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# Use of EPDM Rubber (Ethylene Propylene Diene Monomer) as a Bitumen Modifier: A Review

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**ABSTRACT:** Many studies have been conducted in the past on the effects of modification of bitumen by adding various modifiers including various virgin and recycled polymers like EVA, SBS, HDPE; LDPE, etc. This paper presents the review of usage of EPDM as a modifier for modification of conventional bitumen for improving the physical, chemical and Rheological properties of the binder. EPDM is an artificially synthesized rubber which finds its usage in automobile industry and construction; in glazing windows and doors as a sealant its properties are similar to that of Crumb Rubber. Using polymers to modify bitumen improves the physical and rheological properties of bitumen, reduces the effect of ageing, stripping, moisture damage and excessive loading. This paper reviews the study conducted on EPDM modified bitumen binders. Work done with regard to the effects of modification of bitumen with EPDM has been presented and discussed in this paper. The benefits of using/adding EPDM as a modifier have been analyzed in light of former researches. The environmental and economic effects have also been discussed as EPDM comes as a waste from automobile industry and limitations of using the modifier have also been noted.

**KEYWORDS:** EPDM, Modified Bitumen, storage stability, Rheological properties, stripping

## I. INTRODUCTION

With the increase in the vehicular traffic as well as the loads, the service life of many flexible pavements has drastically reduced (Yousefi AA. et al. 2003) and due to the increase in the cost of bitumen because of various reasons, many researchers are trying to find methods to improve and increase the durability, stability and service life of the pavement (Jahromi SG et al. 2011). In spite of the low quantity of bitumen in pavement ~ (4 - 6 %), due to its key role on the strength of pavements and erosion stability, majority of the studies in road construction industries have been done on bitumen, and it has been concluded that any upgrading in the properties of bitumen enhances the performance of the pavement (Abtahi SM et al, 2008) Bitumen when used without any modification are usually unable to resist high axle loads, variation of temperature and pressure exerted by the tyres hence leading to the premature failure in the pavement (Polacco et al., 2015; Yousefi, 2003) many natural and synthetic polymers and rubbers are used to modify the bitumen in terms of the physical properties, resistance to deformation, ageing and fatigue etc. Use of waste polymer or waste rubber has additional benefits on the environment in management of waste (Kalantar et al., 2012) as well as the economy as it reduces the cost and bitumen demand natural or synthetic rubbers and polymers, fibers and different additives like anti stripping agents etc are added sometimes even a combination of these modifiers are also used for the modification. Recycled thermoplastics from agricultural sectors and other industries consist of different types of polyethylene (PE) polypropylene (PP), and ethylene vinyl acetate (EVA) (Airey, et al. 2002; Kalantar et al., 2012; Murphy et al., 2000). Polymers are known as one of the most commonly used additives of bitumen and have been added to improve the efficiency and performance of bitumen (Sadradinidi MR et al, 2002). Out of the innumerable available polymers only a few can be used as a modifier in bitumen mixes to enhance the properties of the binder as the polymer must be compatible and must not degrade at or

before the mixing temperature of bitumen and should improve the thermal susceptibility of the mix (Formela K et al 2016). Amongst the many polymers, rubbers are amongst the most striking ones due to their distinctive characteristics such as, high molecular weight, low cost and a low glass transition temperature. In the years, bitumen has been modified with polyethylene (Panda M et al, 1999; Polacco G et al, 2005, Roman C, et al, 2018), polypropylene (PP) (Giavarini C et al, 1996; Moubark S et al 2017) natural rubber (NR) (Khadivar A et al, 2013; Al-Mansob RA et al 2106) , styrene – butadiene – styrene (SBS) (Galooyak SS et al 2010; Müller AJ et al 2003; Singh SK, et al 2017; Sienkiewicz M et al 2017), styrene - butadiene - rubber (SBR) ( Zhang Q et al 2107; Zhang J et al 2008), other polymers (Yousefi AA et al 2002; Padhan RK et al 2018) and even Recycled Rubber (Navarro F et al 2005; Wang S et al 2015; Senise S et al 2017), but EPDM rubber which has an extensive use in a lot of areas is an area that has been left relatively untouched in the studies to be used as a modifier.

