International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Performance Evaluation of Different Types of Plastic Incorporated in Hot Mix Asphalt (Hma)

Bimal Bastola[1], Aakanshya Ghimire[2], Nirajan Ghimire[3], Ajay K.C[4], Rajiv Subedi[5]

[1,2,3,4,5]Green Road Waste Management Pvt. Ltd., Matepani-12, Pokhara, Nepal

Abstract

The global plastic waste crisis poses a significant environmental challenge, requiring innovative and sustainable solutions for its management. This study explores the integration of various plastic waste (PP, MLP, LDPE, and crumb rubber) into asphalt mixtures. It conducts a comparative assessment of four distinct plastic materials by analyzing their Marshall properties.

Laboratory experiments demonstrated that including various plastics at an approximate rate of 8% significantly reduces the demand for virgin bitumen in asphalt mixes, indicating the potential for bitumen replacement by waste plastic to some extent. Plastic waste is added to hot aggregates, resulting in coated aggregates. When used in the asphalt mix, plastic-coated aggregates (PCA) exhibit better binding properties, enhanced resistance to moisture damage, Marshall stability, and density. Additionally, incorporating PCA in road construction leads to a reduction in carbon emissions.

This paper promotes a circular economy, reducing the environmental impact, i.e., carbon footprint of plastic waste, while improving the quality and longevity of our road networks.

Keywords: Asphalt mixture, Plastic coated aggregate (PCA), Marshall properties, carbon footprint, PP, MLP, LDPE.

Introduction

Plastics have become a widespread commodity that infiltrated every aspect of human life. Lacking awareness of being recycled or reused, plastics have rapidly become a major concern of municipal solid waste (MSW) (Abd El-Rahman et al., 2018). Plastic waste management has become a severe problem. The production of plastics grew from 2 million metric tons in 1950 to 322 million metric tons in 2015 (Geyer et al., 2017). The cumulative amount of plastic production reached 8.3 billion metric tons in 2017. Fig. 1 presents the number of tons of plastics generated, recycled, combustion with energy recovery, and landfilled from the American Chemistry Council. To aim for sustainable plastic waste management, incorporating plastics in HMA can be considered as one of the approaches to a circular economy. Hot mix asphalt (HMA) mixture is considered as a promising approach to reuse waste plastics in a large volume. Hence, waste plastics are investigated as potential modifiers for asphalt binders or substitutes for aggregates to achieve sustainable pavements (Gwande et.al 2012). Plastic roads not only solve the waste disposal problem but also enhance road performancse. In the context of consuming waste plastics in the construction offlexible pavements, it must be recognized that there are only certain types of wasteplastics that could potentially be used without risking worker safety, additionalharm to the environment, and/or pavement performance

