



PERFORMANCE EVALUATION OF ETHYLENE-VINYL ACETATE MODIFIED BITUMEN AND MIXTURES

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Abstract

Interconnectivity necessitates the use of transportation facilities and infrastructure. All highway design agencies seek acceptable, long-lasting, and cost-effective strategies while designing these facilities. The traffic demands on roads are much higher than they have been in the past. Increased traffic loads, larger traffic volumes, and insufficient maintenance have all contributed to serious road surface distress (e.g., rutting and cracking) due to rapid development. As conventional asphalt combinations are unable to withstand high axle loads and tire pressures, interest in polymer-modified asphalt has grown. Polymer modification of asphalt is one of the most effective ways to improve asphalt qualities. The practical temperature range of binders is greatly expanded by polymers. The inclusion of the polymer can considerably improve the binder qualities by increasing the stiffness of the bitumen and enhancing its temperature susceptibility, enabling the building of safer roads and lower maintenance costs. This research presents a laboratory investigation of the Ethylene Vinyl Acetate (EVA) polymer-modified bitumen. NHA-B gradation, PARCO 60/70 grade bitumen, and EVA polymer of TPI Polene Public Company Limited were used. Penetration, softening point, ductility, and viscosity tests were used to evaluate the conventional properties of the asphalt binders. Three different percentages of polymers were used i.e., 2%, 4%, and 6%. The impact of the EVA polymer on permanent deformation and moisture susceptibility was investigated. A double wheel tracker (DWT) was used to quantify permanent deformation (rutting), and a Universal Testing Machine (UTM) was used to examine moisture susceptibility using an Indirect Tensile Strength (ITS) test. For different percentages of bitumen volumetric properties according to Marshall Mix Design

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procedure were measured, and then Optimum Bitumen Content (OBC) was evaluated. Performance tests were performed using above mentioned percentages of EVA. The rutting potential of mixes was improved by the addition of EVA as compared to control asphalt mixes. The same effect of the polymer was on the moisture susceptibility of the prepared samples. This showed that EVA polymer can be used in flexible pavements to reduce permanent deformation and high-temperature problems.

Keywords: Ethylene Vinyl Acetate, Polymer modified bitumen, performance evaluation, Optimum Bitumen Content (OBC), Indirect Tensile Strength (ITS)

I. Introduction

Transport is very important to the well-functioning of economic activities and also a key to ensuring social well-being and productive growth of the population. Transport ensures the movement of people and goods which are vital for the growth of the community. Transport infrastructure is a very critical ingredient in economic development at every level of income. It not only plays a significant part in the socio-economic upbringing of any country but is also considered amongst the most valuable assets. According to the economic survey of Pakistan, the mode used mostly for transportation is road transport, which is the fourth largest sector and contributes more than 12% to GDP. It accounts for over 21% of gross fixed capital formation. Road transport of Pakistan carries over 95% of the freight and passenger traffic. In the previous year, Pakistan's road infrastructure suffered from premature pavement failures due to constant growth in traffic volume.

(Khan & Kamal, 2012) Inflexible pavements, one of the most prevalent and harmful pavement distresses is rutting, and it is caused mostly by axle loads exceeding the allowable limit and high temperatures, and also poor mix design is one of the causes of rutting. Rutting in asphaltic concrete is dependent upon numerous factors which include, type of binder, aggregates type, gradation, % of bituminous binder, degree of compaction, environmental factors, repeated traffic loading cycles, bearing capacity of subgrade, and air voids content.

(O'Sullivan & Wall, 2009) The link between aggregate and asphalt binding material in the asphalt mix is weakened by moisture susceptibility, which is a critical concern for pavement performance. Moisture damage is caused by air voids, which has a negative impact on the asphalt mix's durability and strength. Moisture damage is classified into two types: adhesive failure and cohesive failure. Cohesive failure occurs when the binder's strength is diminished due to moisture degradation, whereas adhesive failure happens when the aggregates adhere to the binder.

Premature rutting of flexible pavements is one of our country's most serious pavement problems. Pakistan has National highways of 12130 km and Motorways of 3714 km. Most of the road network in Pakistan is flexible pavements with bituminous surfacing as wearing course.

Even though rutting seen on pavements is the result of failures happening in one or more layers of the asphalt structure and sub-grade, however the failure visible in the topmost layers is considered as the real reason for rutting. For minimizing this

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distress, it is important to give careful consideration to material determination and mix design.

Even though asphalt from refineries meets current criteria, investigations have shown that the failure of flexible pavements is mostly due to the poor strength of regular asphalt mixtures to handle the repeated application of wheel load.

II. Research Objectives

The research's primary goals are as follows:

- To evaluate the physical properties of modified bitumen and virgin bitumen.
- To evaluate volumetric properties of HMA using Marshall Design method.
- To evaluate indirect tensile strength of asphalt mixture using modified and virgin bitumen.
- To evaluate rutting resistance of asphalt mixture containing modified bitumen.
- To evaluate moisture susceptibility of asphalt mixture containing modified bitumen.

