

An Experimental Investigation on the Effect of Mixing Procedures on Polypropylene Modified Bituminous Mix

Gandu Srikanth, Arpita Saha, Rajiv Kumar

Abstract: The study investigated the marshall properties of the polypropylene modified bituminous mixes by different mixing methods. Three sets of marshall samples were prepared by means of the wet, dry and control process with VG-30 grade of the binder, well-graded aggregates for bituminous concrete layer (>13.5mm). Polypropylene a class V or thermo plastic plastomer type was used for modification. During the wet process, three modified bitumen samples were prepared with 1,3 and 5 % PP by the weight of the binder. Basic binder tests were conducted, and results compared with Polymer modified bitumen code values then modified binder was used for the preparation of Marshall sample to find marshall properties of polymer modified mix (wet process). On the other hand, polypropylene was added to mix (aggregates) by 1,3 and 5% by the weight of aggregates. Here polymer was added with aggregates while preparation of marshall mix (dry process). In wet process the visco-elastic and thermodynamic properties of binder get change while the addition of polymer and changes take place in maltenes content of binder then results in hardening of the binder. In the dry process, the polymer sticks to aggregates and help to improvise coating ability during mixing and voids ratio of the specimen. So, in both the processes the marshall properties get varies due to visco-elastic and thermodynamic properties, coating, and void ratio. By comparing the results of the modified binder with neat bitumen and control marshall test results with dry and wet mix marshall test results it was concluded that dry process gives better results than wet process. In this paper investigation of the mixing process with merits and demerits, importance of polymer modification, mechanism involves in both physical and chemical changes, advantages, and disadvantages are discussed.

Keywords: Polymer Modified Bitumen, Visco-elastic properties, marshall properties, maltenes.

I. INTRODUCTION

Bitumen is an hydrocarbon produced by removing lighter materials from crude petroleum[1]. Since industrial revolution the traffic volume and load of vehicles increase rapidly and due to population and climatic changes various type of pavement distresses came in so, researchers start emerging new materials in pavement construction to reduce

distresses and on the other hand US start working on various type of chemical polymers. Then polymer modified bitumen came out as solution for many pavements distress like rutting, fatigue life, thermal cracking, density [21][22] etc[2][3][4][5]. An effective polymer modification results to an thermodynamically unstable but kinetically stable system in which polymer is partially covered with lighter components of bitumen[5]. As polymer content increase polymer phase replacement take place and polymer reach to dominant phase and bitumen goes to non-dominant phase results in stiffness and hardening of binder. However, polymer have two interlocked continuous phase which is responsible for optimum polymer content in binder modification. With these two phases polymer modified bitumen gives better results in terms of storage stability, mechanical properties and cost-effectiveness. Now-a-days utilization of plastic rises rapidly and few of the metropolitan cities keep ban on this plastic also but ban on few types of plastics only Polypropylene is one of the highest importing plastic type in India for last few years this polymer is used for manufacture of home appliances like buckets, mugs, water bottles etc. So, the utilization of post-consumer or post-industrial polymeric materials could be a suitable way to reduce plastic waste. According to the data given by European Asphalt Pavement Association (EAPA) claim that consumption of PMB is only 20% in last few years [23]. It is because of cost factor. So, here in this research focusing on utilization of PP in bitumen mix in different mixing processes.

A. Background

Polymer modified bitumen start even before refine bitumen starts in starting people use natural rubber for bitumen modification. Synthetic polymers come in light after world war-II. One of popular polymer during 1950's was neoprene (polychloroprene) latex in North America. PMB was first used in roofing and later in paving industry in 1965 atactic polypropylene (APP) a bi product of isotactic polypropylene (IPP) in roofing industry at Italy then the first commercial product marketed in 1967, Europe 1970 and around 1980 USA. During 1980's concept of thin layer pavement draws a huge attention which leads to focus on PMB's. In 1987 US Congress established Strategic Highway Research Program (SHRP) to promote these PMB. From 2000 the research on PMB divided into two category 1) to do deep investigation on mechanism of PMB 2) to work on PMB's disadvantages.

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B. Advantages and disadvantages of polypropylene modified bitumen

It improves binding ability, elastic behavior, thermal susceptibility [6], ageing retardation [20], increase in stiffness, resistance to permanent deformation, cohesion, better behavior to fatigue and thermal cracking [13].

