Effect of Nano Particle Based Anti-Stripping Agent on Moisture-Induced Damage for Bituminous Concrete Mixes

Teekam Singh¹, B L Swami², Pawan Kalla³, Harshwardhan Singh Chouhan⁴ and Pradeep Kumar Gautam⁵

¹Assistant Professor, Jaipur Engineering College and Research Centre, Jaipur Rajasthan, India
²Professor, Civil Engineering Department, MNIT Jaipur, Rajasthan, India
³Associate Professor, Civil Engineering Department, MNIT Jaipur, India
⁴Associate Professor, Civil Engineering Department, Poornima College of Engineering, Jaipur, Rajasthan, India
⁵Assistant Professor, Civil Engineering Department, NIT Mehalaya, India
Email: teekamsingh.ce@jecrc.ac.in

Abstract. Moisture damage occur due to loss of bond between bitumen and aggregates. Ingression of water in bituminous mixes leads to various damage. The objective of this study is to investigate extent of performance of Nano particle based anti-stripping agent (Wet Bound- S) in resisting the moisture damage and improving the durability of bituminous mix. Bituminous mixes were prepared with polymer modified binder (PMB-40); optimum binder content was found using Marshall testing procedure. To check the resistance toward moisture, specimen was prepared at three void ratios of 3%, 5% and 7%, each sample set was tested in dry condition and moist condition by injecting moisture at 30 psi and 40 psi. Then each of these sample set were subjected to indirect tensile strength ratio test and dynamic creep test. Use of anti-stripping agent was done to see its effect under adverse condition. From the outcome of this study, it was observed that PMB-40 with additive exhibit more resistance to moisture.

Keywords. Pavement material; moisture susceptibility; moisture induced stresses; anti-stripping agent

1. Introduction
Moisture damage is the major cause of damage of bituminous pavement [1]. It is an extremely complicated mode of pavement distress [2]. Infiltration of water cause the weakening of bond between aggregates and binder reducing the service life of pavement. When a vehicle’s tire rolls over submerged pavement, the water entrapped between the tire and the pavement is subjected to high pressure. This forces the water into the accessible pores into the bituminous mix. When vehicle’s tire rolls away from this area creating a negative pressure (suction) as a result the water drains or is pulled out from the pores back to the surface of the bituminous pavement. It is very important to assess the moisture susceptibility of flexible pavements.[3]. A pavement that is suffering from moisture damage can self-deteriorate itself even without the application of loading, and the damage is accelerated when this moisture induced pavement is introduced to traffic, resulting in loss of stiffness or strength of pavement[4][5]. Decades of research have been conducted to find a solution to this problem[6][7][8][9]. Through the development of laboratory testing facilities and experimenting with different anti-stripping agents, advanced progress has been made in producing more resilient pavements, with an increasing emphasis towards sustainability. A
Nanotechnology based material known as wet bond-S (WBs) has been used to study its feasibility to prevent the moisture damage of bituminous mixes.

2. Material and experiments

2.1 Aggregates and asphalt binder
Aggregates used in the design of bituminous concrete mix (BC) were procured from crushing plant Delhi-Najafgarh border. Aggregates were tested for physical properties as per the relevant code, the result of which are summarized in table 1. Polymer Modified Bitumen (PMB-40) was used in the design of bituminous concrete. PMB-40 used in the present study was tested for their physical properties such as penetration, softening, elastic recovery, viscosity, specific gravity etc., the obtained and permissible values of which are summarized in table 2.

| S. No. | Property                          | Test                          | Result   | MoRT&H Specifications |
|--------|-----------------------------------|-------------------------------|----------|-----------------------|
| 1      | Particle Shape                    | Combined Flakiness and Elongation Index | 32.34%   | < 35%                 |
| 2      | Strength                          | Log Angeles Abrasion          | 25.58%   | < 30%                 |
|        |                                   | Aggregation Impact Value      | 17.6 (3%)| < 24%                 |
| 3      | Water Absorption                  | Water Absorption              | 0.40%    | < 2%                  |
| 4      | Striping Value                    | Without additive              | 2%       | < 5%                  |
|        |                                   | With additive                 | Traces   |                       |
| 5      | Specific Gravity                  | Coarse aggregate.            | 2.68     | N.A.                  |
|        |                                   | Fine aggregate               | 2.83     |                       |
|        |                                   | Stone dust                    | 2.86     |                       |

Table 2. Properties of binder PMB-40

| S. No | Properties                        | Test Results | Recommendations as per IS:15462-2004 |
|-------|-----------------------------------|--------------|--------------------------------------|
| 1     | Penetration at 25 °C, 0.1 mm, 5 sec | 47           | 30-50                                |
| 2     | Softening Point, °C, min          | 61.65        | Min.60                               |
| 3     | Specific Gravity                  | 1.03         | ---                                  |
| 4     | Viscosity, 150 °C, Poise          | 5.55         | 3.0-9.0                              |
| 5     | Elastic recovery, 15 °C, %        | 70.17        | Min.70                               |

