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EVALUATION OF BITUMINOUS MIXES WITH EPOXY-MODIFIED ASPHALT BINDERS

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Abstract

Road surfaces have long been made with bituminous mix because of its low cost and versatile applications. However, environmental variables, traffic loads, and ageing frequently affect its endurance. Many additives have been introduced to overcome these problems, and epoxy resin has shown great promise. This study evaluates bituminous binder and bituminous mixes with different percentages of epoxy modification. Epoxy asphalt binder's (EAB) rheological properties were described. Following that, an evaluation was conducted on the engineering properties of an epoxy asphalt mixture (EAM). The results demonstrated that the rheological properties of EAB outperform those of neat binders. Furthermore, the outcomes demonstrated that EAM had better moisture damage performance in terms of static immersion test and retained Marshall stability test than the conventional hot dense graded bituminous mixes. According to the results, the ideal content for both VG 30 and VG 40 binders is 2% epoxy modification. Out of all the mix permutations, bituminous mixes with 2% epoxy modification yielded the best results. Comparing blends with control mixes or unmodified bituminous mixes, on the other hand, revealed a lower resistance to moisture damage than mixes with 3% epoxy modification with both binders. The study concludes that epoxy resin can significantly improve the performance and longevity of asphalt concrete roadways, offering benefits to the road construction industry.

Keywords: *Sustainable pavement; Bituminous Mix, Epoxy Modified Asphalt, Rheology; Marshall Stability.*

I. Introduction

Hot mix asphalt (HMA) pavements can function better when modifiers or additives are used to treat different types of distress, such as fatigue, low-temperature cracks, permanent deformation, and moisture damage. As binder modifiers, a variety of chemicals can be added directly to the bitumen (asphalt binder) (Roque et al., 2005; Bahmani et al., 2021). Polymers are among the most commonly used among them for bitumen alteration. By interacting chemically or at molecule level with the binder, a carefully chosen polymer is added to the bitumen to form a new supporting system or secondary network. The correct dispersion of the polymer inside the bitumen is essential for the effective development of a functional modified bitumen system, and the bitumen's chemical composition is a major determinant of this (Isacsson and Lu, 1995).

Epoxy resin is one of the polymers gaining attention from researchers for enhancing bitumen properties. Bitumen and epoxy resin are combined with a curing agent to create bitumen modified with epoxy (Bocci et al., 2015). Prominent characteristics of this modification process include resistance against fatigue, low-temperature crack resistance, high-temperature stability, and increased durability (Yu et al. 2009; Cong et al. 2011a,b; Modarres and Hamedi, 2014; Zhou et al., 2017). Additionally, it is advised to utilize modified bitumen to mitigate problems with asphalt concrete, such as rutting, bleeding, cracking, stripping, and ageing (Cubuk et al., 2009). According to Fuhaid et al. (2018), adding more epoxy to a bituminous mix did not significantly affect its Marshall stability, but it did raise the sample's flow value. El Rahman et al. (2012), however, found that the Marshall stability improved with the amount of epoxy material used. As a result, the Marshall properties and volumetric characteristics of the mix may be affected differently by different types of resins. Additionally, a key factor in the Marshall stability of epoxy-asphalt mix is the interlocking of aggregate particles (Huang et al., 2011). To fully understand the impact of the kind, content, and interaction of epoxy resin with aggregate particles, more research is needed. Additionally, the Marshall stability, flow, and other mix properties may be impacted by the epoxy asphalt-modified production process.

The objective of this study was to evaluate the feasibility of bituminous mix properties when employing asphalt binders modified with epoxy. After testing to ascertain the penetration, softening point, and ductility of epoxy asphalt binder, tests were conducted to evaluate bituminous mixes' resistance to moisture damage.

