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Experimental Study on Warm Bituminous Mix Modified With Waxes

M.Sandhya[1], K.Gopi Shankar[2]
M-Tech Student[1], Assistant Professor[2]
Department of Civil Engineering, GMR Institute of Technology, Rajam, Srikakulam, A.P, India

***Abstract:** Rising energy prices, global warming, and more strict environmental regulations have resulted in an interest in warm mix asphalt (WMA) technologies.WMA is a technology that allows significant lowering of the production and compaction temperature of conventional Hot Mix Asphalt (HMA) by reducing the viscosity of bitumen and increasing the workability of mixture. In recent years the use of WMA is gaining its popularity because of reduced production, compaction temperatures, improved workability, reduced energy consumption and reduced emissions as compared to HMA. In the present study, VG 30 bitumen was modified with two types of warm mix wax additives (polyethylene wax and Rice bran wax).The physical properties binder were studied and Marshall Properties were analysed by determining flow and stability values. Furthermore to evaluate moisture susceptibility indirect tensile strength test was performed and tensile strength ratio (TSR) is determined. Test results shows that the Bitumen viscosity decreased with the addition of wax additives. Marshall Stability and Indirect Tensile Strengths (ITS) of the WMA mix with wax as an additive were found to be higher than those of HMA mix.TSR values of unmodified mixes were greater than those of modified. Based on overall test results it can be concluded that polyethylene wax and Rice bran wax as WMA additives are effective in producing WMA mixes which have high strengths at lower temperatures.*
***Keywords:** Warm mix Asphalt (WMA), indirect tensile strength, Polyethylene wax, Rice Bran wax, Moisture Susceptibility*

I. INTRODUCTION

The focus in construction has recently shifted toward sustainability and environmentally friendly practices because of global awareness and strict environmental regulations are actively being implemented to prevent the worsening effects of climate changes and depletion of fossil fuel reserves, especially crude oil which currently serves as the main source of energy. The average oil demand growth has been roughly 0.15 mb/d annually and India's government has embarked upon a massive programme of infrastructure creation, aiming to construct 30 km of highway roads per day this will increase oil demand [1].The cost of pavement construction depends on the amount of energy consumed, it is necessary to reduce the total cost of pavement construction by using new energy saving technologies while also conforming to stringent environmental regulations in accordance with the need for sustainable development. The concept of sustainable development implies equilibrium between various factors, including environment, economy, security, and social issues, which must all be considered for the preservation of nature for future generations [2].

Over the years asphalt industries depend on hot mix asphalt technology (HMA) that was used in the road construction. Hot mix asphalt (HMA) is produced in a manufacturing process that requires high temperatures (150°C - 180°C) for its preparation and subsequent compaction [3]. These elevated temperatures are necessary to evaporate water contained in the granular material and to create a suitable viscosity in the asphalt to coat the aggregates with the binder and to provide the adequate workability to place and compact the mix. These elevated temperatures cause high energy consumption and emissions from the burning of fossil fuels, fumes, and odours generated at the production plant and the work sites [4].

To address all these issues without comprising on the performance of the mix asphalt industry developed an emerging new technology called warm mix asphalt (WMA). The basic principle of this technology is that by adding certain additives at the final stages of the mix production, the coating of the aggregates by the binder is greatly improved and can be achieved at a considerably less temperature typically 30°C less which means reduced productions and compaction temperatures implies low fuel consumption, any emissions either visible or non-visible that may contribute to health, odour problems, will also be reduced and reduce greenhouse gas emissions as much as 25-30% and controls global warming. Apart from these advantages some other advantages like longer paving seasons, reduced wear and tear of the plants, longer hauling distances, ability to open the paved site to traffic sooner, reduced oxidation and aging of the binder in mixes and thus reduced fatigue cracking are some of the most promising advantages [5].