And disadvantages are its economical, Can-not get compactable polymers with binder, mixing, temperature of placing and mixing storage [24][25].

II. LITERATURE REVIEW

A. Characterization of visco-elastic properties of binders

Bitumen undergoes various changes under different load due to axial load and climatic conditions and result pavement deformation with time. With fast load and low-temperature binder become stiff and elastic and at high-temperature binder become softer like viscous material so the stress-strain behavior of binder under loading conditions is used to define the viscoelastic behavior of bitumen [7].

The viscous deformation segment discontinues when the load is removed, but the deformation is not recovered. The paused elastic deformation element is gradually recovered at a decreasing rate. The load is linear where the deformation is proportional to load at any temperature and time. Resistance to deformation is can be defined by the relative distribution of resistance to elastic and viscous values within linear range and this distribution is based on bitumen properties, the rate of loading and temperature [14].

In long-term defects aging is the main defect of bitumen this type of aging is called as oxidative aging it is because of due to the presence of hydrocarbons present in bitumen get expose to atmospheric air and volatilization they increase the viscosity of binder and make more brittle. Aging is determined by temperature and time of exposure. So indirectly this aging also making some viscos-elastic properties of binder Most of this aging can see in Hot Mix type because of its temperature will cause volatilization [15].

B. Characterization of visco-elastic properties of modified binders

Polymer modification makes a binder to withstand temperature susceptibility and resistance to permanent deformation fatigue and thermal cracking. These polymers and binder can form a homogeneous mix, so this was one of the reasons behind to use polymer. After modification, these modified binders form a three-dimensional network structure within the modified binder. So, for every heating cycle, these PMB alter their properties[8].

When polymers get mixed with binder, they digest the Maltenes portion results in an increase in the volume of the binder by 9%. These polymer and binder remain in a single phase at ambient temperature. Hence at this temperature, PMB's have more than one phase and every phase have different properties. Due to the different chemical structure of polymer and binder min, it forms two phases. These two phases are "Polymer rich phase" and "Bitumen rich phase" or bitumen polymer phases.

C. Classification of Polymer Modified Binders

They classified these polymers into two types [6]

Based on chemical structure polymers divided into two types

Polyolefins: Polymerization of molecules with normal double bond

Styrenic: Based on polystyrene with simple small molecules (Butadiene).

Based on physical properties

Elastomers: They have the high elastic response, so they have resistance to permanent deformation by regaining its own shape.

Plastomer: They form a rigid, tough 3-D network to resist deformation and they exhibits plastic behavior

D. Type of polymer modification

Wet Process: Asphalt consist of three components asphaltenes, maltene and saturated hydrocarbons. Asphaltenes and maltene are responsible for bonding, stickiness Polymer have two interlocked phases and have long carbon chain length. When these polymers get mix with asphalt polymers get dominant and binder get non-dominant phases (Fig-1) [4]. Past studies concluded by addition of polypropylene in wet process increase the marshall stability up to 20 % as well as stiffness of bituminous mix. In wet mix optimum bitumen content will get decrease so cost of binder also get decrease [4][16]

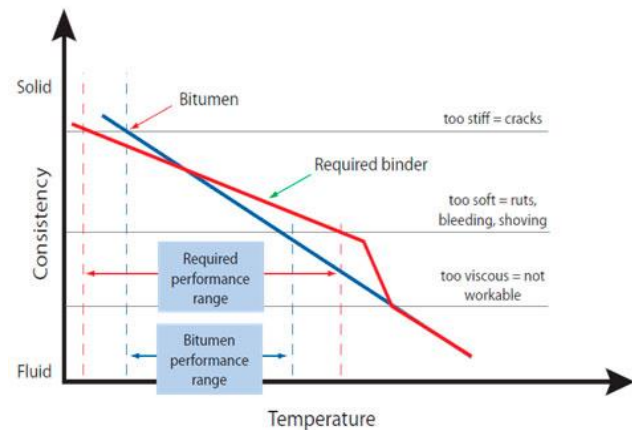


Fig -1 Behavior of binder at various point of temperature [6]

Dry Process: In this method polymers act the as surfacing agents and form a thin layer between binder and aggregate surface to improve coating ability. So, to increase the coating effect polymer is heated and mixed with aggregates like binder. The PP act as plastic and fibers i.e, PP can also act as binder in this type of mix. The results shown in dry process conclude the change in marshall properties of bituminous mix it decreases flow value, increase stability and fatigue life increase significantly [9][16].

