Simulation-Based Analysis of Perpetual Pavement by Using IITPAVE Software

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***Abstract*—The core concept of perpetual pavement revolves around keeping pavement deterioration below specific thresholds, termed endurance limits, to ensure longevity. The endurance limit establishes a thickness threshold, beyond which no structural benefits are gained, potentially leading to financial inefficiencies. This research begins by examining the necessity for perpetual pavements in India and seeks to broaden the scope of pavement design by incorporating alternative materials such as cementitious and crumb rubber-modified bitumen, analysing them using the IITPAVE software. Furthermore, the research emphasizes methodologies for design traffic calculations and performance analysis of the designed pavements. Softening point test outcomes reveal that all crumb rubber (CR) modified binders demonstrate improved resistance to high-temperature effects compared to unmodified binders. Additionally, the study indicates that 5% CR-modified mixes exhibit superior fatigue and deformation qualities compared to standard mixes, alongside reduced temperature susceptibility and enhanced moisture resistance. This research evaluates the feasibility of implementing perpetual pavements within the Indian context, highlighting its significance as India advances towards adopting perpetual pavements for major highways.**

***Keywords*— IIT Pave Software, Perpetual Pavement, Crumb Rubber, Marshall Test, Cementitious Materials.**

I. INTRODUCTION

Perpetual pavements are flexible bituminous pavement systems that can withstand large vehicle loads and last for four to five decades without requiring significant structural repair. The main problems that flexible pavements face are reflective cracking, fatigue cracking, thermal cracking, and rutting. Numerous causes, including poor building practices, uneven material quality, faulty design methodologies, improper material characterization, and increased traffic volume and load, can cause these issues. Bottom-up fissures are the most difficult to identify and fix among these problems. High tensile strains and stresses are usually the cause of these cracks near the base of the bituminous layers.

If pavement structure can counter structural rutting and bottom-up fatigue cracking over time, it will be able to serve for longer periods. Increasing the thickness of the pavement layer and adjusting its stiffness based on the kind of distress the layer is supposed to endure are two ways to do this. Effectively designed perpetual pavements can give better engineering performance resulting in economic efficiency.

The idea of perpetual pavement is not an entirely new concept. From the 1950s several full-depth bituminous pavements have been designed for larger service periods and minimum maintenance and rehabilitation activities. Deep strength pavement concept where pavement is built on a thin granular base course and the concept of full-depth pavement where pavement is built directly on the subgrade soil is not new. (Newcomb et al.,) Using similar sorts of concepts, pavements can be designed to be perpetual.

Initially, a mainly empirical approach was used to develop such pavements. Pavement responses like stress, strain, and displacements, under different traffic loading conditions, were used to develop a design system. The aim of the deep strength and full depth pavement concept was to decrease the rate of progression of structural damages. This approach is useful to reduce lifecycle costs, to achieve low user-delay costs as minor surface rehabilitation is a short-term activity, and to reduce carbon footprint by reducing the amount of material resources required over the pavement's service period. The major problem with this type of approach is overdesigning the pavement as increasing the thickness beyond a certain limit doesn't give any structural improvements and doing so will result in an unfounded financial burden. This limitation to layer thickness gave birth to the concept of perpetual pavements. (Uhlmeyer et al.,)

The main requirement in the perpetual pavement is an impermeable top structural layer placed on the durable intermediate layer and a fatigue-resistant base layer to deal with distresses developing to loading. (Dumitru, C et al.,) The life of any type of flexible pavement depends on traffic volume, axle load properties, design method, material type, climatic conditions, and periodic maintenance. Better fatigue and rutting resistance results in better service life. (Newcomb et al.,)(Uzan et al.,)

FPAVE has been expanded into the software IIT-Pave. The thickness of the pavement layers, the elastic modulus of each layer, the load on the pavement surface, the depth at critical spots, tire pressure, wheel spacing, and Poisson's ratio are the input data needed by this software. The mechanical parameters updated in the output are: normal stress (Sigma Z), tangential stress (Sigma T), radial stress (Sigma R), shear stress (Tao RZ), vertical displacement (Disp Z), normal strain (ϵZ), horizontal stress (Sigma RZ), vertical & horizontal stress (Sigma R), tangential strain (ϵT) and horizontal radial strain (ϵR). The main objectives of this study are to:

1. To determine the Engineering properties of aggregate & bitumen for pavement.
2. To investigate suitable percentage of rubberized bitumen for perpetual pavement.

