STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/JOPC/

Review JoPC

Reusing Waste Plastics to Enhance Flexible Pavement Performance

U. Ramakrishna[1,*], R. Saipreethi[2], K. Vivek Vardhan[2], G. Satvik Reddy[2]

Abstract

The disposal of plastic garbage Plastic products including cold drink bottles, carry bags, chocolate and chip wrappers, and all other types of plastic produce serious environmental and financial issues. These plastic types use a lot of energy and deplete the environment in a number of ways. Plastics are non-biodegradable, resulting in long-term environmental pollution and contributing to hazards such as microplastic contamination, marine debris, and threats to wildlife. Additionally, the improper disposal of plastics exacerbates climate change through greenhouse gas emissions during production and degradation processes. Because plastic is strong, lightweight, and reasonably priced, it is a preferred material for handling and packing goods in the manufacturing and construction sectors. The plastic waste that is utilised includes polyethylene, polystyrene, and polypropylene. The softening point of these polymers is determined by temperature variations between 120ºC and 160ºC. When plastic garbage is shred and spread over aggregate, it is combined with heated bitumen to create a mixture that is used to construct pavements. This mixture not only makes the pavement more durable but also strengthens it. This paper's major goal is to explain the value of plastic in terms of cost savings. It also shows how heating plastics may strengthen their strength and durability, eliminate air spaces with plastic coating aggregates, and bind aggregates to offer stability. It's both cost-effective and sustainable.

Keywords: Flexible pavement, plastic waste, plastic roads, bituminous mix, sustainable pavement materials

INTRODUCTION

Waste plastic is used to make flexible pavements by mixing leftover plastic components into the pavement mixture (Figure 1). The objective of this novel methodology is to augment the pavement's operational efficiency, longevity, and ecological sustainability. These pavements possibly enhance the mechanical qualities of the road surface while lowering plastic pollution through the recycling and use of discarded plastic. Typically, bitumen or asphalt mixes are combined with shredded or granulated plastic to provide a more durable and environmentally friendly pavement option. Given the lower cost of recycled materials, using waste plastic in pavement construction may occasionally result in cost savings. Temperature Sensitivity: Fit for a range of climates, the adjusted blend could also work better in extremely hot or cold conditions. It is noteworthy that the efficacy of this methodology may vary based on variables like the kind of plastic employed, the composition of the mixture, and the particularities of the roadway [1].

In order to optimise performance and sustainability, research and development in this sector are still investigating the best ways to incorporate waste plastic into flexible pavements.

***Author for Correspondence**
U. Ramakrishna
E-mail: uppari.ramkrishsna@vbithydc.ac.in

[1]Associate Professor, Department of Civil Engineering, Vignana Bharathi Institute of Technology, Hyderabad, Telangana, India
[2] Student, Department of Civil Engineering, Vignana Bharathi Institute of Technology, Hyderabad, Telangana, India

Received Date: August 06, 2024
Accepted Date: November 22, 2024
Published Date: December 18, 2024

Citation: U. Ramakrishna, R. Saipreethi, K. Vivek Vardhan, G. Satvik Reddy. Reusing Waste Plastics to Enhance Flexible Pavement Performance. Journal of Polymer & Composites. 2025; 13(1): 173–183p.

Figure 1. Plastic waste usage in road construction.

The disposal of plastic garbage is a major issue in India, where it poses a significant risk to both human and animal health. Plastic waste is widely available due to the ubiquitous nature of plastic items in daily life. At the moment, land filling or incineration are used to get rid of them if they are not recycled. The environment is thus affected in some way by both of these processes. Thus, we deduced that the discarded plastic is put to use in building roads. Even viscoelastic relatively [2] used in building application, it is a relatively new practice in India to use discarded plastic for road construction. A modest amount of plastic (5 to 10% by weight) added to bituminous mixes of asphalt has improved pavement stability, strength, and durability, according to laboratory testing. The two main types of plastic are thermoses and thermoplastics. Thermosets are strong and durable materials that are usually used in construction because they harden irreversibly when heated. Trash made of plastic doesn't biodegrade and adds to the greenhouse impact and global warming. A number of experiments have been carried out to investigate the possibility of making useful use of discarded plastic. According to a number of publications, waste plastic will coat hot aggregates in a thin layer of plastic and, when combined with a binder, these aggregates exhibit improved strength, resistance, and performance over time. It is affordable and sustainable. For roads within 50 km of the edge of metropolitan regions with a population of more than 50,000, the use of waste plastic as the default method of periodic replenishment with a hot mix has been approved by the Government of India (2015) and the National Rural Road Development Agency (2019). Additionally, the nation has promoted the use of waste plastic in flexible pavement mixtures when building rural and national highways. The Indian Road Congress [3] and the National Rural Road Development Agency established guidelines in 2013 for the use of waste plastic in hot bituminous mixtures (Figure 2).

