Investigation of rheological and performance characteristics of oxidized polyethylene polymer blended with SBS modified bitumen

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Abstract. This research article investigates the influence of oxidized polyethylene (PE) polymer on rheological and performance properties of SBS modified bitumen at an optimum dose of 0.5 % by weight. To evaluate the impact of PE polymer on SBS modified bitumen different performance testing such as indirect tensile strength and resilient modulus was conducted on PE polymer blended bituminous concrete mixes and rheology of modified bitumen was determined using dynamic shear rheometer. It was concluded that the intrusion of PE polymer in SBS modified bitumen improved elastic recovery and viscosity. The findings of resilient modulus test indicated that the addition of PE polymer enhanced the response of modified bituminous mixes under repeated loading (Mr value) by 11%, 20% and 16% at 25°C, 35°C and 45°C respectively as compared to SBS bituminous mix.

1. Introduction

India has mixed traffic in terms of both volume and axle loads. About 98 % of the total Indian roads network is comprised of bituminous roads. After laying, most of the roads develop distress conditions like ravelling, rutting, cracking, bleeding, shoving and potholing. Different studies indicated that useful lifespan of road structures have reduced to four to six years due to increased traffic density, overloading of vehicle beyond permissible limits, higher tyre pressure, varying pavement temperatures and an insufficient degree of maintenance [1],[2]. The accelerated deterioration of bituminous pavement affects the availability of funds for new construction. It is a global view that the higher lifespan and performance of flexible pavements must be ensured in order to reduce the cost of maintenance. Therefore, modification of conventional bitumen with natural and synthetic polymer binder gives a way to meet the new required traffic demands.

Increased shear modulus, better resistance to thermal fracture at low temperatures and reduced plastic flow at high temperatures can be achieved by proper modification of conventional bitumen using different polymers [3]. The results of various studies revealed that the performance of conventional 60/70 bitumen can be improved by SBS polymer modification. The various bituminous mixes
prepared with SBS modified bitumen has shown improved resistance to rutting and moisture sensitivity as compared to conventional bitumen. Pavement construction technique requires the binder to remain stable previously and during construction of road. Therefore, for improved stability and workability SBS modified bitumen may be used in conjugation with other polymer additive such as PE polymer for better elastic and tensile properties to bituminous mixes.

2. Materials

2.1. Bitumen
For this study, SBS modified bitumen (STYRELF PMB-40) was used as control binder which was provided by TOTAL Group situated at Rohut-Jodhpur (Rajasthan). PE polymer was provided by Honeywell Group. Worldwide their additive is known as TITAN (7686). The optimum dose of PE polymer determined was 0.5% by weight of control binder and blended with SBS modified bitumen using melt blending technique. For melt blending, SBS modified bitumen was heated and maintained at a temperature of 160°C and the optimum dose of PE polymer was added steadily. The contents were continuously stirred at 1000 rotation per minute for about 60 minutes at 160°C temperature to produce homogenous mixture. The blended bitumen was cooled and stored for further physical testing, results of physical properties of PE polymer blended bitumen and SBS modified bitumen are presented in Table1.

Table 1. Physical properties of control SBS binder and PE modified SBS binder

| Sl. No | Physical properties | Control SBS binder | PE modified SBS binder | Specification |
|--------|---------------------|---------------------|-----------------------|---------------|
| 1.     | Viscosity at 150°C  | 8.65                | 8.85                  | ASTM D2983 [4]|
|        | Poise               |                     |                       |               |
| 2.     | Specific gravity at | 0.98                | 0.99                  | IS 1202 [5]   |
|        | 27°C                |                     |                       |               |
| 3.     | Softening point °C  | 68                  | 70                    | IS 1205 [5]   |
| 4.     | Elastic recovery %  | 70                  | 71                    | IRC SP 53 [6] |

2.2. Aggregate
Locally available crushed granite coarse aggregate and stone dust as fine aggregate was used to design bituminous concrete (BC) mix as per MoRTH specifications [7]. Maximum nominal aggregate size of 20mm, 10mm and 6mm were used. The physical properties of coarse and fine aggregate as per IS: 2386-1963 (Part 1-6) [8] are represented in Table 2.

Table 2. Physical properties of aggregate

| Sl. No | Physical properties | Observed Value | Value |
|--------|---------------------|----------------|-------|
| 1.     | Specific gravity    |                |       |
|        | 20mm                | 2.64           |       |
|        | 10mm                | 2.65           |       |
|        | 6mm                 | 2.58           |       |
|        | Stone dust          | 2.80           |       |
|        | Lime                | 2.80           |       |
| 2.     | Water absorption    | 0.12           |       |
3. Mix composition

To evaluate the influence of PE polymer on bituminous mixes, BC mix for 50-65 mm thickness was designed as per MoRTH specifications [7]. Marshall method of bituminous mix design was adopted to determine optimum binder content (OBC) for the required BC mix. Between (160-170)°C mixing temperatures, different Marshall samples were prepared with varying SBS modified binder content at 0.5% incremental increase. Proportioning of different aggregates for BC mix design are shown in figure 1. and observed Marshall parameters are recorded in Table 3.