WMA technology involves three different types of approaches: Foaming technologies use fine water droplets to expand the volume of binder in the mix by causing it to foam. This has the effect of increasing the volume of the bitumen, lowers the viscosity enabling it to coat aggregate at lower temperatures and better workability. Organic or wax additives are used to attain the temperature reduction by reducing the viscosity of binder. The process shows a decrease of viscosity above the melting point of the wax and mix is produced at lower temperatures and thus allows lower mixing and paving temperatures. Chemical additives are Surfactants that reduce surface tension between the polar aggregates and non-polar bitumen, improve wetting and reduces internal friction, and allows a reduction of 28-50°C in mixing and laying temperatures [6]. In the present study two organic or wax additives are used and to investigate their suitability mechanical properties were analysed by determining flow and stability values. Furthermore to evaluate moisture susceptibility as production temperature is less than HMA indirect tensile strength test was performed and tensile strength ratio (TSR) is determined.

II. MATERIALS AND PROPERTIES

A. Aggregates

Aggregates form a major portion of the pavement structure and the mechanical properties of the aggregates are the utmost vital for the long life of the pavements. For the present study, the aggregates were collected from a local stone crusher and they are suitable to use in bituminous concrete (BC) mix as per Indian Specifications. Different tests were conducted to check the physical properties of aggregates and the results are given in Table 1

TABLE I PROPERTIES OF AGGREGATES

Property	Test	Result	Recommendations as per IRC 111-2009	Test Method
Particle shape	Flakiness and elongation index(combined)	16.77%	Max 35%	IS:2386 Part 1
Strength	Los Angeles Abrasion Test	27.24%	Max 30% For bituminous concrete	IS:2386 Part 4
	Aggregate Impact	20.23%	Max 24% for bituminous concrete	IS:2386 Part 4
Water Absorption	Water Absorption	0.5%	Max 2%	IS:2386 Part 3
Specific Gravity	Specific Gravity	2.67	2.6-2.9	IS:2386 Part 3

B. Aggregates Gradation

In the present study, the bituminous concrete (BC) mix was designed for 19 mm nominal size of aggregates according to gradation. The Aggregates taken for the mix are the combination of coarse aggregates passing 26mm IS sieve and retained on 2.36mm IS sieve, fine aggregate passing 2.36mm IS sieve and retained on 0.075mm IS sieve and stone dust is adopted as the filler which is passing 0.075mm IS sieve[10]. The gradation curve is shown in Figure.1

C. Bitumen

Bitumen acts as a binding agent to the aggregates, fines, and acts as stabilizers in bituminous mixtures. Durability and flexibility of the mix depend on the binder. Binder characteristics affect the bituminous mixture behaviour viz., temperature susceptibility, visco-elasticity, and aging. In the present study viscosity grade (VG) 30 bitumen was selected as the binder. To confirm the grade of the bitumen basic engineering tests were conducted. The test results with and without wax additive are in Table 2