Why Use Plastic?

- One big issue is how to dispose of used plastic.
- It exhibits non-biodegradability.
- Pollution to the environment results from burning these used plastic bags.
- Low-density polyethylene makes up the majority of it.
- To discover its application in bituminous mixtures for building roads.
- Bituminous blends were the subject of laboratory performance investigations. Studies in the lab have demonstrated that leftover plastic improves the mix's qualities.
- Bituminous mix properties offer an effective technique to dispose of waste.
- Sturdy and immune to rust.
- It lasts longer and is more affordable.
- Low maintenance requirements.
- Lightweight; & Simple to install and process.

Figure 2. Using waste plastic in concrete mix.

LITERATURE REVIEW

Indian scientist [4][5]. specialises in trash management. In addition to helping to speed up traffic, this technique will protect the environment from hazardous plastic debris. On April 15, 2008, he paid a visit to Mahatma School as well. Additionally, there is more resistance on the road to damage from strong rains. These days, many rural road construction projects employ his technique of building new roads. The Padma, India's fourth-highest civilian honour, was given to Dr. R. Vasudevan. In India, the idea of using waste plastic to create flexible road pavement has been implemented since 2000 [6]. In the process of creating flexible pavements, bitumen covers the aggregate and acts as a binding agent. It also helps to keep road pavement stronger and longer-lasting. It is not very resistant to water, though. It is a method for modifying the chemical composition of bitumen by mixing it with synthetic polymers to improve bitumen quality. The use of plastic waste in bitumen is similar to bitumen that has been polymerised. "Using plastic waste will help reduce the need for bitumen by around 10%, increase the strength and performance of roads," claims [7][8][9] [10]. According to Rokdey, "the bitumen becomes harder when plastic is added [11]." By giving non-biodegradable materials a useful purpose, incorporating waste plastic into pavements lessens the environmental impact of plastic trash [12]. By incorporating plastic waste management into asphaltic mixtures, plastic pollution's negative environmental effects can be mitigated, supporting the objectives of sustainable development. By using recycled plastic in pavements, we may lessen our reliance on imported materials like bitumen, which helps to preserve natural resources and lower our carbon footprint. By replacing bitumen, a non-renewable resource, with recycled plastic materials, the use of waste plastic in road construction helps save resources.

According to [13], asphalt amended with plastic shows improved resilience to rutting and cracking, resulting in a longer pavement life. Research findings suggest that asphalt pavements modified with plastic have enhanced resilience to deformation and better performance across a range of loads and environmental scenarios. The tensile strength and flexibility of asphalt mixes are enhanced by the use of various polymers, such as polyethylene (PE) and polypropylene (PP), which also improves structural integrity. Additives including polyethylene and polypropylene increase the mechanical characteristics of asphalt mixtures, making pavements more resilient to fatigue and less vulnerable to moisture-related deterioration.

Large-scale initiatives using waste plastic in road construction have been launched in nations like India, showing notable benefits in pavement durability and environmental stewardship [14]. The extensive use of plastic-modified roads in India has been shown to improve pavement performance, lower maintenance costs, and lessen the buildup of plastic waste. Field tests and longitudinal research show that pavements enhanced with plastic operate well over time, deteriorating little and holding up well against ageing and weather conditions. Field observations verify the long-term sustainability and financial advantages of this technique by demonstrating that pavements changed with plastic retain their structural integrity and functional qualities [14]. In addition to improving infrastructure resilience and sustainability, the use of waste plastic in flexible pavements presents a compelling answer to the environmental issues related to plastic waste [15]. Extensive investigation and advancement are imperative to enhance material compositions, processing methodologies, and standardisation procedures in order to foster extensive implementation and optimise the advantages of pavements modified with plastic.

