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Optimizing Bituminous Concrete Mixes with Waste Plastic for Enhanced Pavement Performance

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Abstract— This research paper clarify about the integration of waste plastic into bituminous concrete mixes presents a promising solution to both environmental pollution and infrastructure durability challenges. This study explores the optimization of bituminous concrete mixes by incorporating various types and proportions of waste plastic, aiming to enhance pavement performance. Laboratory experiments were conducted to evaluate the mechanical properties, including tensile strength, rutting resistance, and durability, of bituminous concrete modified with waste plastic. The results demonstrated significant improvements in the performance characteristics of the modified concrete, with optimal plastic content enhancing the material's resistance to deformation and extending its lifespan. Additionally, the environmental impact assessment highlighted the potential of this approach in reducing plastic waste in landfills. This research underscores the dual benefits of incorporating waste plastic into bituminous concrete: promoting sustainable waste management and advancing the development of more resilient and long-lasting pavements. Further studies are recommended to refine the mix design and assess long-term field performance.

Keywords: Bituminous Concrete (BC), waste plastic, Flow value, environmental pollution, tensile strength

1. INTRODUCTION

The escalating environmental crisis posed by the proliferation of plastic waste and the pressing need for sustainable infrastructure solutions have catalyzed research into innovative material applications. One promising avenue is the incorporation of waste plastic into bituminous concrete mixes used in road construction. Bituminous concrete, a critical material for pavement surfaces, can benefit from the addition of plastic waste, potentially improving its performance and durability while addressing environmental concerns.

The conventional methods of plastic waste disposal, such as landfilling and incineration, are increasingly unsustainable due to their adverse environmental impacts. Conversely, recycling plastic waste into construction materials offers a dual benefit: mitigating the environmental burden of plastic waste and enhancing the properties of construction materials. In this context, bituminous concrete modified with waste plastic represents an innovative solution that aligns with the principles of circular economy and sustainable development.

The primary objective of this study is to optimize the incorporation of waste plastic into bituminous concrete mixes, with a focus on improving pavement performance. By systematically evaluating the effects of different types and proportions of plastic on the mechanical properties of bituminous concrete, this research aims to identify optimal mix designs that maximize performance enhancements. Key performance indicators such as tensile strength, rutting resistance, and durability are analyzed to determine the efficacy of plastic-modified bituminous concrete.

This introduction sets the stage for a detailed exploration of the methodology, experimental results, and practical implications of using waste plastic in bituminous concrete mixes. The anticipated outcome is a comprehensive understanding of how plastic waste can be effectively utilized to produce more durable, cost-effective, and environmentally friendly pavement materials. Through this study, we aim to contribute to the body of knowledge in sustainable construction practices and support the development of infrastructure that meets both current and future demands.

In this research paper section I contains the introduction, section II contains the objective details, section III contains the details about Waste plastic is a concern, section IV describe the related work, section V provide details of basic material, section VI describes the experimental work, section VII provide the result details, section VIII provide conclusion of this research paper.

2. Objectives of mix design

The bituminous mix design focuses to estimate the proportions of bitumen, filler material, fine aggregates, coarse aggregates & polythene to produce a mix which should have workability in the appropriate range so that there is no segregation under load- Enough strength to survive heavy wheel loads & tyre pressures.

- Sufficient durability
- Must be economical

3. Waste plastic is a concern

Plastics are durable & non-biodegradable cannot be decomposed the chemical bonds make plastic very durable & resistant to normal natural processes of degradation. Since 1950s, around 1 billion tons of plastic have been discarded, and that they may might persist for hundreds or even bunch of years. The plastic gets mixed with water, does not disintegrate, and takes the form of small pallets which causes the death of fishes and many other aquatic animals life as well as waster ecosystem. Today the availability of the plastic wastes is in huge amount, as the plastic materials have become the part of our daily life. Either they get mixed with the Municipal Solid Waste or thrown over a land area. If they are not recycled, their present disposal may be by land filling or it may be by incineration process. Both the processes have significant impacts on the environment. If they are incinerated, they polluted the air with very unwanted gases such as carbondioxide,nitrogendioxide etc, and if they are dumped into some place, they cause soil & water pollution. Under these circumstances, an alternate use for these plastic wastes is required.