III. Literature Review

Rutting is a major distress mechanism in asphalt pavements that manifests itself as irreversible deformation. Rutting has been the most common mode of failure in the flexible pavement as truck pressure has increased in recent years. Rutting is mostly produced by a build-up of persistent deformation in the pavement structure's various layers and portions of layers.

(Garba, 2002) described that the average gross weight of trucks has increased and is functioning near to the limits of legal axle loads. In countries with the relaxed implementation of the legal axle load limit, the trucks operate at axle loads and thus exceed the legal limit of axle load. An increase in axle loads and the use of increased pressure in tires results in high stresses due to the contact area between the tire and the pavement which causes larger deformation in flexible pavements in the form of excessive wheel track rutting. Permanent deformation in wearing course thus accounts for a larger percentage of rutting on flexible pavements exposed to high tire pressures due to heavy axle load. Thus, a continuous depression in the top layer along the path of the wheel is referred to as rutting with pavement disruption through the edges of the rut. Major structural failure and hydroplaning caused by rutting is a safety hazard. Rutting can take place in all pavement layers and results from lateral side densification and distortion.

According to (Ahmed & Ahmed, 2014) Moisture damage is the result of the moisture effect and is defined as the deterioration of the strength and durability of asphalt mixtures. In asphalt mixes moisture damage can occur if the fine aggregate and asphalt binder lack enough bond strength required for their bond integrity. Moisture damage occurs when moisture interacts with the adhesive between aggregate and binder in the asphalt mix, which increases the susceptibility of the asphalt mixture to moisture during cyclic loading.

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(O'Sullivan & Wall, 2009) stated that moisture damage occurs when moisture in the air spaces compromises the HMA's durability and strength. Moisture damage can take two forms: cohesive failure and adhesive failure. Adhesive failure occurs when the aggregate and binder are separated, whereas cohesive failure occurs when the binder's strength is weakened due to moisture degradation.

The tensile strength of HMA is very important since it is a decent pointer to confirm the HMA mixture's probability of cracking. The mixture which exhibits high tensile stain demonstrates that HMA is extra probable to struggle against cracking and permit higher strains.

The significance of the ITS test is determining the potential of bituminous mixes against rutting and cracking. Specimen split when even tensile stress is along a perpendicular diametrical plane and vertical to functional load (Yoder & Witczak, 1975).

(Sengoz & Isikyakar, 2008) investigated modified bitumen with copolymers of SBS and EVA. The findings revealed that the type of polymer used, as well as its content, influenced the shape and characteristics of modified asphalt, as well as the mechanical characteristics of HMA modified with polymer. Samples with low polymer concentration displayed dispersed polymer particles in a continuous bitumen phase, whereas samples with high polymer content revealed a continuous polymer phase. The typical properties of base bitumen, such as softening point, penetration, temperature susceptibility, and so on, were improved through polymer modification. The HMA mechanical properties, such as Marshall Stability created using SBS PMB samples, improved when the percentage of the polymer was increased.

In his comparative performance study, (Ameri, Mansourian, 2013) a variety of EVA modified bitumen and mixes were studied based on three significant flexible pavement distress modes: fatigue damage, low-temperature cracking, and rutting. On modified asphalt mixtures comprising 2 percent, 4 percent, and 6 percent EVA, as well as a combination of asphalt and the original base bitumen, dynamic creep experiments, indirect tensile fatigue tests, indirect tensile strength tests, and creep compliance tests were carried out. When compared to original base bitumen asphalt blends, the inclusion of EVA enhances rutting and fatigue resistance, according to the findings of a dynamic creep test and an indirect tensile fatigue test performed on the EVA-modified asphalt mixtures. When compared to original base bitumen asphalt blends, the low temperature cracking resistance of EVA-modified mixes increased by 4%. EVA-modified bitumen has rutting resistance better than the original base bitumen, according to the results of this experiment. The EVA-modified bitumen is more fatigue-resistant than the base bitumen.

According to (Chegenizadeh et al., 2021) The fatigue and rutting behavior of stone mastic asphalt (SMA) were affected by EVA. Wet methods were used to fuse EVA with the C320 binder, and SMA mixes were created. The amount of EVA used in the study ranged from 2 percent to 6 percent. A wheel rutting test, four-point flexural beam test, flow number test, Schellenberg test, and dynamic modulus test were all performed on the mixtures. In the four-point bending test, the results showed that increasing the amount of EVA enhanced rutting resistance and the cycle to failure.

