International Journal of Engineering, Management and Humanities (IJEMH)
Volume 2, Issue 1, pp: 05-11 www.ijemh.com

# An Experimental Evaluation of Bitumen with Waste Plastic and Waste Rubber

Krishnav Sekhri
*The British School, New Delhi, IN*

Date of Submission: 25-01-2021 Date of Acceptance: 10-02-2021

**ABSTRACT:** Sustainability is the need of the hour across the globe. While many countries are facing a challenge in managing the solid waste, use of waste plastic and rubber tires in road construction has been a great way of recycling these non-biodegradable substances. Infusing these materials in road construction has a great potential to elevate the performance of the pavements and prevents early pavement distress. Plastic-Rubber Modified Bitumen (PRMB) has been found to be an excellent modifier to bitumen which enhances its rheological properties and makes it more resistant to temperature variations and rutting which in turn reduces the maintenance and premature failing. In this paper, the results of the fundamental binder consistency and advanced tests carried out on PRMB are presented and the results are compared with that of the Virgin Bitumen. Furthermore, the advanced test results of the PRMB sample have been compared with the standard values of Polymer-Modified Bitumen specified in IS:15462 for severe climatic as well as standard to extremely heavy traffic roads.

**KEYWORDS: PRMB, Rheological properties, distress**

## I. INTRODUCTION

According to the market research firm Euromonitor International, more than 583 billion plastic bottles alone are being produced worldwide. With India being the second largest population in the world, it has witnessed the exponential growth in production and consumption of plastic. A statement has been made by the Supreme Court of India, that “We are sitting on a plastic time bomb” after the Central Pollution Control Board(CPCB) reported that India generates 5.6 million tonnes of plastic waste annually. The United Nations Environmental Programme has published a report which is specifically designed for policymakers which guides them through the introduction of measures to curb consumption and improve management of single-use plastics. In line with this, the honorable Prime Minister of India Mr. Narendra Modi, while addressing the 74th session of the United Nations General Assembly reiterated the fact that India was initiating a huge campaign towards making the country free of single use plastic. Although a variety of innovative solutions have been proposed to combat this issue, yet the application of such solutions need to be completely brought into practice. Another solid waste which is being generated in abundance globally is the waste rubber tires. Both plastic and rubber tire waste are non-biodegradable and are disposed either in the form of landfills or incineration and in many places, it is littered in the environment. Consequently, solid waste management has been a challenging task. It is evident that there is a lack of proper solid waste management techniques especially in developing countries like India.

Road traffic and its intensity has been spiking globally. This in turn warrants the necessity to increase the performance of the pavements through innovative, sustainable and economical means. Across geographies, many studies have been conducted to come up with innovative ideas and/or solutions to enhance the performance of the pavements. There are two types of pavements namely: Flexible and Rigid Pavements. This study focuses on appraising the performance of the flexible pavements using waste plastic and waste rubber tires which serves two purposes primarily by eliminating plastic and rubber tire waste in the environment to an extent possible and secondarily, by modifying the rheological properties of the bitumen to enhance its sustainability.

Bitumen is an imperative component of flexible pavements, it plays a key role in keeping the aggregates intact. However, the varied temperatures and loading conditions significantly affect the performance of the bitumen due to which the flexible pavements fail prematurely. The serviceability of the pavements is greatly affected by the two major failure distress namely: “Fatigue and Rutting”. These two types of distress are directly controlled by the properties of the bitumen and greatly influenced by the temperature variations. Therefore, it has been a widespread practice to modify the neat bitumen to enhance the rheological properties in order to withstand increased vehicular loading and repetitions. Waste plastic such as polythene carry bags, cups, etc. and waste rubber tires have been identified as the potential modifiers to bitumen. When the waste plastic and rubber tires are used as modifiers, it is obvious that the modified bitumen must be subjected to several fundamental and advanced tests to ensure that the modified bitumen reflects enhanced properties in terms of performance and durability. There have been a variety of studies conducted globally on the use of Plastic and crumb rubber blended with bitumen for road construction. There are two methods in blending plastic and rubber waste with bitumen, the most widely practiced mechanism is the dry process in which the waste materials are together with bitumen and mineral components. There seems to be less emphasis on the wet process mechanism which involves processing of waste materials with the bitumen before it is mixed with the aggregates . This study evaluates the experimental tests results obtained by conducting fundamental and advanced tests on the bitumen blended with waste plastic, crumb-rubber (wet process) at the Department of Civil & Environmental Engineering Indian Institute of Technology Tirupati, by the sponsorship of Tinna Rubber & Infrastructures Limited, New Delhi.

