Effect of Short-Term Aging on the Properties of Crumb Rubber and Fumed Silica Modified Bitumen

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Abstract - *Bitumen, in its pure form, could not possess all the necessary properties to withstand different climatic conditions and traffic loads. By adding different additives, bitumen may be made more appropriate for usage on road pavements. This study intends to enhance bitumen characteristics and performance by modifying asphalt binder with 6% Crumb rubber and fumed silica at varying contents of 0.5%,1%, 1.5%, 2%, and 2.5% by weight of binder. This study investigates the effect of fumed silica and Crumb Rubber on the properties of bituminous binder before and after aging. The physical characteristics of the modified binders have been examined, and test results have been compared with those of the unmodified binder. The binder's characteristics were found to improve with the addition of crumb rubber and fumed silica. The maximum viscosity, softening point, and minimum penetration value are determined for the sample containing 6% crumb rubber and 1.5% fumed silica.*

Key Words: Bitumen, Crumb rubber, Fumed silica, Physical characteristics

1. INTRODUCTION

Bituminous materials, often known as asphalts, are commonly utilized in road construction due to their strong binding and waterproofing capabilities, as well as their relatively cheap expense [8]. Various flaws have been identified in flexible pavements, such as cracks, rutting, and potholes [6]. Bituminous concrete mixes often deform permanently when subjected to repeated loads and hot temperatures. Global research is being conducted to enhance the qualities of asphalt concrete by using additives in the binder or mix preparation [10]. Crumb rubber is recycled from automobile tyres. Adding crumb rubber to hot bituminous mixes improves pavement performance, protects the environment, and leads to faster and more cost-effective roadways [12]. The addition of crumb rubber to a hot mix asphalt mixture is regarded as a sustainable construction technique. The use of crumb rubber as an ingredient in hot-mix asphalt mixtures is regarded as a sustainable building strategy. The use of crumb rubber increased both the strength and the quality of the asphalt mix [13]. Using a dry procedure to add crumb rubber additives in varying sizes and percentages significantly improved bitumen mix characteristics and performance [2].

The use of crumb rubber in bituminous binders also has adverse effects. Using high percentages of crumb rubber (CR) in asphalt pavement using the dry process can negatively impact adhesion, leading to poor mix performance, fatigue, and rutting, as well as increased susceptibility to moisture damage [3]. The settling of the crumb rubber particles in bitumen modified with crumb rubber, however, may result in storage problems [Ibrahim]. Challenges with Crumb rubber-modified asphalt include inadequate storage stability, elasticity, and high-temperature rutting [5]. Crumb rubber is a cross-linked substance that has inadequate compatibility between its particles and bitumen. Two strategies to overcome this issue include nanomaterials and pretreated CR particles [7]. The inclusion of nanomaterials, such as nano-silica, enhances storage stability. The nano-silica and crumb rubber-modified asphalt binder is stable and can be stored for long periods without settling. This property makes it ideal for paving applications [5].

Fumed silica is a cost-effective, non-toxic nanomaterial used to modify bitumen. The use of fumed silica nanoparticles may improve bitumen's mechanical and rheological properties, as well as its resistance to moisture damage and ageing [4]. The inclusion of fumed silica improves asphalt binder characteristics, including penetration index [10]. The optimal fumed silica percentage is 1.5 %. Using 1.5% fumed silica in 6% CR modification improves softening point, reduces temperature sensitivity, improves rheological characteristics, and improves low-temperature parameters [1]. Modifying bitumen with crumb rubber and fumed silica is to reduce the environmental damage caused by discarded automotive tires. Also, the modification intends to improve the properties of the bituminous binder. The study compared the physical properties of unmodified and modified bitumen binders, such as viscosity, penetration, softening point, and specific gravity.

2. MATERIALS

2.1 Crumb Rubber

Crumb rubber is tiny pieces of discarded tire shredded from automobiles that pose a severe disposal issue [9]. Crumb rubber modification increases bitumen characteristics by improving storage and loss modulus, as well as its susceptibility to high and low temperatures. Adding crumb rubber might be challenging due to the poor rutting performance of binders at high temperatures. Crumb rubber (CR), an asphalt modifier, has poor compatibility with bitumen due to its cross-linked structure [7]. Crumb rubber is obtained from Rubbers India Private Ltd.