II. Experimental Program

Materials

The aggregates utilized in the study were sourced from the Tapanga stone crusher site in Khordha. The aggregates were found to meet the necessary physical requirements. The results of various physical tests conducted on the aggregates are presented in Table 1. For the construction of wearing courses on Indian highways, viscosity-grade binders are commonly employed. In this study, viscosity grade 30 (VG 30) and viscosity grade 40 (VG 40) binders were used. These binders were supplied by Tikitar Industries (Gujarat). The physical properties and their corresponding requirements for VG 30 and VG 40 binders, as per the specifications outlined in IS 73-2006, are summarized in Table 2.

Table 1: Physical properties of aggregates

Name of test	Test results	Acceptance limits
Aggregate crushing value %	21.1	30% max (IS: 2386 Part IV)
Aggregate impact value %	20.7	24% max (IS: 2386 Part IV)
Flakiness and Elongation index (combined)	33.8	35% max (IS: 2386 Part I)
The specific gravity of coarse aggregate	2.80	2.5-3.0 (IS: 2386 Part III)
The specific gravity of fine aggregate	2.87	2.5-3.0 (IS: 2386 Part III)
Water absorption of coarse aggregate %	0.2	2% max (IS: 2386 Part III)

Table 2: Properties of asphalt binders

Test Property	Result of VG 30	Result of VG 40	Specification for VG 30	Specification for VG 40	Test method
Softening point	49	51.7	> 45	> 50	IS:1205
Penetration at 25 °C	60.8	37.4	> 45	> 35	IS:1203
Ductility @25 °C	60.5	71	> 40	> 25	IS:1208
Absolute Viscosity @60 °C	2989	4102	2400 to 3600	3200 to 4800	IS:1206(PART 2)
Kinematic Viscosity @135 °C	516.0	627.0	> 350	> 400	IS:1206 (Part 3)
Flashpoint, °C	321	315	> 220	> 220	IS:1448 (Part 69)
Solubility in Trichloroethylene, %	99.68	99.55	> 99	> 99	IS:1216
Viscosity Ratio @60 °C	3.22	3.45	< 4	< 4	IS:1206 (Part 2)

Epoxy resin is a type of polymer that needs a hardener added to it to improve its qualities. Curing is the process of mixing an epoxy resin with a hardener. During this process, the hardener and epoxy resin undergo reactions to achieve a fully cured state. The duration required for curing, referred to as curing time, depends on specific conditions and determines when the reactions between the hardener and epoxy resin are complete. In this particular study, bisphenol-A diglycidyl ether (also known as YD-128), an epoxy resin produced by Balaji Enterprises in Delhi, was utilized. The hardener employed in the study was cycloaliphatic amine, also produced by the same company and commercially known as KH-816.

Design of Bituminous Concrete (BC) Mixes

In Indian highway construction, the dense-graded bituminous concrete (BC) serves as the commonly employed surface layer. Figure 1 illustrates BC-Grading 2 (13.2 mm nominal maximum aggregate size NMAS), the selected aggregate gradation for bituminous mix design, which aligns with the specifications detailed in the Ministry of Road Transport and Highways (MoRTH) 2013 guidelines. For the formulation of bituminous mixes, the Marshall method is utilized as the mix design procedure. This method is executed in strict compliance with the stipulations outlined in MoRTH-2013, IRC 111: 2009, and MS-2 guidelines.

The mix specimens were prepared by adjusting the binder content in increments of 0.5%, ranging from 5.0% to 6.5% of the total mixture's weight. To establish the optimum binder content (OBC) for the control mix, which did not incorporate epoxy modification, the process involved determining the mixing and compaction temperatures for VG 30 and VG 40 grade binders. These temperatures were ascertained as per the guidelines outlined in MS-2, resulting in respective values of 160ºC and 150ºC for VG 30 binder, and 165ºC and 160ºC for VG 40 binder.

For each specified binder content, a set of three samples was prepared. Post-mixing, the samples underwent a 2-hour conditioning period in a forced air-draft oven at the compaction temperature. Following this, the specimens were compacted by applying 75 blows on each side of the sample. The compacted specimens were subsequently subjected to a battery of tests to assess their volumetric characteristics, including voids in mineral aggregate (VMA), voids filled with bitumen (VFB), air void content (AV), as well as Marshall stability and flow.