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The flow number increases as the EVA concentration is increased. By increasing the concentration of EVA bitumen drainage was minimized. By increasing the quantity of EVA in the mix, the phase angle of the mixtures is also reduced. The results of the wheel rutting tests revealed that non-treated SMA blends have a low rutting resistance. Boosted EVA increased rutting resistance, according to the findings. The fatigue life of SMA-EVA treated samples was dramatically improved as compared to non-treated samples. The incorporation of EVA at 6% was found to be the most effective percentage in this investigation for improving fatigue life. In terms of initial flexural stiffness, the same pattern was seen. When comparing non-treated SMA blends to treated SMA blends, the drain-off values decreased but the EVA percentage increased. The addition of the EVA polymer to the mix successfully lowered drain-off rates to less than 2%, according to the findings. Adding EVA to the mix increased the FN cycle values, according to the FN test. The higher the FN number, the better the rutting resistance.

(Dekhli et al., 2015) discussed the impacts of EVA on the traditional properties and rheological properties of virgin bitumen. The results showed that polymer modification improved the base bitumen's traditional qualities such as penetration, softening, and temperature susceptibility. UV fluorescence microscopy was used to study the variation in PMB morphology as a function of polymer concentration. The findings reveal that when polymer concentration increases, rheological models may accurately replicate the effect of polymer modifications by raising initial modulus and decreasing relaxation time and phase angle.

(Janmohammadi et al., 2020) tested the asphalt performance of mixes made with EVA modified bitumen containing various concentrations of glass fibers in a laboratory setting. According to the findings, adding 5 percent EVA and 0.3 percent glass fiber to the Marshall Stability increased it by around 25% and 20%, respectively. It was also revealed that combining the two compounds increased Marshall Stability more than doing so independently. The resilient modulus, on the other hand, revealed that At two different temperatures of 25 and 40 °C, increasing the amount of EVA and glass fiber in the asphalt mix individually and simultaneously improved the resilient modulus. However, as the temperature rose, the resilience modulus of the asphalt mix decreased. In comparison to the control sample, adding 3% EVA to the asphalt mix reinforced with 0.3 percent glass fiber increased Marshall Stability. According to the findings, the sample with 3 percent EVA and 3 percent glass fiber has the highest Marshall Stability, which is equal to 1210 kg. The increasing viscosity of bitumen and the armament of the asphalt mix are the causes. As the polymer concentration rises, the flow of EVA polymer-containing samples becomes more erratic.

(Aljanadi, 2020) investigated that in hot and arid climates, the potential of employing EVA as a modification of HMA for use as a flexible pavement preservation material. The strength and durability of asphalt that has been treated with EVA at different percentages, namely 2 %, 4 %, 6 %, 8 %, and 10 %, were investigated. Indirect Tensile Strength Test (ITS) at various temperatures, Marshall Stability Test at 20°C, 40°C, and 60°C, and unconfined Compressive Strength Test (UCS) (45°C) were all performed. The results showed that as the EVA modifier was increased,

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marshal stability and Marshal Quotient increased. When the EVA modifier is increased, however, Marshal Flow decreases. With an increase in the EVA modifier, all values of UCS and ITS rose. Because EVA is temperature tolerant and may avoid asphalt cracking, it could be utilized as an aggregate alternative for flexible HMA in hot and arid climates. According to the results of ITS and UCS testing, Hot Mix Asphalt amended with a 4% EVA mixture performed best at all temperatures. When compared to HMA unaltered with Ethylene-Vinyl-Acetate (EVA) mixes, HMA modified mixtures were more responsive to temperature fluctuations. Temperature influences the ITS; when the temperature rises, the ITS decreases. EVA composition has also an impact on the ITS and UCS.

IV. Research Methodology

Coarse and fine aggregates from Khattar quarry were used, as well as penetration grade 60/70 bitumen obtained from Pak Arab Refinery Limited (PARCO). Ethylene Vinyl Acetate polymer of TPI Polene Public Company Limited was used. Mandatory testing on the used aggregates and asphalt binder was completed in a manner that was consistent with ASTM and AASHTO standards and specifications for material characterization. Conventional bitumen tests were employed using various EVA percentages. OBC was determined using different percentages of asphalt binder by weight of aggregates using Marshall mix design. Performance tests including rut resistance and moisture susceptibility were evaluated using 0%, 2%, 4%, 6% of EVA content and OBC. The properties of EVA used are shown in table 1.

Table 1: EVA Properties

Properties	Test Method	Unit	Typical Value
Melt Flow Index (2.16 kg / 190°C)	ASTM D1238	g/10 minutes	3.0
VA Content	TPIPL Method	%	18
Density	ASTM D1505	g/cm ³	0.941
Vicat Softening Temperature	ASTM D1525	°C	62
Melting Temperature	ASTM D638	°C	86
Tensile Strength at Yield	ASTM D638	MPa	4.5
Tensile Strength at Break	ASTM D638	MPa	24
Ultimate Elongation	ASTM D638	%	820
Hardness Shore D	DIN 53505	-	28

Aggregate Tests

The center element of the mix is the aggregate skeleton, which gives continuous deformation resistance and is expected to give a strong skeleton for resisting repetitive loads. To determine the aggregate fundamental features of each stockpile, such as thorough gradation and specific gravity laboratory experiments were conducted. Results of aggregate tests are shown in Table 2.