METHODOLOGY

The methodology is the overarching research approach that specifies how the study is to be conducted and, among other things, what methods are to be employed. To finish a study by the deadline and come to a conclusion, a well-structured research plan is necessary. Getting the materials and doing initial testing on the bitumen and aggregates are the first steps. Aggregate is investigated experimentally using a variety of tests, such as crushing, impact, abrasion, etc. Shredded polyethylene and polypropylene plastic is combined with a hot bituminous mix. The procedure used in our research is to subject this bituminous mix to a Marshall Stability Test, with the results compared with a standard mix to determine the ideal bitumen content.

Materials Used

- Aggregate of size 12.5mm,10mm, 4.75mm, 2.36mm
- Stone dust
- Bitumen of 80/20
- Plastic waste
- Polyethylene terephthalate
- High density polythene

Aggregate

To hold the aggregates together, cement or bituminous materials are utilised. There are some situations where mixing rock dust with water produces a slurry that acts as a binder. There are two types of aggregates: natural and artificial. Again, the natural aggregates are separated into two categories: fine aggregates, which consist of sand, and coarse aggregates, which consist of broken rock aggregates or gravel as shown in fig 3. The most common type of blast furnace slag utilised in road construction is the by-product that is extracted from blast furnaces. Hard, resilient, long-lasting, and hydrophobic stone aggregate is ideal for use in road construction on bituminous surfaces. Gravel needs to be finely graded and have a minimum fineness modulus of 5.75.

Bitumen

Bitumen is utilised as binders for building pavements. Bitumen can be produced from naturally existing asphalt residue left over from the refinery. According to the American Society of Testing Materials, bitumen is defined as "Mixtures of hydrocarbons of natural or pyrogenous origin, or combination of both, frequently accompanied by their non-metallic derivations, which may be gaseous, liquid, semi-solid, or solid (Fig 4), and which are completely soluble in carbon dioxide". Large amounts of solid mineral stuff are present in bitumen, which is found in asphalt in its native state. Refineries utilise fractional distillation to sort petroleum crudes according to decreasing volatility. Distilling the leftover bituminous residue yields straight-run bitumen. Paving grades and industrial grades are the terms for the bitumen grades used in pavement construction and water proofing, respectively, of buildings. The climate of the area where surface dressing is to be built influences the grade of straight run bitumen selection.


Figure 3. Aggregate.


Figure 4. Bitumen sample.

Journal of Polymer & Composites
Volume 13, Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Waste plastic

Plastics are strong and break down very slowly; the same chemical links that give plastic its strength also prevent it from breaking down naturally. One billion tonnes of plastic have been thrown away since the 1950s, and this plastic may last for hundreds or perhaps thousands of years. Nurdles, the basic ingredient used to make all plastics, provide perhaps the greatest environmental danger associated with plastics. Many fish and birds are killed by these small pre-plastic pellets, which they mistake for food. The manufacture of polystyrene contributed to the ozone layer's depletion before the use of CFCs in polystyrene extrusion (and general use, with the exception of life-critical fire suppression devices; see Montreal Protocol). Currently, non-CFCs are used in the extrusion process (*Table 1*). While thermoset plastics can be crushed up and used as filler, thermoplastics can be remoulded and reused, albeit each cycle of reuse tends to reduce the material's purity. Plastics can be broken down into a feedstock condition using certain techniques (Figure 5).

Table 1. Plastic waste usage in road construction.

Waste Plastic	**Origin**
Low Density Polythene (LDPE)	Take along sacks, bottles of detergent and cosmetics, milk pouches, bin liners, and bags.
High Density Polyethylene (HDPE)	Carry bags, milk packets, bottle caps, household items, etc.
Polyethylene Terephthalate (PET)	consuming bottles of water, etc.
Polypropylene (PP)	bottle closures and caps, detergent wraps, biscuit vapour packs, etc.,
Polystyrene (PS)	Clear bottle caps and egg packs. Food trays, egg boxes, throwaway cups, protective packaging, and other items made of foamed polystyrene.
Polyvinyl Chloride (PVC)	Toys, credit cards, pipelines, gutters, mineral water bottles, medical disposables, etc.

