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Analysis of the Use of Waste Plastics Low-Density Polyethylene (LDPE) along with Bitumen in the Construction of Asphalt Pavement using the Marshall Test

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Abstract

Plastic disposal is a significant problem as it is non-biodegradable and causes air pollution if burned. The utilization of waste plastics in road construction has gained attention due to environmental concerns and the need for sustainable development of infrastructure. This research investigates the performance waste plastics, low-density polyethylene (LDPE) and, in the asphalt road along with the bitumen based on the Marshall Stability Test. The Optimum bitumen content (OBC) is found to be 5.2%. Different concentrations of LDPE (8% and 10% by weight of bitumen) were used. The use of LDPE on the asphalt pavement has Marshall Stability and Marshall flow values in the usable range as specified in the specification criteria of the Standard Specification for Road and Bridge Works (SSRBW). Also, the use of waste plastics in the pavement reduces the cost and helps to promote an environmentally friendly approach to infrastructure development

Keywords: Marshall Stability, Marshall Flow, Mix Design, Hot Mix, Optimum bitumen content, low-density polyethylene, standard specifications for road and bridge work.

1. Background

Hot Mix Technology, which has been used for many years in the construction of pavements, involves heating aggregates and bitumen, mixing, and laying the mixture at a high temperature of around 120°C–165°C. (Kaujageri, P, & N, 2018)

1.1 Advantages of Hot Mix Asphalt:

Durability and Longevity: It is known for its strength, resilience, and ability to withstand heavy traffic and extreme weather conditions.

Seamless Finish: It offers a smooth, uniform surface that enhances driving safety and comfort.

Fast Curing Time: It cools and sets quickly, allowing roads and driveways to be opened to traffic shortly after the paving process. (PetroNaft Co. research team, 2024)

Plastics are typically organic polymers of high molecular mass and are usually synthetic. Due to their relatively low cost, manufacture, versatility, and imperviousness to water, plastics are being used in enormous quantities for the packing, production, and manufacturing of automobile parts, furniture, and toys (Roy, Sinha, & Sarkar, 2015). It is reported that Nepal imported around 380,000 tons of plastic and plastic articles in FY2021/22, and the domestic production for the same year is estimated at around 165,000 tons. Because of the lack of plastic management mechanisms in Nepal, most of these plastics are leaked into the environment. It is estimated that in Nepal, about 20.7 kilotons of plastic per year leak into the environment, which is about 9% of the total annual plastic consumption. (Ghimire & Bajracharya, 2023). Different types of plastics include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), etc. The focus of this research paper is low-density polyethylene (LDPE) waste in the form of packing plastics. Also, the use of LDPE in roads increases the stability value of Marshall (Dubey & Gupta, 2019).

2. Literature Review

Sasidharan, Torbaghan & Burrow (2019) Laboratory tests have shown that the use of plastics in small amounts (5-10% by weight) results in positive results in improving pavement stability, strength, and durability. (R.Manju, S & K (2017) When plastic is placed on the heated aggregate, it develops an oily coat on the surface of the aggregates which helps to bind the bitumen and aggregates which results in increasing the performance also the experiments of field observation showcase that the plastic fillers can bear stress and extend the life of the roads reducing environmental problems. (Sabina, Khan, Sharma, Sangita & Sharma (2009). This paper concluded that the use of plastics (8% and 15 %) results in the improvement in the Marshall stability, and rutting.

(Genet, Sendekie & Jembere (2021) This paper investigated the use of three different waste plastics (LDPE) at different percentages 4, 6, 8 and 10 % and found that asphalt mix modified by using 6.5% plastics has a 33.67% higher stability value compared to non-modified asphalt.

Saleh (2023) LDPE from 6% to 18 % was tested based on the Marshall Flow and stability. It was found that the modified mixture was more stable than the conventional mixture; also the addition of 14.8 % of LDPE to the asphalt mixture gave the best improvement in the pavement performance.

3. Study Area

The study area was focused only on the quarry of Lalitpur District only.

4. Detailed Methodology

Based on the literature review and references, all the tests are conducted in the MEHA Geo-Engineering Services lab. The methodological flowchart is shown below.

