**ASSESSMENT OF BITUMINOUS CONCRETE MIXTURES INCORPORATING POLYETHYLENE WASTE**

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**ABSTRACT :** Bituminous concrete, a composite material, is commonly employed in construction for paving parking lots, roadways, and airports. This material consists of asphalt or bitumen mixed with mineral aggregates, which are combined, layered, and compacted. Given the high traffic volumes from commercial vehicles and the significant daily and seasonal temperature fluctuations, there is a need to explore various modifications to enhance the pavement's quality and performance while balancing strength and cost. Additionally, from an environmental perspective, the widespread use of polyethylene has led to substantial pollution, as these materials are non-biodegradable. Therefore, there is a pressing need to repurpose waste polyethylene for beneficial applications. This study investigates the effects of incorporating polyethylene waste into bituminous concrete mixtures. Different percentages of polyethylene were used to prepare these mixtures, with evaluations conducted according to the IRC Code. The study examines how polyethylene affects various engineering properties by preparing Marshall samples of bituminous concrete with and without the polymer. Key Marshall properties such as stability, flow value, unit weight, and air voids are analyzed to determine the optimal polyethylene content for a bitumen grade of 80/100.

**1. INTRODUCTION:**

Over the past two decades, both developed and developing countries have grappled with challenges related to productivity and economic competitiveness. To enhance their competitive edge, manufacturers have increasingly turned to producing larger vehicles for goods delivery. In the early days, highways had minimal traffic and lower axle loads. However, the Indian Road Ministry has raised the permissible axle load for various commercial vehicles by about 25%, leading to a significant increase in the number of large vehicles on the roads. These larger vehicles contribute to a reduction in the expected lifespan of pavements. Improving building materials or construction methods could partially address this problem.

Population growth has also led to increased production of waste materials. The safe disposal of non-biodegradable waste with little or no salvage value presents a serious environmental challenge for both developed and developing countries. Plastics, widely used for their convenience, pose environmental issues after use. Their visibility as waste is a significant concern in solid waste management. Due to their non-biodegradable nature, plastics persist for a long time. Uncontrolled burning of plastics releases hazardous air pollutants, varying by plastic type. Plastics can be recycled into new applications through thermal treatment, though each recycling process degrades their quality. As a non-biodegradable material, plastic waste does not decompose over time and can re-enter the environment from landfills, affecting air and water, blocking drains, and harming wildlife.

Flexible pavements, which constitute over 95% of the global road network, are the most common pavement type. The substantial daily consumption of raw materials for pavement construction leads to resource scarcity over time. The properties and performance of bituminous mixes depend largely on the quality of raw materials and construction practices. Studies show that incorporating waste plastic into bituminous mixes can enhance their engineering properties. Waste plastic can be added to bituminous mixes using two methods: the wet method (polymer modified bitumen) and the dry method. In the wet method, plastic is blended with bitumen, while in the dry method, plastic is applied to aggregates before they are used in the mix (Sangita et al., 2011; Sabina et al., 2009).

The Indian Road Congress (IRC: SP: 98-2013) provides guidelines for using waste plastic in hot bituminous mixes (dry process) for flexible pavements, detailing the advantages and limitations of this approach.

# Advantages: -

 Enhanced resistance to permanent deformation

 Better resistance to damage caused by water

 Increased durability

 Improved stability and strength

 Safe management and disposal of waste plastic

 Cost efficiency

# Limitations: -

* Recommended use of waste plastic made up of polyethylene terephthalate, low and high density polyethylene only
* Restriction on use of black coloured plastic waste
* Restriction on use of poly vinyl chloride - due to release of lethal levels of dioxins
* Wrong implementation of technology may produce harmful gases as waste plastic undergo thermal degradation at temperature beyond 180° C.

# CLASSIFICATION OF PLASTIC

Plastics are classified as thermoplastic or thermosetting materials based on their chemical makeup. Under controlled heat and pressure, thermoplastic material can be molded into desired shapes; upon cooling, it solidifies. The same heat and pressure conditions can be used to remould them. Thermosetting materials shaped once cannot be softened / remoulded. Types of thermoplastic and thermosetting resigns are given in Table 1.1.