4. RELATED WORK

4.1 Evolution of mix design concepts

- During 1900's, this technique, of using bitumen in pavements, was firstly used on rural roads in order to stop rapid removal of the fine particles such as dust, from Water Bound Macadam, which was caused because of fast growth of automobiles [Roberts et al. 2002]. At initial stages, heavy oils were used as dust palliative. An eye estimation process which is called pat test, was used to estimate the required quantities of the heavy oil, in the mix.
- The 1st formal technique of mix design was Habbard field method, which was actually developed on sand-bitumen mixture. Mixtures with larger sized aggregates particles could not be handled during this technique. This was one limitation of this procedure.
- Francis Hveem, 1942; who was a project engineer of California, Department of Highways enginering, has developed the Hveem stabilometer in 1927. He did not have any previous experience on judgement that, the required mix from its colour, hence he decided to measure various mixture parameters to find the optimum quantity of bitumen [Vallegra and Lovering 1985]. He had applied the surface area calculation concept, (which was already in use, at that time for the cement concrete mix design), to estimate the quantity of bitumen actually required.
- Bruce Marshall developed the Marshall testing machine just before the World War
- It was adopted in the US Army Corpes of Engineers in 1930's and subsequently modified in 1940's and 50's.

4.2 Polymer modification

- Bahia and Anderson, 1984; studied about the visco-elastic nature of binders and found that, the complex modulus & phase angles of the binders, need to be measured, at temperatures and loading rates with which different resemble climatic and loading conditions as well as past conditions.
- Shukla and Jain (1984) described that the effect of wax in bitumen can be decreased by adding EVA (Ethyl Vinyl Acetate), aromatic resin and SBS in the waxy bitumen. The addition of 4% EVA or 6% SBS or 8% resin in waxy bitumen effectively degraded the Susceptibility to high temperatures, bleeding at high temperature and brittleness at low temperature of the mixes.
- The findings of the studies conducted by the Shell Research and Technology Centre in Amsterdam indicated that the rutting rate is enormously reduced by the result of SBS modification of the binder. Button and Little (1998) on the basis of stress controlled fatigue testing at 20 and 0^0C, reported that SBS polymer exhibited superior fatigue properties as compared to straight AC-5 bitumen.
- Shuler et al. (1987) found that the tensile strength of SBS modified binder rised considerably as compared to unmodified asphalt mix at -21, 25$^{and\ 410}$C.
- Collins et al. (1991) and Baker (1998) reported that SBS modified asphalt mixes have longer lives than unmodified asphalt mixes. The addition of SBS polymer to unmodified bitumen also increases its resistance to low temperature cracking.
- Denning and Carswell (1981) according that asphalt concrete using polyethylene modified binders were more resistant to permanent defor mation at elevated temperature.
- Palit et al. (2002) found improvement in stripping characteristics of the crumb rubber modified mix as compared to unmodified asphalt mix.
- Sibal et al. (2000) evaluated flexural fatigue lifetime of asphalt concrete modified by 3% crumb rubber as a part of aggregates.
- Goodrich (1998) according that fatigue life and creep properties of the polymer modified mixes increased considerably as compared to unmodified asphalt mixes.
- The Indian Roads Congress Specifications Special Publication: fifty three (2002) indicate that the period of next renewal may be extended by 50% in case of surfacing with modified bitumen as comparing with unmodified bitumen.

4.3 Recent applications

- A 25 km plastic changed bituminous concrete road was set in Bangalore. This plastic road showed superior smoothness, uniform behaviour and fewer rutting as compared to a plastics-free road which was laid at same time, which began developing terrible "crocodile cracks" very soon after. The process has also been approved, in 2003 by the CRRI (Central Road Research Institute Delhi).
- Justo et al (2002), at the Centre for Transportation Engineering, at Bangalore University used processed plastic luggage bags as associate additive in asphalt concrete mixes. The properties of this modified bitumen were compared to that of ordinary bitumen.

It was noted that penetration and ductility values, of modified bitumen was decreasing with the rise in proportion of the plastic additive, up to 12 % by weight.