The calculation of the OBC adhered to the methodology specified by the National Asphalt Paving Association (NAPA), targeting an air void content of 4%. This air void content aligns with the average range of 3-5% delineated in the Asphalt Institute Manual Series-2 Specifications.

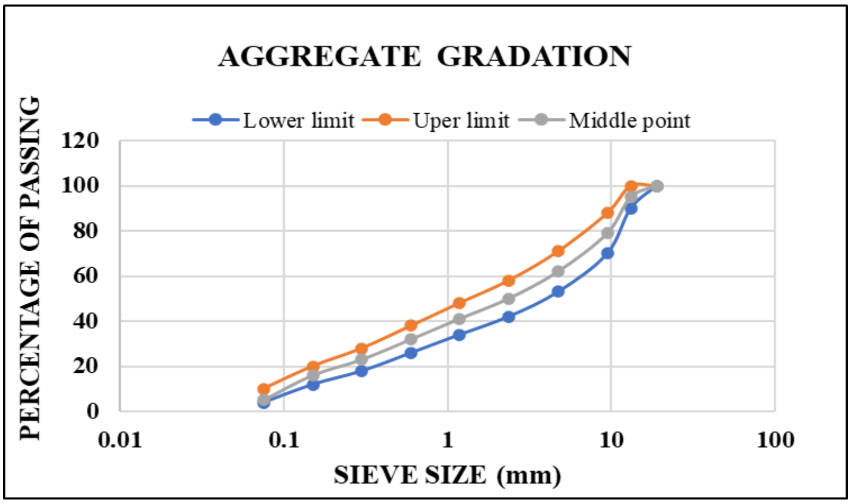

Fig. 1. Aggregate gradation used for BC mixes

Preparation of Epoxy Modified Bitumen

To modify the base bitumen, various percentages of epoxy resin, specifically 1%, 2%, and 3% by the weight of the neat binder were added. The process began by heating the base asphalt until it reached a fluid state. The heated base asphalt was then carefully poured into a 1000 mL container. A specific quantity of hardener was added to the base asphalt, and the mixture was thoroughly blended for 10 minutes at a speed of 1500 rpm and a temperature of 130 °C. After that, the bitumen mixture including the hardener was mixed with epoxy resin at the required weight percentage. The combined blend underwent an additional 10-minute mixing process at 1500 rpm while maintaining the temperature at 130 °C. Following the mixing process, the modified bitumen samples were allowed to cure and harden for one day at 25 °C, after which they were stored at 110 °C for an hour. This curing and hardening process was essential for achieving the desired properties and characteristics of the modified bitumen. Figure 2 shows the bitumen modification process.

Fig. 2. Preparation process of epoxy-modified asphalt

III. Results and Discussion

Properties of Epoxy-Modified Asphalt

To assess the physical properties of the epoxy-modified asphalt binder, penetration, softening point, and ductility tests were conducted on VG 30 and VG 40 binders with varying percentages (0%, 1%, 2%, and 3%) of epoxy modification. The variations in penetration value, softening point value, and ductility values are illustrated in Figures 3, 4, and 5, respectively. The results are the averages of three determinations.

Comparing the results to the control binder (without epoxy modification), an increase in the percentage of epoxy content in the bitumen modification led to reduced penetration, increased softening point, and ductility values. Notably, it was observed that a 2% dosage of epoxy had the greatest effect in enhancing the stiffness of the bitumen. However, the effectiveness of the epoxy dosage diminished at the higher 3% dosage. This trend was consistent for both VG 30 and VG 40 binders. In summary, the addition of epoxy modification resulted in improved properties of the bituminous binder, as indicated by the penetration, softening point, and ductility values. The dosage of 2% epoxy content had the most significant impact on enhancing the stiffness of the bitumen, while a dosage of 3% showed slightly reduced effectiveness. This trend was observed for both VG 30 and VG 40 binders.