2.2 Fumed Silica

Fumed silica is a white, fluffy powder. When fumed silica is added, the penetration index of unmodified asphalt increases [10]. The modification of bitumen using fumed silica nanoparticles and clay significantly decreased stiffness and increased resistance to permanent deformation. The precise concentration of clay and fumed silica nanoparticles greatly influences the mechanical stability of the modified asphalt [4]. Studies indicate that fumed silica and CR additives make the binder more consistent and reduce its fluidity at high temperatures [1].

2.3 Bitumen

In this experimental study, VG30 asphalt binder was used. The bitumen is modified using 6% crumb rubber and 0.5% - 2.5% of fumed silica. To determine the characteristics of the binder, physical properties tests were conducted.

3. EXPERIMENTAL METHODS

3.1 Penetration

The penetration test grades bituminous materials by measuring the depth to which a standard needle can penetrate vertically under specific conditions [9]. The reduction in penetration value indicates that the consistency of asphalt changes and gets harder, thereby making it better [11]. In this study penetration values at different percentages of additives are determined.

3.2 Softening Point

The softening point is the temperature at which bitumen reaches a specific level of softening under standard testing conditions. This test was performed using a ring and ball apparatus. Bitumen does not immediately change from solid to liquid, but as the temperature rises, it softens and flows easily [9]. The susceptibility of bituminous binders to variations in temperature and their resilience to elevated temperatures were ascertained by the use of softening point testing [1]. The softening point test was conducted as per IS:1205-1978

3.3 Viscosity

The viscosity of the modified and unmodified bituminous binder was determined using a Brookfield rotational dial viscometer. A rotating viscometer test was conducted to assess the fluidity of bituminous binders at high temperatures. The viscosity results were used to calculate the mixing and compaction temperatures of modified bituminous mixes [1]. Viscosity defines the fluid characteristics of bituminous materials and influences their ability to coat particles, which affects the strength of the paving mix [9]. The viscosity test is conducted based on ASTM D4402 standard

3.4 Specific Gravity

Specific gravity is defined as the mass of a certain volume of bituminous material divided by the mass of an equivalent amount of water. The chemical composition of the binder has an important impact on its specific gravity. [9]. The test is conducted as per IS:1202-1978

3.5 Rolling Thin-Film Oven Test

The Rolling Thin-Film Oven (RTFO) replicates the short-term ageing of bituminous binder during production and paving operations. The sample was placed into a separate RTFO bottle, with a mass of 35g. It was then subjected to ageing at a temperature of 163±0.5ºC for 85 minutes as per ASTM D 2872-19.

4. RESULTS AND DISCUSSION

4.1 Physical Property of VG30 Bitumen

Physical property test was conducted on the neat binder to evaluate its properties. Table 1 shows the physical characteristics of the neat binder include penetration, ductility, softening point, and rotational viscosity. The penetration value obtained for VG 30 in the physical property test is 68, which falls within the required range of 60-70 as per IS73:2013 for VG30. The softening point of the VG30 binder is 48°C, which exceeds the specified minimum of 47°C. Viscosity is Brookfield viscometer and value is obtained as 1205 cP.

Table -1: Physical Properties of VG30 binder

SL. NO.	Parameter	Value	Codal Provision
1.	Penetration Value (dmm)at 25°C,0.1mm,100g,5s	68	IS:1203- 1978
2.	Softening point (°C)	48	IS:1205- 1978
3.	Specific gravity	0.97	IS:1202- 1978
4.	Viscosity (cP) at 135°C	1205	ASTM D 4402
5.	Ductility Value (cm)	102	IS:1208-1978

4.2 Physical Property of Modified Bitumen

Physical property test conducted on the modified binder and properties of the modified are provided in Table 2