## II. LITERATURE REVIEW

Many countries have put forth the idea of using waste plastic and waste rubber for road construction and is also currently being practiced. This innovative technique has proven to be economical , durable and eco-friendly which is why it has gained much attention and research scope in the recent days. There is a huge mass of literature available on the current research and its related topics. Some of the key findings identified from the literature reviewed are briefed in this section.

Minakshi Singhal et al. found that the optimum percentage of waste plastic to be used to modify the bitumen to obtain maximum results is between 5% to 10% [2]. Study conducted by Imran M. Khan et al. concluded that the elastic behavior of the neat bitumen can be significantly modified by the Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE), and Crumb Rubber (CR) to increase the service life in terms of reduced susceptibility to rutting and cracking[3]. Shankar S et al. observed that the addition of crumb rubber improved the characteristics of the bitumen when compared with straight run bitumen in terms of resistance to temperature variations [4]. A study conducted at the Centre for Transportation, Bangalore University to compare modified bitumen to that of an ordinary bitumen resulted in significant findings. The penetration and the ductility values of a modified bitumen found to be decreasing with the increase in percentage of plastic additive up to 12% by weight of bitumen [5]. Shubham Bansal et al. concludes that the use of waste plastic bottles and rubber tires improves the strength and overall durability of the Bituminous concrete mix, they also concluded that the targeted characteristics of Bituminous Concrete can be achieved with the application of the waste materials in fixed proportions[6]. A study conducted by Nabin Rana Magar, suggests that the best size of the crumb rubber to be used as a bitumen modifier to obtain the highest stability is 0.3 - 0.15mm [7]. Murat Karacasu et al. in their study concluded that rubber-modified asphalt concrete mitigates vibrations generated by traffic loading and results in reduced damage from cyclic straining. The use of polymer-modified bitumen provides improved longevity and marked whole-life cost benefits, increasing the sustainability of pavements [8]. Mena I. Souliman et al, in their study found that the Asphalt modified with rubber exhibited higher cost-effectiveness i.e, 4.1 times higher than that of an unmodified mixture. Also, the polymer-modified mixture was identified to be 2.6 times higher cost effective than the unmodified mixture [9].

## III. MATERIAL SAMPLE

**PRMB:** The Plastic-Rubber Modified Bitumen was reported to be developed with a combination of waste plastic, crumb rubber from waste radial tires of trucks / bus and some additives; the approximate portion of waste components was reported to be 90% with 10% additive in the total blend of modified bitumen. This PRMB sample was claimed to be furnished by Tinna Rubber & infrastructures Limited, New Delhi, India.

**VG 30**: Viscosity Graded-30 bitumen is a virgin or neat bitumen. This sample has been used to conduct the conventional binder consistency results to compare its results against the PRMB test results.

## IV. TESTS CONDUCTED

The fundamental binder consistency and advanced rheological characterization tests conducted on the

PRMB sample and the VG-30 Bitumen are briefed below:

i) **Softening Point:** The softening point is defined as "*the temperature at which the sample is soft enough to allow the ball, enveloped in the sample material, to fall a distance of 1 inch (25.4mm)*". This test indicates how susceptible the sample is with respect to temperature. This test was reported to be conducted as per the standards outlined in ASTM D36.

ii) **Penetration:** Penetration test is a measure of the consistency of semi-solid bitumen. The value obtained by this test determines the hardness-softness of the bitumen. This test was reported to be conducted as per the guidelines available in ASTM D5-19.