III. RESEARCH METHODOLOGY

A. Materials

Materials used in this study include VG 30 grade of bitumen is obtained from Indian Oil Pvt Ltd from Chandigarh. The polypropylene granules from Reliance Petro Chemicals Pvt Ltd online. Aggregates including coarse, fine and filler aggregates were taken from local available crusher outskirts of Jalandhar, Punjab.

B. Sample Preparation

1) Polymer Modification Blend

Polymer contain long carbon chain length when bitumen(hydrocarbon) mixes with these polymers carbon chain length and carbon bonds get alter the physiochemical properties of bitumen [5]. So, the properties get change. It is possible only both bitumen and polymer get mix properly and form a homogeneous blend. For preparing these blends an shear mixer of 300 RPM @170oC for not less than 45 min required to prepare homogeneous blend.[12].

Table 4 Modified Binder test results as per IS-1203

PP %	Penetration	Ductility	Softening Point	Penetration Index
0	50	69	51	-0.95
1	45	69	52	-0.95
3	31	60	58	-0.44
5	24	52	65	0.32

2) Marshall Samples

Wet process: Additives added directly to binder and mix were prepared with that modified binders.

Dry Process: Additives added directly to aggregates while preparing mix.

Coarse aggregates, fine aggregates and fillers were taken from MoRTH 500 with nominal aggregate size the range of 13.2 mm. 1200 gm of aggregates and fillers was required to prepare one sample (Table 5). Trail mixes were prepared with 4.0%, 4.5%, 5.0%, 5.5% and 6.0 % bitumen by weight of aggregates. The aggregates and binder were heated at 150-165oC mix them properly and filled mold and 75 blows were given for the sample on both sides' samples kept for 24 hours and took weights and thickness and perform marshall stability test. Calculate and plot the required graphs for getting optimum bitumen content.

For modified bitumen mixing temperature and compaction temperature is higher than neat bitumen. While preparing wet & dry mixes the main consideration is temperature and homogeneous mix

Table 5 Aggregate gradation table

Aggregate Size	Range %	Adopted weight of aggregates(gm)
13.2	90-100	60
9.5	70-88	200
4.75	53-71	200
2.36	42-58	140
1.18	34-48	100
600	26-38	100
300	18-28	100
150	20-Dec	110
75	10-Apr	70
Filler		120

C. Laboratory

1) Bitumen

Viscosity Grade- 30 [10]

Basic Physical tests were conducted to meet the specifications according IS -1203 and IRC-SP-53 for modified binders.

Table 1 Test results of binder

Test	Results	Range & IS Code
Penetration Value	50 mm	50-60 /IS 1203
Ductility Value	69 mm	Min 40/ IS 1203
Softening Point	50 °C	Min 47 / IS 1205
Fire & Flash Point	300 & 250 °C	250 / IS 1448

2) Polypropylene

Polypropylene granules were purchased from Reliance Petrochemicals Pvt Ltd. It plays double role as plastic and fiber.

Table 1 Polypropylene properties

Properties	Value
Color	Transparent
Density	0.89 g/cm ³
Melting Point	150-165 °C

3) Aggregates

Well graded aggregates confirmed as per MoRTH [11]

Table 3 Aggregate test results

Test	Results	Range & IS Code
Impact Value	12.1 %	24 Max / MORTH
Abrasion Value	11 %	24 Max / MORTH
Water Absorption Value	0.45	2 % max/ MORTH
Flakiness and elongation Value	21 %	35 Max/ MORTH

4) Marshall Stability Test

By adopting gradation table-5 trail mix and modified mixes were prepared and tested as per AASHTO : T 245-97(2004).