- Mohammad T. Awwad et al (2007), polyethylene as synthetic resin collectively variety of polymers employed to research the potential prospects to boost asphalt mixture properties. The objectives also include determining the best type of polyethylene to be used and its proportion. Two types of polyethylene were added to coat the aggregate
- High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). The results indicated that grinded HDPE polyethylene modifier provides better engineering properties. The recommended proportion of the modifier is 12% by the weight of bitumen content. It is found to extend the stability and soundness, reduce the density and slightly increase the air voids and the voids of mineral aggregate.
- Shankar et al (2009), crumb rubber modified bitumen (CRMB 55) was blended at specified temperatures. Marshall's mix design was applied by ever changing the modified bitumen content at constant optimum rubber content and subsequently tests have been performed to determine the different mix design characteristics and for conventional bitumen (60/70) additionally. This has resulted in much improved characteristics when compared with straight run bitumen and that too at reduced optimum modified binder content (5.67%).

5. Basic materials

5.1 Aggregate

Aggregate constitutes the granular part in bituminous concrete mixtures which contributes up to 90-95 % of the mixture weight and contributes to most of the load bearing & strength characteristics of the mixture. Hence, standard of the quality and physical properties of the aggregates should be controlled to ensure a good pavement. The properties that aggregates should have to be utilized in pavement are shown below-

- Aggregates should have minimal plasticity for better output. The presence of clay fines in bituminous combines can result in problems like swelling and adhesion of bitumen to the rock which may cause stripping problems. Clay lumps and friable particles should be limited to utmost 1%.
- Durability or resistance to weathering should be measured by sulphate soundness testing.
- The ratio of dust to asphalt cement, by mass should be a maximum of 1.2 & a minimum of 0.6.It is suggested for better result AASHTO T-209 to be used for determinant the maximum specific gravity of bituminous concrete mixes.

5.2 Bitumen

- Asphalt binder 60/70 and 80/100 are used in this research. The bitumen used should have the following required properties.
- Grade of bitumen used in the pavements should be selected on the basis of climatic conditions and their performance in recent days.
- It is usually recommended that the bitumen should be accepted on certification by the supplier (along with the testing results) and also the State project, verification samples. The procedures for acceptance should provide information, on the physic al properties of the bitumen in timely manner.
- The physical properties of bitumen used which are very important for pavements are shown below. Every State should obtain this information (by central laboratory or supplier tests) and should have specification necessities for each property except specific gravity of bitumin.

5.3 Mineral Filler

Mineral filler consists of, very fine, inert mineral matter that is added to the hot mix asphalt, to increase the density and enhance strength of the mixture. These fillers should pass through 75µm(micron) IS Sieve.
The fillers may be cement or fly ash.

6 EXPERIMENTALcWORK

6.1 General

It involves mainly 2 processes. i.e.

a) Preparation of samples
b) Void analysis
c) Testing

Prior to these experiments, the specific gravity of polythene used was calculated as per the guidelines provided in ASTM D792-08.

Determination of specific gravity of polythene
The procedure adopted is given below

- The weight of the polythene in air was measured by a balance. Let it be denoted by "a".
- An immersion vessel full of water was kept below the balance.
- A piece of iron wire was attached to the balance such that it is suspended about 25 mm above the vessel support.
- The polythene was then tied with a sink by the iron wire and allowed to submerge in the vessel and the weight was measured. Let it be denoted as "b".
- Then polythene was removed and the weight of the wire and the sink was measured by submerging them inside water. Let it be denoted as "w".

The specific gravity is given by

$$s = a / (a + w - b)$$

6.2 Mixing Procedure

The mixing of ingredients was done as per the following procedure (STP 204-8).

- Required quantities of coarse aggregate, fine aggregate & mineral fillers were taken in an iron pan.
- This was kept in an oven at temperature 160^{0}C for 2 hours. This is because the aggregate and bitumen are to be mixed in heated state so preheating is required.
- The bitumen was also heated up to its melting point prior to the mixing.

- The required amount of shredded polythene was weighed and kept in a separate container.
- The aggregates in the pan were heated on a controlled gas stove for a few minutes maintaining the above temperature.
- The polythene was added to the aggregate and was mixed for 2 minutes.
- Now bitumen (60 gm), i.e. 5% was added to this mix and the whole mix was stirred uniformly and homogenously. This was continued for 15-20 minutes till they were properly mixed which was evident from the uniform colour throughout the mix.