II. METHODOLOGY

The approach utilized in this research involves conducting laboratory examinations on various

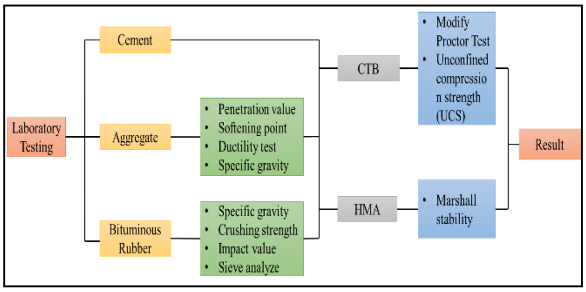

Fig. 1: Flow Chart showing the procedure of the project work

materials, including cement, aggregates, and bituminous rubber. For aggregates, assessments such as penetration, softening point, ductility, and specific gravity are performed to assess their characteristics. In a similar manner, bituminous rubber is evaluated for specific gravity, compressive strength, impact value, and sieve analysis to ascertain its suitability. These materials are categorized for use in cement-treated substrates (CTB) or hot mix asphalt (HMA). In the case of CTB, essential evaluations include the modified Proctor test to ascertain optimum moisture content and density, along with unconfined compressive strength (UCS) to assess the material's load-bearing capability. For HMAs, Marshall stability tests are conducted to gauge the mixture's resistance to deformation under load. The findings from these tests are analyzed to verify whether the material complies with the required standards and specifications for the intended road construction use. This organized method guarantees selecting and constructing high-performance, durable road layers.

III. MATERIALS AND METHODS

The bitumen analyzed according to standard laboratory protocols was VG10/20. The results of these tests are shown in Table 1. In this research, crumb rubber in powdered form was used as a modifier. Table 1 displays the specific gravity of the rubber particles. A standard heavy-traffic gradation for hot mix asphalt (HMA) is referenced from the Ministry of Road Transport & Highway (MoRTH.250.2013). The chosen gradation is depicted in Fig. 2.

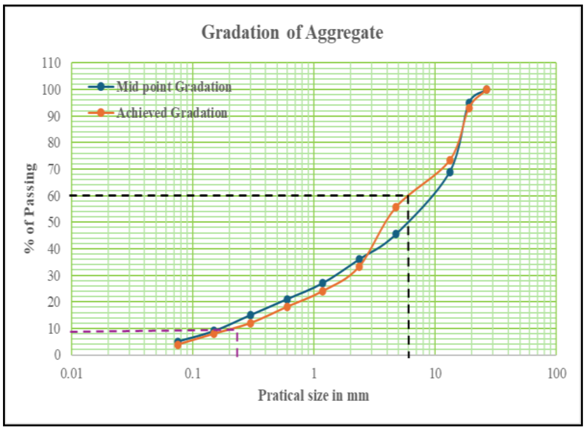

Fig. 2: Gradations of aggregates for HMA

IV. CRUMB RUBBER MODIFIED BINDER PREPARATION

During this process, a 10/20 penetration grade asphalt is heated to 160°C before introducing crumb rubber. The mixture is stirred at a low speed for about 5 minutes. Following this, the blend is heated further to 175°C. The blending temperature is maintained between 175 and 180°C. In contrast to the 10/20 asphalt binder, the modified binders exhibited lower penetration and ductility values, while their softening point values were elevated. At 25°C, the penetration of the modified binder was considerably higher than that of the original asphalt. As a result, this binder is expected to maintain flexibility at lower temperatures

Table. 1: Physical Characteristics of the Materials

Materials	Measured parameter	Value
Asphalt (10/20)	Penetration value	115mm
	Softening point	57.5°c
	Ductility	89cm
Coarse aggregate	Specific gravity	2.730
	Water absorption	0.60%
	Impact value	11.85%
	Crushing strength	14.82%
Fine aggregate	Specific gravity	2.605
Crumb rubber	Specific gravity	1.019

while preventing excessive softness at higher temperatures. The basic characteristics of the modified binders and the 10/20 asphalt are presented in Table 2.