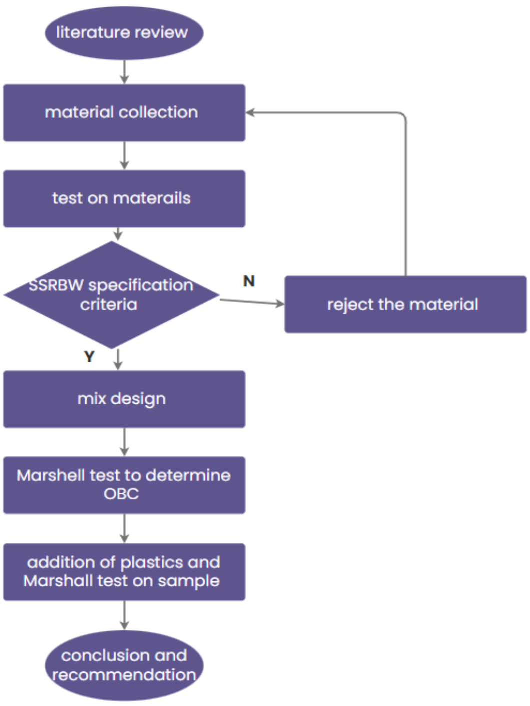

Figure 1. Methodological Flowchart

4.1 Materials

Bitumen

The bitumen used for this research study is VG-30 grade, generally used in Kathmandu Valley. The bitumen is selected based on the table specified by the Standard Specification for Road and Bridge Works (SSRBW).

Table 1. Selection Criteria for Viscosity-Graded (VG) Paving Bitumen Based on Climatic Conditions (SSRBW, 2073)

Lowest Daily Mean Air Temperature, °C	Highest Daily Mean Air Temperature, °C		
	Less than 20°C	20 to 30°C	More than 30°C
More than 10 °C	VG-10	VG-20	VG-30
	VG-10	VG-10	VG-20

Aggregates

Aggregates of size 20mm down, 10 mm down, and stone dust are used for study. This entire material was collected from the quarry at Kathmandu, which supplied the material from Dukuchhap. The aggregate tests and evaluations carried out based on the specifications provided in the table below

Table 2. Physical Requirements for Coarse Aggregate for Bituminous Concrete (SSRBW, 2073)

Name of test	**Specification**	**Test standards**
Aggregate impact value	Max 24 %	Is 2386 (part 4)
Water absorption test	Max 2%	Is 2386 (part 3)
Los Angeles abrasion test	Max 30 %	Is 2386 (part 4)
Specific gravity test		AASHTO T166
Combined EI +FI	Max 32%	Is 2386 (part 1)

Waste Plastics

The study involves the use of Low-density polyethylene (LDPE), LDPE is collected from waste packing plastics.

4.2 Lab Test

Job Mix Design

The aggregate blending portion was calculated using the trial-and-error method. The portion satisfying the specification in Table 13.31 is tabulated below.

Table 3. Job Mix Desing

Name of aggregate	**% Used**
20 mm down aggregate	42%
10 mm down aggregate	8%
Stone dust	50%
Total	100%

Marshall Test

The Marshall Test is the basis for this research project. All the results and recommendations follow the Marshall Test standards.

Marshall stability test steps

- Specimens are heated to 60 ±1 C either in a water bath for 30–40 minutes or in an oven for a minimum of 2 hours.
- The specimens are removed from the water bath or oven and placed in the lower segment of the breaking head. The upper segment of the breaking head of the specimen is placed in position, and the complete assembly is placed in position on the testing machine.
- The flow meter is placed over one of the posts and is adjusted to read zero.
- The load is applied at a rate of 50 mm per minute until the maximum load reading is obtained.
- The maximum load reading in kilo Newtons is observed. At the same instant, the flow as recorded on the flow meter in units of mm was also noted.
- Three samples for each different percentage of bitumen by weight are tested (4%, 4.5%, 5.5%, and 6%), and a graph of the data is plotted to determine the optimum binder content (OBC).

