Grenze International Journal of Engineering and Technology, June Issue

Effect of Bentonite Incorporation on the Physical and Rheological-Properties of Polymer Modified Bitumen

Ankit I. Malviya[1] and Tripti B. Gupta[2]
[1]Research Scholar, Department of Civil-Engineering, Ramdeobaba University-(Shri Ramdeobaba College of Engineering and Management), Nagpur-440013, Maharashtra, India, Assistant Professor, Department of Civil-Engineering-DRGIT&R, Amravati-444602, Maharashtra, India.
Email: ankitmalviya375@gmail.com
[2]Assistant Professor, Department of Civil-Engineering, Ramdeobaba University-(Shri Ramdeobaba College of Engineering and Management), Nagpur-440013, Maharashtra, India.
Email: guptatb@rknec.edu

***Abstract*— The finding indicate that PMB provides superior performance compared to standard binders yet its Storage-Stability together with its rheological properties face difficult challenges. The study demonstrates how bentonite affects the rheological and physical characteristics of PMB materials. Bentonite was added at 0, 2, 4 and 6 percent by weight of binder. The standard testing procedures is used to evaluate the modified binders through penetration, softening, rotational viscosity and Storage-Stability testing. The results demonstrate that bentonite changes the behavior of PMB materials. The penetration testing showed a decrease from 62 to 42 (0.1 millimeter) at 6% bentonite which resulted in a stiffness increase of approximately 32%. The Softening-Point increased from 58 degree celsius to 70 degree celsius which results enhanced thermal resistance. Rotational viscosity at 135 degree celsius increased from 1800 to 3300 mPa.s, showing greater resistance to flow at high temperature. Storage-Stability also improved markedly, with the Softening-Point difference reducing from 6.0 degree celsius for the control PMB to 1.6 degree celsius at 6% bentonite. Based on performance and workability, 4% bentonite was found to be the optimum content. The study shows that locally available bentonite can be used as an effective and economical modifier for enhancing PMB performance.**

***Index Terms*— Polymer modified bitumen, Bentonite, Penetration, Softening-Point, Rotational viscosity, Storage-Stability.**

I. INTRODUCTION

PMB is commonly used for enhanced temperature resistance, viscoelastic behavior, and durability compared to pure bitumen. However, incompatibility between polymer and bitumen often leads to phase separation and rheological instability during storage [1][2]. Based on the above limitations, the use of mineral additives such as bentonite has been explored. Bentonite is a layered alumino silicate clay rich in montmorillonite characterized by high surface area and ion-exchange capacity, enabling high interaction between the polymer and the bituminous phases and improving the physical, rheological, and stability features of PMB [3][4]. Past investigations have revealed that bentonite improves the penetration resistance, Softening-Point, viscosity, and Storage-Stability of PMB by hindering molecular movement inside the polymer-bitumen matrix [5].

Grenze ID: 01.GIJET.12.2.310_22

In contrast, most of the work carried out so far focused on nano or chemically treated bentonite and investigations of dosage effects with conventional tests especially with Indian bentonite are limited [6]. Bentonite containing a high amount of silica and alumina, is an economic material with a great potential as a stabilizing additive [7].
This paper therefore investigates the result of bentonite content on the physical-rheological properties of PMB by penetration, softening, rotational viscosity, and Storage-Stability tests.

II. Materials and Methods

A. Base Bitumen

The base binder was 60/70 penetration grade bitumen, locally sourced and widely used for polymer modification due to its good compatibility with polymer additives and stability in behavior when modified [8][9]. As such, the base bitumen was characterized on the basis of penetration and the Softening-Point in order to establish reference properties for comparison with the modified binders. Its physical properties were evaluated according to relevant IS and ASTM standards as shown in Table I., which implies that it is suitable for polymer modification within the scope of this research work.