# Table 1.1: Thermoplastic and Thermosetting Resigns

|  |  |  |
| --- | --- | --- |
| **Sr. No.** | **Thermoplastic** | **Thermosetting** |
| 1 | Polyethylene Terephthalate | Bakelite |
| 2 | Poly-Vinyl Acetate | Melamine |
| 3 | Poly-Vinyl Chloride | Urea - Formaldehyde |
| 4 | Polypropylene | Epoxy |
| 5 | Low - Density Polyethylene | Polyester |
| 6 | High - Density Polyethylene | Alkyd |
| 7 | Polystyrene | - |

 **1.4 SCENARIO OF WASTE PLASTIC**

Production of waste plastic reached an unprecedented record of about 299 million metric tons in year 2013, which was increased 498% as compared to generated in year 1976 as shown in Figure 1.1. Annual globally plastic waste estimated in 2015 was 15 million metric tons and expected to reach 85 million tons by the year 2020. World over , top five exporters United State of America, Japan, Germany, United Kingdom and Hong Kong have effective waste plastic collection systems. Global plastic trade which utilized about 29-33% of the post-consumer plastic wastes is not sufficient to extract its resource value” (Sojobi et al., 2016). India consumed 8 million tonnes plastic per year and converted 15342 tonnes per day as waste. Waste plastic

consumption based on income for some Asian countries are shown in Table 1.2 (Pankaj et al., 2015).

350

300

250

200

150

World

Europe

100

50

0

**Years**

**Production volume in million metric tonnes**

# Figure: 1.1 Productions of Plastics Worldwide from 1950 to 2013 (Sojobi et al., 2016)

1950

1976

1989

2002

2008

2009

2010

2011

2012

2013

**Table 1.2: Waste Plastic Consumption based on Income of some Asian Countries (Pankaj et al., 2015)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr.****No.** | **Countries** | **GDP,PPP Capita Estimated for 2017 (USD)** | **Generation of Waste Plastic****(Kg/capita/day)** |
| 1 | Hong Kong | 35,385 | 0.4275 |
| 2 | Japan | 33,010 | 0.0990 |
| 3 | Singapore | 31,165 | 0.1298 |
| 4 | Taiwan | 31,040 | 0.1467 |
| 5 | South Korea | 23,331 | 0.0700 |
| 6 | Malaysia | 12,702 | 0.0675 |
| 7 | Thailand | 9426 | 0.1529 |
| 8 | China | 8854 | 0.0304 |
| 9 | Philippines | 5409 | 0.0690 |
| 10 | Indonesia | 5096 | 0.0720 |
| 11 | Sri Lanka | 5047 | 0.0313 |
| 12 | India | 3794 | 0.0090 |
| 13 | Vietnam | 3502 | 0.0308 |
| 14 | Lao PDR | 2260 | 0.0546 |
| 15 | Nepal | 1760 | 0.0087 |

# 1.5 SOURCES OF WASTE PLASTIC

Major areas of waste plastic collection are residential areas, streets, parks and waste dumps.

# THERMAL CHARACTERISTICS OF WASTE PLASTIC

Thermal behaviors of various polymers used as commercial plastic are as given in Table 1.3.

Table 1.3: Thermal Behavior of Polymer

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr.****No.** | **Commercial****Plastic** | **Plastics** | **Thickness****(µ)** | **Softening****Point (°C)** |
| 1 | Cup | Polyethylene | 150 | 100-120 |
| 2 | Carry Bag | Polyethylene Terephthalate | 210 | 170-180 |
| 3 | Water Bottle | Polyethylene Terephthalate | 210 | 170-180 |
| 4 | Cold Drink Bottles | Polyethylene Terephthalate | 210 | 170-180 |
| 5 | Chocolate Covers | Polyester + Polyethylene +Metalized Polyester | 20 | 155 |
| 6 | Parcel Covers | Polyethylene | 50 | 100-120 |
| 7 | Supari Covers | Polyester + Polyethylene | 60 | 120-135 |
| 8 | Milk Pouch | Low Density Polyethylene | 60 | 100-120 |
| 9 | Biscuit Covers | Polyester + Polyethylene | 40 | 170 |
| 10 | Decoration Papers | Polystyrene | 100 | 110 |
| 11 | Film | Polyethylene | 50 | 120-130 |
| 12 | Foam | Polyethylene | NA | 100-110 |
| 13 | Foam | Polystyrene | NA | 110 |

