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# EFFECT OF REDUCTION IN PRODUCTION TEMPERATURES ON PROPERTIES OF BITUMINOUS MIXES WITH AN ORGANIC WMA ADDITIVE

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## ABSTRACT

Warm mix asphalt (WMA) refers to the group of technologies that allow a considerable decrease in production, placement and compaction temperatures of bituminous mixes through the addition of organic additives, chemical additives or foaming processes. The use of modified binders in the bituminous courses has become common practice to sustain the high vehicular traffic, climatic variations, and heavy axle loads. This paper presents properties of bituminous concrete (BC) mixes at different additive contents and production temperatures for two modified binders (polymer modified, PMB, and crumb rubber modified, CRMB). WMA additive selected in the study belongs to an organic family. Statistical analysis is performed to analyse the effects of individual factors and their interactions on the test results. Results show that an increase in the additive content improves bulk density and Marshall stability of WMA mixes at all production temperatures. Warm mixes prepared with both binders (PMB and CRMB) were able to satisfy all the requirements set forth by MoRTH specifications of India up to 40°C reduction in production temperatures. Statistical analysis revealed that binder type, additive content, and reduction in production temperature significantly affect properties of BC mixes.

**KEYWORDS**: warm mix asphalt; modified binders; production temperature; organic additive

## INTRODUCTION

Hot mix asphalt (HMA) is being used as a high quality engineered paving material in the asphalt industry since many decades. It is a combination of aggregates, sand, or gravel bound together with bitumen, and is traditionally produced in a batch mix or a drum mix plant at production temperatures of around 150 to 170°C. These high production temperatures result in higher fuel consumption, higher emissions, shorter paving time, and unhealthy working conditions for paving personnel. WMA technologies gained importance since 2002 under the Kyoto protocol to address the issues of high fuel consumption and emissions during production of HMA. WMA refers to a number of processes and additives that help in reducing the production temperatures either by lowering viscosity of asphalt binder or by increasing workability of the mix. WMA mixes are produced and compacted at temperatures 20-50°C lower than those of HMA [1,2]. Due to lower mixing and compaction temperatures involved during mix production, WMA technologies offer various benefits such as low fuel consumption, longer hauling distances, reduced binder aging, quicker turnover to traffic, cool weather paving, low plant wear and tear, improved workability, and better working environment for the paving crew [3,4].

Traditionally, bituminous mixes in India are designed as per the Marshall method of mix design which includes evaluation of volumetric parameters, namely: density, air voids (AV), voids in mineral aggregates (VMA), voids filled with bitumen (VFB), and Marshall parameters: stability and flow. Mix volumetric elements play a major role in the durability of pavements. Mixing and compaction temperatures are one of the utmost important parameters that are responsible for delivering mix workability and the desired mix volumetric properties. Mixing temperature is the minimum temperature at which the binder viscosity allows complete coating of aggregates quickly and enables sufficient amount of asphalt absorption by the aggregates. The compaction temperature is the minimum temperature required to achieve the desired workability and in-place density. Excessively elevated mixing temperature may result in lean mixes, whereas, lower mixing temperature may provide poor bitumen coating around the aggregate [2]. Similarly, extremely higher compaction temperature causes lateral movement of mix during the compaction and drain down of the asphalt binder in some coarser mixes whereas, lower compaction temperature leads to poor compaction leading to inadequate densities.

Mixing and compaction temperatures are determined at viscosities of 170±20 cSt and 280±30 cSt respectively, as stipulated in Asphalt Institute Manual Series No.2. These viscosity ranges do not hold good for modified binders and often result in high mixing and compaction temperatures [5,6]. Mixing and compaction temperatures for modified binders are always higher than neat bonders resulting into higher fuel consumption and emissions. Therefore, use of WMA technologies for bituminous mixes with modified binders is more beneficial to reduce the production temperatures associated with modified binders.

However, reduction in production temperatures of HMA mixes with modified binders and WMA additives needs to be evaluated in order to ensure desired durability and performance of mixes. This study was instigated to determine the properties of warm bituminous mixes prepared with the use of an organic type WMA additive as a function of production temperature, percentage of WMA additive, and binder type. Different volumetric properties of warm mixes were evaluated and also compared with those of control mixes (without WMA additives) produced at standard mixing and compaction temperatures.

## MATERIALS AND EXPERIMENTAL PROGRAM

### Aggregates

Aggregates used in the study were procured from a local stone crusher plant in Assam, India. Aggregates were sieved and washed before use. Physical properties of aggregates were tested according to MoRTH [7] specifications and the test results are presented in the Table 1.