IV. RESULTS AND DISCUSSION

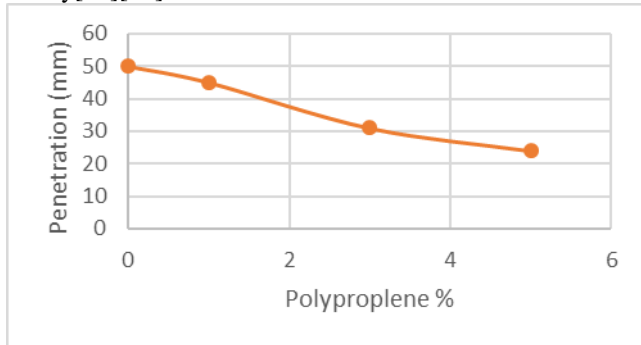
Primary test on binder and marshall stability on mix were conducted in order to characterize them as per standard codes. For binder physical tests like penetration, ductility and softening point were conducted and with obtained results penetration index value also calculated as per standard code of testing for binder.

For mixes marshall stability test was conducted as per AASHTO guidelines from that stability, flow, air voids, voids filled with aggregates / bitumen and density of mix were calculated.

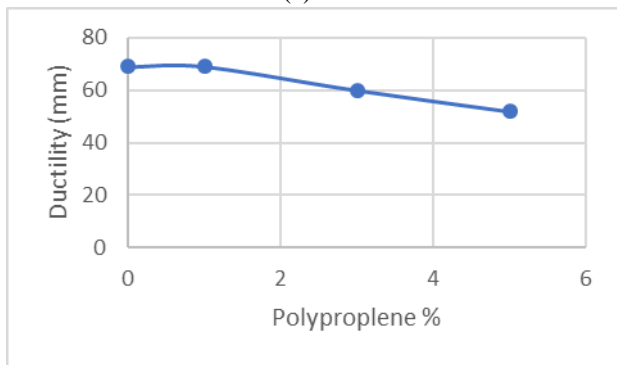


A. Modified Binder Characterization

Penetration and ductility; In Fig 2 (a) and (b) PP% vs Penetration and pp% vs ductility from 0(neat), 1%,3% and 5 % value's get have sharp decrease which is because of higher molecular content of polymer due to thermoplastic influence of these polymers the penetration value decreases and viscosity increased. The melting point of these polymer is between 150-165 °C so they absorb the lighter oils present in binder results in hardening of binder. This harden bitumen have good stiffness property, so it has good load spreading ability[17][19].



(a)

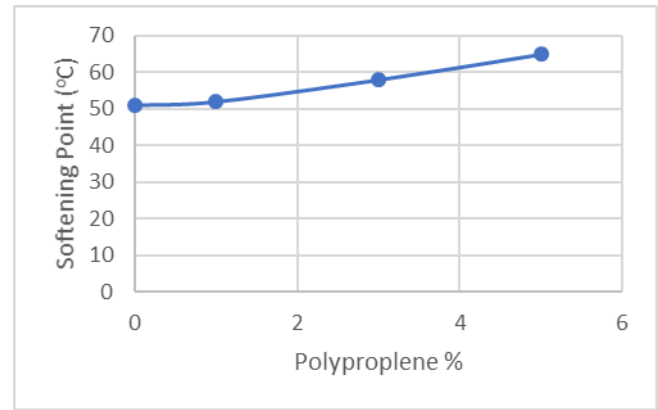


(b)

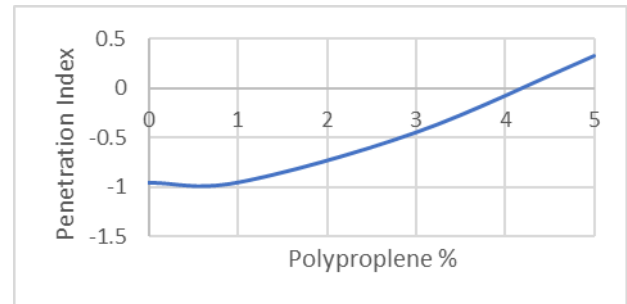
Fig -2 Penetration and ductility test results of modified binder with varied PP %

Softening Point From fig -3(a) PP% vs Softening Point the softening point before 3% does-not have any huge change compare to neat bitumen. So, it concludes that before 3% PP the modified binders are thermodynamically stable which is a positive sign to enhance the pavement performance in terms of rutting moisture susceptibility and fatigue. Homogeneity achieved at lower PP % with bitumen shows good storage stability and rutting resistance at higher temperature[18]