TABLE I: PHYSICAL PROPERTIES-BITUMEN (60 / 70 GRADE)

Sr. No.	Property	Results	Standard Followed
1	Penetration at 25 Degree Celsius (0.1 millimeter)	60 - 70	IS-1203 / ASTM-D5
2	Softening (Degree Celsius)	48 - 56	IS-1205 / ASTM-D36
3	Ductility at 27 Degree Celsius(centimeter)	≥ 75	IS-1208 / ASTM-D113
4	Specific Gravity at 27 Degree Celsius	1.01 - 1.03	IS-1202 / ASTM D70
5	Flash-Point (Degree Celsius)	≥ 220	IS-1209 / ASTM D92
6	Fire-Point (Degree Celsius)	≥ 250	IS-1209 / ASTM D92
7	Loss on Heating (Percentage)	≤ 0.2	IS-1212 / ASTM D6
8	Solubility in Trichloroethylene (Percentage)	≥ 99	IS-1216 / ASTM D2042

B. Polymer Modifier

The polymer modifier utilized for the production of polymer modified bitumen (PMB) was obtained from commercial suppliers. Elastomeric polymers, such as styrene-butadiene-styrene (SBS), are acquired from industrial chemical distributors in the local area. These polymers find wide application in bitumen modification as they improve binder elasticity and thermal stability and rheological characteristics. The polymer was chosen based on its established efficacy in creating a uniform polymer-bitumen phase and its accessibility through local suppliers.

C. Bentonite

In this research bentonite obtained from nearby mineral suppliers. Bentonite enhances the rigidity and hardness of bituminous binders together with all other materials due to its high surface area and layered structure [8][9]. A commercially available bentonite was selected to ensure consistent results and reproducible outcomes. Indian bentonite contains high levels of silica and alumina along with small amounts of other oxides as demonstrated in Table II.

TABLE II. CHEMICAL COMPOSITION OF INDIAN BENTONITE USED IN THIS STUDY

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	SO_3	P_2O_5	MnO	Cr_2O_3
58 - 65	15 - 20	4- 7	2 - 4	1 - 3	1- 3	0.5-2	0.3 - 1.0	< 1.0	< 0.2	< 0.2	< 0.05

D. Sample Preperation Process

The process of PMB production, the base bitumen which required heating together with ploymer mixing and bentonite addition under specific conditions that ensured both proper material distribution and PMB stability throughout the entire process. Bentonite were added 0% to 6% by weight of PMB (2% and 4%). While using 0% as the control group. Bentonite replaced an equivalent fraction of PMB to maintain the constant overall binder mass so that Storage-Stability, viscosity, softning and penetration compaired directly.

E. Testing of Binder Samples

In this research, the two materials analyzed are polymer modified bitumen (PMB) and bentonite modified polymer modified bitumen, subjecting both materials to a test series of standard binder tests in order to stability of the two materials. Before the test, the two materials are put through a conditioning process in order to remove air pockets and attain uniform temperature in the material.

F. Penetration Test

The penetration test was conducted to find out the stability of the binder at standard temperature. The test was done at 25 ± 0.1 degree celsius using a standard penetration setup. A 100g needle was allowed to penetrate into the binder specimen for 5 seconds, and the penetration value was recorded in units of 0.1 millimeter. For each binder composition, three penetration readings were taken and the mean value was reported. The test was carried out as per IS-1203.

G. Softening-Point Test

The Softening-Point of the binder samples was find-out by the Ring and Ball method, in which to assess the temperature at which the binder-attains a specified softness degree. The test was conducted by heating the binder-filled rings in a controlled manner, and the temperature at which the steel ball passed through the binder was recorded as the Softening-Point. Distilled water or glycerin was used as the heating medium as per the applicable temperature range. The test was performed as per IS 1205.

H. Rotational Viscosity Test

The rotational viscosity of the binder specimen was measured to assess flow characteristics and workability at high temperatures. Measurements were made using a rotational viscometer at temperatures commonly used for modified binders. The binder was heated to the test temperature and held under stable conditions before measuring viscosity. Viscosity is expressed in Pascal-seconds (Pa.s). The test followed ASTM-D4402.

