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# Comparative Analysis of Asphalt Pavement using Partial Waste Plastic Material

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## Abstract

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Increasing the plastic waste can affect the environment, utilizing the plastic waste generated by incorporating with the bitumen can improve the pavement performance. This approach provides a sustainable solution by reducing landfill accumulation and decreasing reliance on non-renewable resources like natural aggregates and petroleum-based bitumen.

The objective of this study is to analyze the cost-effectiveness of using recycled waste materials in asphalt pavement construction by comparing materials and to compare the properties and performance of recycle mixes. Experiments conducted here, explored the feasibility of reusing waste plastic in a productive manner. Paper consistently indicates that when waste plastic is added to hot aggregates, it forms a thin coating over the aggregate particles.

Plastic coated aggregate when mixed with bitumen improve the overall performance of the asphalt mix. Results in improved strength, increased resistance to water, weather, and superior long-term performance. Integration of waste with bitumen not only extends, life of pavement but also enhances its smoothness, riding quality, cost-effective and environmentally sustainable.

Findings of this study are Plastic additive in asphalt pavement improves strength and flexibility in road construction. It is concluded that such roads enhanced Marshall Stability, and reduced flow values. It is concluded about the, cost-effectiveness, designing and testing of the asphalt pavement along with the road designed by using recycled plastic waste.

**Keywords:** *aggregate, asphalt pavement, bitumen, marshal stability, shredded material*

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## Introduction

Plastics production has increased globally (≈380 million tons by 2015 , creating a waste management crisis. A promising reuse strategy is to incorporate waste plastics into road materials – either by blending shredded plastic into bitumen (wet process) or by coating aggregates with melted plastic (dry process) (Sedai, Ghimire, & Devkota, 2025). Reviews report that adding waste plastic to asphalt often significantly improves high-temperature performance of the pavement Abd Karim, et al. (2023) suggesting better rutting resistance and durability in hot climates. In fact, modified asphalt mixtures with plastic typically show higher stiffness and binding strength than conventional mixes (Abd Karim, et al., 2023; Sedai, Ghimire, & Devkota, 2025).

Plastics such as polyethylenes are ubiquitous because they are cheap, lightweight, and durable (Ibrahim, 2022) . For example, low-density polyethylene (LDPE) – used in films and bags – is one of the primary thermoplastic polymers, alongside PET, HDPE, PVC, PP, and PS (Ibrahim, 2022). These thermoplastics soften when heated and can be remolded (Ibrahim, 2022), which in principle enables recycling. However, the very properties that make them valuable (e.g. long-lasting, easy to mold) also mean that, without effective processing, they persist in waste streams and create pollution (Ibrahim, 2022). Consequently, managing LDPE and similar plastics is a major challenge for waste management systems.

Multiple studies document that plastic-modified asphaltyields superior mechanical properties. For example (Sedai, Ghimire & Devkota, 2025), found LDPE-modified asphalt increased mixture stiffness by over 170% (at 25 °C) and tensile strength by 51% compared to unmodified asphalt (Sedai, Ghimire & Devkota, 2025). Similarly, many investigations report higher Marshall Stability, indirect tensile strength, and resistance to permanent deformation and fatigue in plastic-bitumen blends (Abd Karim, et al., 2023). Laboratory tests often show that plastic-coated aggregates form a thin polymer film that improves aggregate binding and abrasion resistance (Xu, Zhao & Li, 2021). In practice this translates to roads with better load-bearing capacity and longer life: researchers note plastic roads tend to have fewer potholes, higher water resistance, and lower deformation under heavy traffic (Abd Karim, et al., 2023; Xu, Zhao & Li, 2021).

The enhanced performance also means less material or bitumen may be needed. For instance, waste-plastic-modified bitumen mixtures have demonstrated greater density and stability than plain bitumen mixes (Xu, Zhao & Li, 2021). This reduces bitumen demand and maintenance needs. In India's recent trials, pavements with LDPE-modified asphalt showed up to 42% longer rutting life and up to 57% longer fatigue life than conventional pavements (Sedai, Ghimire & Devkota, 2025).

## Objectives of the Study

Analyze the cost-effectiveness of using recycled waste materials in asphalt pavement construction by comparing material and construction costs with conventional methods.

Compare the properties and performance of recycle mixes.

### Study Area

**Material Properties:** Comparison of the engineering properties, behavior and performance of the asphalt mixes with conventional mixes.