iii) **Elastic Recovery by Ductilometer:** This test is especially conducted to examine the elastic recovery of the bituminous binders modified with thermoplastic elastomers. This test measures the recoverable strain of the modified bitumen binder after subjecting it to an elongation.

iv) **Rotational Viscosity:** This test is usually performed to measure the resistance of bitumen to flow. It is expressed in terms of the ratio between applied shear stress and the rate of shear. In the present study the temperature at which this test was conducted ranges between 38 and 260 and is performed with the help of a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature. This test has been conducted as per the standards outlined in ASTM D4402.

v) **Dynamic Shear Rheometer:** Dynamic Shear Rheometer test determines the rheological characteristics of bituminous binders with the help of a Dynamic Shear Rheometer (DRS) at specified test temperatures and frequencies. Complex modulus |G*| and phase angle (), at specific frequencies and loading have been measured with a measuring system having 25 mm diameter parallel plate (PP) and 1mm gap. The test was conducted for the unaged conditions with a strain level of 12% and an angular frequency of 10 rad/s (1.59Hz). The higher temperature performance grading (PG) of the PRMB sample were also identified using DSR, as per the standard protocols: ASTM D7175-15, ASTM D6373-16, and AASHTO T315.

vi) **Loss of mass using rolling thin film oven aging test:** The Rolling Thin Film Oven (RTFO) is used to simulate the short-term aging that occurs while producing and paving operations. The effect of heat and air on a moving film of bituminous binder can be measured with this test. The PRMB sample was subjected to short-term aging using RTFO according to ASTM D2872-13.

vii) **Multiple stress and creep recovery (MSCR) test of short-term aged samples:** Multiple Stress Creep Recovery Test is conducted to evaluate the bitumen binder's resistance to fatigue cracking. In the current study, it is noted that this test has been performed at four different stress levels: Standard traffic, heavy traffic, very heavy traffic and extremely heavy traffic within the permissible limit (max 75%) at a specified temperature of 100.

viii) **Pressure aging vessel (PAV) test and performance grading verification:** The long-term aging or the in-service oxidative aging of the bituminous binder can be simulated by a Pressure aging vessel by exposing the bituminous binder to elevated temperatures in a controlled environment as per ASTM D6521-13. The performance grading verification for PAV aged samples has been conducted to determine the fatigue cracking.

## V. TEST RESULTS

The results of the various tests conducted on PRMB sample as mentioned in the previous section of this document have been tabulated and compared with the standard values for Polymer Modified Bitumen(PMB) as specified in IS: 15462 (2019).

For the purpose of comparing the conventional binder consistency test results of PRMB, the conventional binder consistency tests have also been conducted on the virgin bitumen sample, Viscosity Graded -30 (VG-30). The results of these binder consistency tests of PRMB and VG-30 were tabulated and the $A_i$-$VTS_i$ relationship has been derived for the selected different bituminous binders at unaged conditions as shown below

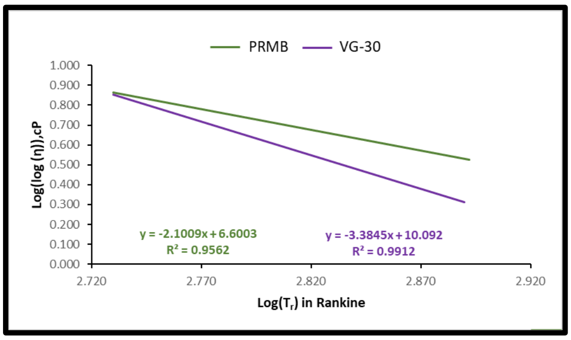

**Fig1 :** *ASTM $A_i$-$VTS_i$ relationships for the bituminous binders*

The binder consistency tests include Penetration, Softening point and the Viscosity tests. The regression parameters $A_i$-$VTS_i$ relationships have been established in accordance with ASTM D2493-16. ASTM $A_i$-$VTS_i$ relationships are found to be important to understand the selection of a binder for varied temperatures that prevail in different geographical areas. The mathematical equation that provides the relationship between viscosity and temperature for a typical bituminous binder is shown in *Equation 1*

$$\mathbf{Loglog\ \eta(cP) = A_i + VTS_i \times Log\ T_r} \qquad \mathbf{(1)}$$

Where,
$\eta$ = Kinematic viscosity, cP
$A_i$ = Intercept of the curve
$VTS_i$ = Slope of the curve
$T_r$ = Temperature, degree Rankine