Penetration Index the PI value ranges between -3 (high temperature susceptible) to +7 (Low temperature susceptibility). From fig -3(b) results showing that PP % up to 3% are in -ve region i.e, high temperature susceptible at 5% PP the value rise in +ve region showing its falling in direction of low temperature susceptibility. The main objective of wet modification is to improve temperature susceptibility by increasing binder stiffness at higher service temperature and vice-versa



(a)



(b)

Fig-3 Softening and penetration index of modified binder with varied PP%

B. Mixes Characterization

Dry Process; from fig-4 (a) results shows that decrease in strength while increasing in bitumen content it is because of the polymer exist in 2 forms like plastic and fibers here Polypropylene due to its melting point (<150-165>) while mixing it melt with aggregates and turn like fibers and acting as fiber reinforcement to bituminous mix. If it is like so the utilization of bitumen gets decrease and issues with pollution also decrease so it decreases overall cost. The energy consumption for boiling binder also decrease which is almost half energy required to prepare mixes. If strength is higher the layer thickness also decreases so utilization of aggregates and corresponding cost and energy required also decrease simultaneously.

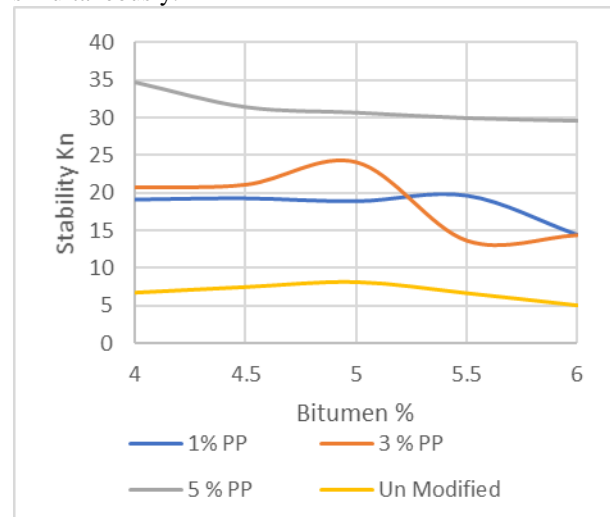


Fig -4 (a) Stability of dry mix with varied PP %

In wet Process the maximum strength have been achieved as the polymer content increased and meanwhile the binder content also get decrease from 1% to 3% and 3% to 5% max strength get achieved at 5.5,5.0 and 4.5 i.e, 0.5% binder content increase in every increase in PP content. Results explain that bitumen form homogeneous mix and it convert binder convert into PMB. So, the viscosity gets increases.

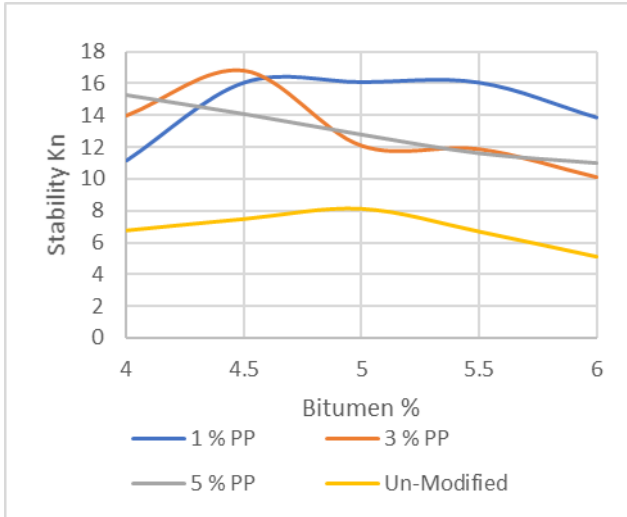


Fig-4(b) Stability of wet mix with varied PP %

From fig 5(a) PP@1% and 3% doesn't show any huge effect in VMA but PP@5% show slight variation in increasing trend. Here the polypropylene after 3% aggregates are no more accepting to make bond for further so remaining fiber polypropylene turn into plastic and fill the voids.