* 1. **IMPORTANCE OF RESEARCH TOPIC**

The topic “Assessment of Bituminous concrete mixtures incorporating polyethylene waste” has been selected for the research to determine suitability of waste plastic in road construction. This will help to increase the performance along with decrease in cost of road as well as saving of environment degradation in terms of reduced pollution.

The uses of plastic in common practice are increasing all over the world. However, the disposal of this plastic after its use in huge amount has been a problem, particularly in metro cities. The mixing up of these wastes with other bio-degradable organic waste materials in the garbage of the urban areas generates problem. Therefore, attempts are being made in some areas to limit or even to prohibit the use of plastic for packing and other common use, so as to control this "undesirable waste material" from getting mixed up with the other organic garbage. Being, a non- biodegradable material, waste plastic does not decay over time. After dumped in landfills, it reaches back to environment through air and water erosion, which choke the drains and drainage channels and can be eaten by unsuspecting grazing animals causing them illness and death. Identification of waste plastic salvage value and development of waste plastic so that its economic potential can be explored. This will reduce the disposal problems as well.

So, there is a need to use plastic waste in environmental and eco-friendly way for its safe disposal. The prime significance of this study is to find out an alternate for disposal of plastic waste, that too with value addition in road construction along with economy.

**2.LITERATURE SURVEY:**

**1.Awwad and Lina (2007)** studied the effect of low and high density polyethylene on engineering properties of bituminous mixes. Better engineering properties can be achieved through high density polyethylene. Appropriate amount of the modifier was 12% by the weight of binder content. It was observed that stability, air voids and voids in mineral aggregate increased whereas density of mixture decreased with inclusion of modifier.

**2.Awanti et al. (2008)** studied effect of waste plastic made up of styrene butadiene styrene on rheological properties of bitumen and mechanical properties of bituminous concrete via wet process. Amount of styrene butadiene styrene was taken as 3.5% by weight of binder content. Value of softening point and viscosity were observed to be 16% and 98% higher, whereas the penetration was observed 36% lower for modified bitumen as compared to neat bitumen. Stability and flow parameters observed for modified mix were 56% and 39% higher as compared to normal bituminous concrete mix at optimum bitumen content. The static indirect tensile strength for modified mixes was higher in the range of 49 to101% as compared to neat mixes in 15 - 40°C temperature range. Modified bituminous mixes showed tensile strength and resilient modulus ratio14% and 19% higher as compared to neat mixes.

**3.Hamid et al. (2008)** studied the effect of styrene butadiene styrene and ethylene vinyl acetate on bituminous mixes in the range 3% to 6% (with an increment of 1%) using wet process. The recommended optimum dose of modifier was 3% by the mass of bitumen content. Strength of mixture improved with reduction in air voids.

**4.Chen et al. (2009)** observed an improvement in rutting, stiffness and temperature susceptibility of the mixture with addition of polymer. Adhesion and degree of cohesion also improved with addition of polymer in bitumen.

**5.Zoorab and Suparma (2000)** studied the effect of waste plastic. They replaced mineral aggregates with low density polyethylene of equal size. It is observed that in case of bituminous concrete mix, by 30% replacement of aggregates, stability value increased by 250% times as compared to conventional material. Creep stiffness of modified mix after one hour loading at 60°C was observed to be lower; whereas indirect tensile strength was more as compared to conventional mix.