Table 4. Percentage of Bitumen to determine OBC

% Of bitumen content	Number of samples
4	3
4.5	3
5	3
5.5	3
6	3
Total	15

TEST RESULTS

Table 5. Test Result of Bitumen

S. N	Name of test	Unit	Bitumen VG:30(HP)	Specification limit as Standard Specification for Roads and Bridge Works with Amendment 2078
1	Penetration 25 degrees Celsius, 100 g, 5 s, 0.1 mm, min	1/10mm	45	45(Min)
2	Absolute viscosity at 60 °C, Poises	Poises	2852.27	2400-3600
3	Flashpoint (Cleveland open cup), degree Celsius, min	Degree Celsius	285/312	220(min)
4	Solubility in trichloroethylene, % by weight (min)	%	99.70	99(min)
5	Softening point (Rand B), degree Celsius min	Degree Celsius	49.50	47(min)
6	Specific gravity		1.04	1.00-1.50

7	Loss on heating (5 hrs. at 163 degrees Celsius)		0.18	0.50
8	Ductility at 25 degrees Celsius, min.	Cm	100	40 (min)
9	Water content, by weight		nil	0.20

B. Test Result of Aggregates

Table 6. Test Result of Aggregates

Name of test	observation	Standard specification	Remarks
Combined elongation index (EI)+flakiness index (FI)	31.88%	Max 35 %	ok
LAA (LOS Angeles Abrasion Test)	15.82%	Max 30%	Ok
Aggregate impact test (AIV)	12.86%	Max 24 %	ok
Water absorption 20 mm down aggregate	0.32%	Max 2%	ok
Water absorption 10 mm down aggregate	0.6%	Max 2%	Ok
Specific gravity 20 mm down aggregate	2.71		Ok
Specific gravity 10 mm down aggregate	2.64		Ok
Specific gravity stone dust	2.68		Ok

C. Data of Sieve Analysis

Table 7. Data of Sieve Analysis

Stone dust	10 mm down	20 mm down
% Passing	% Passing	%Passing
100	97.89	99.28
78.42	59.46	50.03
64.13	7.48	12.63
48.36	3.84	0.38
38.22	3.55	0.29
27.30	3.21	0.29
9.69	1.45	0.29
3.76	0.41	0.29

4.3 Determination of OBC

The Marshall test is performed in the Marshall cake and the following data are observed. Based on the data different graphs are plotted to find the OBC

Table 8. Marshall Test data

Bitumen content	bulk density	air voids	VMA	VFB	Stability	flow
4.00	2.375	6.09	15.23	60.01	18.47	3.32
4.50	2.378	5.26	15.55	66.17	19.00	3.52
5.00	2.382	4.41	15.86	72.19	19.98	3.79
5.50	2.387	3.52	16.14	78.19	15.05	4.33
6.00	2.380	3.09	16.82	81.63	12.20	4.60

Table 9. Bitumen content calculation

Name	Bitumen %
Bulk Specific gravity	5.50
4% Air void	5.20
Max Stability	4.90
Bitumen requirement = 5.2%	