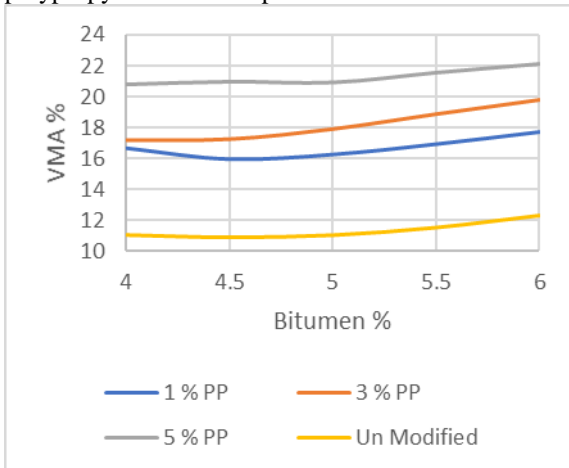


Fig 5 (a) VMA of dry mix with varied PP %

In wet process from fig 5(b) the binder content increase VMA also increase it is because of filler materials also get mix with binder and become thick material in the same way here as the viscosity increase with PP% the VMA also getting increase.

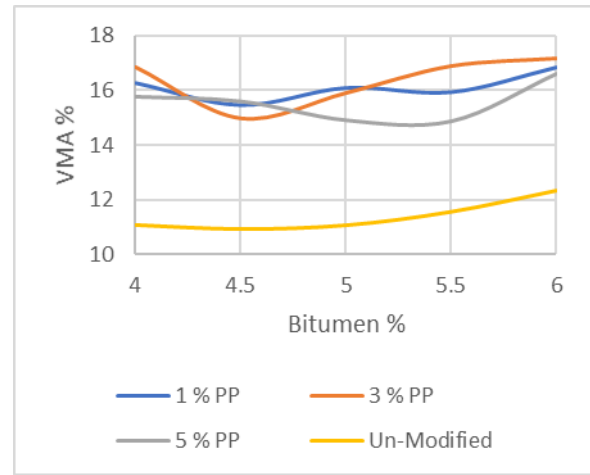


Fig 5 (b) VMA of wet mix with varied PP%

In wet process from fig 6(a) the binder content increase VMA also increase it is because of filler materials also get mix with binder and become thick material in the same way here as the viscosity increase with PP% the VMA also getting increase.

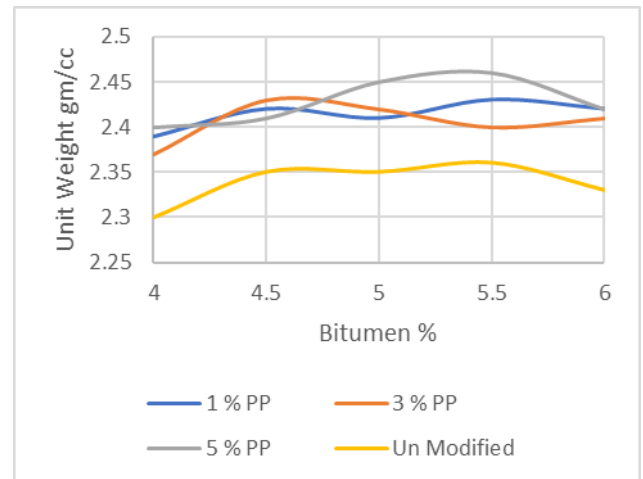


Fig 6 (a) Unit Weight of Wet mix with varied PP%

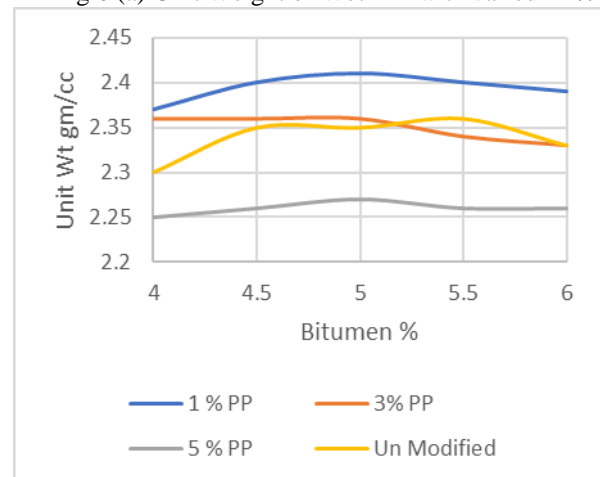


Fig 6 (b) Unit weight of dry mix with varied PP%

In dry process Polymer density is very low compare to normal aggregates so as the content increase the unit weight of the mix also getting decrease. From fig 6 (b) it's in decreasing curve comparatively high than in wet process it is because of the content in wet process PP% is by weight of binder and in dry process it by the weight of mix.