Table 2: Aggregate Tests

Test	Specification		Result	Limits
Flakiness Index	ASTM D 4791		15%	≤15%
Elongation Index	ASTM D 4791		2.3%	≤15%
Aggregate Absorption	Fine	ASTM C127	0.6%	≤3%
	Coarse		0.9%	≤3%
Impact Value	BS 812		19%	≤30%
Specific Gravity	Fine Agg	ASTM C128	2.58	-
	Coarse Agg	ASTM C127	2.63	-
LOS Angles Abrasion	ASTM C131		21%	≤45%

Modified binder tests

Consistency, safety, and purity are the three properties of binder which are essential to be considered. The consistency of the asphalt binder changes as the temperature changes. As a result, for testing asphalt binder consistency, a standard temperature is required. The softening point, penetration, and ductility tests were performed on virgin and EVA modified binder. With increasing, EVA content penetration and ductility value decreased while softening point increased. Various results of binder testing are shown in table 3.

Table 3: Asphalt binder Tests

% Of EVA in bitumen	Penetration Value	Softening point	Ductility
0	66	51	119
2	64	53	105
4	61	55	100
6	54	58	80

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Gradation Selection

The aggregate gradation employed was NHA class B. According to Marshal Mix Design, for class B wearing coarse gradation, the nominal maximum aggregate size was 19 mm (MS2). Table 4 displays the selected gradation, and Figure 1 shows the gradation plotted against percentage passing and sieve sizes.

Table 4 : Gradation

S. No	Sieve Size mm	NHA Specification Range (% Passing)	Mid gradation Selected (% Passing)	% Retained
1	19	100	100	0
2	12.5	75-90	82.5	17.50
3	9.5	60-80	70	12.50
4	4.75	40-60	50	20
5	2.38	20-40	30	20
6	1.18	5-15	10	20
7	0.075	3-8	5.5	4.50
8	Pan	-	-	5.50

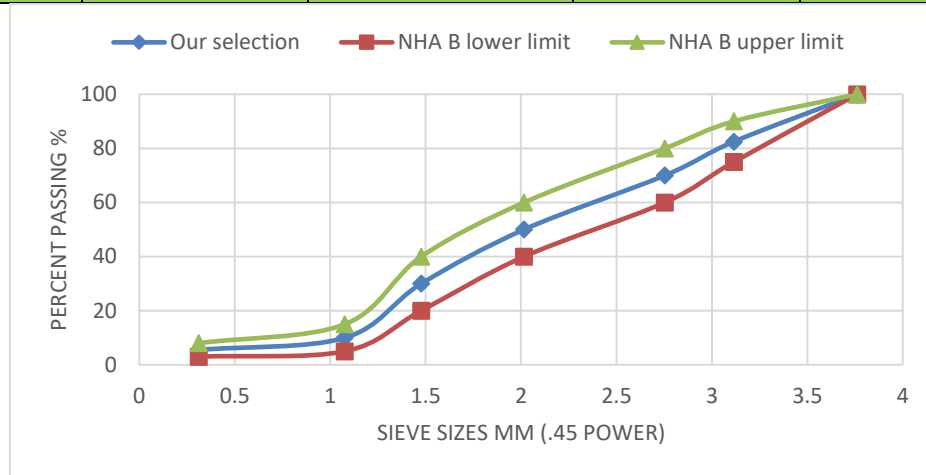


Fig 1. Gradation Plot

Determination of OBC from Marshall Mix Design samples

Samples were prepared using different percentages of bitumen by weight of aggregate. A total of 15 samples were prepared, using percentages (3.5%, 4%, 4.5%, 5%, 5.5%). 3 samples were prepared for each percentage. These samples were tested for Marshall stability, flow, and volumetric properties to determine OBC for the mix. Volumetric properties of the mix are shown in table 5 while OBC was determined using the graphs shown below in Figure 2-6.

Table 5: Volumetric Properties

Volumetric Properties of Mix									
S.No	Binder %	Flow (mm)	Stability (KN)	G _{mb}	G _{mm}	Air (VA)	Voids	VMA	VFA
1	3.5%	2.21	10.72	2.24	2.47	6.72		15.42	48.62
2	4.0%	2.52	12.61	2.27	2.45	5.32		15.26	53.72
3	4.5%	2.8	13.15	2.31	2.44	4.42		14.85	64.23
4	5.0%	3.3	12.82	2.35	2.42	3.48		14.62	71.57
5	5.5%	3.8	11.56	2.39	2.41	2.68		15.16	75.25

The graphs relating volumetric qualities and asphalt contents, flow, and stability were drawn according to the MS-2 handbook to determine the OBC of virgin mix, as shown in Figures below.