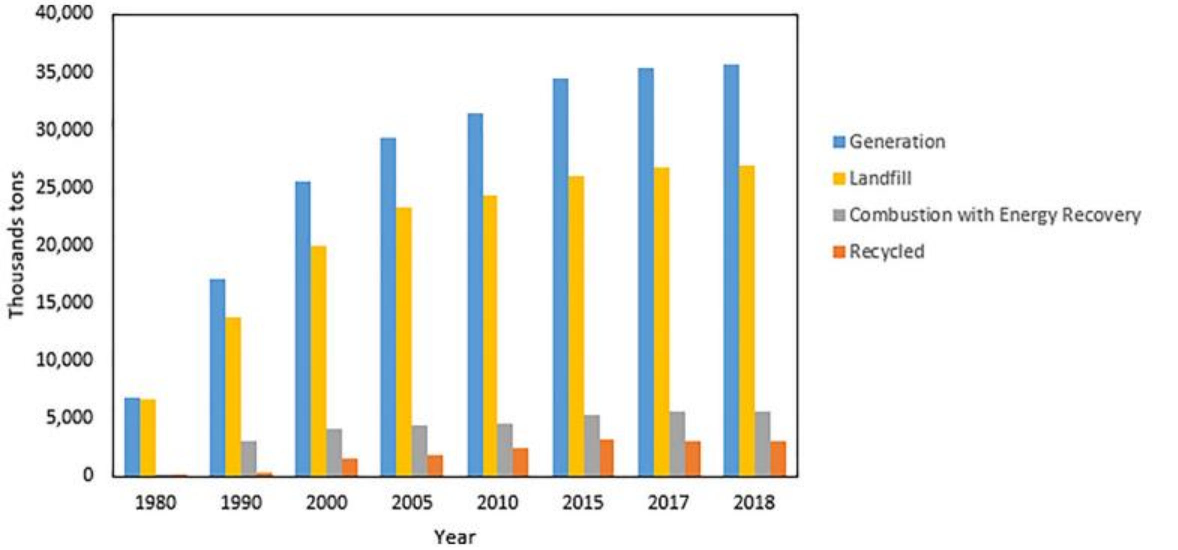

Fig 1: Tons of Plastic Generation and Different Treatments

Literature Review

The use of waste plastic in road construction has been extensively studied and explored as a sustainable solution to address the growing plastic waste crisis and enhance the performance of asphalt pavements. Numerous researchers have investigated the incorporation of various types of plastic waste into bituminous mixes and evaluated their effects on the properties and performance of the modified asphalt mixtures.

Vasudevan et al. (2012) conducted pioneering research on the utilization of waste plastics in road construction. Their study demonstrated that the addition of waste plastics in small doses (about 5-10% by weight of bitumen) significantly improved the stability, strength, fatigue life, and other desirable properties of bituminous mixes. These improvements resulted in enhanced longevity and pavement performance. Similarly, Behl et al. (2012) reported that the incorporation of waste plastic in bituminous mixes increased their durability and resistance to deformation and water-induced damage, indirectly contributing to user satisfaction and accident reduction. According to Javier J. Garcia et. al (2024), the study shows that AC mixes containing waste HDPE-modified binders were less susceptible to moisture-induced damage. It appears that using waste HDPE-modified binder is feasible where improving adhesion and resistance to moisture-induced damage.

Several studies have highlighted the economic benefits associated with the use of waste plastic in road construction. Vasudevan and Rajasekaran (2006), Rashid et al. (2009), and Behl et al. (2012) reported a reduction in bitumen consumption and costs when waste plastic was added to the bituminous mix. This cost-saving aspect is particularly attractive for road construction projects, especially in developing countries where resources are often limited.

In the context of consuming waste plastics in the construction of flexible pavements, it must be recognized that there are only certain types of waste plastics that could potentially be used without risking worker safety, additional harm to the environment, and/or pavement performance. (Imad Al-Qadi, et al.(2024).The performance of various types of waste plastic in bituminous mixes has been evaluated by numerous researchers. Kalantar et al. (2012) conducted a comprehensive review of using waste and virgin polymers in pavement construction. They found that the incorporation of waste plastics, such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), can improve the mechanical properties and durability of asphalt mixtures.

Zoorob and Suparma (2000) investigated the use of recycled polyethylene in hot-mix asphalt and observed improved resistance to permanent deformation and moisture damage. Khursheed and Singh (2017) studied the utilization of waste plastic bags in bituminous mixes and reported enhanced stability, density, and void properties compared to conventional mixes.

In addition to traditional plastics, researchers have explored the potential of incorporating crumb rubber from waste tires into asphalt mixtures. Manju et al. (2017) evaluated the use of plastic waste and crumb rubber in bituminous pavement and found improved Marshall stability, flow value, and air voids compared to conventional mixes. Xunhao et al. (2024) proved that the tests and simulations show that rubber filler plays a positive role in enhancing the fracture properties of the asphalt mortar.

Research Gap: Despite the extensive research on plastic-modified asphalt mixtures, there is still a need for a comprehensive performance analysis indicating the effects of various types of plastics, such as multi-layered plastics (MLP), polypropylene (PP), low-density polyethylene (LDPE), and crumb rubber, on the Marshall properties of asphalt mixes. This study aims to address this research gap by conducting a comparative assessment of different plastic types incorporated into hot mix asphalt (HMA) and evaluating their impact on the Marshall properties.

Thus, the major objective of the study is to utilize waste plastic in asphalt pavement construction and evaluate the effect of different types of plastic in an asphalt mix.