As seen from Figure **1**, the PRMB sample exhibits the flattest slope ($VTS_i$ = 2.1009). This clearly indicates that PRMB has higher resistance to rutting owing to higher stiffness at higher temperatures and will resist cracking owing to softness characteristic at lower temperatures relative to the virgin binder. Evidently, PRMB binder provides better serviceability across several low and high temperatures. The results of $A_i$, $VTS_i$, and regression coefficients ($R^2$) for the different bituminous binders are given in *Table 1*.

| Binder Type | $A_i$ | $VTS_i$ | $R^2$ |
|---|---|---|---|
| PRMB | 6.6003 | -2.1009 | 0.9562 |
| VG-30 | 10.092 | -3.3845 | 0.9912 |

***Table 1*:** ASTM $A_i$-$VTS_i$ magnitudes for Bituminous binders at unaged conditions

The results of the advanced tests conducted by P-RMB and the standard values of "PMB 76-10" as specified in IS:15462 (2019) have been presented in *Table 2.* The rutting and fatigue cracking performance of PRMB samples at both unaged and aged conditions for different stress levels and temperatures is shown in *Table 3.*

The values of fundamental consistency parameters such as softening point and viscosity of "PRMB" were found to be higher than the values specified in IS:15462 (2019) for "PMB 76-10".

The upper Performance Grading (PG) failure temperature for unaged PRMB samples was observed to be 118, which is significantly higher than the IS:15462 (2019) specified "PMB 76-10".

RTFO aging corresponds to loss of fluidity and workability during hot bituminous mixture production and laying for any binder (commonly called short-term aging). The upper PG failure temperature for RTFO-aged PRMB residue was identified corresponding to $|G^*|/\sin\ \delta$ equal to 2.2 kPa, whose magnitude was 106, that was higher than the IS:15462 (2019) specified "PMB 76-10".

From the MSCR test, it was found that the PRMB sample had a loss of elastic recovery for standard, heavy, very heavy, and extremely heavy traffic within the permissible limit (max 75%) even at high temperature of 100.

PAV aging in the laboratory corresponds to continuous stiffening of in-service bituminous mixture for a minimum of 7 years after opening to traffic (commonly called long-term aging). The lower PG failure temperature for PAV-aged PRMB residue was identified corresponding to $|G^*|\sin\delta$ of 6000 kPa, whose magnitude was 13. Thus, the cracking resistant temperature of PAV-aged PRMB samples was specified as 16, which is significantly lower than that of IS:15462 (2019) specified "PMB 76-10".