***Table 1. Physical properties of aggregates***

| Tests | Requirement | Result |
|---|---|---|
| Cleanliness test, % | Max. 5 passing 0.075 mm Sieve | 1.6 |
| Combined elongation and flakiness index, % | Max. 35 | 29.7 |
| Los Angeles abrasion value, % | Max. 30 | 27.0 |
| Impact test value, % | Max. 24 | 21.3 |
| Stripping value of aggregates, % | Min. retained coating 95 | 100 |

### Binders

Polymer modified bitumen (PMB) Grade 40 and crumb rubber modified bitumen (CRMB) Grade 60 used in the study were selected as per IRC: 111 [8] guidelines, based on climatic conditions prevalent in most regions of India. Both binders were tested for physical properties as per IRC SP:53 [9] specifications and the test results are reported in Table 2. The binders used in the study were provided by TikiTar Industries, Gujarat.

### WMA Additive

An organic type WMA additive, also known as Fischer-Tropsch (F-T) wax, was selected for the study. It is obtained from coal gasification process that has a fine crystalline structure with a long aliphatic polymethylene hydrocarbon having a chain length of C40 to C100 plus10,11. These long chains of F-T wax help in reducing the binder viscosity at typical asphalt mixing and compaction temperatures [12]. It has a melting point range of approximately 85°C to 115°C and is completely soluble at temperatures above 115°C. It forms a homogenous blend with the bitumen above its melting point and reduces the binder viscosity. As it cools, it crystallizes completely at 65°C and forms a regularly distributed, microscopic, stick-shaped particles in the binder (like a crystalline network structure), which leads to an additional stability and stiffness of binder and mixes [13]. Manufacturer recommended dosages of the additive are from 0.8% to 3.0% (by weight of the binder). In the present study, three dosage rates of the organic additive (1%, 2%, and 3%) by weight of binder were used.

### Design of Bituminous Concrete Mixes

Aggregate gradation conforming to bituminous concrete (BC) Grading-2 with 13.2 mm nominal maximum aggregate size (NMAS) as specified in MoRTH7 specifications was selected. Figure 1 shows the BC gradation used in the study along with upper and lower limits. Standard Marshall method of mix design, as recommended by Indian specifications (MoRTH7), was used for design of BC mixes. Mixing and compaction temperatures used for both modified binders are shown in Table 3, and were recommended by the binder manufacturer. After mixing the aggregates with bitumen, loose mixes were conditioned in forced air draft oven for 2 hours ± 5 minutes at their respective compaction temperatures following the AASTHO R30-02 [14] mix conditioning protocol. This conditioning represents the ageing of binder as well as absorption of bitumen into aggregate pores that occurs during production and paving of mix [15]. Automatic Marshall impact compactor was used to compact the loose conditioned samples with 75 blows on each side of the face. Three replicates were prepared at four bitumen contents (5.5%, 6%, 6.5%, and 7% by weight of mix) to determine the optimum binder content (OBC) for bituminous mixes without organic additive (designated as control mix). OBC was determined at 4% air void content and was found to be 6.2% for PMB mix and 6.6% for CRMB mix. Obtained properties of PMB and CRMB mixes at OBC and their requirements are shown in Table 4.

***Table 2. Physical properties of modified binders***

| Tests | PMB 40 | | CRMB 60 | |
|---|---|---|---|---|
| | Requirements | Results | Requirements | Results |
| Penetration at 25°C, 0.1 mm, 100g, 5 s. | 30 to 50 | 39 | <50 | 35 |
| Softening point, R&B,°C | Min.60 | 64 | Min.60 | 65 |
| Ductility at 27°C, cm | 50 | 61.6 | NA* | NA |
| Flash point by COC, °C | Min.220 | 300 | Min.220 | 320 |
| Elastic recovery of half thread in ductilometer at 15°C, % | Min.75 | 76.5 | Min.50 | 68 |
| Separation difference in softening point, R&B, °C | Max.3 | 1.9 | Max.4 | 2.9 |
| Viscosity at 150°C, poise | 3 to 9 | 7.85 | NA | 8.90 |
| Thin Film Oven Test (TFOT) Residue | | | | |
| Loss in weight, % | Max. 1 | 0.62 | Max. 1 | 0.56 |
| Increase in softening point, °C | Max. 5 | 4.1 | Max. 5 | 3.5 |
| Reduction in penetration of residue, at 25°C, % | Max. 5 | 4.1 | Max. 5 | 3.5 |
| *Note: * NA– Not Applicable* | | | | |