**Civil Engineering (Pavement Design):** Analyzing the mechanical performance (e.g., strength, durability, stability) of asphalt pavements through laboratory testing, such as Marshall Stability and flow tests, to compare recycled and conventional mixes.

**Economic Analysis:** Exploring the cost-effectiveness of recycled asphalt mixtures, including potential savings in construction and maintenance costs.

## Statement of Problem

Nepal is facing two major problem while developing the road infrastructure: the rapid growth of non-biodegradable waste and frequent damage of the roads due to high traffic load and poor durability. Road constructed form the conventional method becomes not only costly but also unsustainable practice. Yearly a large quantity of plastic waste are generated which is a challenging for waste management authority, Although international research studies had concluded using plastic waste in road construction will increases the strength, durability and resistance to weathering also sustainable practice also it reduces the cost. But it is not properly started in Nepal due to limited research and implementation practice. This gap demand the urgent need to investigate the performance, cost effectiveness of plastic modified asphalt in Nepal.

# Literature Review

### Use of Plastic in Pavements

Incorporating waste plastics (LDPE, HDPE, PET, etc.) Can significantly improve high-temperature performance of pavements, offering economic and environmental benefits. (It also notes performance depends on plastic type, plastic content and blending conditions, and identifies challenges in stability and low-temperature performance (Pan, et al., 2025).

This comprehensive review emphasizes that waste-plastic binders boost high-temperature stability and often fatigue resistance; e.g. mixtures with LDPE/EVA showed the best overall rutting and fatigue performance. It highlights both engineering benefits and environmental concerns (Radeef, et al., 2021).

### Modification Methods

### Dry Process

This study investigates an "enhanced" dry-mixing method. Conventional dry mixing (adding shredded plastic to hot aggregate) was found to "deviate the aggregate structure" at high plastic contents, whereas the new process yielded more uniform particle coating and greatly improved performance at ~20% binder replacement (Kovács, et al., 2024).

Discuss key differences of the dry method. They note the dry process requires no new equipment (can be done in any asphalt plant) and is "more cost-effective", but mixtures often show "relatively poor water stability" (higher susceptibility to moisture damage). This underscores that dry-mix asphalt tends to be cheaper and simpler to implement but may need attention to moisture resistance (Shaikh, et al., 2017).

### Wet Process

Describe the wet method: waste plastic (often as powder or granules) is blended into hot bitumen in a high-shear mixer before mixing with aggregate. The result is a high-viscosity modified binder that coats aggregates uniformly. The modified asphalt binder produced by the wet process has a higher viscosity, which allows a better coating of the aggregate particles, without exudation or drainage problems. However, it requires specialized mixing/storage equipment and extra energy (Pan, et al., 2025).

The wet processing yields better plastic–asphalt integration but at higher cost. Their review states the wet process enhances asphalt and plastic integration but demands high energy and specialized equipment. In short, wet mixing produces a more uniformly modified binder (better thermal stability), but with greater equipment and energy requirements (Radeef, et al., 2021).

### Types of Plastics Used in Studies

This study added recycled LDPE (from bags) to asphalt. It found an optimum 6% LDPE by binder weight produced a homogeneous modified binder meeting all specifications, with no capital upgrades needed at the asphalt plant. The result was an asphalt meeting target penetration and softening criteria, demonstrating LDPE's feasibility in dry blends (Shaikh, et al., 2017).

# Methodology

### Material Collection and Preparation

Material are collected from the local recycling center and the material collected should be cleaned and properly shredded into the required size

**Conventional Aggregates:** Stones and gravel are collected from and sieve analysis to obtain the proper gradation of the aggregates.

**Waste Plastic:** Low-density polyethylene (LDPE) will be collected from local waste recycling centers. We have done this test for only LDPE plastics. Plastics will be cleaned to remove the impurities. Plastic are then shredded into 2-5 mm before mixing with aggregate

**Bitumen:** Bitumen of Viscosity grade VG30 is used throughout the tests.

**Mix Design**

Asphalt mixes are made by using the Marshall Mix design method. Two types of mixture is made one is control mix and the other one is plastic modified mix. Plastic is incorporated in bitumen at varying percentage 5%, 10%, 15% by weight of bitumen and into aggregate as well-known as Wet process and dry process respectively. Mix Design mold are basically made by two process called Wet Process and Dry process. In Wet process The aggregate are heated separately at 150–170°C and bitumen at 135–160°C now the shredded plastics are added into hot bitumen and when it melts hot aggregate are added in this way we can create mold for the wet process, now this process is done for 5%, 10%, 15% plastic content by weight of bitumen. In Dry Process plastic are added into the hot aggregate to form a plastic coated aggregate which is then mixed with hot bitumen to form mold for the dry process. After preparation of mixes it is placed in Marshall Compaction machine and compacted using compaction hammer to achieve standard specimen sizes (101.6 mm diameter, 63.5 mm height).