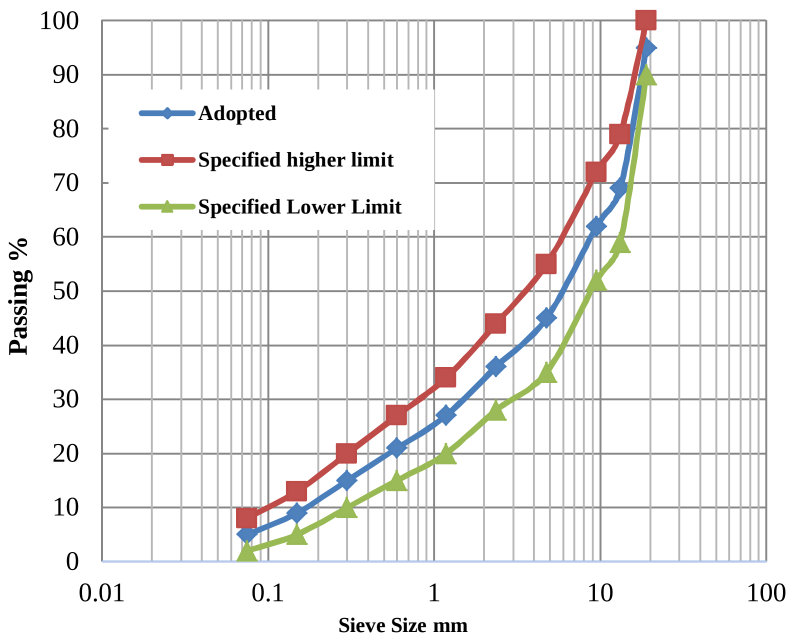

Fig.1 Gradation Curve

Table Ii Properties Of Bitumen Vg 30 With And Without Wax

Property	Results			Recommendations	Test method
	Without wax	With 3%PE wax	With 5%RB wax		
Penetration (100 g, 5sec),0.1mm	62	48	42	Min 45	IS 1203 1978
Ductility at 25˚c in cm	88	94	105	Min 40	IS 1208-1978
Softening Point(˚c)	50.5	72	68	Min 47	IS 1205-1978
Viscosity at 135˚c (Cst)	485	279	237	Min 350	IS 1206 part3-1978

D. Wax Additives

1) *Polyethylene Wax (PE Wax):* Ultra-low-molecular-weight polyethylene (*ULMWPE* or *PE WAX*) is one type among many others like high density polyethylene, High Molecular Weight Polyethylene, Low Density Polyethylene etc. of polyethylene classified based on its molecular weight, density, and branching. Polyethylene has chemical formula $(C_2H_4)_n$. Polyethylene wax is acquired from Coral petro products jeedimetla, Hyderabad, Telangana. Polyethylene wax is a warm mix organic or wax additive which improves the viscosity of the binder with this property it reduces production and compaction temperatures. Properties of polyethylene wax are given Table 3
2) *Rice Bran Wax (RB Wax):* Rice (Oryza sativa) bran wax is the natural vegetable wax extracted from the bran oil of rice bran which is a by product (waste material of dewaxing) of rice milling. The main constituents of rice bran wax are aliphatic acids

(wax acids) and higher alcohol esters. The aliphatic acids consist of palmitic acid (C16), behenic acid (C22), lignoceric acid (C24), and other higher wax acids [7]. RB wax is acquired from Vijay Agro Products Pvt.Lmd, Enikepadu, Vijayawada, Andra Pradesh. Rice Bran wax is used as the wax additive which reduces the production and compaction temperature of the mix by reducing the viscosity of the binder above the melting point of the wax thus increasing the workability of the mix. The properties of rice bran wax are given in Table 4

Table III Properties Of Polyethylene Wax (Pe Wax)

Test parameter	Test method	Specifications	Test Results
Appearances	Visual	White Flakes	White Flakes
Drop melting point (˚C)	ASTM D-127	105-115	113
Penetration	ASTM D-937	05-08	5
Flash point (˚C)	ASTM D-92	>170	190

Table IV Properties Of Rice Bran Wax (Rb Wax)

Property	Value	Test Method
Melting Point ˚C	77	IS 5762-1970
Iodine value	12.2	IS 548 part1 1964
Saponification value (mg KOH/g)	84.6	IS 548 part1 1964
Acid Value (mg KOH/g)	6.1	IS 548 part1 1964

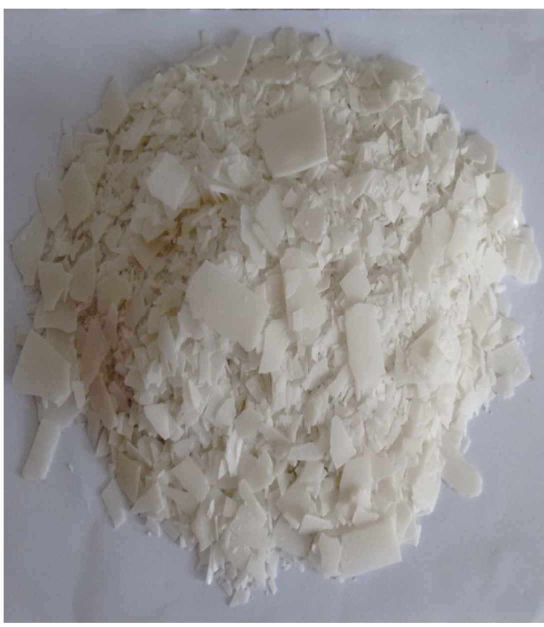

Fig.2 Polyethylene Wax

Fig.3 Rice Bran Wax

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III. EXPERIMENTAL METHODOLOGY