Ethylene Propylene Diene – Monomer (EPDM) is a polymer made from three monomers Ethylene, Propylene and diene monomer as a side chain that provides the unsaturation for cross linking (Barlow, et al; 1988). EPDM is used in various places such as roofing membranes, non-tyre automotive parts such as gaskets, belts, tyre flaps, weather strips, window seals and electrical insulators. EPDM has high temperature, weather, acid, alkali and Ozone resistance (Ghoreishi et al., 2018; Ginic - Markovic et al., 2001). In non tyre rubbers EPDM consist of more than half of the total non tyre rubbers. (Fukumori et al, 2003) annual consumption of EPDM rubber is reported at approximately 926,000 tonnes. (Threadingham et al, 2000). EPDM consists of ~ 90 % Carbon ~ 7 % Oxygen ~ 1.5 % Sulfur and traces of elements like Zinc, Calcium, Silicon, Iron, Aluminum, Chlorine and Magnesium (A. kumar et al., 2019)

There has been very limited study on EPDM as a modifier for pavement bitumen

## II. BACKGROUND LITERATURE

### 1. Analysis of Physical properties, mechanical properties and Storage Stability

**AbdellatifAit-Kadi et.al** (1996) conducted a study incorporating bitumen mixes modified with 9:1 ratio of HDPE and EPDM in the same order for illustrating the possibilities of using the polymer as a modifier to be added in the bitumen. 1 - 5 % of polymer was added to the bitumen by wt. % and viscoelastic properties were studied over temperatures ranging between -15 °C to 60°C. Various tests were conducted on the specimen like the Ring & Ball Softening Point test, Frass - Break Point Test and Thin Film Oven Test. The samples were analyzed for dynamic mechanical analysis and morphological analysis. 150 - 200 penetration grade bitumen was used as the base binder for modification. A high Shear Mixer was used for preparation of Polymer - modified bitumen mixes. Bitumen modification was done at 170° C using 1 %, 3 % & 5 % wt. HDPE & HDPE : EPDM and storage was done at -4 °C in small metallic containers. Overall Properties of the bitumen binder were improvised when HDPE polyethylene polymer mixed with EPDM (Ethylene Propylene Diene Monomer) polymer was added as a modifier. For modification (10% EPDM in HDPE), it was noted on the basis of morphology, Ring & Ball test for softening point, linear viscoelasticity, Thin Film oven test for ageing and Frass - break point test, 1 % HDPE & EPDM modified bitumen exhibited the most promising outcomes. With the presence of EPDM in the mix the morphology before the TFOT aging was much more stabilized. Optimum Designing is much needed in order to obtain the material with desired properties. They concluded in the study that by altering the binder using polymer as a modifying additive is an effective way for improving the properties of bitumen.

**John B. Metcalf et.al** in the year 2000 conducted a study in which the main goal was to investigate the application of EPDM as a modifier of bitumen in HMAC mixtures. A usual dense graded mix was selected for the process. Using 5 different types of bitumen binders (PAC - 40, HG, AC - 30 AC – 30 modified with EPDM and AC – 10 modified using EPDM) testing was done to compare the Stiffness of the binders. AC - 10 was added in the moisture susceptibility study for this, three types of commercially available liquid anti-stripping agents were used (Perma – Tac - 99 (AS #1), Paver Bond T – Lite (AS # 2) and Adhere HP – Plus (AS#3)).the Indirect Tensile Resilient Modulus Test, ITS (Indirect Tensile Strength) test and the unconfined uniaxial creep tests were executed on the HMA mixes in order to compare changes in the stiffness of the mix. Specimen were tested for moisture susceptibility using tests including the Modified Lottman test, Boil test, Retained Resilient Modulus Test and