Table -2: Physical Properties of Modified Binder

	6% CR	Percentage of Fumed silica				
		0.5%	1%	1.5%	2%	2.5%
Viscosity (cP) at 135 °C	1035	735	950	1880	1675	1185
Penetration (dmm) at 25°C, 0.1mm, 100g, 5s	56	52	48	46	55	60
Softening Point (°C)	52	48	54	58	52	44
Specific gravity	0.98	1	0.99	1.018	0.99	0.97

4.3 Penetration test results

The penetration test evaluates the consistency of asphalt materials for grading purposes [9]. Penetration tests were conducted on unmodified and modified samples. The incorporation of crumb rubber into the neat binder lowers penetration by 17.64% when compared to the neat binder. Adding fumed silica to crumb rubber-incorporated bitumen reduces the penetration value. The sample with 1.5% fumed silica achieves a minimum penetration value of 46 dmm, which is 29.41% lower than VG30 bitumen. The decline in penetration value indicates that the consistency of bitumen alters and the binder becomes hard [11]. Figure 1 shows the variation of penetration with percentage additives.

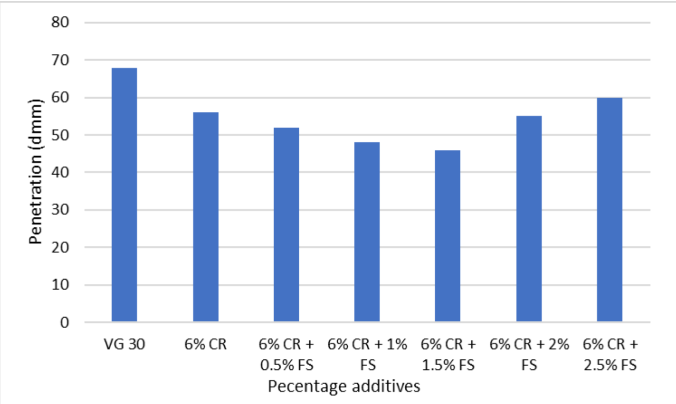

Fig-1: Variation of penetration with percentage additives

4.4 Softening Point

Softening point tests were conducted on bitumen to evaluate their temperature sensitivity and resistance to high temperatures [1]. The softening point test was conducted on both modified and unmodified binders. The addition of crumb rubber increases the softening point by 8%. Adding fumed silica to the crumb rubber modified sample further increases the softening point, and a maximum value of 58°C is obtained for the sample with 1.5% fumed silica, which is about 20% greater than unmodified binder. From the test result, it is observed that adding more than 1.5% fumed silica reduces the softening point. Increased softening point indicates increased high-temperature binder properties. Binders with high softening point values tend to be more rigid and hard than others. This indicates that the binder will be more immune to rutting and degradation at higher temperatures [1].

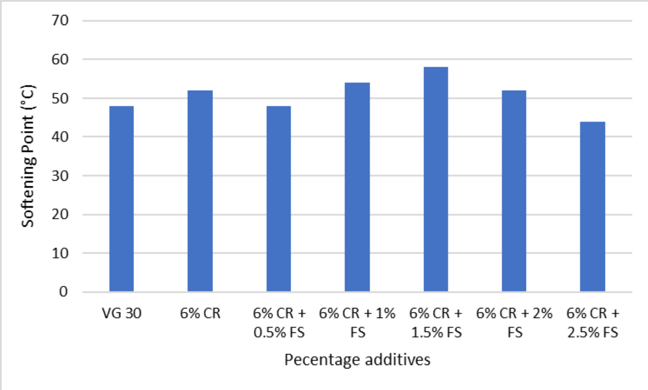

Fig. 2: Variation of softening point with percentage additives

4.5 Viscosity

Viscosity describes the fluid properties of bituminous materials. Bituminous material spreads, penetrates voids, and coats aggregates based on its fluidity at a given temperature. The addition of crumb rubber, along with fumed silica, enhances viscosity. The maximum viscosity is obtained for the sample with 1.5% FS, which is 56% greater than the neat binder even though a low percentage of fumed silica results in lower viscosity. It was found that adding crumb rubber and fumed silica improves the binder's consistency and enhances its durability at high temperatures.