To determine the Optimum bitumen content (OBC) and effect of additives on the stability and flow value Marshall Stability test is conducted. As Warm Mix Asphalt (WMA) is produced at a lower temperature reduction in mixing and compaction temperatures of 30 to 50°C than HMA [8]. Due to the lower mixing and compaction temperatures, moisture contained on the aggregate surface does not completely evaporate during the laying and mixing process which leads to stripping so to evaluate moisture susceptibility property of the mix, Resistance of Compacted asphalt mixture to moisture induced damage (AASTHO T283) test is conducted. In the present study, two warm mix additives are used as bitumen modifiers their optimum content is determined based on viscosity offered by them to the binder by determining kinematic Viscosity in accordance with IS code.

A. Resistance of Compacted Asphalt Mixture to Moisture Induced Damage (AASTHO T283)

To study about the moisture induced damage of the mix AASTHO T283 test is performed. For this test 6 specimens are prepared for each mix i.e., total 18 specimens are prepared to have 7±1% air voids by trial and error method by altering the number of blows given to the specimen. One set with unmodified bituminous mixture (6), other with PE wax (6) and last one for RB wax (6). These specimens are divided into 2 group's first group (9 specimens) were conditioned by applying vacuum pressure in a vacuum chamber until the specimen achieves 70-80% of saturation, saturated specimens are covered with plastic film and wrapped in the plastic bag containing 10ml of water and bag is sealed then they undergo freeze cycle of -18˚c for at least 16 hours and then placed in water bath at 60±1˚c for 24 hours. Finally conditioned and unconditioned specimens are then transferred to the water bath at 25±1˚c for 2 hours before testing. Indirect tensile strength test was performed by loading the specimens at a constant rate i.e. at 50mm/min and measuring the peak force required to break the specimen. The average tensile strength values of the conditioned specimens are compared to the unconditioned specimens to determine the Tensile Strength Ratio (TSR).

$$\%TSR = \frac{Avg Tensile strenght of conditioned samples}{Avg Tensile strenght of unconditioned samples} * 100$$

$$\text{Tensile strength} = \frac{2P}{\pi t D} \text{ in N/mm}^2$$

Where, P= Maximum load in N,
t= Height of the specimen in mm and
D= Diameter of specimen in mm

B. Marshall Stability Test

As per the code IRC 111 the Gradation for the bituminous concrete mixtures is taken for the preparation of the specimen. For each specimen a mix of coarse aggregates, fine aggregates, and filler weighing 1200 g is taken and heated to a temperature of 175-190°c and bitumen is heated to a temperature of 121 to 145°c and mix of aggregates, filler and binder are heated to temperature of 154-160°c(Heating temperature is different for the WMA) then mix is placed in the preheated mould and compacted by a hammer of 4.54kg weight having 45.7 cm height of fall with 75 blows on either side of the specimen. Compacted specimen should have the thickness of 63.5±3mm and have a diameter of 10.16mm.The specimens are removed using sample extractor. The specimen maintained at 60±1°c for 30 to 40 minutes in a thermostatically controlled water bath. The specimens are taken out one by one and placed in the Marshall Test head and loaded at 50 mm/minute and tested to determine Marshall Stability value which is the maximum load before failure. Marshall Stability of the mix is defined as a maximum load carried by the specimen at a standard test temperature of 60°c before failure. The flow is measured as the deformation in units of 0.25 mm between no load to the maximum load carried by the specimen during the stability test. Marshall Quotient (MQ) is a ratio of stability to the flow and can be used as an indicator of the stiffness of the mixes. Higher values of Marshall Quotient usually represent good rutting resistance of the mixture.

$$\text{Marshall Quotient (MQ)} = \frac{\textbf{Marshall Stability}}{\textbf{flow}}$$

IV. RESULTS AND DISCUSSION

For the ease of reporting the results, the nomenclature as given in Table 5 is used for mix identification.