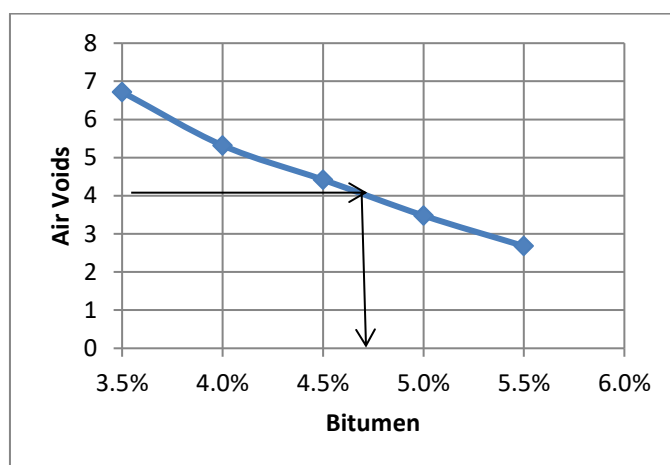


Fig 2. Bitumen vs VA

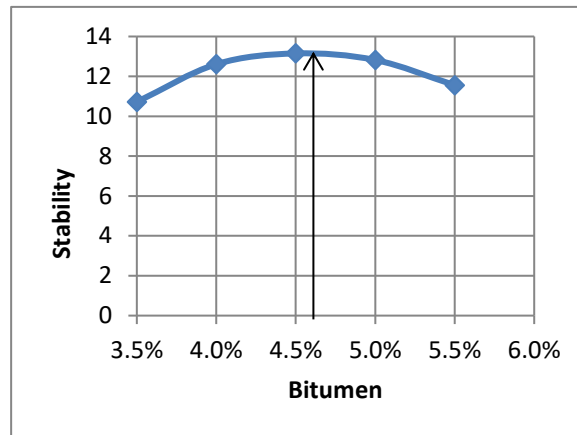


Fig 3. Bitumen vs VMA

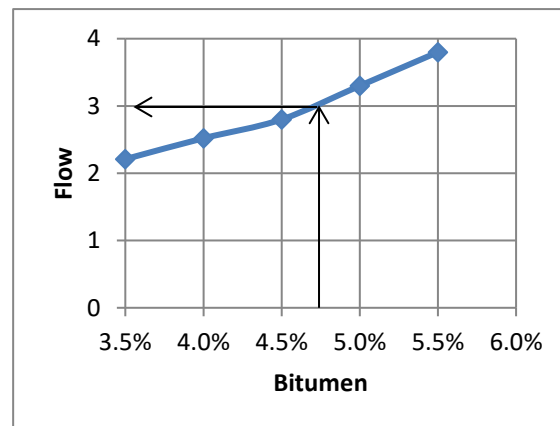


Fig 4. Bitumen vs Flow

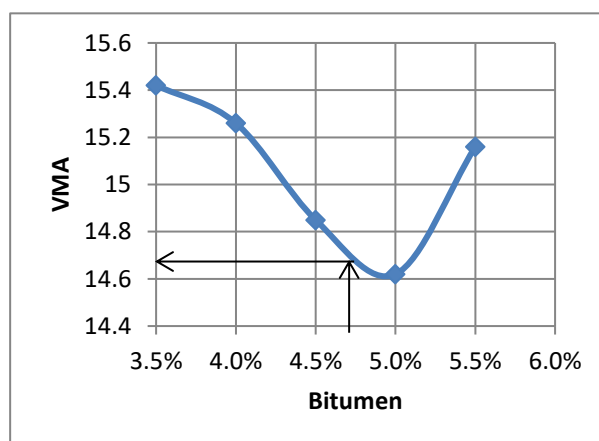


Fig 5. Bitumen vs Flow

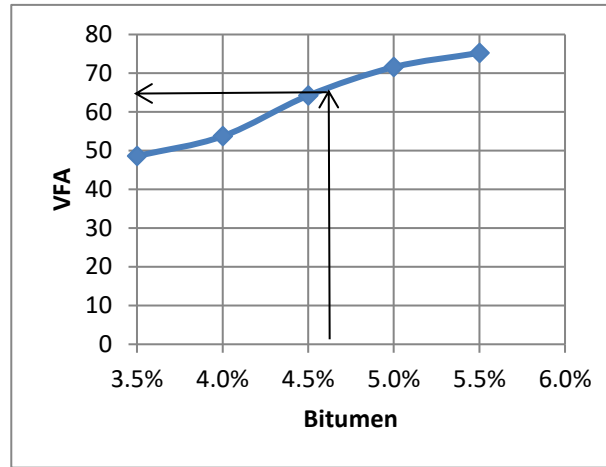


Fig 6. Bitumen vs VFA

The asphalt content at 4% Air void is called OBC. The mix has an OBC of 4.72%. The mix characteristics, flow, and stability according to OBC were determined from the graphs. Table 6 shows the job mix formula of the virgin mixture. It is clear from the table that all the characteristics, meeting the criteria for stability and flow. The VMA should not be less than 13% and its value was 14.68% from calculations of this study. VFA should be between 65 and 75 percent, and its computed value was 67 %. According to the standards, the stability value should not be less than 8.006 KN, yet it was 12.9 KN in this situation. The measured flow number was 3.1 mm, which is within the acceptable limit.