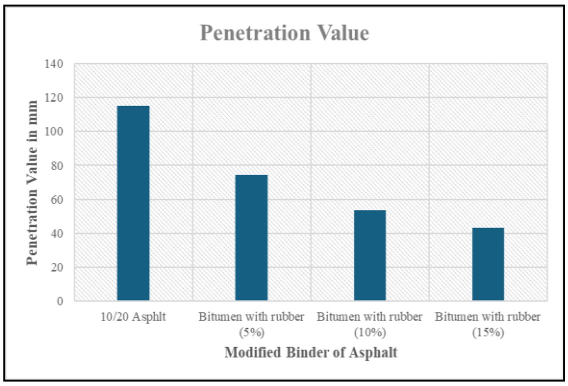

Fig. 3: Variation of penetration value for different binders

An elevation in rubber concentration resulted in a reduction in penetration and a rise in the softening point. The differences in softening point and penetration measurements between the CR10 and CR15 binders are not especially significant. However, the penetration ratio and elastic recovery metrics for the CR5 binder outperform those of the other concentrations.

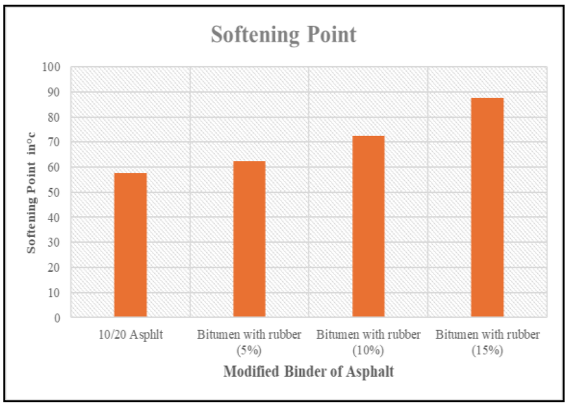

Fig. 4: Variation of softening point for different binders

An elevation in rubber concentration resulted in a reduction in penetration and a rise in the softening point. The differences in softening point and penetration measurements between the CR10 and CR15 binders are not especially significant. However, the penetration ratio and elastic recovery metrics for the CR5 binder outperform those of the other concentrations.

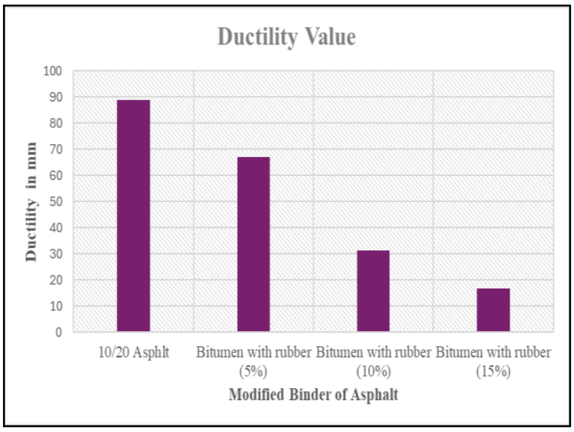

Fig. 5: Variation of ductility for different binders

V. MARSHALL STABILITY

This testing method is outlined in Standard No. ASTM-D1559, referred to as "Standard Testing Method for Determining the Resistance of Asphalt Mixtures to Plastic Deformation Utilizing the Marshall Method." The processes for producing and preparing asphalt mixture samples for mix design comply with the Standard Method (ASTM-D1559). In this method, cylindrical samples of compacted asphalt mixture are formed, with dimensions of approximately 63.5 mm in height and 101.6 mm in diameter. Compaction is performed using a metal hammer with a circular cross- section (98.4 mm in diameter), weighing 4.5 kg, which is dropped freely from a height of 45 cm.