Table V Identification Of Different Mixes

Binder Type	Additive	Mix Identification (ID)
VG 30	Plain mix(No Additive)	VP
VG 30	Polyethylene Wax (3%)	VPE
VG 30	Rice Bran wax (5%)	VRB

A. Mixing and Compaction Temperature

As Warm Mix Asphalt (WMA) is produced at a lower temperature, reduction in mixing and compaction temperatures of 30 to 50°C than HMA[8] there are no previous specifications available regarding the mixing and compaction temperatures for WMA mixture the mixing and compaction temperatures are adopted as per table 6 [9]

Table VI Mixing And Compaction Temperatures

Mix Type	Mixing Temperature		Compaction Temperature(°C)
	Aggregate(°C)	Binder(°C)	
VP	145-150	145-150	132-137
VPE	127-121	127-121	121-115
VRB	127-121	127-121	121-115

B. Optimum Wax Content

The modification of the VG 30 was carried out by adding wax between 1 to 5% of dry weight of bitumen. As wax was added to bitumen viscosity decreases the optimum content was selected based on the viscosity values. The wax content which provides the highest viscosity to the binder was selected as an optimum percentage of wax. This process led to an optimal percentage of 3% for polyethylene wax and 5% for Rice Bran Wax as shown in Figures 4 and 5 respectively.