#  3. Experimental Program

This chapter explores the properties of materials and the methodology used to examine two types of bituminous mixes—Bituminous Concrete (Grade II) and Dense Bituminous Macadam (Grade II). These mixes are commonly applied in flexible pavements designed for traffic exceeding 5 msa. The investigation involves varying the percentage of waste plastic (0%, 4%, 6%, 8%, 10%, 12%, and 14%) within the bitumen content. The waste plastic used in this study is Polyethylene Terephthalate (PET). The chapter provides detailed explanations of the testing methods employed to measure mechanical properties such as Marshall Stability, Flow, Marshall Quotient, Retained Stability, Indirect Tensile Strength, and Rutting, as well as volumetric properties including bulk density, theoretical density, volume of air voids, volume of bitumen, voids in mineral aggregates, and voids filled with bitumen.

# 3.1 METHODOLOGY FOR PRESENT STUDY

The detailed methodology adopted in the present study is expressed in the form of a flow chart, Figure 3.1. The objectives of present study is to characterize the materials used for making bituminous mixes and mix designing of bituminous mixes with and without waste plastic using dry process, satisfying the requirements of strength and durability.

Identification of

Problems

Literature Review

Procurement of Materials

Preliminary Testing on Materials

Proportioning of Materials

Casting of Specimens

Testing

Result and Discussion

Modelling of Results

Conclusions

#  Figure 3.1: Methodology for Present Study

The methodology followed in the present research was decided with aim to–

* + - Study the information about the existing and possible future use of plastic waste in bituminous mixes.
		- Study the effects of varied percentages of Polyethylene Terephthalate (PET) on mechanical and volumetric properties of Bituminous Concrete (Grade -II) and Dense Bituminous Macadam (Grade -II) mixes.
		- Discuss the suitability of waste plastic (PET) in flexible pavement with special reference to India

**4 . RESULT ANALYSIS :**

This chapter presents the outcomes of various tests, including Marshall Stability, Indirect Tensile Strength, and Rut Testing, conducted on both conventional and modified bituminous concrete and dense bituminous macadam mixes. It encompasses the analysis of several volumetric properties such as bulk density (Gm), theoretical density (Gt), volume of air voids (Vv), volume of bitumen (Vb), voids in mineral aggregates (VMA), and voids filled with bitumen (VFB). Additionally, the chapter details mechanical properties including stability, flow, Marshall Quotient, retained stability, indirect tensile strength, tensile strength ratio, and rutting.

# 4.1 VOLUMETRIC PROPERTIES OF BITUMINOUS CONCRETE MIXES

* + 1. **Bulk Density of Bituminous Concrete Mixes**

This chapter presents the outcomes of various tests, including Marshall Stability, Indirect Tensile Strength, and Rut Testing, conducted on both conventional and modified bituminous concrete and dense bituminous macadam mixes. It encompasses the analysis of several volumetric properties such as bulk density (Gm), theoretical density (Gt), volume of air voids (Vv), volume of bitumen (Vb), voids in mineral aggregates (VMA), and voids filled with bitumen (VFB). Additionally, the chapter details mechanical properties including stability, flow, Marshall Quotient, retained stability, indirect tensile strength, tensile strength ratio, and rutting..

# Table 4.1: Bulk Density of Bituminous Concrete Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Bulk Density (gm/cc)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 5.0 | 2.264 | 2.266 | 2.275 | 2.275 | 2.259 | 2.251 | 2.240 |
| 2 | 5.2 | 2.271 | 2.273 | 2.278 | 2.279 | 2.272 | 2.268 | 2.262 |
| 3 | 5.4 | 2.279 | 2.287 | 2.299 | 2.309 | 2.306 | 2.302 | 2.298 |
| 4 | 5.6 | 2.290 | 2.308 | 2.314 | 2.316 | 2.313 | 2.309 | 2.303 |
| 5 | 5.8 | 2.305 | 2.309 | 2.321 | 2.324 | 2.316 | 2.312 | 2.307 |

2.5

PET (%)