Table. 3: Values of Marshall Stability test properties of asphaltic concrete

Binder in the mix	Optimum binder content (%)	Marshall stability (kN)	Flow value (mm)	Bulk density (kg/m³)	Air voids (%)
CR0	5.17	14.294	3.18	2.220	3.31
CR5	5.27	19.386	3.40	2.254	5.43
CR10	5.33	15.110	4.35	2.248	4.66
CR15	5.39	13.830	4.58	2.295	3.26

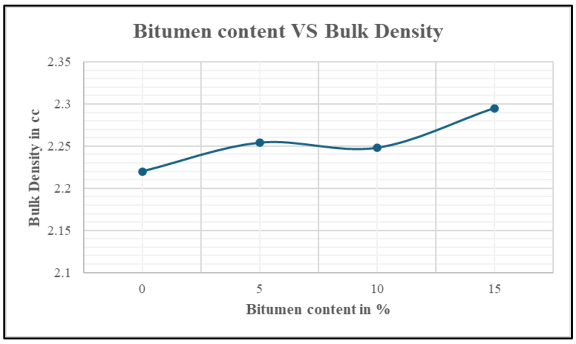

Fig. 6: Bitumen concentration compared to Bulk density

Marshall tests were performed on both standard and altered mixtures that contained MoRTH aggregate gradation illustrated in Fig.2. The results are presented in Table 3 & shows in Fig. no. 6, 7, 8 & 9. The stability values measured for various concentrations of CR are nearly identical to those recorded for mixtures with standard binder.

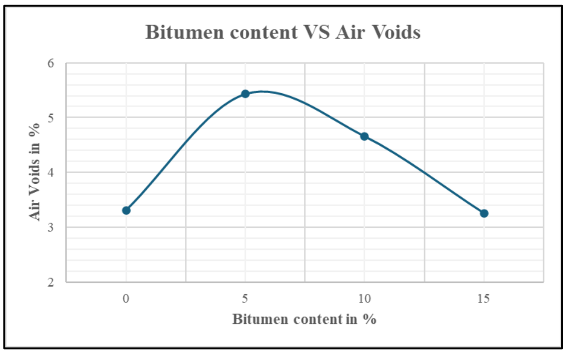

Fig. 7: Bitumen concentration compared to Air voids

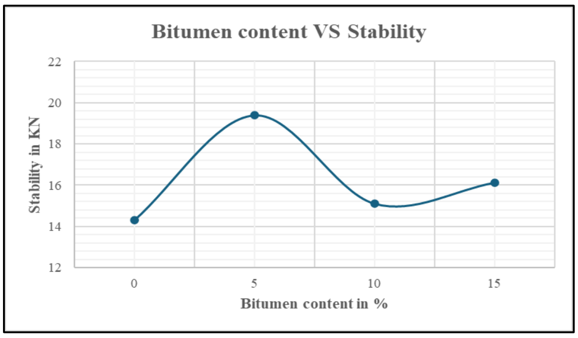

Fig. 8: Bitumen concentration compared to Stability

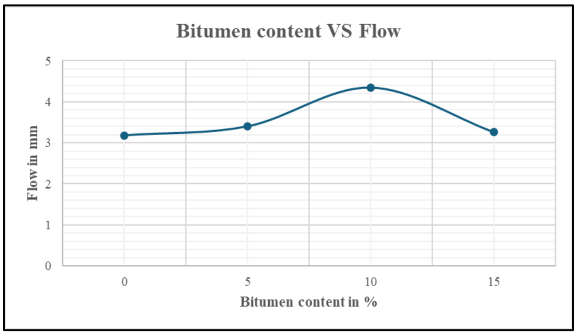

Fig. 9: Bitumen concentration compared to Flow

The binder with a CR5 concentration produced the highest Marshall stability value. Flow values exhibited a slight increase with higher CR levels. The amount of air voids displayed a declining trend as the CR concentration increased. The Marshall outcomes for various mixes do not offer a clear assessment of their relative performance.