Objective

1. To determine the Optimum Binder Content (OBC) by incorporating the 4 different plastics in Hot Mix Asphalt (HMA) and comparing them with the conventional mixes.
2. To assess the physical properties of Plastic Coated Aggregate (PCA).
3. To evaluate the performance of different plastic mixed HMA.
4. To compare the Marshall properties of different plastic mixed HMA.

Methodology

Materials

1. Multi-layered Plastic (MLP): Multilayer plastic refers to a type of packaging material composed of multiple layers of different plastic films or sheets. Each layer in the structure serves a specific purpose, contributing to the overall performance and functionality of the packaging.
2. Polypropylene (PP): Polypropylene (PP), also known as polypropene, is a thermoplastic polymer used in various applications. It is produced via chain-growth polymerization from the monomer propylene.
3. Low-density Polyethylene (LDPE): LDPE is known for its flexibility, toughness, and transparency. It is commonly used for plastic bags, squeeze bottles, and flexible packaging.
4. Crumb Rubber: Crumb rubber is recycled from automotive and truck scrap tires. During the recycling process, steel and tire cord (fluff) are removed, leaving tire rubber with a granular consistency. Continued processing with a granulator or cracker mill, possibly with the aid of cryogenics or mechanical means, further reduces the particles' size.

Physical Test on Fresh Aggregates and Bitumen:

The following tests were performed on the virgin aggregates and bitumen to confirm the specified properties.

Test for Aggregates	Test for Bitumen
Los Angeles Abrasion Test(LAA)	Penetration Test at 25 C
Aggregate Impact Value (AIV)	Flash and Fire Point Test
Aggregate Crushing Value (ACV)	Softening Point
Soundness Test	Loss on Heating
Flakiness Test	Solubility in Trichloroethylene
Stripping Test	Ductility after loss on heating
	Specific Gravity
	Absolute Viscosity at 60 C
	Kinematic Viscosity at 135 C
	Viscosity Ratio

Incorporating Plastics into Asphalt:

In the process of laying plastic roads, plastic waste material is initially collected from various areas such as landfills or dump yards. The waste plastic material is then washed or cleaned using an appropriate method and dried for some time. Subsequently, a shredding machine is utilized to shred the plastic waste into suitable sizes. The appropriate size of aggregates for road construction is then selected. Two distinct processes can be employed for this purpose:

1. **Wet Process**: In the wet process, polymers are blended with bitumen at high temperatures to produce bituminous binders before mixing with aggregate. Consequently, the wet process necessitates additional machinery and equipment to shred the plastics into powders and mix them with hot asphalt binder afterward. Plastics with relatively low melting points, especially PE, are suitable for this process (Fang et al., 2013; Ge et al., 2016).
2. **Dry Process for Bitumen Mix**: In the dry process, waste plastics serve as coating materials. The waste plastic should conform to the size passing a 2.36 mm sieve and retained on a 600-micron sieve, with dust and other impurities not exceeding 1 percent. The aggregate mix is heated to 140-175 ºC, and the requisite percentage of waste plastic to the weight of bitumen is injected. The waste plastic initially coats the heated aggregates before bitumen is added. The plastic waste-coated aggregate is mixed with hot bitumen at a temperature of 150-170 ºC for about 15 seconds, resulting in an improved aggregate quality with respect to voids, soundness, and moisture absorption, while decreasing porosity and enhancing pavement performance.

Note: In this research work, the dry process was followed.

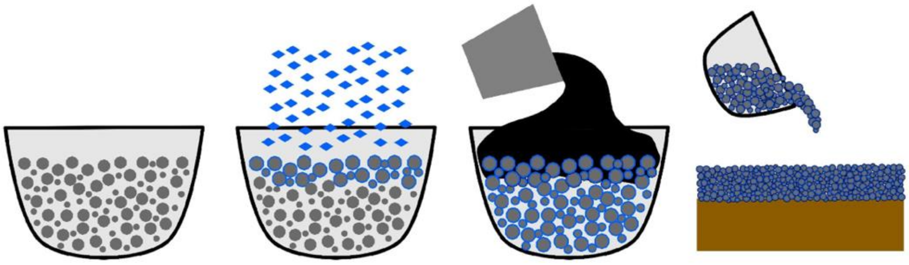

Fig 2. Steps of Incorporating Plastics into Hot Aggregate (Dry Process)

Physical Test on Plastic-Coated Aggregates

For the asphalt pavement, specific stone aggregate characteristics are utilized for road laying, selected based on strength, porosity, and moisture absorption capacity. The aggregate was coated with waste plastic material through the following process: waste plastics, including films, cups, and foams, were shredded to the required size of 2.5–4.36 mm. The aggregate was heated to 170°C, and the shredded waste plastic was sprayed over the hot aggregate, softening and coating the plastics over the aggregate.