RESEARCH TESTIMONIALS

- Aggregate collection in various sizes
- Collection of plastic
- Polyethylene Terephthalate
- High density Polythene
- Collecting the Bitumen

Tests On Aggregate

Crushing test

A relative measure of resistance to crushing under a gradually applied crushing load is provided by the aggregate crushing value. IS: 2386 part-m standardizes the exam Table 2.

Figure 5. Waste plastic.

Table 2. Crushing test.

S.N.	Observation	Readings
1	Total weight of dry sample (W1) in gm	2758
2	Weight of fines passing 2.36mm sieve (W2) in gm	609
3	Aggregate crushing value = W2/W1*100	22.08%

Impact test

The purpose of the aggregate impact test is to determine how resilient aggregates are to impact. Aggregates that pass through a 20 mm sieve and are held on a 12.5 mm sieve are placed into a cylindrical steel cup with an internal diameter of 10.2 mm and a depth of 5 cm. This cup is connected to the impact testing machine's metal base. The material is filled in three levels, and each layer is compacted with twenty-five blows. A metal hammer weighing between 13.5 and 14 kg is set up to fall with a free fall of 38.0 cm using vertical guides, and the test object is struck fifteen times. The 2.36mm IS sieve is permitted to pass through the crushed aggregate (Table 3). The percentage of aggregate that passes the sieve is used to calculate the impact value. IS: 2386 part-IV1963.

Table 3. Impact test.

S.N.	Observation	Readings
1	Total weight of aggregate sample filling cylindrical measure (W1) kg	319
2	Weight of aggregate passing through 2.36mm IS sieve (W2)	69.5
3	Aggregate impact value=(W2/W1)*100	21.75%

Tests on Bitumen

Penetration test

The hardness or softness of bitumen is measured in tenths of a millimetre, or the depth to which a standard loaded needle will penetrate vertically in five seconds. BIS standardised the equipment and test protocol. A 100g needle assembly plus a mechanism that locks and releases material placed into containers at least 15 mm deeper than expected penetration make up the penetrometer. A specific temperature of 25 °C must be reached for the test to be conducted. Note that the penetration value is greatly affected by inaccuracies in the pouring temperature, needle size, weight on the needle, and test temperature. When bitumen is graded 40/50, it means that the penetration value typically ranges from 40 to 50 when tested under standard conditions (Table 4). In hotter climates, a lower penetration grade is preferable. It is done in accordance with IS: 1203-1978.

Pouring Temperature: Room Temperature

- *Room temperature*: 27C
- *Period of cooling in atmosphere*: 45 minutes
- *Duration of Releasing the penetration needle*: 55sec
- *Average Penetration value*: 17

Table 4. Penetration test.

Penetration	Test 1	Test 2	Test 3	Average
Initial	0	0	0	0
Final	13	13	25	17

Softening point test

The term "softening point" refers to the temperature at which, in accordance with test criteria, bitumen reaches a given degree of softness. IS: 1205-1978 is followed in conducting the test (Table 5).

- *Bitumen Grade*: 80/20
- *Period of cooling*: 50 minutes
- *Rate of heating*: 4C/min

- 1st Ball = 68.8C
- 2nd Ball = 75.2C
- Average Softening point value = 72C

Table 5. Softening point test

Time/Min	Temperature
0	58
1	68.8
2	75.2

Ductility test

The quality of bitumen that allows for significant elongation or deformation is called ductility. This examination was conducted (Table 6) in compliance with IS:208-1978.

- *Pouring temperature*: 90C
- *Period of cooling in atmosphere*: 40 minutes
- *Test temperature* 25C

Table 6. Ductility test

Briquette number	Test 1	Test 2
Initial	0	0
Final	63cm	78.5cm

Marshal Stability Test

Routine test programs for paving operations heavily utilise the Marshal test. The mix's stability is defined as the highest load that a compacted specimen can withstand at the typical test temperature of 600CDuring a stability test, the flow is expressed as the deformation in units of 0.25mm between the specimen's highest load and no load (the flow value can also be expressed in terms of deformation units of 0.1mm). The goal of this test is to determine the ideal binder content given the kind of aggregate mix and traffic intensity. This test aids in the illustration of Marshall Stability versus bitumen percentage. The required sample comes from the Marshall Stability graph; choose the coarse, fine, and filler proportions in a way that satisfies the specifications. The mixture should weigh 1200g in total.