Marshall test for Retained Stability. The study showed that a usual job mix of HMA with EPDM modified AC can be mixed and made - up in a lab by using normal equipment and design procedures. The results of the study were that the AC - 10 modified EPDM HMA mixes (i.e., E 10) were better as compared to unmodified AC - 30 HMA mixes (i.e., A 30) in terms of indirect tensile strength, Marshall Stability and flow, and creep properties. As Compared to usual PAC – 40 HG HMA mixes (i.e., P 40), the E – 10 mixes performed in a better way in indirect tensile strain at failure, creep stiffness, permanent strain, Marshall Flow, and creep slope. AC-30 HMA mixes modified with EPDM (i.e., X30) outperformed the unmodified AC- 30 HMA mixes (i.e., A30) in indirect tensile strength at 25°C and 40°C, Marshall Stability, and in resilient-modulus at 4°C, 25° and 40°C. The X30 mixes performed equal or superior than the P 40 mixes in creep stiffness, Marshall Flow, Marshall Stability, Indirect Tensile Resilient Modulus at 4°C, 25 °C, and 40 °C and Indirect Tensile Strength (ITS) at 25 °C and 40 °C. The outcomes from the tests for moisture susceptibility of the specimen revealed that HMA mixes modified using EPDM were susceptible to stripping and hence need an anti-stripping agent. Use of AS #1 as an antistripping agent was very effective in both modified and unmodified mixes.

In 2001 **K. Gopalakrishnan et al** in order to observe the susceptibility of moisture on unmodified HMA mixes and HMA mixes modified with EPDM as well as for estimating the relative efficiency various anti stripping agents on the mixes, conducted this study using a typical Louisiana Type 8 mix. Five types of bitumen mixes (PAC - 40 HG, AC - 30 AC – 30 modified with EPDM and AC – 10 modified using EPDM) and 3 varieties of commercially available antistripping agents were used. Tests performed for moisture susceptibility of the mixes were Ten Minute Boil Test, Modified Lottman Test, Marshall Test for retained stability and Retained Indirect Tensile Resilient Modulus Test. The experimental bitumen was created by modification of AC -10 & AC – 30 by adding 3% bitumen by wt. %. The EPDM particles were blended with the bitumen using a high shear mixer at 175 °C and 1500 - 2000 rpm. Three amine based commercially available anti stripping agents were used in this study which were Perma – tac - 99 @ (AS # 1), Pave Bond T – Lite @ (AS # 2), and Adhere HP – Plus @ (AS # 3). Dosages of 0.5% were selected for all the 3 antistripping agents. Conclusions from the study were that Modified Lottman test was found to be extremely efficient for finding the mixes that were moisture susceptible. Outcomes from the tests presented that HMA mixes which contained EPDM i.e. AC – 10 Modified with EPDM & AC – 30 modified with EPDM polymer were liable to damage from moisture. Adding AS # 1 considerably enhanced the values of TSR for all the 5 mixes. The ten minute Louisiana boil test results favored using AS # 1 as none of the mixes failed when AS # 1 was added. The ITRM test (Indirect Tensile Resilient Modulus) presented trends which were comparable to that of the Modified Lottman test. HMA mixes modified with EPDM exhibited higher resistance to the damage induced by moisture in RRM terms than TSR. Hence, using AS # 1 proved to be effective. In both of the tests, indirect tensile resilient modulus and modified lottman, even without using an antistripping agent the binder P 40 mix exhibited substantial resistance to moisture damage. Marshall Stability test was found to be quite ineffective for detecting moisture susceptibility of the mixes or for evaluation of efficiency of antistripping agents. Results obtained from the study showed that amongst the three antistripping agents incorporated in the study, AS # 1 was found to be the most efficient antistripping agent for improving the resistance to stripping for the mixes.