| Sr. No. | Characteristics | PMB 76-10 (IS 15462- 19) | PRMB | Remarks |
|---|---|---|---|---|
| **(a) Results of the Tests conducted on original binders** | | | | |
| 1 | Softening point, °C | 70 | 71.2 | Minimum 60 °C, as per IS:15462-2019 |
| 2 | Elastic recovery of half thread in ductilometer at 15 °C, percent, min | 70 | 78 | 70-85 as per IS: 15462-2019 |
| 3 | Penetration, (0.1 mm) | - | 40 | - |
| 4 | Viscosity at 150 °C, Pa-s | 1.2 | 1.2 | 1.2-1.6 as per S:15462-2019; actual experimental Value was 2.82 Pa-s |
| 5 | (\|G*\|/Sinδ), min 1.0 kPa, at 10 rad/s, upper temperature °C Phase angle (δ ), degree, | 76 | 76 | 64-82 °C as per IS:15462-2019; actual experimental value was 112 °C |
| 6 | Phase angle (δ ), degree, max | 75 | 65.5 | 75 as per IS:15462- 2019 |
| **(b) Results of the tests conducted on Rolling Thin Film Oven (RTFO) residues** | | | | |
| 7 | Loss in mass, % max | 1.0 | 0.022 | 1.0% as per IS:15462-2019 |
| 8 | \|G*\|/Sinδ ), min 2.2 kPa, at 10 rad/s, upper temperature °C | 76 | 76 | 64-82 °C as per S:15462-2019; actual experimental value was 100 °C |
| 9 | Phase angle (δ ), degree | - | 63.2 | - |
| **(C)Results of the MSCR test** | | | | |
| 10 | Standard traffic (s) $J_{nr3.2}$, max 4.5 kPa$^{-1}$ $J_{nrdiff}$, max 75%, test temperature °C | 76 | 76 | 64-82 °C as per IS:15462-2019; actual experimental value was 100 °C |
| 11 | Heavy traffic (H) $J_{nr3.2}$, max 2 kPa$^{-1}$ $J_{nrdiff}$, max 75%, test temperature °C | 76 | 76 | |
| 12 | Very heavy traffic (V) $J_{nr3.2}$, max 1 kPa$^{-1}$ $J_{nrdiff}$, max 75%, test temperature °C | 76 | 76 | |
| 13 | Extremely heavy traffic (E) $J_{nr3.2}$, max 0.5 kPa$^{-1}$ $J_{nrdiff}$, max 75%, test temperature °C | 76 | 76 | |
| **(D)Result of the test conducted on Pressure Aging Vessel (PAV) residues** | | | | |
| 14 | \|G*\| Sinδ at max 6000 kPa using 8 mm plate, 2 mm gap, at 10 rad/s at a temperature °C | 37 | 31 | 31-40 °C as per IS:15462-2019; actual experimental value was 16 °C |

***Table 2*****:** Advanced Binder Test Results of Rubber Polymer-Rubber Modified Bitumen

| Test condition | Reference Temperature, $T_r$ ℃ | Failure Temperature, $T_f$ ℃ | Rutting \|G*\|/Sin δ at $T_r$ ℃ | Rutting \|G*\|/Sin δ at $T_f$ ℃ | Fatigue cracking \|G*\|Sinδ at $T_r$ ℃ | Fatigue cracking \|G*\|Sinδ at $T_f$ ℃ |
|---|---|---|---|---|---|---|
| Upper PG of unaged binder at \|G*\|/Sinδ , min 1.0 kPa, at 10 rad/s | 76 | 118 | 28.005 kPa | 0.794 kPa | - | - |
| Upper PG of RTFO aged binder at \|G*\|/Sinδ , min 2.2 kPa, at 10 rad/s | 76 | 106 | 15.499 106 kPa | 1.906 kPa | - | - |
| PG verification of PAV aged binder at \|G*\|Sinδ , | 25 | 13 | - | - | 2597 kPa | 6078 kPa |

| | | | | | | |
|---|---|---|---|---|---|---|
| max 5000 kPa, at 10 rad/s | | | | | | |

***Table 3:*** Rutting and Fatigue Cracking Performance of Rubber Bituminous Binder at different temperatures and varying aging conditions

## VI. DISCUSSIONS AND CONCLUSIONS:

- The fundamental consistency results indicate that PRMB products can perform satisfactorily in regions of high pavement temperatures.
- The teste results indicate that PRMB promotes good serviceability and eliminates permanent deformation or rutting during hot summer months.
- It is evident that the PRMB product will not show any permanent deformation over its design life until the pavement surface temperature reaches 100. However, the pavement surface temperature of 100 is a rarity in country like India across any season.
- The MSCR tests indicate that the PRMB pavements eliminates the requirement of any maintenance at the earlier stages of service life after the road is open to traffic.
- The PAV aging indicates that though the PRMB product undergoes continuous hardening for seven years in the field, it does not develop load-induced cracks (fatigue cracking) on the pavement surface even at lower temperature of about 16, as found in the laboratory.
- It was observed that the reduction in the loss of mass for "PRMB was 0.022%, which is within the maximum permissible limit of 1%, conforming to IS:15462 (2019) specifications.
- All the tests listed in section 4 were reported to be conducted at controlled conditions of temperature and pressure in the laboratory. Therefore, the authors urge that the verification of those values in the field is deemed necessary to understand the product's actual performance. Also, it has been noted that all tests conducted in the laboratory were those of the PRMB bituminous binder product alone. Hence, the interaction of this binder with aggregates as a mix matrix are not covered in this needs study which to be verified in future.