RESULTS AND PERFORMANCE EVALUATION

Marshal Stability Test

Stability and flow value determination (Table 7)

- *% weight of coarse aggregate*: 33.5%
- *% weight of fine aggregate*: 26.66%
- *% weight of filler*: 40%
- *% weight of bitumen mix*: 4.5%

Table 7. Marshal Stability and flow value determination.

Sample no.	Bitumen content %	Maximum proving ring reading	Measured stability, kg	Corrected stability, kg	Flow dial reading	Flow value 0.25mm, units
1	4.5%	243	1358.37	1127.44	140	1.40
2	4.5%	283	1581.97	1313.03	105	1.05
Average	4.5%	263	1470.17	1220.23	122.5	1.22

PET plastic stability and flow value readings (Figure 6 & Table 8)

- *Grade of bitumen*: 80/20
- *Mixing temperature*: 120°C

- *Compacting temperature*: 115°C
- *No. of blows on either side*: 50 blows
- *Proving ring calibration factor*: 5.6
- *Flow value dial 1, division*: 0.01

Table 8. PET Plastic stability and flow value determination.

Sample no.	Bitumen content %	Maximum proving ring reading	Measured stability, kg	Corrected stability, kg	Flow dial reading	Flow value 0.25mm, units
1	0%	263	1470.17	1220.23	122.5	1.22
2	6%	222	1240.98	1030.01	85	0.85
3	8%	258	1442.22	1240.30	165	1.65
4	10%	274	1537.25	1275.25	186	1.86