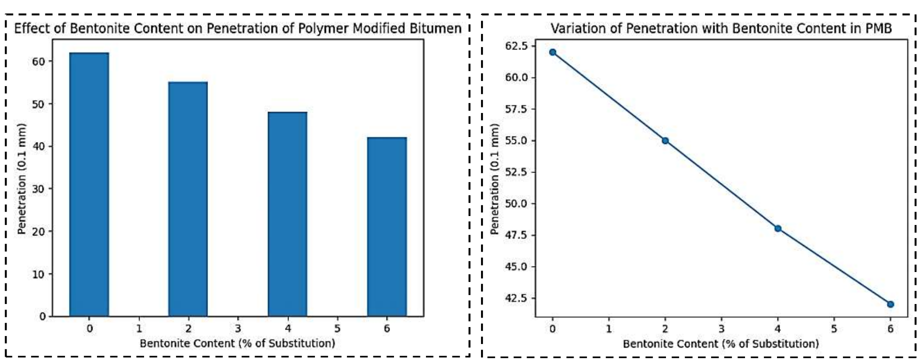
I. Storage-Stability Test

This test was conducted to determine the tendency of the polymer modified bitumen to phase separation during long term storage at high temperature. The binder samples were transferred to aluminum tubes and kept vertical in an oven maintained at 163 ± 5 Degree Celsius for 48 hr. After conditioning, the tubes were allowed to cool before being sectioned into three parts of approximately equal length. The softening of the samples from the top and bottom portions were measured. The difference between these two values was taken as a measure of Storage-Stability. ASTM-D7173 was followed.

III. Result and Discussion

The role of bentonite addition on the performance characteristics of PMB was assessed through the three basic tests, penetration, Softening-Point and rotational viscosity [10]. The numerical results proved that bentonite acted as an active stiffening and stabilizing additive within the polymer bitumen system. A discussion of the measured parameters and their comparisons are as follows.

A. Penetration Characteristics and Binder Stiffness Evolution



(a) (b)

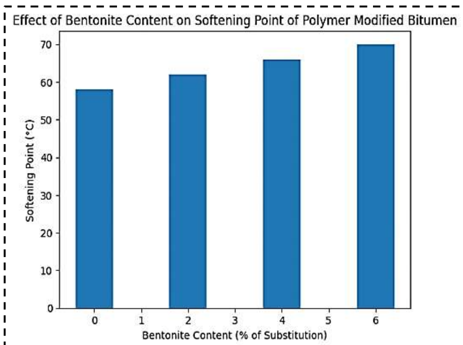
Figure 1. Penetration behavior with bentonite incorporation: (a) bar chart and (b) graphical representation.

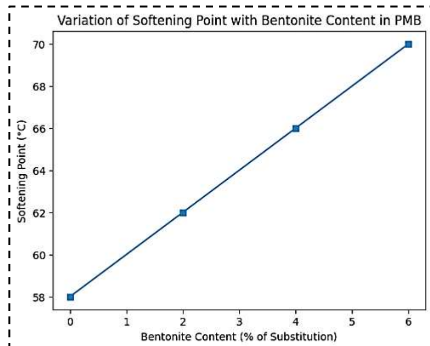
The control PMB without bentonite was 0% bentonite, showed a penetration value of 62 (0.1 millimeter), which indicates that softer binder consistency suitable for polymer modification. With the incorporation of bentonite, penetration values decreased systematically to 55, 48, and 42 (0.1 millimeter) for 2%, 4%, and 6% bentonite, respectively. Numerically, this corresponds to, 11.3% reduction at 2% bentonite, 22.6% reduction at 4% bentonite and 32.3% reduction at 6% bentonite.

The reduction in penetration with increasing bentonite content indicates a significant increase in binder stiffness due to improve particle binder interaction and restricted molecular mobility. Bentonite is layered structure and high surface area develop absorption of lighter fractions, improving deformation resistance, even if excessive stiffening at 6% may affect low-temperature flexibility. Figure 1 shows the progressive decrease in penetration with bentonite incorporation.