VI. PREPARATION OF CEMENT TREATED SUB-BASE (CTSB)

For cementitious (cement-treated) sub-base, the materials may include soil, crushed aggregates, natural gravel aggregates, reclaimed concrete aggregates, or a soil-aggregate mixture supplemented with cementitious materials like fly ash, cement, lime, and commercial stabilizers, among others. With the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the CTSB material listed in Table 4, the suggested aggregate grading for the material matches Grading IV in Table 400-1 of the MoRTH Specifications, as seen in Fig. 10.

Table. 4: Proctor Test

Cement content in %	Maximum dry density (MDD) in gm/cc	Optimum Moisture content (OMC) in %
3	2.229	4.323
4	2.237	4.354

5	2.220	3.887
6	2.223	3.913

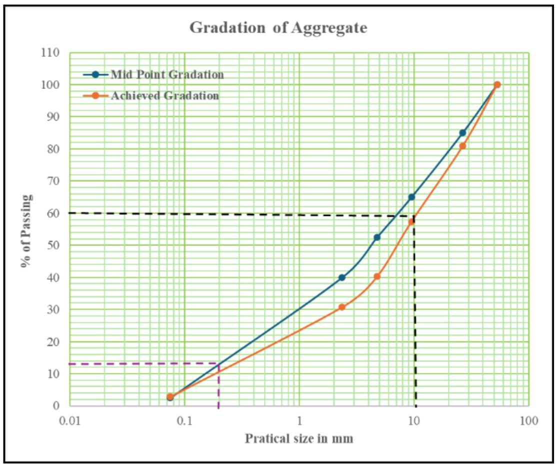

Fig. 10: Gradations of aggregates for CTSB

VII. UNCONFINED COMPRESSIVE STRENGTH TEST (CTSB)

According to Clause 403.2.6 of MoRTH, the cement content should be at least 2% by weight of the dry soil. The design mix must be determined based on the 7-day unconfined compressive strength (UCS) and/or durability assessments after 12 wet-dry cycles. Results for laboratory strength must be at least 1.5 times higher than the lowest UCS values seen in the field. When tested using cylindrical or cube specimens that are compacted to the density at the ideal moisture content, carried out in compliance with IS: 2720, following a seven-day moist curing time, the mix design seeks to achieve a strength of 1.75 MPa.

Table. 5: Variation of Cement content

Sr.no	Percentage of cement	Unconfined Compressive Strength for 7 days of Curing (MPa)	Elastic Modulus E for CTSB at 7 Days Strength
1	3	1.66	1660
2	4	1.99	1990
3	5	4.43	4430
4	6	5.21	5210

VIII. CONCLUSION

The following conclusions can be drawn from the results of experimental research done on conventional and crumb rubber-modified asphalt mixtures.

1. When compared to regular mixtures, crumb rubber modified mixtures showed a lower chance of permanent deformation; the CR5 type showed the lowest chance of such deformation.
2. The performance variations between the different combinations were not clearly seen in the Marshall test rubber-modified results. The adjusted mixtures of crumb rubber were shown to have significantly better fatigue and rutting performance than the conventional mixtures, despite the fact that there was no discernible difference in the Marshall properties of the two mixtures.
3. Binders treated with crumb rubber showed less sensitivity to temperature changes. Because of their lower resilient modulus, mixtures including changed binders were more flexible at lower temperatures, whereas at higher temperatures they were more stiff and had a higher tensile strength.
4. Results that are consistent with MoRTH standards were obtained from experiments on cementitious material combinations to be applied to soil and the evaluation of the results for unconfined compressive strength.
5. The Cement Treated Soil Base (CTSB) demonstrated greater strength in comparison to conventional materials, leading to a reduction in required maintenance work. This, in turn, will decrease maintenance costs and positively impact the lifecycle cost of the project.

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