2.3

2.0

1.8

1.5

5.0

5.2

5.4

**Bitumen Content (%)**

5.6

5.8

0

4

6

8

10

12

14

**Figure 4.1: Bulk Density of Bituminous Concrete Mixes at different PET Content**

**Bulk Density (gm/cc)**

# MECHANICAL PROPERTIES OF DENSE BITUMINOUS MACADAM MIXES

**4.2.1 Un-conditioned Marshall Stability of Dense Bituminous Macadam Mixes**

Marshall Stability value of un-conditioned specimen for dense bituminous macadam mixes are shown in Table 4.2 and Figure 4.2. It is clear from the table and graphs that un-conditioned stability value for conventional mixes increasing up to 4.5% bitumen content and decrease with further increase in bitumen content. The un- conditioned stability value of modified mixes increases up to 10% PET content. This increase in stability value by adding PET attributed to better adhesion developing between the materials of modified mix and show reduction in adhesiveness after 10% PET content. The maximum value of stability for conventional mixes is 16.24kN.The maximum value of stability is 17.47kN for modified mix of designation DBM4.5-P10, which is 7.57% higher as compared of conventional mix of same bitumen content. Results of stability and air voids give more durable bituminous mix with addition of PET up to some extent.

**Table 4.2: Un-conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content**

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Un-conditioned Marshall Stability (kN)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 14.90 | 15.38 | 15.74 | 16.22 | 16.63 | 16.04 | 15.59 |
| 2 | 4.3 | 15.66 | 15.96 | 16.29 | 16.55 | 17.20 | 16.65 | 16.23 |
| 3 | 4.5 | 16.24 | 16.91 | 17.38 | 17.19 | 17.47 | 17.23 | 16.43 |
| 4 | 4.7 | 15.95 | 16.50 | 16.83 | 17.00 | 17.31 | 16.51 | 16.18 |
| 5 | 4.9 | 15.72 | 16.32 | 16.47 | 16.69 | 16.89 | 16.34 | 15.90 |

20.0

17.5

15.0

12.5

10.0

PET (%)

0

4

6

8

10

12

4.1 4.3

4.5

**Bitumen Content (%)**

4.7

4.9

14

**Figure 4.2: Un-conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content**

**Stability (kN)**

# Flow Value of Dense Bituminous Macadam Mixes

The flow values of conventional and modified dense bituminous macadam mixes are shown in Table 4.3 and Figure 4.3. The flow value increases with addition of the PET content up to 10% and decrease after that amount, which can be ascribed to the fatigue cracking of mix due to increase stiffness. Maximum value of flow is 4.10mm for DBM4.9-P10mix.

# Table 4.3: Flow Value of Dense Bituminous Macadam Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Flow (mm)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 3.01 | 3.14 | 3.24 | 3.32 | 3.40 | 3.29 | 3.20 |
| 2 | 4.3 | 3.19 | 3.26 | 3.34 | 3.41 | 3.51 | 3.43 | 3.37 |
| 3 | 4.5 | 3.59 | 3.62 | 3.76 | 3.82 | 3.88 | 3.87 | 3.71 |
| 4 | 4.7 | 3.81 | 3.88 | 3.92 | 3.98 | 4.05 | 3.98 | 3.94 |
| 5 | 4.9 | 3.84 | 3.91 | 3.94 | 4.05 | 4.10 | 3.97 | 3.91 |

5.0

4.5

4.0

3.5

3.0

2.5

2.0

4.1

4.3

4.5

**Bitumen Content (%)**

4.7

4.9

PET (%) 0

4

6

8

10

12

14

**Figure 4.3: Flow Value of Dense Bituminous Macadam Mixes at different PET Content**

**Flow (mm)**

# Marshall Quotient of Dense Bituminous Macadam Mixes

Marshall Quotient of modified dense bituminous macadam mixes are given in Table

4.4 and Figure 4.4. Marshall Quotient measures the resistance to permanent deformation, shear stress and rutting. Higher value of Marshall Quotient of modified dense bituminous macadam mixes indicates that these mixtures can be used in pavements, where stiff bituminous mixture is required.