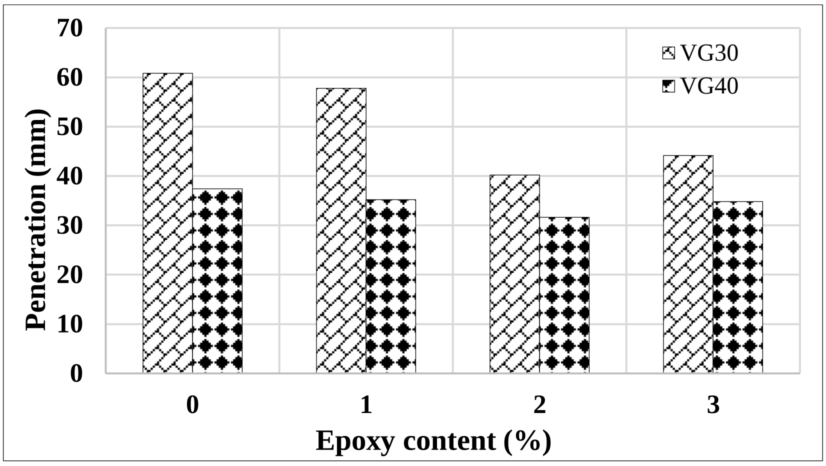

Fig. 3. Penetration values of control and epoxy-modified binder

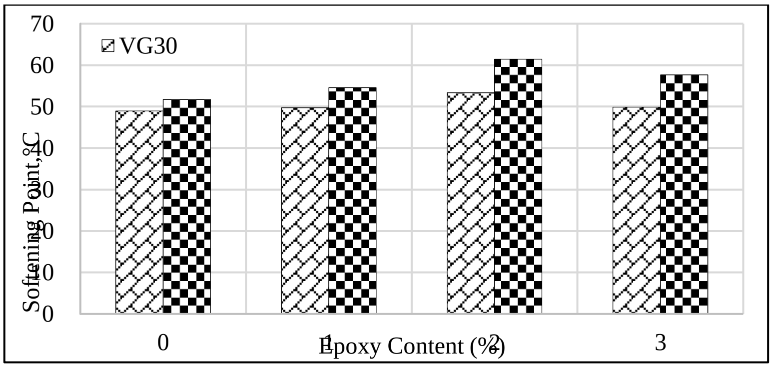

Fig. 4. Softening point values of control and epoxy-modified binder

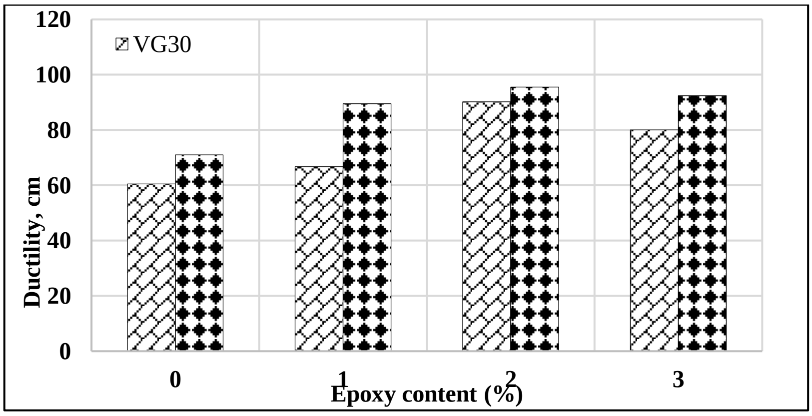

Fig. 5. Ductility values of control and epoxy-modified binder

Optimum Bitumen Content (OBC) Determination

The OBC was determined following the guidelines provided by the National Asphalt Paving Association (NAPA) to achieve a target air void content of 4%. This target air void content aligns with the average range of 3-5% specified in the Asphalt Institute Manual Series-2 Specifications.

