content shift toward left. This implies that the OBC will be decreased as the content of PET increases; this will decrease the amount of bitumen required.

The Marshall Stability value with 0.9% PET was found to be 13.30KN, which is higher than the conventional value of 9.34KN and the percent-

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6.50%	2.250	3.4	18.0	81.1	10.24	3.06

Table 2. 0.3% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.258	6.5	15.9	58.9	10.30	2.40
4.50%	2.267	5.6	16.0	65.0	11.67	2.50
5.00%	2.287	5.1	15.7	67.5	12.09	2.94
5.50%	2.287	4.3	16.0	73.1	11.55	3.52
6.00%	2.275	3.8	16.9	77.5	10.89	3.91
6.50%	2.262	3.4	17.7	80.8	10.93	3.12

Table 3. 0.6% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.247	6.8	16.6	59.1	12.54	2.92
4.50%	2.265	5.5	16.3	66.2	13.28	3.01
5.00%	2.278	4.7	16.3	71.2	13.41	3.19
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6.00%	2.242	3.9	18.5	79.2	11.42	3.36
6.50%	2.232	3.8	19.3	80.5	10.13	3.42

Table 5. 1.2% PET by Weight of Aggregate

Bitumen Content (By Weight of Aggregate)	Bulk Specific Gravity	VIM	VMA	VFA	Stability	Flow
4.00%	2.249	7.6	17.0	55.4	10.16	3.56
4.50%	2.248	7.0	17.5	60.2	10.25	3.47
5.00%	2.261	5.7	17.3	67.0	11.36	3.59
5.50%	2.251	4.8	18.0	73.5	10.98	3.62
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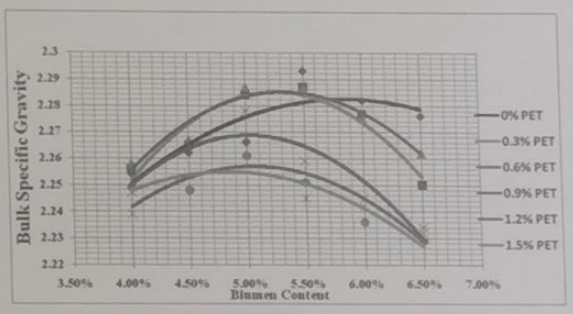


Figure 2. Bulk Specific Gravity Vs Bitumen Content

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The Marshall Stability value with 0.9% PET was found to be 13.30KN, which is higher than the conventional value of 9.34KN and the percent-

age increase in stability value has been found to be 42.4%. On the other hand, the OBC decreased up to some point and starts to go up again, it is found that the OBC of the conventional mix is 5.74% by weight of aggregate and the OBC of 0.9% PET is found to be 5.26% both by weight of aggregate. The Percentage reduction in bitumen content is found to be 8.36%.

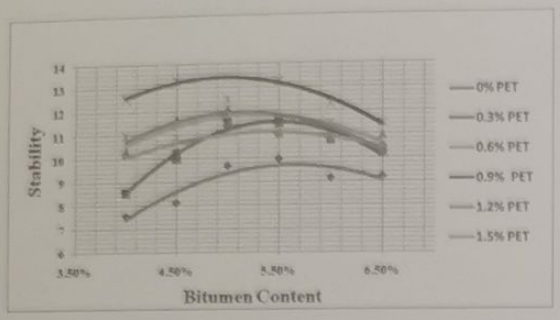


Figure 3. Stability Vs Bitumen Content

The increase in stability is due to the ability of the PET to modify the strength of the aggregate by coating around and forming a thing film, and also by increasing the bonding between bitumen and aggregate. This process can be explained scientifically as follow, Waste Polymers or PET is hydrocarbon with long chains. The bitumen is a complex mixture which is also long chain hydrocarbons. When bitumen is mixed with plastic coated aggregate a portion of bitumen diffuse through the plastic layer and binds with aggregate. The plastic layer has already bonded strongly with the aggregate. During this process three-dimensional internal cross-linked network structure results between polymer molecules and bitumen constituters. Therefore, the bond becomes stronger and the removal of bonded bitumen becomes difficult.