2.2 Testing Program
The objective of the study is to assess the performance of Nano particle based anti-stripping agent wet bound-s (WBs) on moisture resistivity of bituminous mix. Study samples were prepared in two sets, one without the anti-stripping agent and one with anti-stripping agent. Each sample set contained Marshall specimen prepare at three void ratio i.e. 3%, 4% and 7% and each sample was tested for moisture resistivity by introducing to three different temperature condition i.e. 400°C, 500°C and 600°C at two different pressure condition of 30si and 40psi respectively.
2.3 Mix performance

2.3.1 Indirect Tensile Strength test (ITS)

ITS test is used to measure the resistance toward the tensile deformation of sample. The samples were prepared using Marshall method of mix design. Each sample set is divided into two subsets of approximately equal void content. One subset is maintained in a dry condition while the other subset is partially saturated with water to simulate moisture induced damage condition. The ratio of tensile strength of sample in wet condition to dry condition is called as Tensile strength ratio (TSR). A sample having TSR value greater than 80% is considered to have satisfactory resistance toward moisture condition.

ITS test was conducted on a set of three samples for each void content, each condition and average of test result of three samples have been reported as test result. Initially ITS and TSR values were determine for samples soaked as par conventional method and afterwards same at different temperature (40°C, 50°C & 60°C) pressure conditions (30psi & 40psi) Dry & Wet ITS values obtained for each air void content.

2.3.2 Moisture Induced Sensitivity Testing (MIST)

MIST is an accelerated test used to simulate the action of a pavement submerged in water. The test was carried on submerged Marshall sample prepared at different air void condition. Conditioning in MIST of each sample takes approximately four hours to complete. The testing was performed as per the guidelines specified in ASTM D7870/D7870M – 13 for MIST. After processing each sample in MIST. ITS, resilient modulus and creep tests were performed.

2.3.3 Dynamic Creep Test

Dynamic creep test is used to assess the permanent deformation of a bituminous mix under repeated loading condition. This simulates permanent deformation under the moving traffic. Universal Testing Facility is used for this test. During the test, a cyclic stress of 69 kPa was applied with a seating stress of 11 kPa and haversine pulse is applied with loading width of 0.1 s followed by a rest period of 0.9 s. A maximum of 3600 load cycles were applied and accumulated permanent strain was measured and the strain calculated. The test was conducted for two different conditions, dry and wet. Four specimens were prepared for each set of target air voids (3%, 5% and 7%). Due to time constrain for the present study, samples were conditioned in MIST at 60 °C and 40 psi. These parameters were selected to see the maximum effect of moisture damage for on the permanent accumulated strain.

3. Result and Discussion

3.1 Optimum binder content (OBC)

Optimum binder content was taken as maximum of stability value, 4%air void and maximum specific gravity. The OBC value obtained for the bituminous sample prepare with PMB 40 was 5.1. The quantity of WBs added was decided based on trial studies. It was observed adding WBs more than 1% also gave significant result but increased the cost of overall project, hence keeping economical aspect into consideration 1% WBs was set as permissible limit. Since the focus of the paper is to study the durability performance of WBs on bituminous mix, hence the study is not reported in this paper.

3.2 Indirect Tensile Strength Test

Figure 1 and figure 2 shows the test result of dry and wet ITS vale of sample without WBs and with WBs respectively. The indirect tensile strength (dry & wet) of bituminous mixes is less for PMB-40 without
additive mixes compared to PMB-40 with additive mixes, indicating that inclusion of WBs improved resistance against moisture susceptibility.
The MIST was conducted at temperatures 40°C, 50°C & 60°C and pressure 30 psi, 40 psi respectively; the result of which are summarized in figure 3, 4, 5 and 6 respectively. On comparing the results at same psi it can be observed that on increasing the temperature in MIST at 30psi and 40psi pressure the ITS values decreases for all the samples prepared with and without additive. After conducting the entire test, it was observed that use of PMB-40 with additive in bitumen mix improves the ITS and TSR values.

![Figure 1](image1.png)
> **Figure 1.** Dry and Wet ITS value of sample without additive

![Figure 2](image2.png)
> **Figure 2.** ITS value of sample after additive
Figure 3. TSR value without additive after sample subjected to MIST at 30 psi

Figure 4. TSR value without additive after sample subjected to MIST at 40 psi

Figure 5. TSR value with additive after sample subjected to MIST at 30 psi
3.3 Dynamic Creep Test