For the VG 30 binder, the OBC based on the target air void content of 4% was calculated as 5.6%. Similarly, for the VG 40 binder, the OBC was determined as 5.5%. The mix specimens prepared at the respective OBCs were then evaluated for the required Marshall parameters, including VMA, VFB, stability, and flow. It was found that these values satisfied the necessary criteria. Table 4 displays the Marshall parameters at the OBC and the requirements that go along with them, as stated in the MoRTH-2013 specifications for BC mixes. The same bitumen contents were also used to prepare the epoxy-modified mixtures to mobilize the experimental variable as epoxy content and not bitumen content.

Table 3: Marshall and volumetric parameters of control mix at OBC

Parameters	Requirements	Results of VG 30	Results of VG 40
Stability (kN)	Min 9	28.2	22.9
Flow (mm)	2–4	3.45	2.94
Air voids (%)	3–5	4	4
Voids in mineral aggregate (%)	Min 14	15.8	15.6
Voids filled with bitumen (%)	65–75	74.7	74.3
Bulk density (g/cc)	-	2.476	2.483

Moisture Susceptibility of Epoxy-Modified Bituminous Mixes

Moisture susceptibility refers to the vulnerability of materials used in infrastructure to damage or degradation caused by the presence of water or moisture (Pattanaik et al., 2018; Bahmani et al., 2022). It is a complex phenomenon that can lead to significant structural problems, reduced lifespan, and increased maintenance costs. One of the objectives of this study was to evaluate bituminous mixes treated with epoxy about their moisture susceptibility. The mixes were prepared at the OBC with varying percentages of epoxy. Two binders, VG 30 and VG 40, were used. The evaluation of moisture susceptibility was conducted using three different test methods or approaches: (1) static immersion test, (2) retained Marshall stability (RMS) test, and (3) modified boiling water test. These methods were employed to determine the resistance of the epoxy-modified bituminous mixes to moisture-induced distress. The RMS test evaluated the resistance of asphalt mixes to moisture damage based on a reduction in stability, while the static immersion test assessed the performance of the mixes when submerged in water, and the modified boiling water test examined their response under boiling water conditions.

Static Immersion Test

In India and other nations, the static immersion test is frequently used to evaluate the adhesion characteristics and quantify the degree of aggregate stripping in bituminous mixtures. When aggregate particles are exposed to water, the bitumen coating separates off them; this process is known as "aggregate stripping," and it can be used as a surrogate for the strength of the aggregate-binder relationship. Since bituminous mixes are constantly exposed to water, it is imperative to ascertain how water presence affects the adherence of binders modified with epoxy. The static immersion test was conducted to evaluate the performance and durability of the bitumen mix when exposed to water. The test aimed to assess water absorption and potential degradation of the bitumen mix over a specific period. In accordance with the requirements specified by the Indian Standard, static immersion tests were performed as a visual inspection to determine the extent of binder stripping from the aggregate. Viscosity-graded bitumen and about 200g of aggregate were used to create bituminous mixtures. All possible combinations of mixes with varying epoxy concentrations (0%, 1%, 2%, and 3%), as well as two types of viscosity-graded binders (VG 30 and VG 40), were produced. The mixes were transferred to 500 mL beakers and covered with distilled water once they had reached room temperature. After that, the beakers were submerged in a water bath that was kept at 40°C for a full day, making sure that the water level in the bath reached at least halfway up the beaker's height. The beakers were taken out of the water bath and let to cool to room temperature after a full day. The specimens were left in the aggregate to visually assess the level of stripping. The stripping value of the aggregate is defined as the proportion of the uncovered area to the total area of aggregates observed visually, expressed as a percentage. In Indian specifications, a stripping value of 5% or less is considered acceptable.

The results of the static immersion test indicated that all epoxy-modified mixes, including the control mixes, exhibited no significant stripping. This suggests that the adhesion between the aggregate and binder was not compromised. Figure 6 illustrates the results of the stripping tests for both the control mixes and the 3% epoxy-modified bituminous mixes with viscosity-graded binders. The visual inspection indicated that the adhesion between the aggregate and binder was maintained, with no noticeable stripping observed.