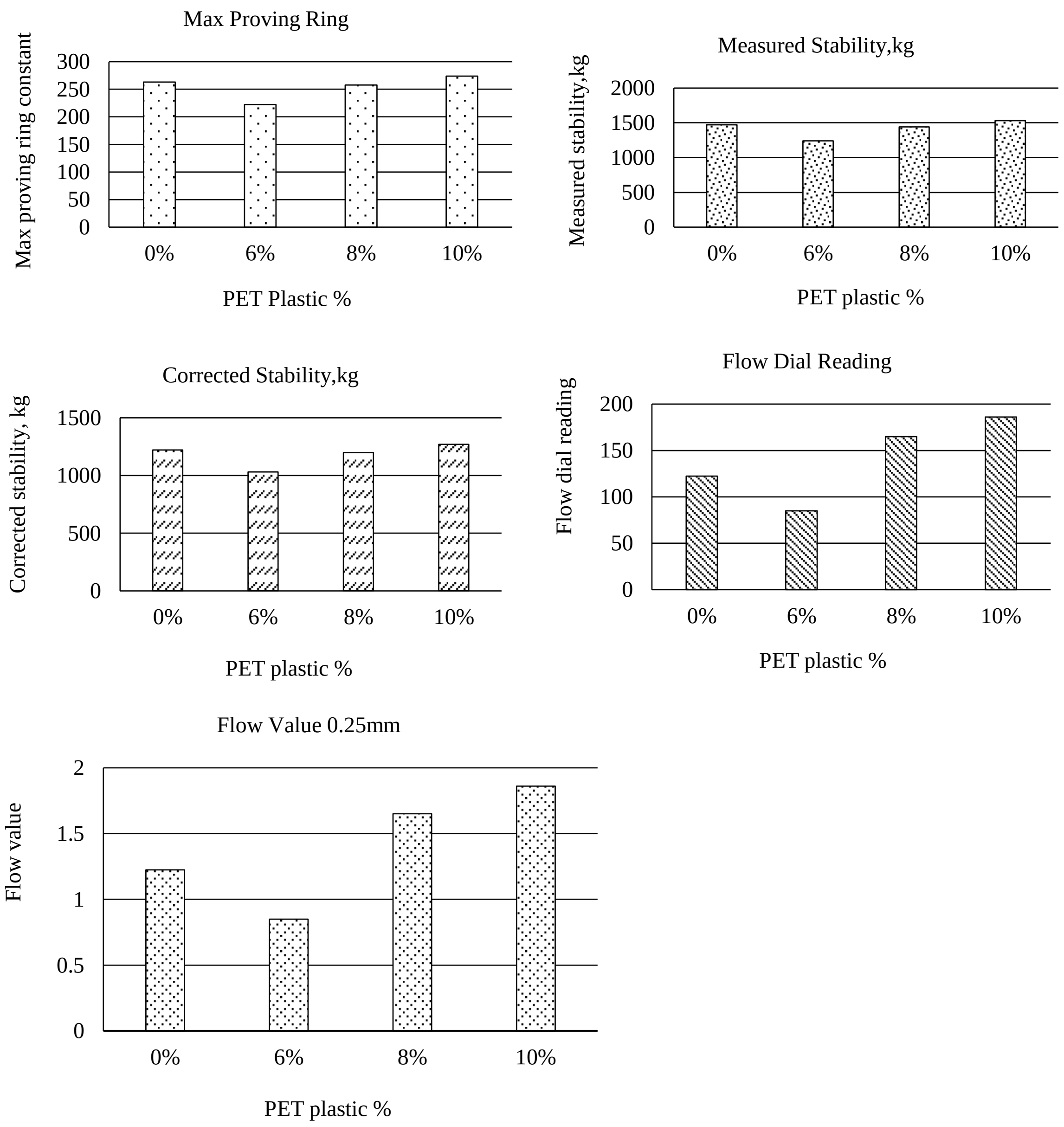

Figure 6. PET plastic stability

Adding of high-density polyethylene (Figure 7 & Table 9)

- *Grade of bitumen*: 80/20
- *Mixing temperature*: 130°C
- *Compacting temperature:* 115°C
- *No. of blows on either side*: 50 blows
- *Proving ring calibration factor*: 5.6
- *Flow value dial 1, division*: 0.01

Table 9. High density polyethylene stability and flow value.

Sample no.	Bitumen content %	Maximum proving ring reading	Measured stability, kg	Corrected stability, kg	Flow dial reading	Flow value 0.25mm, units
1	6%	145	810.55	672.75	85	0.85
2	8%	168	939.12	779.46	62.6	0.62
3	10%	183	1022.97	849.06	105	1.05
4	12%	172	961.48	798.02	116.5	1.16