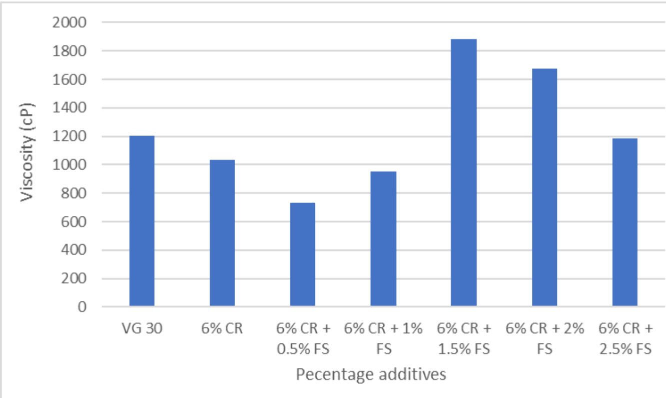

Fig. 3: Variation of viscosity with percentage additives

4.6 Rolling Thin-Film Oven Test

Rolling thin film oven tests have been conducted on various binders to assess the impact of ageing on the modified binders. The physical test conducted on the RTFO residue is shown in Table 3

Table. 3 Basic properties of neat and modified bitumen after aging

	VG 30	6% CR	Percentage of Fumed silica				
			0.5%	1%	1.5%	2%	2.5%
Viscosity (cP) at 135 °C	1350	1145	968	1475	1900	1725	1385
Penetration (dmm) at 25°C, 0.1mm, 100g, 5s	60	52	51	43	36	46	51
Softening Point	49	56	50.5	58	62	57	48
Loss in mass, percent	0.03	0.05	0.04	0.06	0.03	0.04	0.06
Increase in Softening Point °C	1	4	2.5	4	4	5	4
% Reduction in penetration of residue, @ 25 °C	11.76	7.14	1.92	10.42	21.74	16.36	15

The test conducted on RTFO residue indicates that viscosity increased for both the modified and unmodified binder, after ageing demonstrating improved consistency of the binder. Penetration tests conducted on the aged samples indicate a reduction in penetration value for all samples, with the lowest value obtained for the sample containing 1.5% fumed silica, demonstrating improved binder hardness. The softening point test on aged samples reveals that the softening point increases for all samples after ageing, with the maximum value obtained for the sample containing 1.5% fumed silica. The results obtained from loss on heating indicated that the modified binders exhibited a lower value of loss in mass, with all samples falling within the minimal value of 1%. The ageing properties of various binders tested indicate that modified binders offer better properties compared to unmodified binders. Hence it reveals that modified binders have better performance than neat binders.

3. CONCLUSIONS

The study aimed to evaluate the effect of short-term aging on the properties of bitumen containing crumb rubber and fumed silica. Various tests were conducted on both aged and unaged samples to assess their aging characteristics, and the following results were determined:

The penetration test was performed for modified and unmodified samples. The addition of 6% crumb rubber reduced the penetration value by 17.64%. Furthermore, the addition of fumed silica to these samples also reduced the penetration value, with the lowest value obtained for the sample with 1.5% fumed silica, which showed a 29.41% reduction compared to the neat binder. The results of the softening point test indicate that adding crumb rubber and fumed silica improves the softening point of the material. The highest softening point value was achieved when 1.5% fumed silica was added, resulting in a 20% increase compared to the unmodified binder. This suggests that the modified binder has increased resistance to various types of temperature induced damages. The viscosity also improved after addition of crumb rubber and fumed silica reached its peak when 1.5% fumed silica was added, increasing by 56% compared to the unmodified sample.

The rolling thin film oven tests were performed to evaluate the aging characteristics of the modified binder. The test results revealed that the viscosity increased for all samples after aging. Additionally, the penetration value decreased after aging, with the minimum value obtained for the sample containing 1.5% fumed silica, showing a 21.74% reduction in penetration. The softening point increased after modifying the binder with crumb rubber and fumed silica, according to IRC SP 53-2010. The percentage increase in the softening point after aging should be less than 7°C for both unmodified and modified samples and the values are within 7°C. From the study, it is found that adding fumed silica to crumb rubber-modified bitumen improves its properties before and after aging.

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