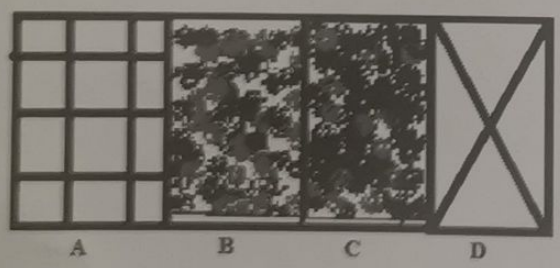


Figure 4. Plastic aggregate bitumen interaction model for the plastic waste coated aggregate, and bitumen mix

Where

A, is Area of Plastic Bonded with aggregate (PET Coating)

B, is area of bitumen- Plastic blend (due to diffusion between molten PET and hot bitumen)

C, is area of loosely bonded bitumen with dispersed PET

D, is area of plain bitumen layer (No PET coating)

6. Conclusion

Overall, the effect of PET on the properties of the Marshall specimen were satisfactory. For the Density - Voids analysis the PET did not cause the values to exceed the suggested range of values in standards. In this study, a total of 114 Marshall samples were prepared and tested. The samples were prepared from a combination of aggregate, mineral filler, bitumen, and PET; the aggregate are graded accoding to ERA 2012 Flexible Pavement Design Manual, where PET of < 1.18 mm sieve size was considered. The effecct of waste plastic bottles in bitumunious asphalt mix has been studied by varying the concentration of asphalt by 0.5% increment and by varying the concentraion of PET by 0.3%. Based on this study, the following findings were made:

- From the Laboratory investigations the Optimum PET content is found to be 0.9% by weight of total aggregate.
- The total amount of PET to be utilized is about 2.07 tone/lane of 3.6m/km with 5cm thickness.
- After the rough cost analysis based on the bitumen reduction, the percentage reduction in cost by utilizing the waste plastic found to be 8.52% compared to the conventional mix with out PET.
- The Flow value of Marshall specimens with PET has shown a slight increament, but with in the limit of 2 - 3.5%.
- The Retained Stability also show an increament, this increament indicate that the presence of PET in the HMA has improved the bonding energy between the aggregate and the asphalt cement. Hence, PET is usefull in decreasing the water susceptability of the bitumnious mixute.

- VIM is the total perecentage of void in the mix; according to the investigation made the VIM increase as the amount of PET increases. This is the effect of the reduction in BSG as the amount of PET increase. Evenif the value of the VIM increased with respect to increament in PET it is within the limit of 2 - 5 %.
- The value of VMA at 4% VIM, is calculated for each PET contents and it is observed that the VMA increased as the Percentage of PET increased. The increament of VMA is due to the presence PET which are not molten even after the dry process for a minimum of 120 seconds.
- The Value of VFA has shown a reduction as the perecentage of PET increased. This is due to the increament of VMA as the perecentage of PET increased.

From all the above observations it is concluded that the use of waste plastic bottles in bitumunious asphalt mix has improved the over all engineering properties of bitumunious mixes. Thus, this investigation explores not only the utilization of plasitc bottles, but also provides an opportuity to improve pavement material in surface courses thus makingn it more durable.

7. Recommendation

One reason why these preliminary results are positive is that it should be possible to improve them significantly through further research. By performing an extensive Marshall Mix design, the OBC for each PET amount could be determined. In addition the aggregate gradation, aggregate type, and size and state of the PET could be altered so that the positive effects of the PET on the internal friction of the mixture could be optimized. The point at which the PET is added to the mixture and mixing temperature could significantly change the properties of the HMA. This concept should be combined with lab and field research done on the PET modified asphalt mixtures. Also Intensive studies are required to improve the PET addition process; the advantages and disadvantages of adding PET to either the aggregate (dry process) or the asphalt cement (wet process) on a large scale must be determined. Most of the successful work in this area involves a separate feed to input the PET simultaneously with the aggregate. Experimentally, this is best represented by the dry process which is used in this study. The benefits, if any, of the wet process should be determined so that the results may be compared. In this specific investigation properties of HMA were only investigated using Marshall Specimens, but in addition to this it would be necessary to study a wider range of properties; including fatigue life, rutting, performance in different temperatures, and stiffness. Hence we recommend further and deep investigation on this area.

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