Table 6 : Job Mix Formula

Parameters	Value Measured	Limits	Remarks
OBC	4.72	-	-
VMA (%)	14.68	≥ 13	Pass
VFA (%)	68	65-75	Pass
Stability (KN)	13	≥ 8.006	Pass
Flow (mm)	3	2-3.5	Pass

V. Results and Analysis

Rutting Test Results

Rutting samples were prepared according to ASTM D6925-15. Samples of 2.5 inches height and 6 inches diameter were prepared using a gyratory compactor. These specimens were evaluated using a Double wheel tracker to determine their resistance to persistent deformation to investigate rutting propensity. The DWT is an electrically powered device that can move a steel wheel with a diameter of 203.2mm

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and a width of 47mm across a test specimen. The weight on the steel wheel is 1581.0 lbs, and the average contact stress produced by the wheel contact is 0.73 MPa with a contact area of 970 mm². The wheel's speed was set to 60 ppm (passes per minute). The number of passes was set to 10,000 (5000 cycles) as required for determining the rutting potential of asphalt mixtures including grade 58 bitumen (PARCO 60/70). The wheel tracker was used by selecting a dry mode for the determination of moisture damage at 40°C temperature. Finally, the test was run, and the wheel started moving forward and backward on the mounted specimen. The number of passes was shown on the laptop connected with the machine. One complete to and fro movement of the wheel was taken as 2 passes. The LVDT (Linear Variable Differential Transformer) measures the impression of a rut in millimeters of the unit at the same time with the motion of the wheel. The machine automatically stopped when the required number of passes were achieved. The results of the DWT test are shown in table 7.

Table 7 : DWT Test Results

No. of cycles	Rut Depth (mm) for unmodified HMA	Rut Depth (mm) for HMA modified with 2% EVA	Rut Depth (mm) for HMA modified with 4% EVA	Rut Depth(mm) for HMA modified with 6% EVA
0	0	0	0	0
1000	2.26	2.04	1.98	1.79
2000	2.58	2.33	2.22	2.04
3000	3.14	2.86	2.57	2.31
4000	3.67	3.29	2.99	2.78
5000	4.02	3.72	3.45	3.16