In the year 2006 **A. Pe´rez-Lepe et al.** conducted a study focusing on the high temperature stability of bitumen mixes modified with different polymers as the researchers identified that one of the key difficulties for commercial usage of PMB (polymer modified bitumen) was the possible separation of phases which could happen after the preparation of bitumen mixes modified with polymer addition due to the difference in their respective densities (Hesp, S. A. et al. 1992; Lu et al 1999) for this they conducted a study aim of the study being researching the resistance against separation of different phases of various PMBs at higher temperatures (~180 °C) The monitoring of phase separation process was done through development of viscous linear along with the viscoelastic properties of specimen, at 75 °C, noting them post multiple storing periods. At 75 °C, the bitumen mixes softened adequately, & henceforth, the process of relaxation of polymer were making the major contributions behind the basic rheological properties of the composite mixture (Lu, X.; et al 1997) In this study EPDM, LDPE, EGA, SBS, EPDM/HDPE (3/1), EPDM/HDPE (1/3) and EPDM/LDPE (1/3) were tested for instability index and as a general conclusion, there was an improvement in the mechanical properties of the binder with the addition of polymer, even though the enhancement is depends upon the mixing process, the nature of polymer and concentration. The results obtained pointed that HDPE containing binders showed an extraordinary enhancement of mechanical properties, when



compared with EPDM, SBS as well as LDPE modified bitumen blends. HDPE was the one polymer, amongst the evaluated ones in the study, which displayed the ability of forming a network in polymer, when added in 3 % and 5 % contents, the enhanced properties were due to the same network discussed before. Instability till an extent was found in all of the polymer modified mixes during their storage at extreme temperatures. Despite of its wide usage in the pavement construction, SBS polymers presented high levels of instability as compared to the binders modified with EPDM or EGA reactive polymers. Phase separation prevailed as a major problem even in HDPE polymer modified binder which possessed preferred mechanical properties. Hence, in order to achieve an effective binder a method to stabilize the HDPE polymer phase in bitumen matrix was very much required. Using the mix of HDPE and EPDM mixes didn't effectually delay the phase separation of polymer from bitumen matrix, although a slight stabilization effect was obvious.

## 2. Analysis of Rheological Properties :

O. Gonza'lez et al in 2002 did a study in which the viscoelasticity of bitumen added with 5 % wt. of LDPE and HDPE and their corresponding mixes with propylene, ethylidene, norbornene and ethylene for modification. Main aim of the study was having comprehension of the link in viscoelasticity and structure for unveiling the rheological effects of interaction of maltenes & asphaltenes with the polymer. The modified mixes were compared with pure bitumen in thermal and mechanical backgrounds identical to the mixes of polymer with bitumen, i.e. under similar conditions as the mixes, but without adding polymer. Rheology was used as a tool to analyze the interaction of Polymer & Bitumen phases in the polyethylene modified mixes, the co-relation between structure and viscoelastic behavior of bitumen. Dynamic Solid state visco - elastic values for each specimen (i.e. polymers, pure bitumen, EPDM rubber with PE polymer mixes, and polymer + binder mixes) were measured with the using a DMTA dynamic mechanical analyzer. The rheological properties of the polymer + bitumen mixes were analyzed in the temperature range from 5 °C to 100 °C using a plate – plate assembly with the dia. of 2 cm using a CSL 100 TA apparatus with stress control. Oscillating & Continuing measurements of flow of EPDM/PE blends and molten form of pure polymers at a temperature of 180 °C were measured using a plate and plate assembly with dia equal to 2.5 cms using ARES equipment. The rheology of the bitumen mixes blended with polymer were tested at temperatures ranging between 5 °C and 100 °C were conducted in plate and plate assembly with the dia. of 2 cm using a CSL 100 TA apparatus with stress control they found out in the study that The Dynamic visco-elastic results in the range 30 - 70 which indicated a viscous reaction ( $G''$  was greater than  $G'$  for all the specimen). Complex viscosity and modulus of elasticity were exceptionally improved when polymer was added, particularly for HDPE as well as HDPE and EPDM mix. The decrease in dynamic functions was highest for HDPE + Bitumen which were followed by the bitumen mixes added with EPDM and HDPE, then by bitumen mixes added with EPDM and LDPE, Bitumen mix modified with EPDM and was found to be least for Bitumen mix modified with LDPE.