**Laboratory Testing**

Laboratory testing help to determine the mechanical properties and performance of different mixes. Test are conducted based on ASTM standards. Testing includes Aggregate test (Normal vs. Plastic coated), Bitumen Test (Normal vs Plastic Modified) and Mix Design Test (Normal vs. Plastic Modified)

**Aggregate Tests:**

**Impact Test**

A test was conducted to analyze the toughness of the aggregate under sudden load. Aggregate coated with plastic (5%, 10%, 15%) by weight and Normal aggregates were tested. The Plastic coated aggregate prepared by heating aggregate and adding the shredded plastic into the aggregate according to their respective percentage to prepare sample aggregate. Each sample are subjected to impact load and the crushed pieces i.e. the sample passing through 2.36 mm sieve was measured. The result obtained is compared to the normal aggregate.

**Crushing Test**

A test was conducted to analyze the resistance of aggregate towards compressive load. Aggregate coated with plastic (5%, 10%, 15%) by weight and Normal aggregates were tested. The Plastic coated aggregate prepared by heating aggregate and adding the shredded plastic into the aggregate according to their respective percentage to prepare sample aggregate. Each sample are subjected to compressive load and the crushed pieces i.e. the sample passing through 2.36 mm sieve was measured. The result obtained is compared to the normal aggregate.

**Los Angeles Abrasion Test**

Los Angeles Abrasion test is conducted on rotating cylindrical drum where aggregate are rotated along with the steel balls in the drum and the abrasion value of the aggregates are calculated. Aggregate coated with plastic (5%, 10%, 15%) by weight and Normal aggregates were tested. The prepared sample is placed in rotating drum along with the steel balls for specified number of revolution. The percentage wear was then calculated by measuring the weight of material passing through 1.70mm sieve.

**Bitumen Tests:**

**Penetration Test**

The Penetration test was conducted to measure hardness and consistency of the bitumen. The test was conducted using a standard needle loaded with 100 grams for 5 seconds at temperature 25 °C. Plastic modified bitumen is made by adding shredded plastic into the hot bitumen. Both Normal bitumen and Plastic modified bitumen (5%, 10%, 15%) are tested and depth of penetration of needle was measured.

**Ductility Test**

The ductility test was conducted to determine the resistance of the bitumen to cracking under tensile stress. Plastic modified bitumen is made by adding shredded plastic into the hot bitumen. Both Normal bitumen and Plastic modified bitumen (5%, 10%, 15%) are tested. The test is conducted by filling the ductility test with bitumen and placed in water bath for an hour after an hour test is conducted at same temperature where the bitumen is elongated at the pull rate of 50 mm/min until rupture. The ductility value are measured in centimeter and the breaking point of bitumen is recorded.

**Mix Design Tests:**

**Marshall Stability and Flow Test**

Marshall Stability and flow test were carried out to determine the strength and deformation characteristics of asphalt mixture prepared by using conventional and plastic modified method.

Cylindrical specimens of 101.6 mm diameter and 63.5 mm height were prepared and compacted with 50 blows on each face. All specimens were conditioned in a water bath at 60 °C for 30–40 minutes before testing. The test is done by using bitumen of VG30, 5% by weight of aggregate. The load was then applied at a rate of 50 mm/min, and the maximum load (stability, in KN) and deformation at failure (flow, in mm) were recorded. We have done test using two different method

**Dry Process**

In Dry process Shredded plastic waste (5%, 10%, 15%) were added separately in hot aggregate heated up to 150-170 °C. The plastic added melts and coat the aggregate surface forming plastic coated aggregate now the hot bitumen VG30 is added into the aggregate to prepare the mix. Now the prepared mix is placed in cylindrical mold for compaction.