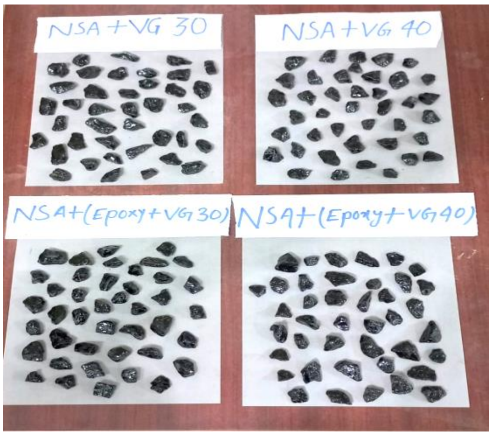

Fig. 6. Stripping determination through static immersion test

Modified Boiling Water Test

The modified boiling water test was conducted to assess the performance and durability of a bitumen mix under exposure to high temperatures using boiling water. To investigate the impact of boiling water on the bond between aggregate and epoxy-modified asphalt binder, a modified boiling water test was used. Figure 7 shows how the increase in epoxy content in both viscosity-graded binders affected the adhesive damage percentage as assessed by the modified boiling test. With a rise in epoxy content alteration, it was found that the percentage of adhesive damage or peeling progressively lowered. The results show that adding more epoxy to bituminous mixes improves their ability to resist moisture. The adhesive damage by immersion should not be more than 5%. All the results were within this range. The results indicate the epoxy modification shows a good effect on adhesive damage.

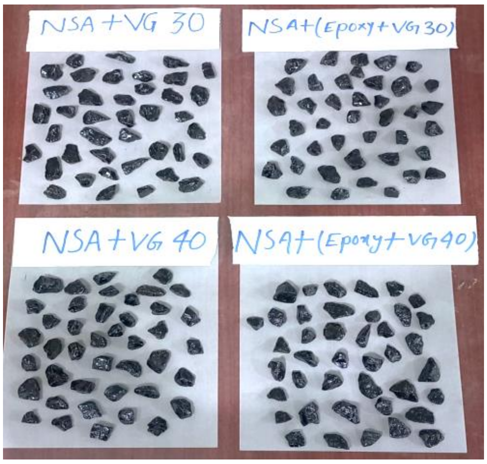

Fig. 7: Stripping determination through boiling water test

Retained Marshall Stability

The retained Marshall stability of epoxy-modified VG 30 and VG 40 mixes are shown in Fig 8 and Fig 9 respectively. The results indicate that with an increase in epoxy percent, the stability also increases till 2% of addition and decreases slightly with the addition of a higher dose of 3%.

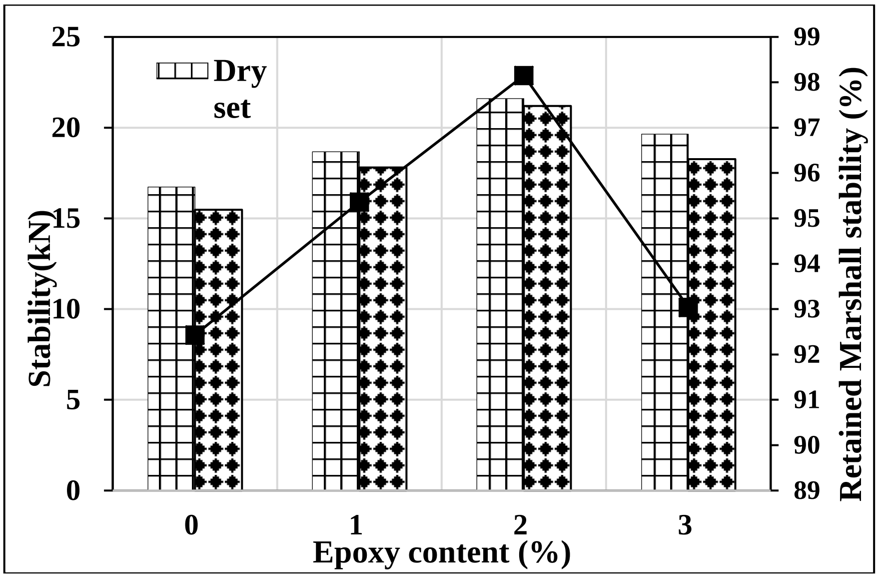

Fig. 8. Retained Marshall Stability of Epoxy modified VG 30 bituminous mixes.