## ACKNOWLEDGEMENTS

I would like to thank Dr. P. K Jain, Head of Department, Flexible Pavements (Retd.), Central Road Research Institute, New Delhi for his valuable support and helping me in doing a lot of research activities with his experience.

## CITATION:

[1]. B. Krishna Prapoorna, Vinay H N and Akjil Charak, "*Advanced Testing of Modified Bitumen Blended with Waste Rubber, Waste Plastic and Additives*, Jan 2020

[2]. Minakshi Singhal, Yudhvir Yadav and Ranadip Mandal, "*Use of Modified Bitumen in Highway Construction*" International Journal for Innovative Research in Science & Technology, (May 2016)

[3]. Imran M. Khan et al, Shahid Kabir, Majed A. Alhussain and Feras F. Almansoor, "*Asphalt Design using Recycled Plastic and Crumb-rubber Waste for Sustainable Pavement Construction",* International Conference on Sustainable Design, Engineering and Construction (2016)

[4]. C.S.R.K., Shankar S. And Prasad. *"Evaluation of Rutting Potential for Crumb Rubber Modified Bitumen In Asphaltic Mixes."* Emirates Journal for Engineering Research, 2009: 91-95

[5]. Justo C.E.G., Veeraragavan A "*Utilization of Waste Plastic Bags in Bituminous Mix for Improved Performance of Roads*", Centre for Transportation Engineering, Bangalore University, Bangalore, India, 2002.

[6]. Shubham Bansal, Anil Kumar Misra and Purnima Bajpai, "*Evaluation of modified bituminous concrete mix developed using rubber and plastic waste materials",* International Journal of Sustainable Built Environment, December 2017

[7]. Nabin Rana Magar, "*A Study on the Performance of Crumb Rubber Modified Bitumen by Varying the Sizes of Crumb Rubber",* International Journal of Engineering Trends and Technology (IJETT), Aug-2014

[8]. Murat Karacasu, Volkan Okur and Arzu Er, "*A Study on the Rheological Properties of Recycled Rubber-Modified Asphalt Mixtures",* The Scientific World Journal, 2015

[9]. Mena I. Souliman, Michael Mamlouk and Annie Eifert, *"Cost-effectiveness of Rubber and Polymer Modified Asphalt Mixtures as Related to Sustainable Fatigue Performance",* International Conference on Sustainable Design, Engineering and Construction, 2016

[10]. IS 15462: 2019, "*Polymer and Rubber Modified Bitumen"*

[11]. IS: 1205-1978 "*Indian standard methods for testing tar and bituminous materials*" (Determination of softening point)

[12]. AASHTO T315 "*Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)*"

[13]. ASTM D2493 / D2493M -16 "*Standard Practice for Viscosity-Temperature Chart for Asphalt Binders"*

[14]. ASTM D7175 -15 "*Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer"*

[15]. ASTM D36/D36M-14e1 "*Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)"*

[16]. ASTM D5/D5M-19a "*Standard Test Method for Penetration of Bituminous Materials*"

[17]. ASTM D4402/D4402M-15 "*Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer"*

[18]. ASTM D6373 -16 "*Standard Specification for Performance Graded Asphalt Binder*"

[19]. ASTM D2872 -13 "*Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)*":

[20]. ASTM7405-15 "*Standard Test Method for Multiple Stress Creep and Recovery (MSCR) of Asphalt Binder Using a Dynamic Shear Rheometer"*

[21]. ASTM D6521 -13 "*Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)".*

Krishnav Sekhri is a senior in The British School, New Delhi. He is an aspiring engineer and dedicated artist – constantly striving to bring my logic, creativity, and passion to build a better, more sustainable world. He is also internationally ranked in taekwondo. Continuing his passion for engineering and sustainability has been a part of several research initiatives.