Results of Dynamic viscoelastic obtained beneath the peak of relaxation, pointed towards a behavior which was elastic ( $G'$  was greater than  $G''$ ) for all specimen, though the maltene segment was well greater than the temperature of glass transition. This indicated that there existed a dense structure, although a behavior which was gel like wasn't foreseen. Effects of adding the polymer were considerably less noticeable at higher temperatures. There weren't any enhancements in the viscoelastic behavior of bitumen with addition of EPDM probably due to the fact that the complex modulus of polymer was lower than the complex modulus of bitumen at lower temperatures.

As the defects in Pavement such initiation of cracking and it's propagation in the regions with lower temperatures and rutting in areas of higher temperatures is not only because of traffic overloading but thermal susceptibility of bitumen as well (Ait-Kadi A et. al 1996) and the thermomechanical resistance, elasticity and adhesive nature of the bitumen can be enhanced with the addition of polymers (Collins JH et al 1991) it is a known fact that the chemical compatibility and conditions of processing eg. time, temperature and the type of device used for mixing or dispersing, etc. are critical for achieving properties which were preferred along with a steady composite of mix. Majority of the polymers are insoluble, to an extent, in the bitumen, that would lead to the gross separation of the two phases (Newman JK et. al 1998) hence A. Pe'rez-Lepe et al. in 2003 did a study in order to optimize the mixing condition, process of mixing and their effects on rheological as well as the mechanical properties of neat and modified bitumen mixed with EPDM, LDPE, HDPE and SBS using a Lab scale and a rotor stator mixer different

mixes were 5% EPDM Lab - scale mixer, 5% HDPE Lab - scale mixer, 5% SBS Lab - scale mixer, 5% LDPE Lab - scale mixer, 5% EPDM Rotor – stator device, 5% HDPE Rotor – stator device, 5% SBS Rotor – stator device, 5% LDPE Rotor – stator device, 5% HDPE : EPDM [3 : 1] Rotor – stator, 5 % HDPE : EPDM [1 : 3] Rotor – stator device, 5% HDPE : EPDM [3 : 1] Rotor – stator device and their steady flow measurement values were checked on both a controlled stress Haake - Rheostress RS 150 rheometer and ARES rheometer with controlled strain Rheometrics with the use of serrated plate and plate geometries. In the study they concluded that high energy was required for stabilization and dispersion of the polymer in the mix which could change the rheological properties due to oxidation. Adding Polymer in the binder enhanced mechanical properties of the bitumen which was dependent on nature of polymer as well as in the process of mixing, the samples of HDPE with EPDM mixes and bitumen modified with EPDM, which were prepared in a rotor – stator mixer, when compared to the bitumen mixes modified using EPDM, SBS and LDPE possessed mechanical properties significantly better than the latter mixes. Binders mixed using a lab – scale mixing device gave results that were less promising. These results were due to much effective dispersal of the polymers by the rotor – stator device that preferred the generation of micro-phases which were rich in polymer. The interaction amongst these might become sufficiently strong, making a spike in mechanical spectrum.

In 2005, A. Pe´rez-Lepe et al. did a research to throw some light on the mechanism of destabilization of bitumen mixes modified with different polymers in which numerous HDPE based modified mixes were manufactured using a high shear mixer. To study the mix the storage of the bitumen mixes modified with polymer was done in tubes at a temperature as high as 180 °C and the observation of mechanism of destabilization was done using optical microscopy. The main aim of this research was to study the destabilization mechanism of 5 % HDPE-modified bitumen mixes during their storage at higher temperatures the storage stability was compared with 25/75 w. w. 5% EPDM + HDPE and 2% EGA modified bitumen mixes.