Slight variation is they're



with respect to neat binder because of change in binder viscosity making variation in wet process.

From fig 7 (a) The modified binder content increases the air voids content get decreasing i.e, the bitumen gets filling the air voids, so PP modified binder content increase the air voids get decrease and vice-versa.

From fig 7 (b) Air voids content increase with increase in PP content it is because of the finer particles get stick with Polypropylene and fill to fill the air voids.

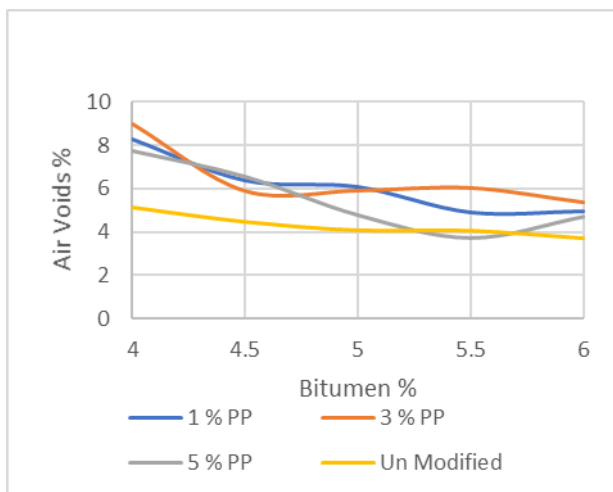


Fig 7 (a) Air Voids of Wet mix with varied PP %

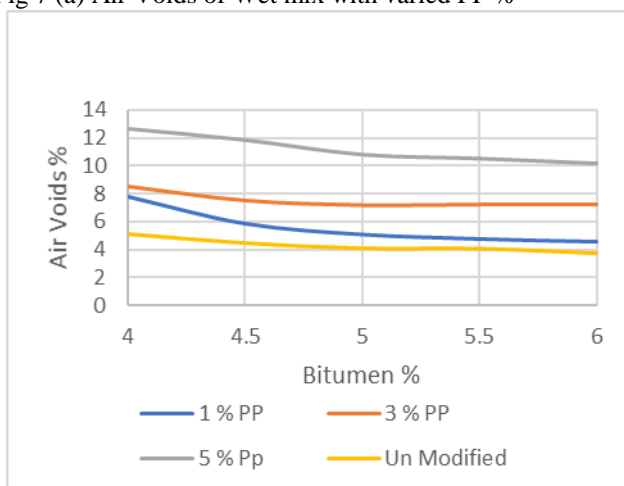


Fig 7 (b) Air Voids of dry mix with varied PP %

V. CONCLUSION

Softening point for modified binder shows that up to 3 % there is no thermodynamic changes occurring in the binder and for further increasing the changes occur due to the binder become polymer dominant phase from the test results 3 % PP is the optimum polymer content based on material properties and mix properties. Due to thermodynamically stable it has good storage stability (Up to 3% Wet Method) after that as PP% increase the storage stability get decrease.

In concern with cost dry method is far better than of wet mix. 5% PP dry method have better results than wet and

normal mix in terms of stability, unit weight etc. In terms of environment also dry method gives satisfactory results.

Density of mixes are in Normal < Wet < Dry method Overall performance of dry mix gives satisfactory results it is only possible if-and-only-if the mixing temperature should be between 150-165C and let PP melt with aggregate for minimum 5-10 min mixing is required before adding binder. But based up on the factors VMA and air voids dry method the values are too different in BC layer if same mix is done for DBM results may be good because of less fine aggregate content.

For dry method no special change in HMA plant required. With my observation I recommend dry process with 3% PP based up on the test because after that may be the strength increasing but in the meanwhile flow value also decreasing which leads to increase in stiffness of the mix, so mix become brittle.

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