# Table 4.4: Marshall Quotient of Dense Bituminous Macadam Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Marshall Quotient (kN/mm)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 5.10 | 5.05 | 5.01 | 5.04 | 5.04 | 5.03 | 5.02 |
| 2 | 4.3 | 5.06 | 5.05 | 5.03 | 5.00 | 5.05 | 5.00 | 4.96 |
| 3 | 4.5 | 4.66 | 4.81 | 4.77 | 4.64 | 4.64 | 4.59 | 4.57 |
| 4 | 4.7 | 4.31 | 4.38 | 4.43 | 4.40 | 4.41 | 4.28 | 4.23 |
| 5 | 4.9 | 4.22 | 4.30 | 4.31 | 4.25 | 4.25 | 4.24 | 4.19 |

6.0

5.5

5.0

4.5

4.0

3.5

3.0

PET (%) 0

4

6

8

10

12

4.1 4.3

4.5

**Bitumen Content (%)**

4.7

4.9

14

**Figure 4.4: Marshall Quotient of Dense Bituminous Macadam Mixes at different PET Content**

**Marshall Quotient (kN/mm)**

# Conditioned Marshall Stability of Dense Bituminous Macadam Mixes

Marshall Stability value of conditioned specimen for dense bituminous macadam mixes are shown in Table 4.5 and Figure 4.5. Marshall Stability of conditioned sample is less as compared to un-conditioned sample. The conditioned stability value increases up to 10% PET content. This increase in stability value by adding PET attributed to better adhesion developing between the materials of modified mix and

show reduction in adhesiveness after 10% PET content. The maximum value of stability is 17.12 kN for modified mix of designation DBM4.5-P10 and 22.81% higher as compared of conventional mix of same bitumen content. The maximum value of stability for conventional mixes is 13.94 kN, which is 14.16% lower as compared to un-conditioned sample.

# Table 4.5: Conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Conditioned Marshall Stability (kN/mm)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 13.27 | 14.04 | 14.72 | 15.70 | 16.32 | 15.76 | 15.05 |
| 2 | 4.3 | 13.71 | 14.15 | 14.91 | 15.81 | 16.87 | 16.34 | 15.45 |
| 3 | 4.5 | 13.94 | 14.53 | 15.38 | 16.03 | 17.12 | 16.89 | 15.49 |
| 4 | 4.7 | 13.18 | 13.76 | 14.55 | 15.32 | 16.53 | 16.15 | 14.90 |
| 5 | 4.9 | 12.46 | 13.20 | 13.60 | 14.80 | 15.75 | 15.57 | 14.56 |

18.0

PET (%)

16.0

14.0

12.0

10.0

0

4

6

8

10

12

14

4.1 4.3

4.5

**Bitumen Content (%)**

4.7

4.9

**Table 4.5: Conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content**

**Stability (kN)**

# Retained Stability of Dense Bituminous Macadam Mixes

It is evident from the results given in Table 4.6 and Figure 4.6 that retained stability increases up to 12% PET content for the dense bituminous macadam and decrease with further increase in PET content. The decrease in retained stability value after 12% PET content attributes to the reduced adhesion between the PET coated aggregate and bitumen. Maximum value of retained stability is 98.26% for DBM4.1- P12 mix. DBM4.1-P10, DBM4.1-P12, DBM4.3-P10, DBM4.3-P12, DBM4.5-P10, DBM4.5-P12

mixes fulfils the requirement of retained stability value for modified mixes.

# Table 4.6: Retained Stability of Dense Bituminous Macadam Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Retained Stability (%)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 89.05 | 91.24 | 93.49 | 96.81 | 98.16 | 98.26 | 96.54 |
| 2 | 4.3 | 87.58 | 88.65 | 91.58 | 95.51 | 98.09 | 98.14 | 95.19 |
| 3 | 4.5 | 85.86 | 85.96 | 88.49 | 93.26 | 98.02 | 98.06 | 94.26 |
| 4 | 4.7 | 82.67 | 83.41 | 86.47 | 90.12 | 95.48 | 97.85 | 92.10 |
| 5 | 4.9 | 79.26 | 80.93 | 82.59 | 88.63 | 93.28 | 95.29 | 91.56 |