Figure 7 shows the relationship between accumulated strain and number of repetitions for dry sample set and samples induced with moisture. Accumulated strain values of PMB-40 for specimen in dry condition are 0.484% for 3% air voids, 0.684% for 5% air voids, 0.764% for 7% air voids after completion of 3600 cycles. While in case of specimen after MIST, accumulated strain values are 0.534 % for 3% air voids, 0.794% at 5 % air voids, 1.01% at 7% air voids for PMB-40 after completion of 3600 cycles. Figure 8 shows the relationship between accumulated strain and number of repetitions. Accumulated strain values of PMB-40 (with additive) dry condition are 0.464% for 3% air voids, 0.538% at 5% air voids, 0.769% at 7%. While in case of specimen after MIST, shown in figure 9, accumulated strain values are 0.534 % for 3% air voids, 0.794% at 5 % air voids, 1.01% at 7% air voids for PMB-40 after completion of 3600 cycles. In case of specimen after MIST of PMB-40 (with additive), result shown in figure 10, accumulated strain values for PMB-40 (with additive) obtained are 0.479 % for 3% air voids, 0.584% for 5 % air voids, 0.878 % for 7% air voids. It was observed that after using PMB-40 with additive the total accumulative strain decreases. It can be seen that for PMB-40 (with additive) accumulated strain is much lower than for PMB-40 (without additive) mixes at 45°C. It was observed that after using additive the total accumulative strain decreases.

![Dynamic Creep Test](image)

Figure 7. Dynamic creep result of control sample
Figure 8. Dynamic creep result of sample containing additive

Figure 9. Dynamic creep result of sample containing additive before MIST

Figure 10. Dynamic creep result of sample containing additive after MIST
4. Conclusions

From the test result it is evident that using Nano technology based (Wet Bond – S) anti stripping additive with PMB-40 prevents the moisture damages and enhances the properties and characteristics of the bituminous mixes, the result is summarized as follows:

- After conducting laboratory performance tests, it was observed Tensile Strength Ratio (TSR) value obtained for 3%, 5%, 7% air voids were more than 80%. The TSR value samples performed on samples conditioned in MIST decreases about 10 % in both the cases of PMB-40 with and without additive.
- The use of PMB - 40 with Nano technology based (Wet Bond – S) anti stripping additive in bituminous mixes increases TSR values of bituminous mixes approximately 6%. This indicates that bituminous mixes prepared using PMB - 40 with additive will exhibit more resistance to moisture damages.
- It was observed that accumulated permanent strain of bituminous mixes with PMB-40 after conditioning in MIST increases and was also observed that use of PMB - 40 with Nano technology based (Wet Bond – S), decreases accumulated permanent strain.
- It was also observed that permanent deformation was lower and stiffness was higher in the bituminous mixes prepared with Nano-technology based (Wet Bond – S) compared to bituminous mixes without additive.
- It was also observed from this study that the MIST in laboratory studies may be carried out at 60°C temperature and 40 psi pressure as the losses observed were significant at this condition and the bituminous mixes able to withstand this condition may be considered suitable for bituminous construction.
- Conventional tests (TSR, retained stability and stripping tests) in laboratories takes more time than MIST to study and observe moisture induced damages in bituminous mixes. In laboratory study, MIST test gave more moisture induced damages in bituminous mixes compared to conventional methods for study moisture damages in laboratory.

Thus, it can be concluded that use of Nano technology based (Wet Bond – S) additive as anti-stripping additive in bituminous mixes improves the moisture resistance of the bituminous mixes and its use in the areas subject to heavy rainfall will produce strong and durable flexible pavements.

Reference

[1] Chen X and Huang B 2008 Evaluation of moisture damage in hot mix asphalt using simple performance and superpave indirect tensile tests Constr. Build. Mater. 22 1950–62
[2] Airey G D, Collop A C, Zoorob S E and Elliott R C 2008 The influence of aggregate, filler and bitumen on asphalt mixture moisture damage Constr. Build. Mater. 22 2015–24
[3] Gautam P K, Kalla P, Nagar R, Agrawal R and Jethoo A S 2018 Laboratory investigations on hot mix asphalt containing mining waste as aggregates Constr. Build. Mater. 168 143–52
[4] Tayfur S, Ozen H and Aksoy A 2007 Investigation of rutting performance of asphalt mixtures containing polymer modifiers Constr. Build. Mater. 21 328–37
[5] Gautam P K, Kalla P, Jethoo A S, Agrawal R and Singh H 2018 Sustainable use of waste in flexible pavement: A review Constr. Build. Mater. 180 239–53
[6] Frigio F, Pasquini E, Ferroatti G and Canestrati F 2013 Improved durability of recycled porous asphalt Constr. Build. Mater. 48 755–63
[7] Lyons K R and Putman B J 2013 Laboratory evaluation of stabilizing methods for porous asphalt mixtures Constr. Build. Mater. 49 772–80
[8] Yilmaz M, Kök B V and Kulog N 2011 Effects of using asphaltite as filler on mechanical properties of hot mix asphalt Constr. Build. Mater. 25 4279–86
[9] Gautam P K, Kalla P, Nagar R and Jethoo A S 2018 Laboratory investigation on use of quarry
waste in open graded friction course *Resour. Policy* 0–1