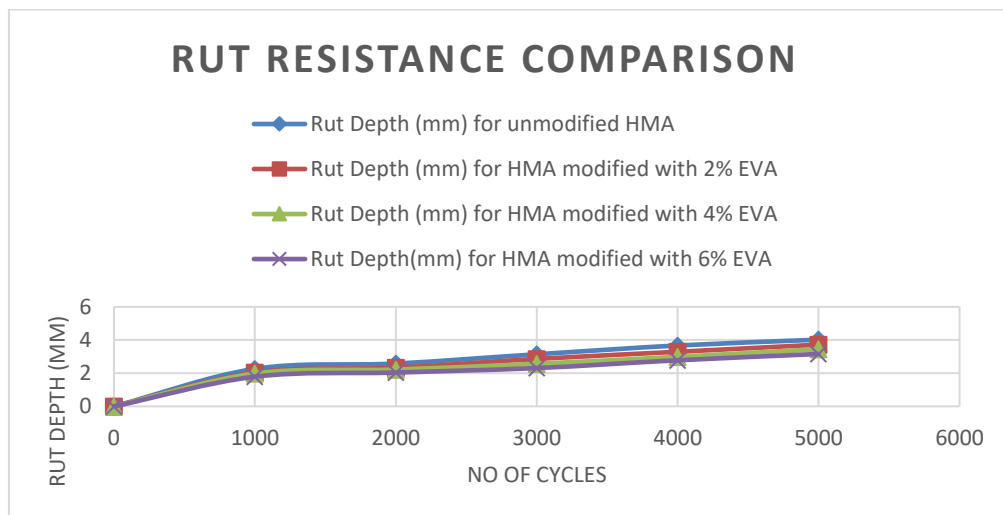


Fig 7. Rut Depth (mm) for a total of 5000 cycles

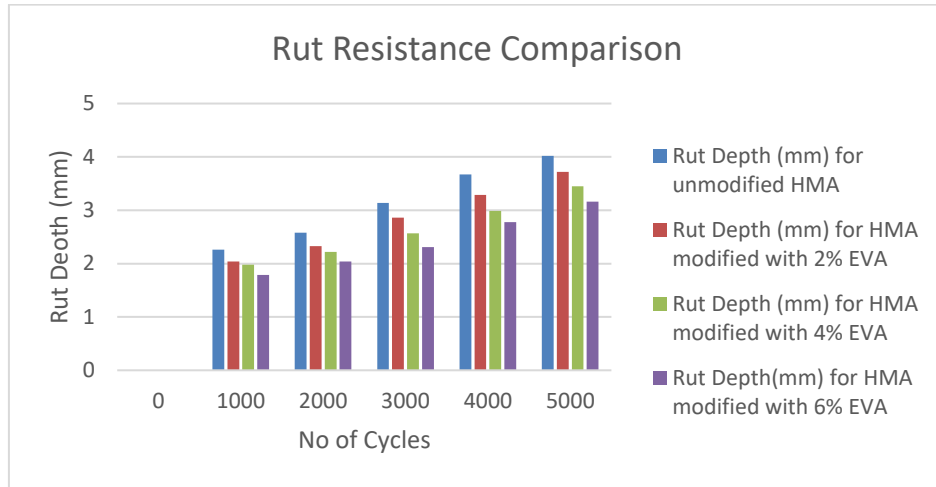


Fig 8. Rut Resistance Comparison

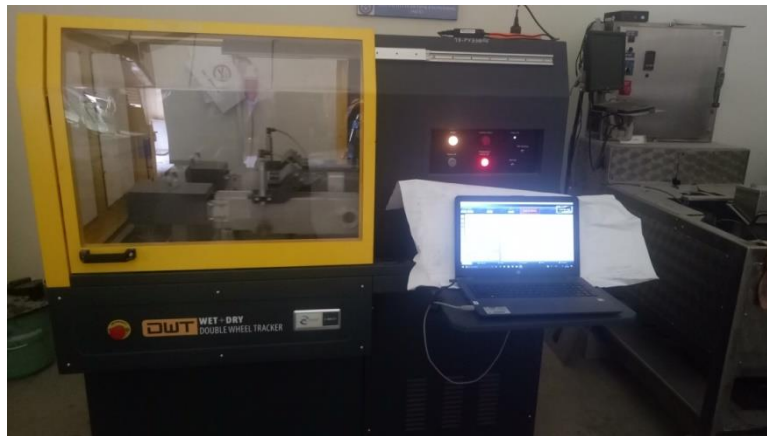


Fig. 9. Double Wheel Tracker Machine

Moisture Induced Damage (ITS) Test Results

According to ASTM D 6931-07, the moisture susceptibility test was performed. Three unconditioned specimens per mix were tested. One hour before testing, these unconditioned specimens were kept in a water bath at 25°C. Conditioned specimens were tested in a separate batch of three per mix. Samples were saturated and were placed in a water bath at 60°C for 24 hours, followed by one hour in a water bath at 25°C according to ALDOT-361. Both unconditioned and conditioned specimens were loaded diametrically at a rate of 50 mm/minute. For each specimen, the tensile strength was then calculated using specimen dimensions and failure load. The tensile strength ratios were calculated by dividing the average conditioned tensile strength by the average unconditioned tensile strength. The acceptable value for the tensile strength ratio employed was 80% (minimum). The TSR, which is the ratio of the conditioned subset's tensile strength to that of the unconditioned subset, indicates the possibility of moisture damage.

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Table 8:b ITS & TSR Results

EVA (%)	Conditioned strength (KPA)	Unconditioned strength (KPA)	TSR Value
0	722.94	758.52	95.3
2	740.47	778.66	95.09
4	757.57	799.06	94.8
6	768.11	814.82	94.2