B. Softening-Point Enhancement and Thermal Stability

The Softening-Point of the PMB binder rises from 58 Degree Celsius in the control formulation to 62 degree celsius, 66 degree celsius, and 70 degree celsius with 2%, 4%, and 6% bentonite, respectively, corresponding to improvements of 6.9%, 13.8%, and 20.7%. The regular increase reflects a rise in high temperature stability and a reduction in susceptibility to thermal exposure. The increase is due to the reinforcing effect of bentonite, which forms a semi rigid network in the polymer bitumen matrix that restricts binder mobility and inhibits flow. The decreased penetration and increased Softening-Point prove that bentonite displaces PMB toward higher stiffness and thermal resistance. Figure 2 shows the increase in the Softening-Point with the addition of bentonite.





(a) (b)

Figure. 2 Softening-Point behavior with bentonite incorporation (a) bar chart and (b) graphical representation.

C. Rotational Viscosity and Rheological Implications

The temperature at 135°C, the value of rotational viscosity increases with the addition of bentonite concentrations of 2%, 4%, and 6%, with values of 2200, 2700, and 3300 mPa.s compared to 1800 mPa.s in the control PMB. This represents an increase of 22.2%, 50.0%, and 83.3%, respectively. The rise in the values shows the considerable rheological effect of bentonite addition, as the formation of layers and large surface area of bentonite will cause increased internal friction and reduced binder's mobility. When the bentonite and polymer molecules interact, they produce microstructures with lower susceptibility to shearing. Values of 2700 mPa.s at 4% bentonite concentrations will be workable, but 6% bentonite will go beyond 3000 mPa.s. as shown in figure 3.

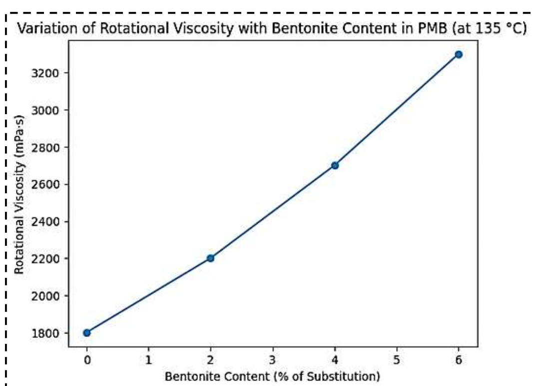


Figure 3. Graphical representation of rotational viscosity behavior with bentonite incorporation.

D. Storage-Stability Analysis

Storage-Stability is a critical performance parameter for polymer modified bitumen. As phase separation between polymer-rich and bitumen-rich phases during high-temperature storage can greatly affect binder uniformity and field performance. The Storage-Stability of PMB with varying bentonite contents was evaluated by measuring the difference between upper and lower sample sections which underwent extended thermal treatment as shown in figure 4.

Numerical Results of Storage-Stability

The control PMB shows a Softening-Point difference of approximately 6.0 degree celsius in between top and bottom layer after storage conditioning, indicating noticeable phase separation. With the incorporation of bentonite, the Softening-Point difference decreased progressively to 4.2 degree celsius, 2.8 degree celsius, and 1.6 degree celsius for 2%, 4%, and 6% bentonite, respectively showed in Table III.

TABLE III. REPRESENTATIVE STORAGE-STABILITY DATA

Bentonite Content (Percentage)	Softening (Top) (Degree Celsius)	Softening (Bottom) (Degree Celsius)	Difference (Degree Celsius)
0	61	55	6
2	63.8	59.6	4.2
4	67.2	64.4	2.8
6	70.8	69.2	1.6

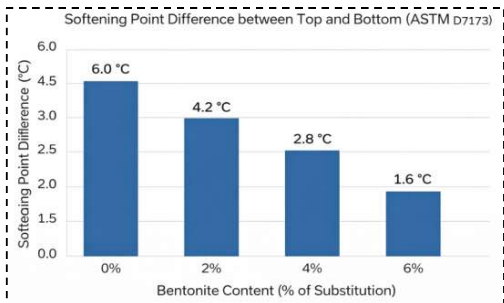


Figure 4. Effect of Bentonite content on the Storage-Stability of PMB.