The following tests were conducted on the plastic-coated aggregates:

1. Los Angeles Abrasion Test (LAA)
2. Aggregate Impact Value (AIV)
3. Aggregate Crushing Value (ACV)
4. Soundness Test
5. Flakiness Test

Preparation of Marshall Specimen

Determination of Optimum Binder Content (OBC) of the normal mix: The binder content for the normal aggregate mix was determined.

Determination of Optimum Binder Content (OBC) of plastic mix: The binder content of plastic-coated aggregates was determined. Different OBCs are obtained for different plastics such as MLP, PP, LDPE, and crumb rubber.

Test Results and Analysis

1) Physical Test of Aggregate

S.N	Test	Without Plastic	Aggregate Coated with MLP	Aggregate Coated with PP	Aggregate Coated with LDPE	Aggregate coated with Crumb Rubber
1)	Los Angeles Abrasion Test (LAA)	32.34%	28.78%	23.54%	28.57%	26.5%
2)	Aggregate Impact Value Test (AIV)	22.22%	16.55%	18.67%	17.52%	16.56%

3)	Aggregate Crushing Value (ACV)	28.09%	24.53%	23.68%	25.51%	23.51%
4)	Soundness Test	4.26%	4.03%	3.75%	3.98%	3.86%
5)	Flakiness Index	15.88%	15.86%	15.44%	15.57%	15.6%

Analysis:

1. The LAA value for PP-coated aggregates showed a notable reduction from 32.34% to 23.54%.
2. AIV value was minimized at 16.55% for MLP-coated aggregate, which is a desirable property.
3. Rubber-coated aggregates demonstrated a significant decrease in ACV value, reducing from 28.09% to 23.51%.
4. Additionally, PP-coated aggregates exhibited a minimal loss in weight (Soundness Test) at 3.75%.
5. The Flakiness index value was also found to be within the specified limit.

2) Summary Sheet of Bitumen Test:

S.N	Description of Test	Result	Units
1	Penetration Test at 25 C	60.33	(1/10)mm
2	Flash and Fire Point Test		
	a) Flash Point	288	C
	b) Fire Point	296	C
3	Softening Point	52	C
4	Loss on Heating	0.118	%
5	Solubility in Trichloroethylene	99.900	%
6	Ductility after loss on heating	>100	cm
7	Specific Gravity	1.036	
8	Absolute Viscosity at 60 C	2774.85	Poises
9	Kinematic Viscosity at 135 C	389.46	Cst
10	Viscosity Ratio	1.155	

Analysis:

All the test result was found within the limit.

3) Determination of Optimum Binder Content (OBC):

S.N.	Sample	OBC Content
1	Without Plastic	5.767%
2	Crumb Rubber	5.600%
3	PP	5.437%
4	LDPE	5.313%
5	MLP	5.290%

Analysis:

1. The test results above showed a decrease in OBC when plastic was added to the conventional mix.
2. Among the 4 different plastics, MLP exhibited a notable decrease in the OBC content.

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

4)Determination of Marshall Properties of the various sample

S.N.	Sample	Stability (KN)	Flow Value(mm)	Bulk Density(gm/cc)	Air Voids %	VMA %	VFB %	Marshall Quotient(Stability/Flow)
	Standard Value	Min. 9 KN	2-4		3-5	Min. 13	65-75	2-5
1	Without Plastic	9.8	2.3	2.344	4	17	76	4.26
2	Crumb Rubber	10.6	2.05	2.348	4.1	16.7	75	5.17
3	PP	11.8	2.47	2.341	4.4	16.7	73	4.78
4	LDPE	9.7	2.2	2.368	3.5	15.7	77	4.41
5	MLP	9.8	2.1	2.373	3.4	15.51	79	4.67

Analysis:

1. The above results indicate that incorporating plastic enhances the Marshall properties.
2. All the plastic mixes showed an increase in stability value. However, the highest stability value of 11.8 KN was observed in PP-coated aggregates.
3. Similarly, the flow value of PP-coated aggregates, at 2.47, was found within the specified range.
4. For PP-coated aggregates, the values of VMA and VFB also met the standard specifications.