100.0

95.0

90.0

85.0

80.0

75.0

70.0

PET (%) 0

4

6

8

10

4.1 4.3

4.5

**Bitumen Content (%)**

4.7

4.9

12

14

**Figure 4.6: Retained Stability of Dense Bituminous Macadam Mixes at different PET Content**

**Retained Stability (%)**

# Un-conditioned Indirect Tensile Strength of Dense Bituminous Macadam Mixes

Un-conditioned indirect tensile strength of different PET dense bituminous macadam modified mixes are given in Table 4.7 and Figure 4.7. Un-conditioned indirect tensile strength increases up to 10% PET content for 4.1%, 4.3%, 4.7%, 4.9% bitumen content and upto 8% PET content for 4.5% bitumen content. This implies that the PET modified dense bituminous macadam are capable of withstanding much larger tensile strains prior to cracking up to these PET content. DBM4.3-P10 and DBM4.9-P14 mix shows the maximum and minimum values of un-conditioned indirect tensile strength.

# Table 4.7: Un-conditioned Indirect Tensile Strength of Dense Bituminous Macadam Mixes at different PET Content

|  |  |  |
| --- | --- | --- |
| **Sr.****No.** | **Bitumen (%)** | **Un-conditioned Indirect Tensile Strength (kN)** |
| **PET (%)** |
| **0** | **4** | **6** | **8** | **10** | **12** | **14** |
| 1 | 4.1 | 0.74 | 0.77 | 0.81 | 0.86 | 0.87 | 0.81 | 0.76 |
| 2 | 4.3 | 0.75 | 0.79 | 0.83 | 0.89 | 0.92 | 0.82 | 0.78 |
| 3 | 4.5 | 0.77 | 0.81 | 0.85 | 0.92 | 0.91 | 0.79 | 0.75 |
| 4 | 4.7 | 0.76 | 0.79 | 0.82 | 0.89 | 0.86 | 0.77 | 0.73 |
| 5 | 4.9 | 0.73 | 0.76 | 0.79 | 0.83 | 0.85 | 0.75 | 0.71 |

1.0

0.9

0.8

0.7

0.6

0.5

4.1

4.3

4.5

**Bitumen Content (%)**

4.7

4.9

PET (%) 0

4

6

8

10

12

14

**Figure 4.7: Un-conditioned Indirect Tensile Strength of Dense Bituminous Macadam Mixes at different PET Content**

**Indirect Tensile Strength (kN)**

**5. CONCLUSION :**

On the basis of experimental and analytical observation on conventional and modified mixes following conclusions are drawn.

* Incorporating waste plastic into bituminous mixes improves their stability. At the optimal PET content level, stability values for bituminous concrete (BC) and dense bituminous macadam (DBM) increased by over 24% and 10%, respectively, compared to conventional mixes.
* The higher Marshall Quotient for PET-modified bituminous mixes indicates that these mixes are stiffer and better suited for roads with heavy traffic.
* At the optimal bitumen content, the tensile strength ratios (TSR) for dense bituminous macadam and conventional bituminous concrete were 86.50% and 85.19%, respectively. PET-modified mixes showed higher TSR values, with 93.45% for BC and 93.70% for DBM, suggesting improved resistance to moisture damage compared to conventional mixes.
* The optimal bitumen content was found to be 5.66% for conventional bituminous concrete and 4.82% for dense bituminous macadam. With the addition of waste plastic (PET), the optimal bitumen content decreased to 4.59% for bituminous concrete and 6.64% for dense bituminous macadam.
* The ideal PET content was determined to be 8% for bituminous concrete and 10% for dense bituminous macadam.
* The addition of PET reduces rutting in both dry and wet conditions for both types of mixes. Rutting for modified bituminous concrete decreased by 23.85% in dry conditions and 24.19% in wet conditions compared to conventional mixes. For dense bituminous macadam, rutting was reduced by 26.41% and 25.32%, respectively.

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