![Figure 1. Combined aggregate gradation chart](image_url)

| % Binder | Bulk Density, (Gb) (gm/cc) | Stability, Kg(l) | Flow (mm) | Air voids, (Vv)% | Voids in mineral aggregates (VMA)% | Voids filled with bitumen (VFB)% |
|----------|-----------------|-----------------|-----------|-----------------|-----------------------------------|---------------------------------|
| 5.0      | 2.34            | 2093.48         | 2.91      | 5.67            | 17.28                             | 66.98                           |
| 5.5      | 2.35            | 2187.29         | 3.17      | 4.64            | 17.17                             | 73.13                           |
| 6.0      | 2.36            | 2018.02         | 4.08      | 3.64            | 17.40                             | 79.11                           |
| 6.6      | 2.35            | 1565.26         | 5.14      | 3.32            | 18.10                             | 81.68                           |

OBC determined for required BC mix was 5.8% by weight of aggregate and different properties of mix at 5.8% OBC are as follows:
Bulk density (gm/cc) = 2.356
Stability (kN) at 60°C = 20.45
Flow (mm) = 3.7
% Voids = 4.04
% VFB = 77

4. Methodology

An experimental investigation was carried out to evaluate the influence of PE polymer, which was broadly divided into binder and bituminous mix characterization. Dynamic shear rheometer (DSR) test was performed for binder characterization whereas, resilient modulus and indirect tensile strength test was conducted on Marshall samples for bituminous mix characterization.

5. Results and discussion

5.1. Dynamic shear rheometer

As per AASHTO T 315 [10] specification two parallel plate oscillating dynamic shear test at (60-110)°C temperature range was performed to measure the failing temperature of PE polymer blended bitumen and SBS bitumen, which is represented in figure 2 & 3 at 10 rad/sec oscillations with 25 mm plates and 1 mm gap. Therefore, the various DSR parameters for PE polymer blended bitumen and SBS bitumen are presented in Table 4. Improvement in DSR parameters due to at low content of PE polymer (0.5%) shows a continuous dispersion of PE particles in binder medium, which were also reported by [11-13] in their studies, with the incorporation different additives in conventional binder.

![Figure 2. DSR graph (G* vs T and δ vs T) for SBS modified bitumen](image-url)
5.2. Resilient modulus
To evaluate performance and response of bituminous concrete under repeated traffic and temperature condition, resilient modulus (Mr) test was performed as per the guidelines of ASTM D 4123 [14]. Improved resilient modulus (Mr) values of PE polymer modified as compared to SBS bituminous samples at 25°C, 35°C and 45°C temperatures are recorded in Table 5. Similar enhancement of Mr values was reported by [15-17]

| Mix                  | Avg. Mr Value At 25°C (MPa) | Avg. Mr Value At 35°C (MPa) | Avg. Mr Value At 45°C (MPa) |
|----------------------|-----------------------------|-----------------------------|-----------------------------|
| SBS modified BC mix  | 4804                        | 1700                        | 802                         |
| PE blended BC mix    | 5317                        | 2212                        | 929                         |

5.3. Indirect tensile strength and tensile strength ratio
To measure moisture sensitivity and adhesiveness of bituminous mix in the presence of water in the compacted BC mix, indirect tensile test (ITS) test was conducted as per the detailed guidelines of AASHTO T 283 [18]. Observed results for ITS and tensile strength ratio (TSR) values for PE polymer and SBS modified compacted bituminous samples are recorded in Table 6. From Table 6.
improvement in ITS values is observed, which is due to cross linking ability [19] of PE polymer with SBS binder.

| Table 6. TSR values of compacted Marshall samples for PE blended binder and SBS modified binder |
|---------------------------------------------------------------|
| Mix               | Avg. Dry ITS (Kg/cm²) T1 | Avg. Wet ITS (Kg/cm²) T2 | Tensile Strength Ratio T1/T2 | Design Requirement |
| SBS modified BC mix | 8.77                      | 7.50                      | 85.50 %                      | Minimum 80%         |
| PE blended BC mix  | 11.30                     | 10.44                     | 92.30 %                      | (as per MoRTH Table 500-17) [7] |

6. Conclusion

The addition of PE polymer (Honeywell Titan 7686) to the SBS modified bitumen has affected the binder properties such as increased softening point, elastic recovery and viscosity profile of the control SBS bitumen. The following conclusion from experimental investigations are:

- PE polymer can be used in conjugation with the SBS modified bitumen to enhances the elastic properties of binder as well as of mix. PE polymer blended BC mixes shows enhanced engineering properties of mix such as stability, workability and resistance to deformation.
- Bituminous concrete mix prepared with PE polymer blended with SBS binder have performed better under the repeated loading. Increased resilient modulus (M_r) values were observed at 25°C, 35°C and 45°C temperatures by 11%, 20% and 16% respectively, as compared to the mix prepared with SBS modified bitumen which will further reduce the required thickness of bituminous layers in flexible pavement.
- Other engineering properties of SBS binder such as viscosity, elastic recovery and critical failing temperature were also found to be improved with the addition of PE polymer.
- Increased TSR values of compacted Marshall samples prepared with PE polymer blended binder was recorded. Increased ITS results of compacted bituminous mix further reduces cracking potential, therefore better mix and pavement life.
- In the present study, the value of G* (complex modulus), G*/sin δ (shear modulus) and G*sin δ (loss modulus) for PE polymer blended SBS binders observed to be higher than control SBS modified binder.

7. References

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