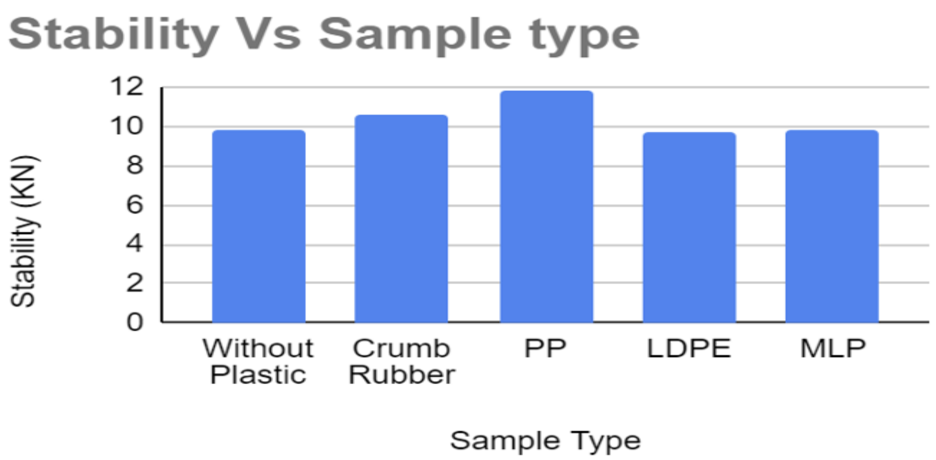

Fig 3. Stability Vs Sample Type

Conclusion:

1. The plastic-coated aggregates exhibited improved physical properties compared to uncoated aggregates, indicating the potential benefits of plastic incorporation in asphalt mixtures.
2. Plastic mix design reduced the Optimum Binder Content (OBC), particularly with MLP, leading to minimized bitumen consumption and cost savings.

3. The comparison between various plastic mix designs and conventional mix designs in terms of Marshall Stability, flow value, density, air void, VMA, and VFB revealed that the PP plastic mix design excelled in all tests and demonstrated the best overall performance.
4. Based on the Marshall properties, PP plastic-coated aggregates exhibited the highest stability of 11.8 KN, while meeting the required standards for flow value, density, air void, VMA, and VFB.
5. The incorporation of plastic-coated aggregates in road construction can contribute to a circular economy by reducing the environmental impact and carbon footprint of plastic waste while enhancing the quality and longevity of road networks.

Acknowledgments

We would like to express our sincere gratitude to the following individuals and organizations for their valuable support and contributions to this research:

- United Nations Development Programme - Global Environment Facility - Small Grants Programme (UNDP-GEF-SGP) for providing the financial support through a grant to conduct this research.
- NIDISI for supporting us in knowledge & experience sharing by connecting us with German Plastic Road Making company EcoPals.
- Mr. Bhushan Tuladhar, Chief of Party (COP) of the USAID-Clean Air Program, for his guidance and inputs in reviewing and publishing the research work.
- Center for Energy & Environment Nepal, Blue Waste To Value and Dr. Ramesh Man Singh for guiding and supporting this research work.
- Viswa Engineering and Quality Research & Development Center (QRDC) of Department of Roads of Nepal for conducting the lab tests.