In the study Tubes with dia of 43 mm and length of 300 mm were used while the storage was done at 180 °C, after different storage times, samples were extracted from the upper part of the tube. Rheology was studied using both, a controlled stress Haake - Rheostress RS 150 rheometer and ARES rheometer with controlled strain Rheometrics. Strain and frequency sweep tests in oscillatory shear and viscous flow measurements were performed after that. Viscosity flow measurements were measured using both, a controlled stress Haake - Rheostress RS 150 rheometer and ARES rheometer with controlled strain Rheometrics, with serrated plate and plate assembly apparatus. While the morphology study of the bitumen polymer blend was done with optical microscopy.

It was found in the study that the stability at 180 °C after 24 hours was highest for EGA because it is a reactive polymer followed by EPDM + HDPE mix the polyethylene was distributed into the bitumen matrix at an elevated temperature, using a high energy mixing process. The outcomes of the experiments demonstrated that the polymers were swollen by some light weight aromatic constituents of the binder. Though, after storing the sample at a temperature higher than the melting point of polyethylene even for a small period of time, the sample faced a gross phase separation issue which took place due to the dissimilarity in densities and the lack of compatibility of polymer and bitumen, the polyethylene rich phase destabilized and coarsened. Even though preferable mechanical properties of bitumen were achieved using HDPE as a modifier, such binders were not found to be relevant for the pavement application at that time, as it was thought that phase separation might occur during the binder's application in pavement construction.

H. Ismail et.al in 2013 did an extensive research to study the changes occurring in the swelling behavior and thermal properties of conventional bitumen and recycled EPDM modified bitumen mixes when they were subjected to dynamic vulcanization. Swelling test and Thermo - Gravimetric Analysis (TGA) neat/virgin Polyethylene (vPE), polyethylene which was recycled (rPE) as well as EPDM TGA analyzer Perkin – Elmer Pyris 6 with a continuous nitrogen flow of 50 ml per minute with a temperature range from 25 °C to 590 °C with rise in temperature at a fixed rate of 20 °C per minute was selected for analyzing the Thermo Gravimetric behavior of the mixes. The loss in weight of the specimen automatically noted in the analyzer ASTM D 471 guidelines were carefully followed for conducting the swelling tests of the mixes. In TGA test, when the degrading temperatures were up to 450 °C, vPE, rPE and EPDM blends added with .6 % and 1.0% sulphur was found to be more resistant to degradation and even

had a better thermal stability in comparison to the bitumen mixes with no added Sulphur. When Ultimate degradation point was achieved, the mixes with sulfur added to them had weight loss lower than the mixes which did not have any Sulphur added to them indicating a cross linking in the polymer phase which eventually improved the thermal stability of the vulcanized mixes.

Their study concluded that integration of Sulphur improved the stability of the polymer bitumen mixes. When quantity of Sulphur added was increased there was an eventual decrease in the total loss of weight of the mix. It was also found noteworthy that the addition of Sulphur decreased the mixes' susceptibility to oils and increased the chemical resistance as well while decreasing the percentage of swelling and swelling index.

Atefeh Ghoreishi, et al. in 2018 studied on EPDM modified bitumen mixes. The aim of the study was to analyze the rheological, thermal and physical characteristics of bitumen modified by adding EPDM elastomer along with hybrid nanoparticles like carbon – nano - tubes (CNTs) master batch and bentonite nano - clay. In the study, 60/70 grade bitumen was used for the modified samples and 3% EPDM, 0.1% CNT master batch and bentonite nano - clay at 1.5% & 4.5% tests for physical properties like penetration, ductility, Penetration Index and softening point, tests for rheological analysis and for thermal analysis thermo gravimetric analysis (TGA) were conducted.