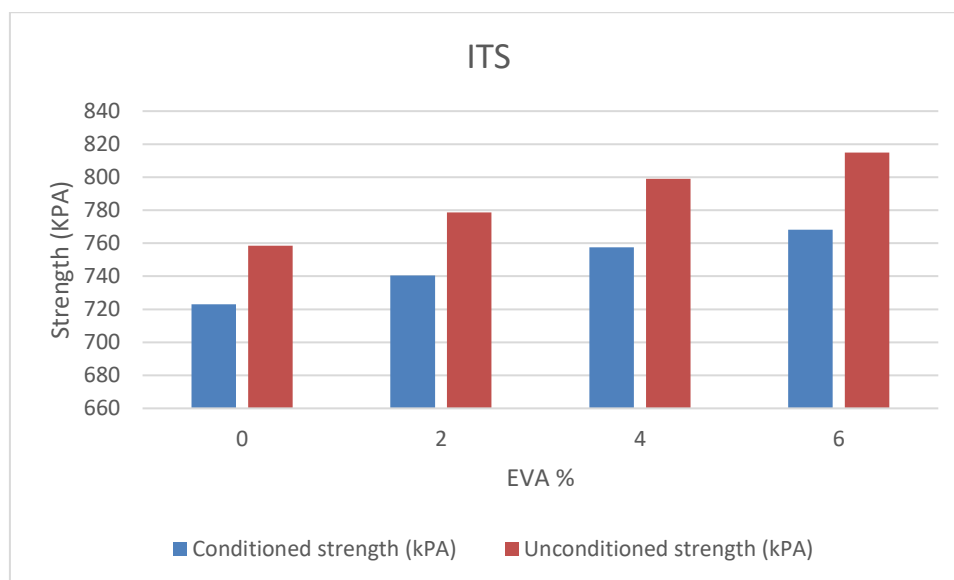


Fig 10. ITS Results for conditioned & unconditioned samples

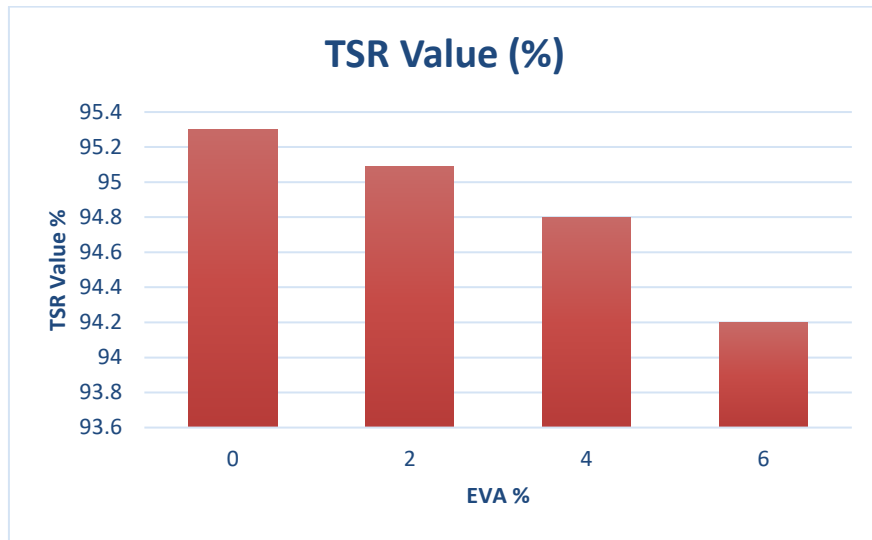


Fig 11. TSR Results for Moisture Susceptibility

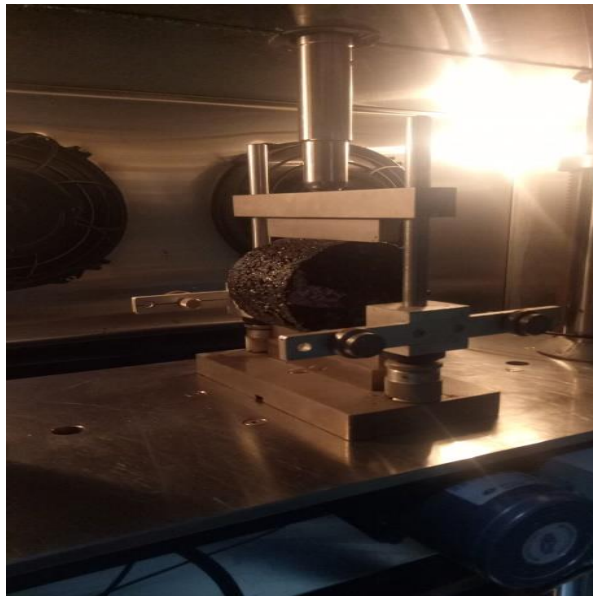


Fig 2. Universal Testing Machine for ITS Tests

VI. Conclusion

Conclusions of research based on the results are as follows:

- Penetration grade of bitumen 60/70 decreased by the addition of EVA thus making it hard and stiff. The softening point of bitumen 60/70 increased by the addition of EVA while ductility of bitumen 60/70 decreased by the addition of EVA.

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- By performing asphalt binder penetration tests and ductility tests on different EVA contents concerning virgin bitumen with the value of EVA content as 4% of the virgin bitumen shows that 4% EVA won't change the binder grade and other properties.
- A criterion for Optimum Bitumen Content was set at 4% air voids and OBC calculated was 4.72%. Other properties were also well within their ranges.
- Samples prepared using a gyratory compactor having EVA modified asphalt binder for rutting susceptibility testing show better rutting resistance than the samples prepared with conventional asphalt binder.
- A rut resistance increases of 14% was observed by using EVA polymer-modified bitumen as compared to unmodified bitumen prepared samples.
- The results of ITS values for samples with EVA modified asphalt binder reveal that the strength values have increased because of the mix having more viscous material performing better under tension, but moisture susceptibility (TSR) value shows a slight decrease but still above the limit.
- By considering all the factors we can use EVA as a replacement of virgin bitumen in HMA.

VII. Acknowledgement

The researchers acknowledge that this is merely a technical paper for experimental testing EVA on moisture damage and rutting susceptibility of HMA. This study does not result in the creation of a specification, standard, or regulation.

Conflict of Interest:

The authors declare that no conflict of interest to report the present study.

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