**Wet Process**

In Wet process Shredded plastic waste (5%, 10%, 15%) were added separately in hot bitumen VG30 heated up to 150-160 °C. The modified bitumen is mixed with hot aggregate to prepare modified asphalt mix. Now the prepared mix is placed in cylindrical mold for compaction

Data Collection Andanalysis

Test results will be analyzed to compare the performance of modified and Normal mixes

**Performance comparison includes:**

Marshall Stability (KN) and Flow (mm).

Ductility (cm), Penetration (0.1 mm)

Aggregate Compression test, impact test, Aggregate Abrasion test

**Impact Test**

***Table 1. Impact Test***

| Sample | Normal Aggregate Impact Test | Plastic coated Aggregate Impact Test (5%) | Plastic coated Aggregate Impact Test (10%) | Plastic coated Aggregate Impact Test (15%) |
|---|---|---|---|---|
| 1 | 25.45 | 4.95 | 5.12 | 14.85 |
| 2 | 25.3 | 5.02 | 5.03 | 14.92 |
| 3 | 25.38 | 4.98 | 5.08 | 14.78 |
| Average Value | 25.38 | 4.98 | 5.08 | 14.85 |

From the test result we can conclude that the Normal aggregate have high impact value i.e. 25.45% which means they have less resistant to impact. When the plastic is coated in aggregate the impact value is dropped and again at 15% the value is again raised which indicates the decrease in performance at 15%.

### Compression test

*Table 2. Compression Test*

| Sample | Normal Aggregate Compression Test | Plastic coated Aggregate Compression Test (5%) | Plastic coated Aggregate Compression Test (10%) | Plastic coated Aggregate Compression Test (15%) |
|---|---|---|---|---|
| 1 | 22.8 | 19.4 | 14.1 | 12.4 |
| 2 | 23.2 | 19.8 | 14.5 | 12.8 |
| 3 | 23.6 | 20.2 | 14.9 | 13.2 |
| Average Value | 23.21% | 19.80% | 14.45% | 12.80% |

From the test result we can conclude that the Normal aggregate have high compression value which means lower strength (weak against compressive load) and high performance at 15%.

### Los Angeles abrasion test

*Table 3. Los Angeles abrasion test*

| Aggregate Type | Normal Aggregate | 5% Plastic Coated Aggregate | 10% Plastic Coated Aggregate | 15% Plastic Coated Aggregate |
|---|---|---|---|---|
| Abrasion test (%) | 23.2% | 18.8% | 17% | 16.2% |

From the test result we can say that the Normal aggregate have high abrasion which means high wear and less resistance to surface friction where are abrasion value keeps on decreasing which shows improve performance with increase of plastic content in aggregate.

### Penetration test

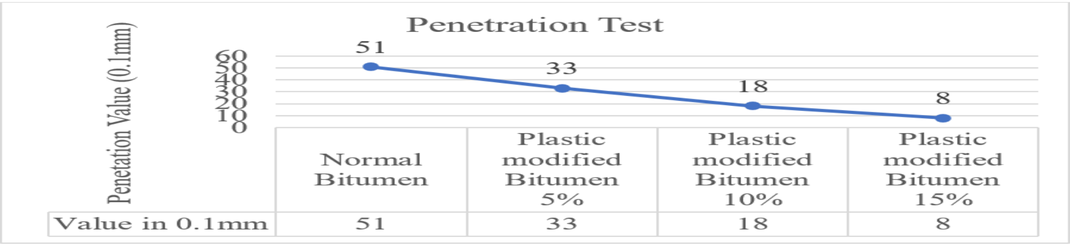


*Figure 1. Penetration test vs. Plastic Content*

From the above graph we can conclude that the penetration value is more at Normal Bitumen means it is softer and more penetrated at Normal condition. The penetration value goes on decreasing when we add plastic content in the bitumen which shows bitumen become harder and stiffer when added plastic in it.