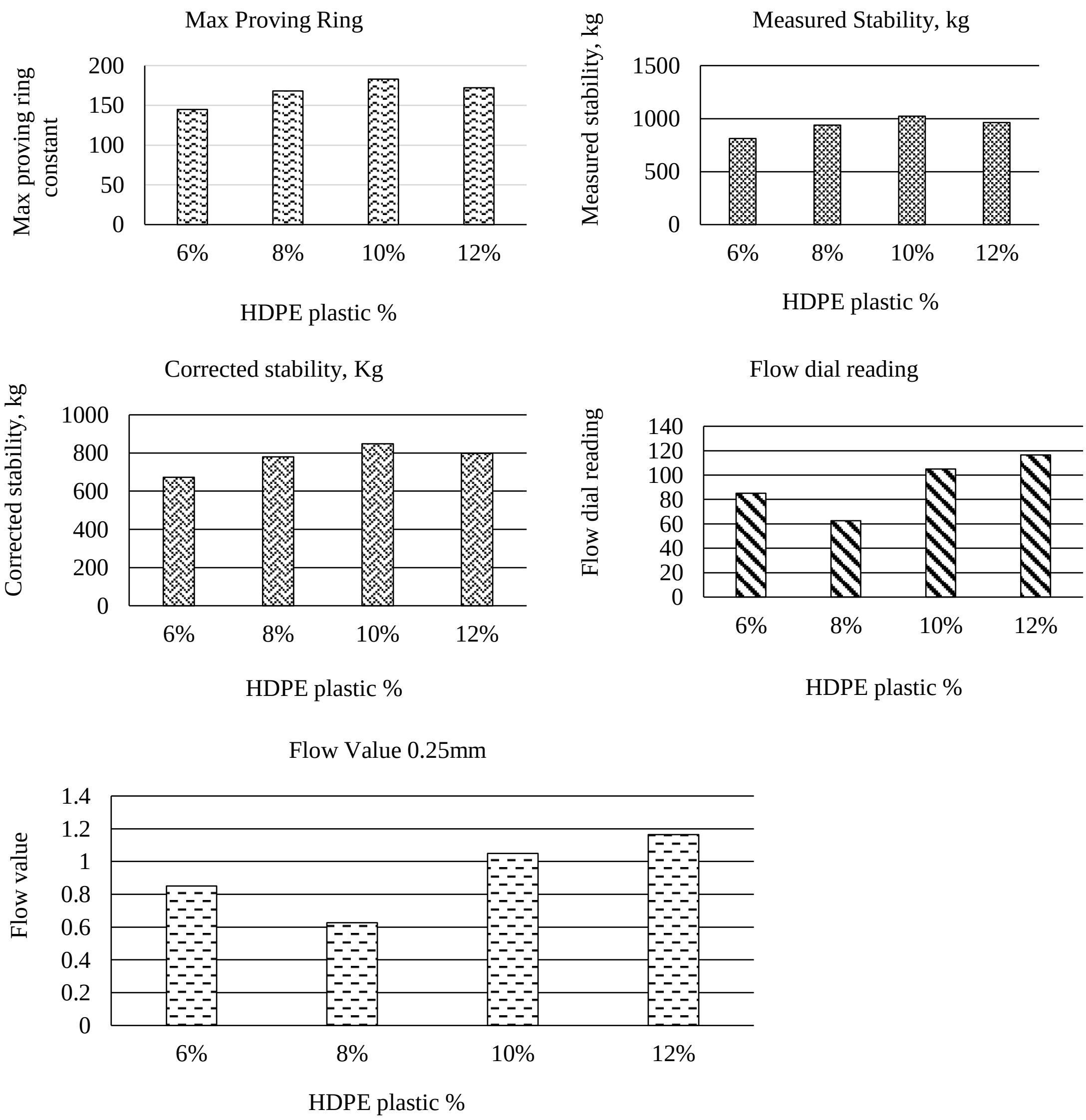

Figure 7. High density polyethylene.

CONCLUSION, LIMITATIONS AND FUTURE SCOPE

Conclusion

- Aggregate and recycled plastic are used to improve road performance. The addition of waste plastic to the bituminous mix improved stability, which in turn increased the road's ability to carry more weight.
- It is demonstrated by the graphs that utilising waste plastic improves stability.
- Plastic softens, functions as a good binder, and is environmentally benign when combined with the hot bituminous mixture.
- Using discarded plastic enhances the mix's binding ability.
- The trials have out shown that 8% was the ideal outcome for waste plastic.
- The inclusion of waste fibre enhanced the bitumen's penetration and softening point qualities.
- High temperatures (50˚C) can also be achieved in regions where plastic roads can be built.
- Road waste plastic significantly improves the roadways' durability and stability value.

Limitations and Future Scope of the Study

Limitations

While using PW in construction has many environmental and financial advantages, there are still certain restrictions that prevent its widespread application. The following is a quick discussion of some of the main restrictions related to using plastic waste in construction applications:

- *Harvesting*: Harvesting PW prior to recycling is one of the main restrictions on its utilisation. Generally, when PW is collected from different streams where it is formed, it is contaminated with different kinds of plastics and other contaminants.
- *Varying composition*: PW is composed of various plastic grades and types, which may cause it to function non-isotropically when utilised for construction, in contrast to building materials like steel. Additionally, because some plastics, like EPS, have complicated compositions that make it unsuitable for reuse through normal recycling procedures, these plastics end up as waste and wind up in places like the marine environment.
- *Low density:* While using low-density materials might be beneficial in some construction projects, plastic wastes have a low density, which makes them inappropriate for uses requiring high toughness and elastic modulus. Due to the PW having to be resized to match the restricted space, the low density also raises the cost of transportation.
- *Lack of knowledge*: The usage and acceptance of PW by contractors for various construction applications has been hampered by their inadequate knowledge of the long-term performance of recycled plastic.
- *Low surface energy:* When plastics are utilised for applications like the incorporation of PW into a composite, their low surface energy typically leads to poor mechanical bonding. The overall mechanical performance of the resultant composite may be diminished as a result of this inadequate bonding.
- *Financial limitations:* the inability to recycle certain plastic kinds stems from the need for sophisticated technology, which is currently costly.
- *Absence of standards:* At the moment, there isn't a standard that backs the implementation of PW in building. Despite several research being conducted, there is currently a lack of commercial standardisation for certain building applications, such as the usage of PW in cementitious composites.