References

1. Abd El-Rahman, A. M. M. (2018). Enhancing the performance of blown asphalt binder using waste EVA copolymer (WEVA). Egyptian Journal of Petroleum, 27(4), 513-521. https://doi.org/10.1016/j.ejpe.2017.12.003
2. Bale, A. S. (2011). Potential reuse of plastic waste in road construction: A review. International Journal of Advances in Engineering & Technology, 1(4), 155-162.
3. Behl, A., Jain, M., Kumar, G., Sharma, G., Narayan, V., & Yadav, M. (2012). Reuse of plastic waste in polymer modified bitumen for road construction. International Journal of Civil Engineering Research & Technology, 3(1), 323-336.
4. Bhoot, N. D., Singh, J., & Chandra, S. (2012). Use of plastic road for improving life and strength of bituminous concrete. Proceedings of the International Conference on Sustainable Civil Infrastructure: Innovative Construction Materials and Technologies (ICSCIT-2012), Roorkee, India.
5. Ding, X., Huang, F., Rath, P., Ye, Z., Buttlar, W. G., & Ma, T. (2023). Comparative fracture resistance assessment of rubber-modified asphalt mortar based on meso-and macro-mechanical analysis. International Journal of Pavement Engineering, 24(1). https://doi.org/10.1080/10298436.2023
6. Gawande, A., Zamare, G., Renge, V. C., Tayde, S., & Bharsakale, G. (2012). An overview on waste plastic utilization in asphalting of roads. Journal of Engineering Research and Studies, 3(2), 1-5.
7. García Mainieri, J. J., Al-Qadi, I. L., & Ghabchi, R. (2024). Effects of waste high-density polyethylene (HDPE) on asphalt binder and airfield mixes. International Journal of Pavement Engineering, 25(1). https://doi.org/10.1080/10298436.2024.

8. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. https://doi.org/10.1126/sciadv.1700782
9. Imad L. Al-Qadi, Ph.D., P.E, Thomas Bennert, Ph.D. Amit Bhasin, Ph.D., P.E. , Jhony Habbouche, Ph.D., P.E., Elie Y. Hajj, Ph.D., Walaa S. Mogawer, Ph.D., P.E. , Brajendra Sharma, Ph.D, Shane Underwood, Ph.D. and Fan Yin, Ph.D., P.E. Roadmap for Repurposing Waste Plastics in Asphalt Mixes. https://doi.org/10.1061/9780784485545.fm
10. Indian Road Congress. (2013). Guidelines on use of plastic waste in road construction. IRC: SP: 98-2013.
11. Kalantar, Z. N., Karim, M. R., & Mahrez, A. (2012). A review of using waste and virgin polymer in pavement. Construction and Building Materials, 33, 55-62. https://doi.org/10.1016/j.conbuildmat.2012.01.009
12. Khursheed, A., & Singh, A. P. (2017). Utilization of waste plastic bags in bituminous mixes. International Journal of Civil Engineering and Technology, 8(6), 718-726.
13. Mahalik, N. P., & Madras, G. (2005). Polymeric materials for layered packaging: Structure, properties, and techniques. Journal of Plastic Film & Sheeting, 21(1), 21-45. https://doi.org/10.1177/8756087905051709
14. Manju, R., Sathya, S., & Sheema, K. (2017). Use of plastic waste in bituminous pavement. International Journal of ChemTech Research, 10(8), 804-811.
15. Poulikidou, S., Schneider, C., Duguay, S., Tawari, S., Gawlik, B.
16. Rashid, M., Karim, M. R., Mahid, M. O., & Mustafaee, S. A. (2009). Utilization of waste plastic bag in construction of low cost road. Project Report, Department of Civil Engineering, Dhaka University of Engineering and Technology, Gazipur, Bangladesh.
17. Vasudevan, R., & Rajasekaran, S. (2006). Utilization of waste plastics in construction of flexible pavement. In Proceedings of the International Conference on Emerging Technologies in Environmental Science and Engineering (pp. 204-209).
18. Vasudevan, R., Ramalinga Chandra Sekar, A., Sundarakannan, B., & Velkennedy, R. (2012). A technique to dispose of waste plastics in an ecofriendly way – Application in construction of flexible pavements. Construction and Building Materials, 28(1), 311-320. https://doi.org/10.1016/j.conbuildmat.2011.08.031
19. Zoorob, S. E., & Suparma, L. B. (2000). Laboratory design and investigation of the properties of continuously graded Asphaltic concrete containing recycled plastics aggregate replacement (Plastiphalt). Cement and Concrete Composites, 22(4), 233-242. https://doi.org/10.1016/S0958-9465(00)00026-3