### Ductility Test

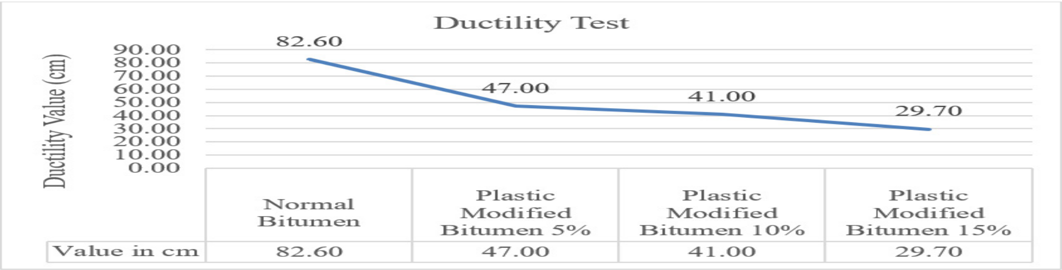


*Figure 2. Ductility Test vs. Plastic Content*

From the chart we can say that the Ductility value is higher for normal bitumen which is best for resistance against cracking low ductility means brittle and crack prone

**Mix design test**

**Marshall Stability and Flow value test**

Marshall Stability and Flow value test help to access the stability and flexibility of asphalt mix under the compressive loads. The Marshall Stability value indicates the maximum load it can withstands and flow value refers to the deformation at maximum loads.

**Normal Bitumen Test**

***Table 4. Normal Bitumen Marshall test***

| S.N. | Marshall Stability Value (KN) | Flow Value (mm) |
|---|---|---|
| 1 | 12.35 | 4.32 |
| 2 | 11.81 | 4.25 |
| 3 | 13.203 | 4.36 |
| Average Value | 12.458 | 4.31 |

**Plastic Modified Bitumen Test**

**Wet Process**

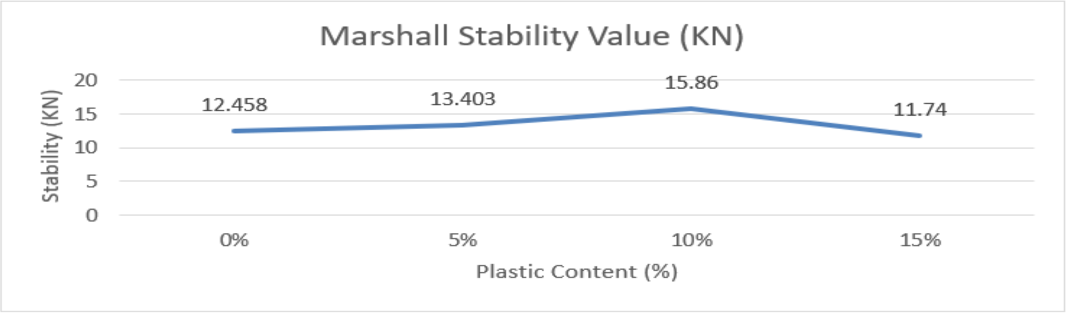


***Figure 3. Marshall Stability Value vs. Plastic Content***

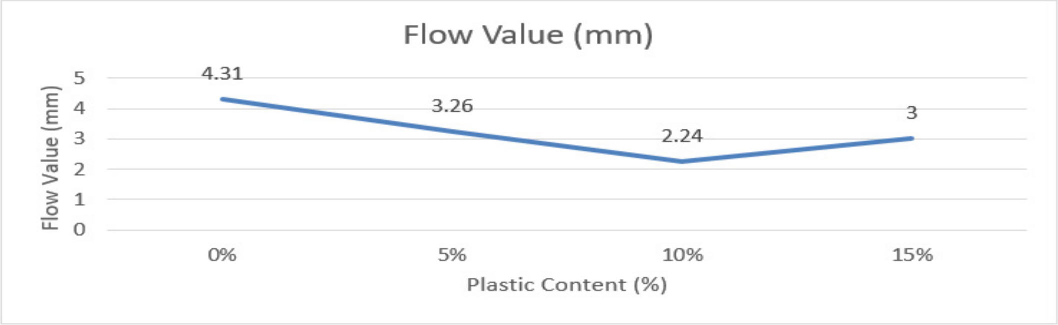


***Figure 4. Flow Value vs. Plastic Content***

The Marshall Stability test (Wet Process) shows that the plastic modified asphalt improve performance compared to the conventional mix. The result shows that the performance peak at maximum at 10% i.e. when we use 6 grams of plastic