Future scope of the study

Envision a roadway composed entirely of plastic debris! Did you know that plastic garbage was used to build 703 kilometres of National Highway in India? 2018 saw the release of recommendations from the Union Road Transport and Highways ministry regarding the use of plastic debris in road construction projects. Since then, the use of plastic garbage for road construction has been tested in around 11 states nationwide. Who would have thought that waste plastic could be turned into something so advantageous and helpful? This program demonstrates how creative solutions may be created to address environmental problems and improve infrastructure, paving the way for a more sustainable and ecologically friendly future. Although utilising recycled plastics for road construction has shown to be effective, scalability is still a problem. Timelines for production and installation can be accelerated by innovation and technological advancements, such as the injection moulding method utilised in Grid Mats, recycled polypropylene mats used in road building. But more companies need to enter the market to increase awareness before there can be true scalability.

Acknowledgments

The tests in this research paper were carried out at the Structural Engineering Laboratory of the Civil Engineering Department at Vignana Bharathi Institute of Technology, Hyderabad, Telangana, India.

REFERENCES

1. Nasr, D., & Pakshir, A. H. (2019). Rheology and storage stability of modified binders with waste polymers composites. Road Materials and Pavement Design, 20 (4), 773–792.
2. Ramakrishna, U., & Mohan, S. C. (2020). Performance of low-cost viscoelastic damper for coupling adjacent structures subjected dynamic loads. *Materials Today: Proceedings*, *28*, 1024-1029.
3. Congress, I. R. (2013). Guidelines for the use of waste plastic in hot bituminous mixes (dry process) in wearing courses. In *Indian Road Congress*.
4. Vasudevan, R. (2004). Use of plastic waste in construction of tar road. *Environmental information system (Envis), Indian Centre for Plastics in the Environment*, *2*, 1-4.
5. Vasudevan, R. N. S. K., Nigam, S. K., Velkennedy, R., Sekar, A. R. C., & Sundarakannan, B. (2010). Utilization of waste polymers for flexible pavement and easy disposal of waste polymers. *International Journal of Pavement Research and Technology*, *3*(1), 34-42.
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. Chavan, A. J. (2013). Use of waste plastic in flexible pavements. *Int. J. Appl. or Innov. Eng. Manag. ISSN*, 2319-4847.
8. Kumar, R., & Khan, M. A. (2020). Use of plastic waste along with bitumen in construction of flexible pavement. *Int. J. Eng. Res. Technol*, *9*, 153-158.
9. Patel, V., Popli, S., & Bhatt, D. (2014). Utilization of plastic waste in construction of roads. *International journal of scientific research*, *3*(4), 161-163.
10. Singh, P., Kumar, A., Singh, S., Rajput, R., & Singh, C. L. (2020). Use of plastic waste in flexible pavement-green highway. *International Journal of Engineering Research and*, *9*(09).
11. Rokdey, S. N., Naktode, P. L., & Nikhar, M. R. (2015). Use of plastic waste in road construction. *International Journal of Computer Applications*, *7*, 27-29.
12. Gautam, P. K., Kalla, P., Jethoo, A. S., Agrawal, R., & Singh, H. (2018). Sustainable use of waste in flexible pavement: A review. *Construction and Building Materials*, *180*, 239-253.
13. Duggal, P., Shisodia, A. S., Havelia, S., & Jolly, K. (2020). Use of waste plastic in wearing course of flexible pavement. In *Advances in Structural Engineering and Rehabilitation: Select Proceedings of TRACE 2018* (pp. 177-187). Springer Singapore.
14. Biswas, A., Goel, A., & Potnis, S. (2020). Performance comparison of waste plastic modified versus conventional bituminous roads in Pune city: A case study. *Case Studies in Construction Materials*, *13*, e00411.
15. Bilema, M. (2024). A review on waste plastic in flexible pavement: types, dosage, mixing, performance and challenges. *Innovative Infrastructure Solutions*, *9*(7), 249.