They concluded in the study that with addition of 3% EPDM, 0.1% CNTs, and 1.5% or 4.5% bentonite nano - clay reduced the degree of penetration, increased the penetration index as well as the softening point of the bitumen. Complex modulus increased while the phase angle decreased in comparison to. As per the graphs of  $G^*/\sin \delta$  v/s temperature, temperature for suitable visco - elastic behavior shifted to higher temperatures for the modified samples which indicated that the rheological properties of bitumen were modified by addition of EPDM, nano clay and CNT master batch concluding bitumen modified with 3 % EPDM, 0.1 % CNT, and 1.5 % bentonite nano - clay could be used as a high performance bitumen in warm areas.

One the most recent study in the topic has been conducted by **Ankush Kumar et.al** in 2018 in which they incorporated EPDM waste from automobile industry. In this study VG 30 bitumen was modified with waste EPDM rubber (passing 300 $\mu$  sieve) and sulfur was used as a crosslinking agent. EPDM was added in percentages ranging between 2 %, 4 %, 6 % & 8 % wt. EPDM and sulfur was added @ 0.3 % wt. of the binder to analyze the bitumen modification were Storage stability test, Softening point, Penetration Value, Viscosity (135°C), Complex Modulus ( $G^*$ ), Phase Angle ( $\delta$ ), Storage Modulus ( $G'$ ) in  $G^*$  %, Rutting parameter ( $G/\sin \delta$ ), Frequency Sweep and Binder Yield Energy Test (BYET) Mixing of bitumen with the modifier was done @ 8000 rpm using a high shear mixer at 150 °C for 45 minutes then sulfur was added and the binder was mixed for another 15 minutes. Phase separation was tested for the mixes by checking the difference in the softening points of top and bottom parts of the mix; the difference increased with the increase of EPDM content and decreased with the addition of sulfur. Penetration difference of the bitumen at top and bottom section decreased with the increase in the addition of EPDM and decreased with the addition of sulfur. Viscosity of bitumen increased with the addition of EPDM and decreased with the addition of sulfur.  $G^*$  value increased with the increase in the EPDM content (105-110% increase) and was further enhanced with the addition of Sulfur (115-120% increase) Phase angle of the modified mix was lower than the unmodified binder and was even much lower for mixes with sulfur.

They concluded in this study that EPDM improved the rut resistance and the elastic behavior of the mix and with the addition of sulfur the storage stability is improved in the modified mixes.

EPDM modification improved the high temperature performance, increased the value of complex modulus and decreased the phase angle of the unmodified mix and these properties were further enhanced with sulfur addition. BYET peak in yield energy was shown at 4 % EPDM along with sulfur which suggested improved fatigue response.

### III. CONCLUSIONS

Conventional Bitumen nowadays is failing prematurely due to a variety of reasons including fatigue failure, overloading, moisture etc for which a lot of modifiers including Polyethylene EVA, SBS, crumb rubber etc that have been well established as bitumen modifiers are used another modifier i.e. EPDM a terpolymer synthetic rubber has

widespread uses in waterproofing membranes, automobile industry and as sealants in doors and windows can be feasibly used in bitumen to modify the physical properties like penetration index, thermal stability, softening point, viscosity, fatigue response etc. and rheological properties like complex modulus ( $G^*$ ), Storage modulus ( $G'$ ) and Phase Angle ( $\delta$ ). There was a substantial rise in the properties which further improved with addition of sulfur. Sulfur acts as a crosslinking agent increasing the homogeneity and decreases the phase separation which is the biggest problem in the use of EPDM and many other polymers as the particles of polymer tend to rise up due to the difference in the densities in comparison to bitumen.

EPDM percentages in modified bitumen on the basis of the previous literature available ranges from 1-10% by weight of bitumen and sulfur addition can be ranged from 0.1 to 1% by weight bitumen can be used to improve the bitumen and using a High Shear mixer was found to be necessary to make a homogeneous mix of the blend. EPDM gave promising results in the tests and can be used as a modifier for bitumen to be used in pavement grade bitumen to improve the pavement characteristics.

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