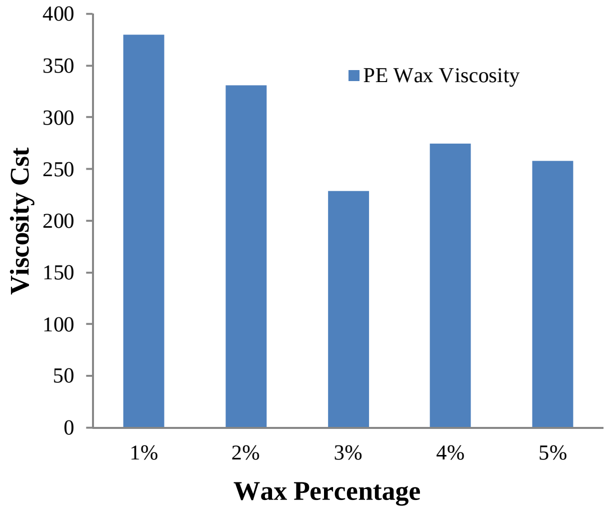

Fig.4 Optimum percentage of PE Wax

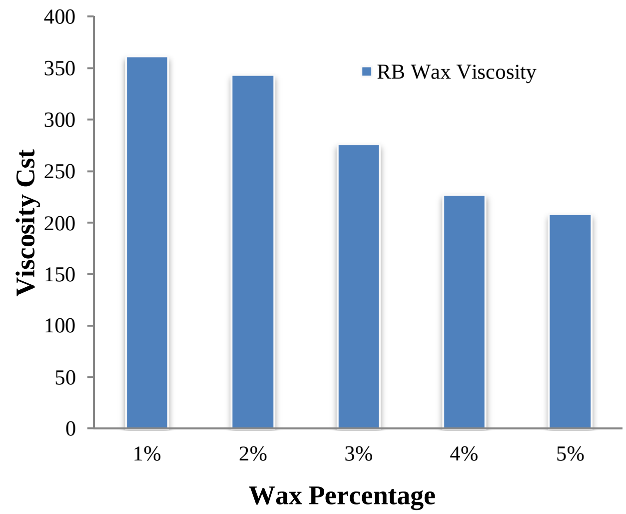

Fig.5 Optimum percentage of RB Wax

C. Marshall Stability Test

1) *Conventional Bituminous Mix*: To determine the optimum bitumen content for a particular blend of aggregates and bitumen, different percentages of the bitumen with an increment of 0.5% are adopted in the range of 4-7 like 4%, 4.5%, 5%, 5.5%, 6%, 6.5 and 7%.OBC is selected to get 4% of the air void in the mix and satisfying all the other requirements in accordance with code IRC 111-2009. From the tests, 5.2% of bitumen satisfying 4% air voids in the mix and it is adopted as OBC. The results of the tests are given below in table 7 correspondingly Marshall Mix Design Curves for VG30 Conventional Bituminous mix are shown in figure 5.
2) *Bitumen Modified with Polyethylene and Rice wax:* Marshall Stability tests were conducted for the binder modified with the optimum wax contents of 3% of PE wax and 5% of RB wax. Marshall Stability and Marshall Quotient (MQ) values were obtained by averaging of three specimens and the obtained results are given in Table 8. From Marshall Stability tests the modified mixtures show better stability than unmodified mixes, RB wax modified mix offered better stability than PE wax. Flow values of the wax modified mixes are lower than that of unmodified mixes. Marshall Quotient of the modified mixes

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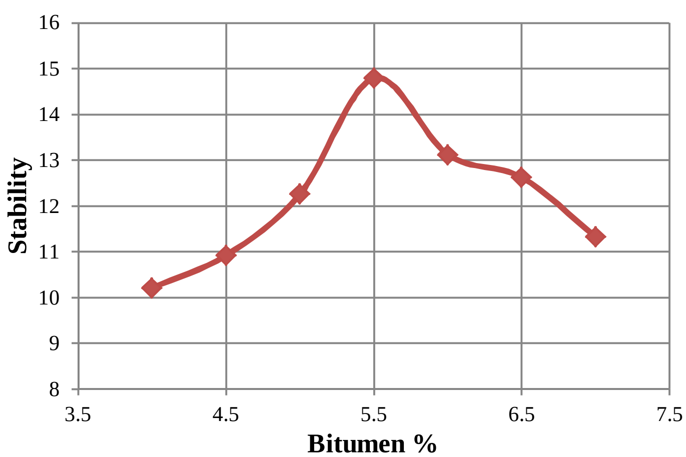
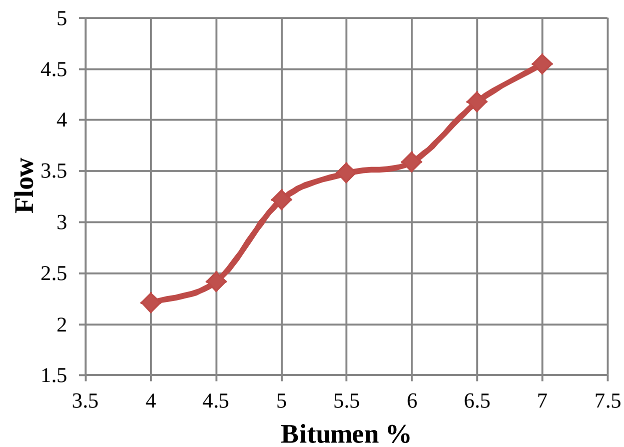
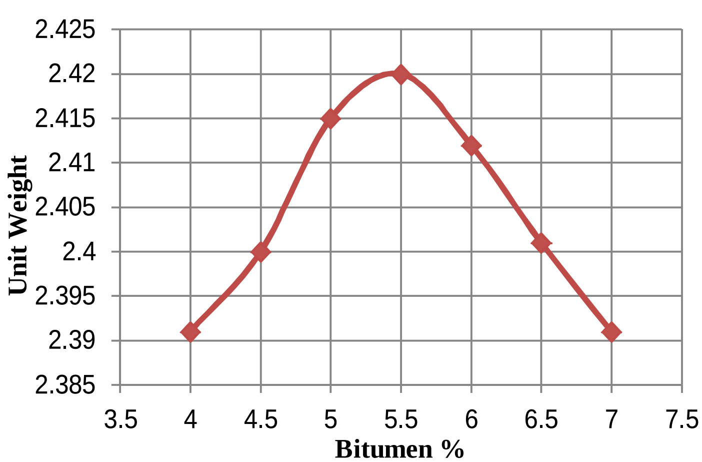
increased 26% for PE wax and 47% RB wax as compared with the unmodified mix. Among all of them, Rice Bran Wax showed more positive effect. This represents the wax modified mixtures especially RB wax modified mixtures, have higher rutting resistance than unmodified mixtures.