- Then the mix was transferred to a casting mould.
- This mix was then compacted by the Marshall Hammer. The specification of this hammer, the height of release etc.
- 75 no. Of blows were given per each side of the sample so subtotal of 150 no. of blows was given per sample.
- Then these samples with moulds were kept separately and marked

Figure – 1: MARSHALL SAMPLES

Figure 2: CLOSER VIEW OF A MARSHALL SAMPLE

7 RESULTS

7.1 Plotting Curves

Five curves were plotted. i.e.

i. Marshall Stability Value vs. Polythene Content
ii. Marshall Flow Value vs. Polythene Content
iii. VMA vs. Polythene Content iv. VA vs. Polythene Content
v. VFB vs. Polythene Content
vi. Bulk unit weight vs. Polythene Content

For each % of polythene, 3 samples have been tested. So the average value of the 3 was taken.

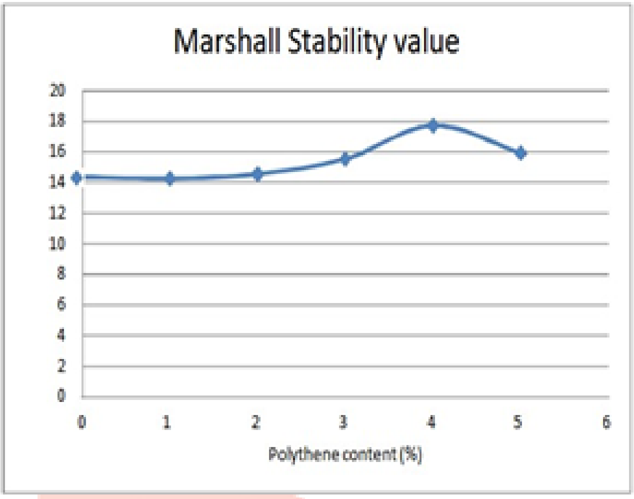

Figure 3 Marshall Stability

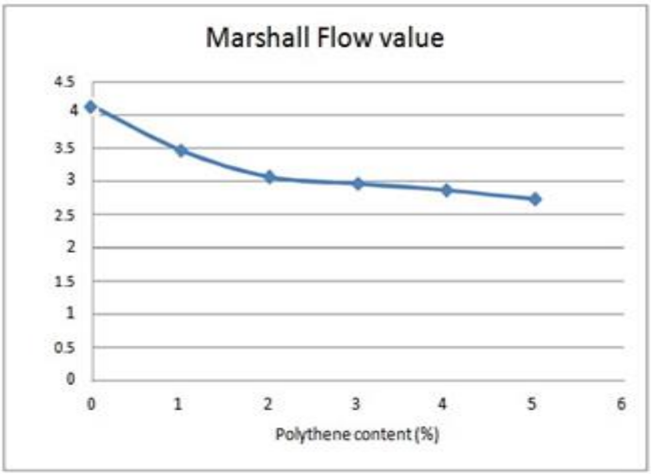

Figure 4: Marshall Flow Value

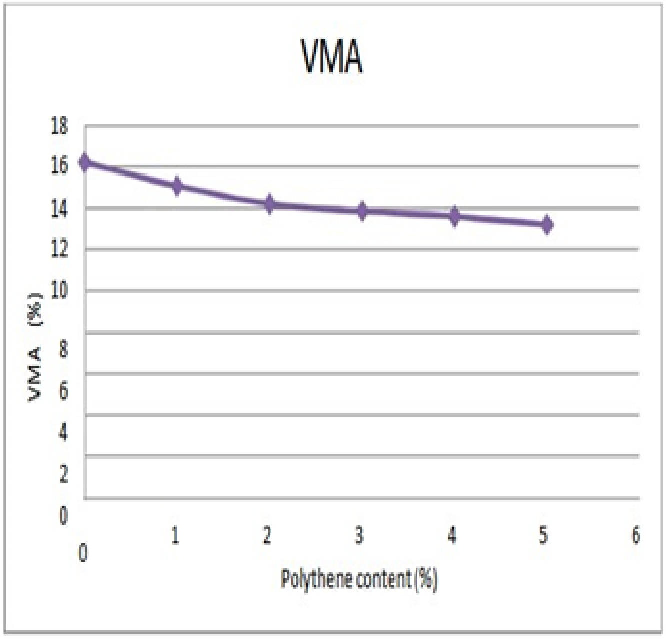

Figure 5 VMA vs Polythene

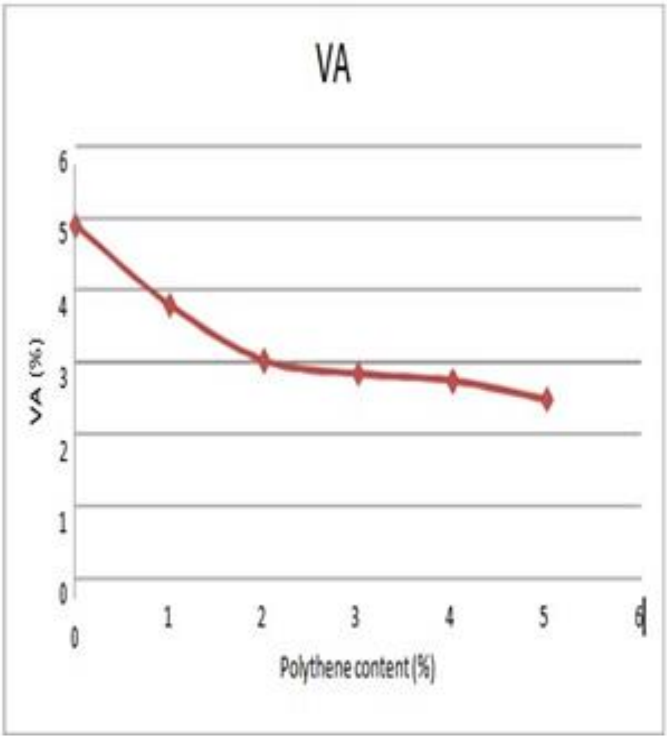

Figure 6: VA vs Polythene

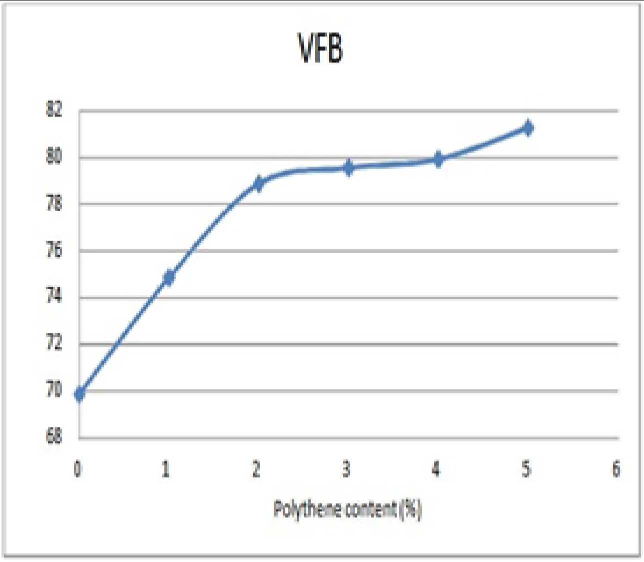

Figure 7: VFB vs Polythene

8 CONCLUSION

The research into optimizing bituminous concrete mixes with waste plastic has demonstrated significant potential for enhancing pavement performance and contributing to environmental sustainability. Through a series of laboratory experiments, we have identified that the inclusion of waste plastic in bituminous concrete can improve key mechanical properties such as tensile strength, rutting resistance, and overall durability. These improvements suggest that plastic-modified bituminous concrete can lead to longer-lasting and more resilient pavements, reducing the frequency and cost of maintenance and repair.

Moreover, the environmental benefits of this approach are substantial. By incorporating waste plastic into road construction materials, we can reduce the volume of plastic waste that ends up in landfills or incinerated, thereby mitigating environmental pollution and conserving resources. This aligns with global efforts to promote recycling and sustainable waste management practices.

The study also underscores the importance of optimizing the type and proportion of waste plastic in the mix to achieve the best performance outcomes. While the results are promising, further research is necessary to refine these mix designs and to conduct long-term field studies that assess the performance of plastic-modified bituminous concrete under real-world conditions. Additionally, considerations such as the economic feasibility, potential health impacts, and long-term environmental effects need to be thoroughly evaluated.

In conclusion, incorporating waste plastic into bituminous concrete mixes is a viable strategy for enhancing pavement performance while addressing the pressing issue of plastic waste. This innovative approach supports the development of more sustainable infrastructure and offers a practical solution to two significant challenges: improving road durability and managing plastic waste. As research progresses, this method holds the promise of transforming road construction practices and contributing to a more sustainable future.

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