Critical Interpretation of Results

The presence of bentonite has a significant reducing effect on the Softening-Point differential, with decreases of 30%, 53%, and 73% at 2%, 4%, and 6% bentonite content, respectively. This proves a significant stabilizing effect on the PMB. In the absence of bentonite, there appears a visible phase separation in the control PMB due to differences in densities and polymer-bitumen incompatibilities. Bentonite works as a physical stabilizer. Due to its highly layered morphology and high surface area, polymer mobility is restricted, and consequently, gravitational separation is reduced. Bentonite develops phase adaptation upon adsorption and interfacial interactions toward the homogeneous binder.

Influence of Bentonite Content on Stability Mechanism

Even with a bentonite content of 2%, the differential Softening-Point is not reduced appreciably to indicate partial stabilization of the PMB system. Increasing the bentonite content to 4% yields a differential less than three degree celsius. This is falls within the threshold of three degree celsius which is accepted for storage stable modified binders. This result indicated that bentonite tends to act effectively for stabilization. The differential reduces to 1.6 degree celsius when further increased to 6% bentonite. This indicating excellent Storage-Stability.

Optimum Bentonite Content for Storage-Stability

Numerical improvements in combination with practical handling considerations, the 4% bentonite formulation shows the best balance. The current level of Softening-Point testing shows more than 50% reduction of Softening-Point difference which proves effective phase separation control. The material maintains its viscosity within a range that permits both mixing and application processes. The results demonstrate that moderate bentonite addition to polymer modified bitumen Storage-Stability while maintaining workability, as shown in Figure 5.

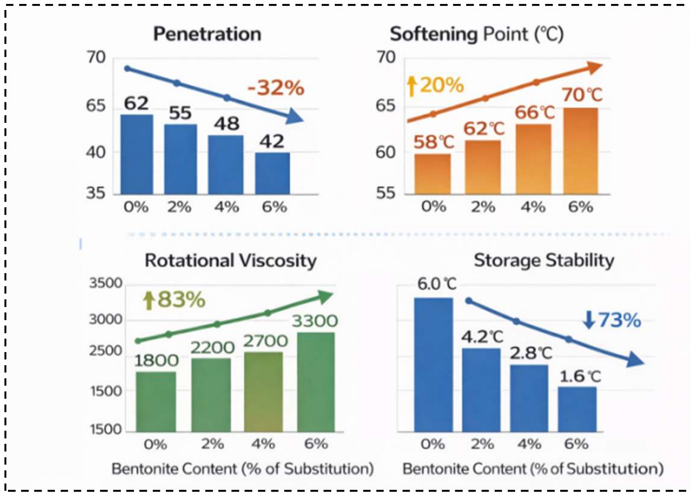


Figure 5. Effect of the overall amount of bentonite on the physical and rheological characteristics of the PMB.

IV. Conclusions

Bentonite improved the physical-rheological performance of Polymer Modified Bitumen. Penetration decreased from 62 to 42 (0.1 millimeter) and the Softening-Point raised from 58 degree celsius to 70 degree celsius, indicating improved stiffness and thermal resistance. Rotational viscosity at 135 degree celsius increased from 1800 to 3300 mPa.s, with values above 4% bentonite potentially affecting workability. Storage-Stability improved markedly, with the Softening-Point difference reducing from 6.0 degree Celsius to 1.6 degree celsius which confirming effective suppression of phase separation. An optimum bentonite content of 4% was identified, which gives balanced improvements in stiffness, thermal stability and stability without excessive viscosity increase. The results show that locally available bentonite is a cost effective and sustainable modifier for PMB.

Future studies may focus on long term aging, durability and microstructural evaluation of bentonite modified PMB under different polymer systems.

Acknowledgment

The authors would like to express-gratitude to Ramdeobaba University-Nagpur, for providing the necessary lab facilities and equipment to perform this work.

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