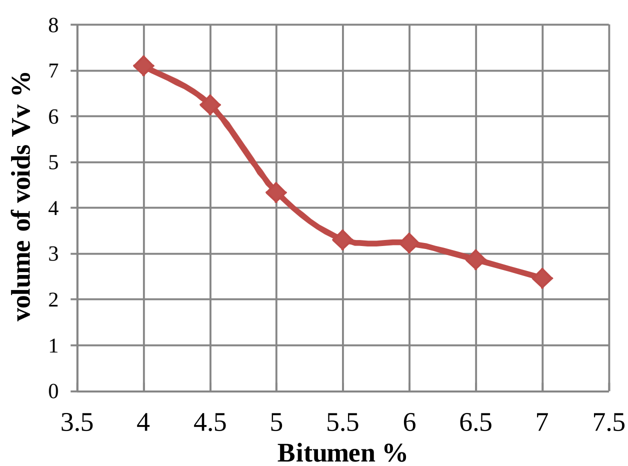
Table VII Properties Of Conventional Marshall Mix Design

S.No	Bitumen (%)	Stability KN	Flow mm	Volume of voids(Vv)%	Voids In mineral Aggregates(VMA)%	Voids filled with bitumen(VFB)%
1	4	11.21	2.21	7.10	16.48	57.00
2	4.5	11.42	2.42	6.25	16.84	62.89
3	5	12.62	3.22	4.34	16.18	73.18
4	5.5	14.11	3.48	3.31	16.36	79.76
5	6	13.31	3.59	3.23	17.42	81.46
6	6.5	12.31	4.18	2.87	18.17	84.25
7	7	12.02	4.55	2.47	18.88	86.92









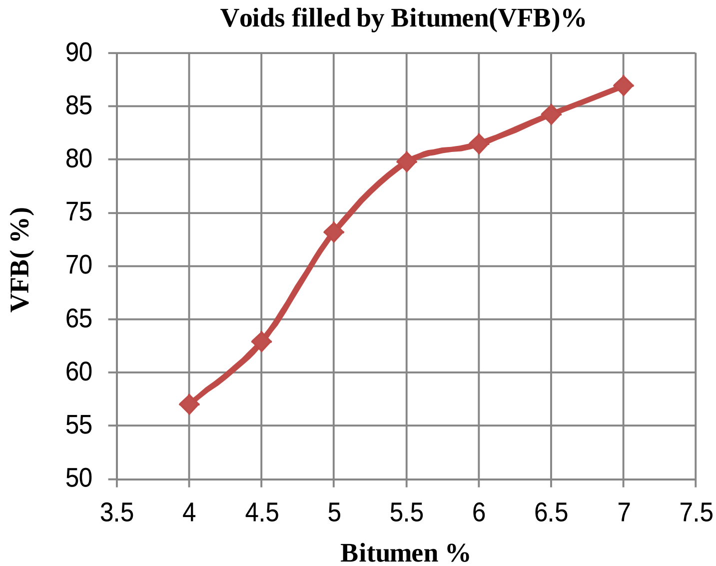


Figure 6 Marshall Mix Design Curves for VG30 Conventional Bituminous mix

Table VIII Marshall Properties With And Without Additives

Bituminous Mix	Blows	Marshall Stability (Kn)	Flow in mm	Marshall Quotient (MQ)
VP	75	13.23	4.16	3.18
VPE	75	14.57	3.63	4.01
VRB	75	16.01	3.42	4.68