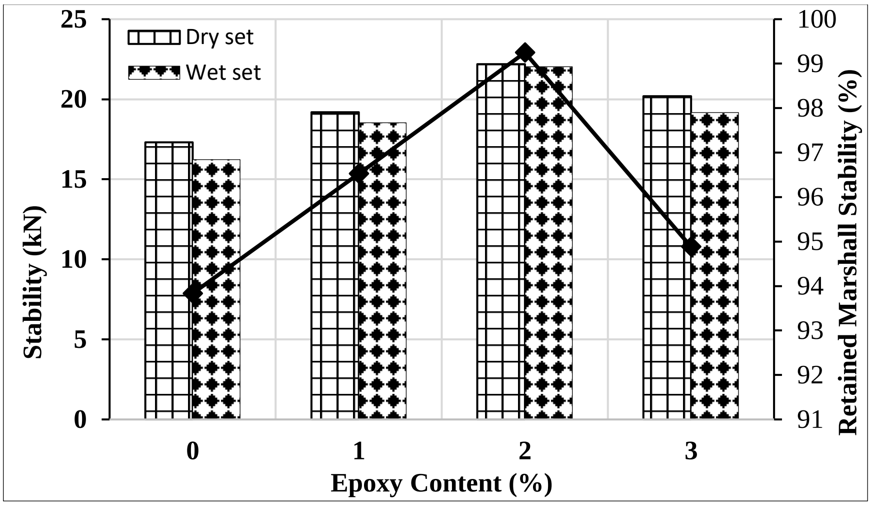

Fig. 9. Retained Marshall Stability of Epoxy modified VG 40 bituminous mixes.

IV. Conclusions

The primary goal of this research was to examine how bitumen treated with epoxy resin affects binders' physical characteristics and asphalt mixtures' susceptibility to moisture. For this investigation, eight combinations of bitumen samples were chosen, including one kind of aggregate, two base bitumen (VG 30 and VG 40), and bitumen treated with 1% to 3% epoxy resins. The study's conclusions are:

- In comparison to the control binder, an increase in the percentage of epoxy content in bitumen modification improved the physical parameters in terms of penetration, softening point and ductility value. Bitumen with 2% epoxy modification presented the best results among all the combinations. However, binders with 3% epoxy modification with both binders showed improved properties compared to those with control/ unmodified bitumen.

- Bituminous mixes containing both the base binder VG 30 and VG 40 were able to meet all bituminous mix design criteria in terms of voids in mineral aggregate (VMA), voids filled with bitumen (VFB), Marshall stability, and flow.
- By comparing the percentage of modified epoxy content to control bituminous mixes, the moisture susceptibility parameters were found to be improved in terms of adhesive damage, stability (both wet and dry), and Retained Marshall Stability (RMS) when tested using boiling water, static immersion, and retained Marshall stability tests respectively.
- Results indicate that 2% epoxy modification is the optimum dosage with both VG 30 and VG 40 binders. Comparing these mixes to control or unmodified bituminous mixes, however, revealed that the mixes with 3% epoxy modification with both binders had better resistance to moisture damage.
- Comparing bituminous mixtures with VG 40 binder to those with VG 30 binder, the former showed improved resistance to moisture damage, higher stability, and higher density.

The future efforts will be directed towards performance evaluation of the epoxy-asphalt mixtures followed by cost-benefit analysis and detailed environmental impact analysis.

Conflicts of interest

All authors declare that they have no conflicts of interest regarding this article.

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