**Dry Process**

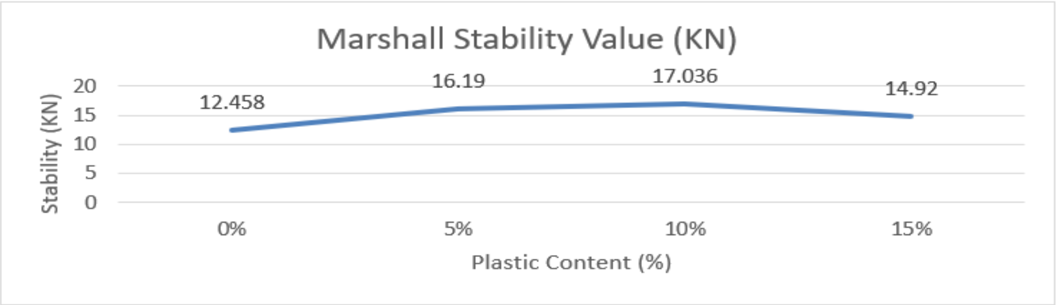


***Figure 5. Marshall Stability value vs. Plastic Content***

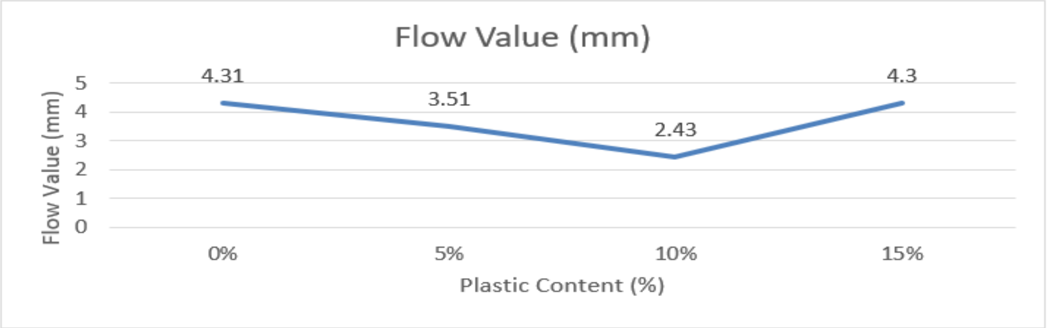


***Figure 6. Flow Value vs. Plastic Content***

The Marshall Stability test (Dry Process) shows that the plastic modified asphalt improve performance compared to the conventional mix. The result shows that the performance peak at maximum at 10% i.e. when we use 6 grams of plastic

## Discussion

This section provides a detailed analysis and findings from the laboratory tests and performance evaluations of asphalt mixtures modified with plastic waste compared to normal asphalt.

The Laboratory results clearly shows that the decrease in the aggregate crushing and impact test which indicates the better performance. We can also see the performance drops slightly at 15%, avoid jumping direct to 15% without proper tests. Similarly we can see that the abrasion loss fall with the increase in the plastic content which indicate the better surface resistance. Penetration values decrease as plastic content rises (bitumen becomes stiffer), ductility values decrease (modified bitumen is less ductile than neat bitumen).

Marshall Stability and overall mix performance for both dry and wet modification methods peak in the same percentage of plastic content around 10% plastic, the experimental mixes showed the maximum near the 10% level. This provides an optimal content for the adding plastic in the Asphalt mix. At higher dosages (15%) several tests showed deterioration or inconsistent results (e.g., impact test, Ductility test and

## Conclusion

This study finds the short term performance of the asphalt mix modified with the plastic waste. The results obtained from the Aggregate, Binder, Mix Design test shows that when plastic are added in controlled amount it can improve the strength and stability of the asphalt mixes. While replacing the bitumen content in the mix it can also reduce the material cost. Aggregate test confirm that when plastic added into the aggregate it forms a protective layer over the aggregate which improve the aggregate toughness and durability. Binder test shows that the penetration value and ductility value decreases with the addition of the plastics which means binder become tough and less resistant to rutting however too much tough also leads to cracking which can be seen in 15% plastic content

Marshall stability and flow test provide a clear idea about the benefits of using plastics in the asphalt mixes. The control mix has a stability and flow value as 12.46 KN and 4.31 mm respectively, Plastic modified mix both wet and dry process shows the improvement in performance with maximum stability at 10% plastics, at this dosage in wet process stability increased by 27% and 37% in dry process compared to the conventional mixes. Similarly Flow value decreased by 37% and 29% in wet process and dry process respectively compared to conventional mixes. Thus we can conclude the optimum quantity of the plastic is 10% plastic by weight of bitumen where strength and stability become maximum.

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