D. Indirect Tensile Strength and AASTHO T283

The tensile strength of bituminous specimens is determined by applying a compressive load to Marshall Specimens which acts parallel to and along the vertical diametrical plane, through two curved steel strips of having same inside radius as that of Marshall Specimens. A nearly uniform tensile stress is developed normal to the direction of applied load and along same vertical plane causing the specimen to fail by splitting along the vertical diameter and failure load is noted as the indirect tensile strength. The test results are given in table 9. From results tensile strength values of the wax modified mixes is higher than the unmodified mix, this increase of strength is due to stiffening of the mixes due to the wax additive. After conditioning of the specimens, tensile strength decreased irrespective of additives due to moisture damage. Furthermore to investigate the moisture susceptibility of mixes TSR is determined and Modified mixes have lower TSR values compared to unmodified mixes and they do not meet the minimum requirement of 80%, From these observations, it can be concluded mixes may be moisture susceptible, that the reduction of TSR in wax modified mixtures may be due to the decreased production temperature the moisture remains in the aggregate and thus causes adhesion failure of the mix.

Table IX Indirect Tensile Strength And Tsr Values For Different Mixes

Mix Type	Dry ITS (kPa)	Wet ITS (kPa)	TSR (%)
VP	235	201	85.5
VPE	342	259	75.7
VRB	402	275	68.4

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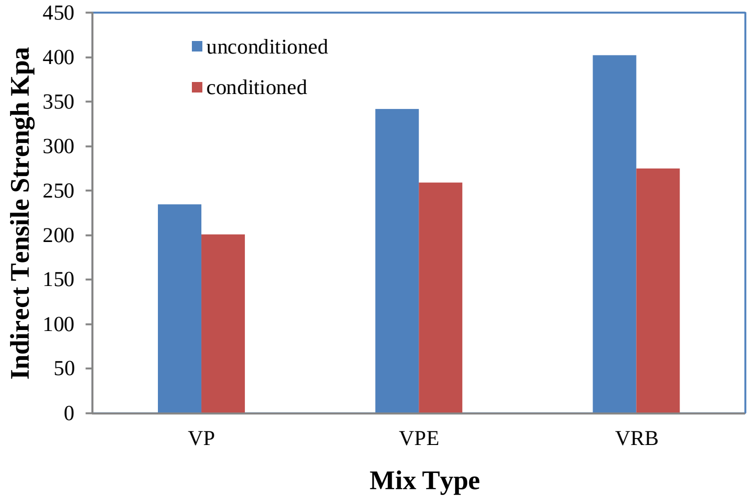

Fig.7 Indirect Tensile strength for conditioned and unconditioned mix

V. CONCLUSIONS

A. According to conventional bitumen test results, the addition of polyethylene wax and Rice Bran Wax in the bitumen decreased viscosity and increased softening point and ductility. This indicates PE wax and RB wax modification reduced the mixing and compaction temperature. Thus, PE wax and RB wax usage as an additive can be beneficial.

B. In the Marshall Stability test, it was obtained that stability values of the modified mixes are higher than the unmodified mixes. Marshall Quotient is increased 26% for PE wax and 47% RB wax as compared with the unmodified mix which shows more rutting resistance. Among all mixes, RB wax modified mix showed higher MQ value.

C. Indirect Tensile Strength test results showed that the tensile strength of the modified mixes is higher than the unmodified irrespective of the conditioned of the specimen. TSR (%) values of the modified mixes were less than unmodified thus shows modified mixes are moisture susceptible.

D. From all these results it can be concluded that PE wax and RB wax showed all positive effects of behaviour of bitumen and mixes by improving mechanical properties except moisture susceptibility, so this can be improved either by using anti-stripping agent or by using lime as filler material and future research should be performed to improve the moisture susceptibility of the WMA mixtures.

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