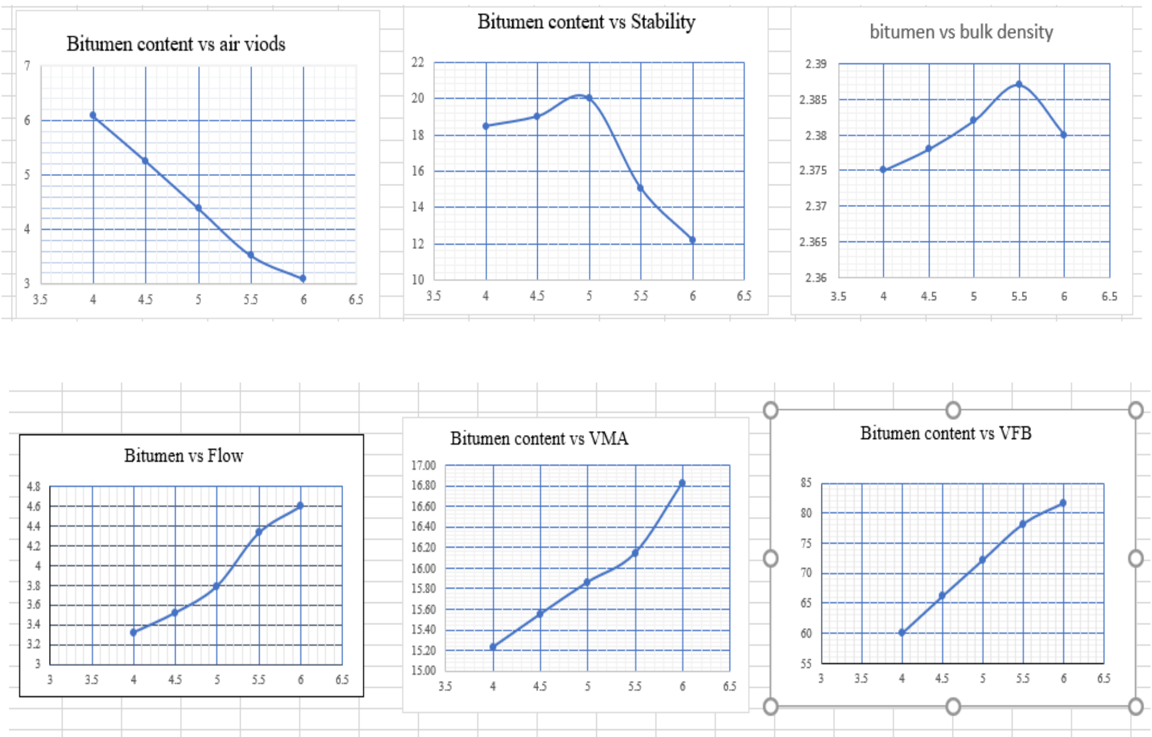

Figure 2. Graph for Optimum Binder Content (OBC)

- Coating of Aggregates with Waste Plastics

Steps to mix the plastics:

- The LDPE is cut into approximately 1 cm for the proper coating on the aggregates
- The aggregate is heated with waste plastic until the plastic completely melts and coats the aggregate. The reduced amount of bitumen found after deducting the weight of plastic added is then added to the mix and is mixed properly.
- The prepared samples are then placed in the Marshall testing apparatus, and the loading is applied keeping the needles in position, until failure for each of the samples prepared (Shrestha & Niraula, 2022)

E. Marshall Test on Plastic Added Cake

The Marshall test is performed on a similar pattern as in OBC determination.

Table 10. Test Observation

%Plastics	Flow	Stability	Density	Air voids	VMA	VFB	Marshall Quotient	Remark
8%	3.8	16.59	2.375	4.27	15.21	71.93	4.37	LDPE
10%	3.9	16.4	2.372	4.4	15.16	70.98	4.21	LDPE

Comparison of the data

The data of OBC and the plastic replaced Marshall is tabulated below. The variation in flow, stability, density, air voids, VMA, and VFB is calculated as shown in the table below. Based on this variation the conclusion and recommendation are drawn.

Table 11. Marshall Test result of both OBC and Plastics (LDPE):

%Plastics	Flow	Stability	Density	Air voids	VMA	VFB	Marshall quotient	Remark
5.20%	4.00	18.30	2.384	4.00	15.95	74.80	4.58	OBC
8%	3.8	16.59	2.375	4.27	15.21	71.93	4.37	LDPE
10%	3.9	16.4	2.372	4.4	15.16	70.98	4.21	LDPE

4.4 Conclusion and Recommendation

Plastics which are non-biodegradable waste have a serious major impact on the environment. Using the waste plastics in the construction of the asphalt pavement could bring a better solution for the plastics waste management problem.

The following conclusion can be drawn from the hot mix Marshall Test.

The conclusion from the results

- The addition of Low-density Polyethylene (LDPE) at 10% by weight of bitumen meets all criteria of stability, flow, density, air voids, VMA, and VFB.

- The addition of Low-density Polyethylene (LDPE) at 8% by weight of bitumen meets all criteria of stability, flow, density, VMA, VFB, and air voids.
- The analysis result shows that using 10% of waste plastics is more economically feasible than using 8% of waste plastics (LDPE).

Recommendation based on Standard specification for roads and works (SSRBW)

- The use of 8% LDPE is found to fulfill all the criteria as per SSRBW that is stability, flow density, air voids, VMA, and VFB. So, the use of 8%LDPE can be recommended in this study.
- The use of 10% LDPE is found to fulfill all the criteria as per SSRBW that is stability, flow, density, air voids, VMA, and VFB. So, the use of 10%LDPE can be recommended in this study

Hence based on SSRBW, 2073 criteria all the plastics percentages that are (8% and 10%) and LDPE seem to fulfill all the criteria. Hence this could be used for the new surface course of flexible pavement.

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