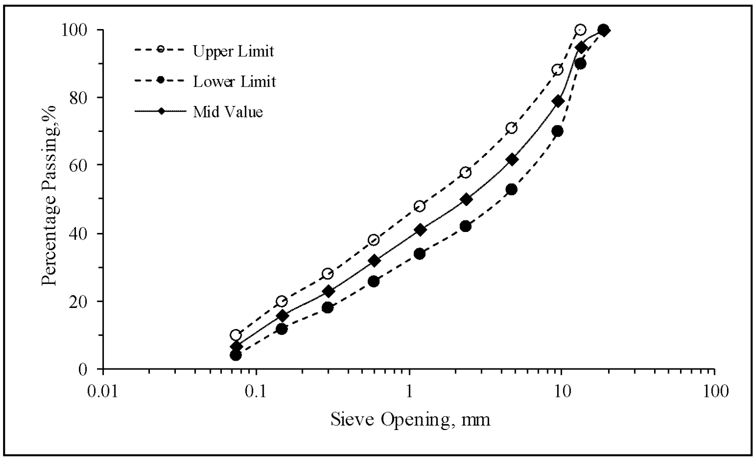


***Figure 1. Aggregate gradation selected for BC mixes***

***Table 3. Mixing and compaction temperatures of modified binders***

| Binder type | Mixing temperature, °C | Compaction temperature, °C |
|---|---|---|
| PMB | 170 | 160 |
| CRMB | 175 | 165 |

***Table 4. Marshall parameters of bituminous mixes at OBC***

| Specifications | Requirements as per MoRTH[7] | Results | |
|---|---|---|---|
| | | PMB 40 | CRMB 60 |
| OBC, % | - | 6.2 | 6.6 |
| Marshall stability at 60°C, kN | Min. 12 | 17 | 19 |
| Flow, mm | 2.5 – 4.0 | 3.5 | 3.9 |
| Voids filled with bitumen (VFB), % | 65 – 75 | 73.9 | 74.5 |
| Air voids (AV), % | 3.0 – 5.0 | 4.0 | 4.0 |
| Voids in mineral aggregate (VMA), % | Min. 14.0 | 15.6 | 15.7 |
| Bulk density (g/cc) | - | 2.321 | 2.325 |

### Preparation of Warm Mixes

Prior to preparation of warm mixes, warm asphalt binders were prepared. Binders were preheated to temperatures around 120°C in a temperature controlled oven and then the required dosage of organic WMA additive was added and mixed thoroughly for 15 minutes using mechanical stirrer to achieve a homogenous blend. Prepared warm asphalt binders were stored and were subsequently used for preparation of warm mixes. Warm mixes were prepared by lowering the mixing and compaction temperatures by 20°C, 30°C, and 40°C from the standard mixing and compaction temperatures (shown in Table 3). Warm mixes were also prepared at standard production temperatures (0°C reduction) same as that for control mixes for one-to-one comparison. Three samples were prepared for each combination of additive dosage and production temperature.

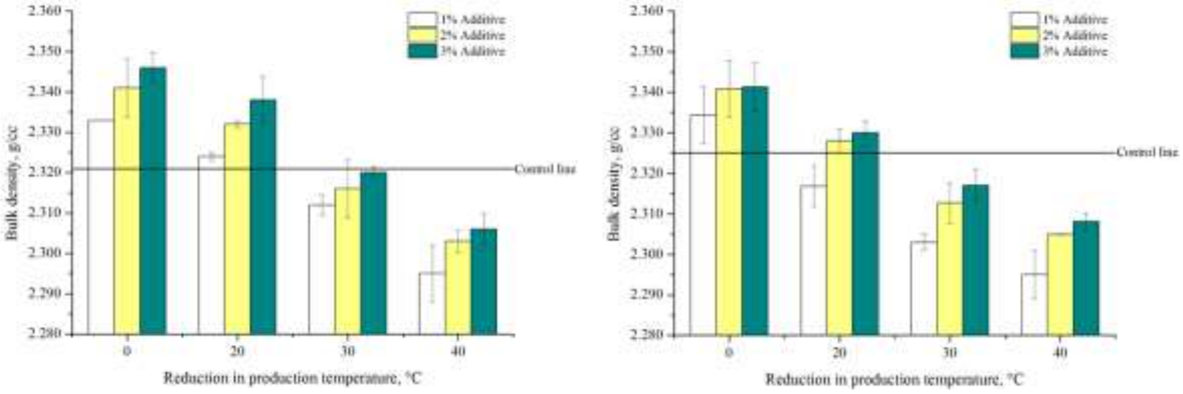
### Statistical Analysis

Analysis of variance (ANOVA) was performed to understand the influence of individual factors (main effects) and their interactions on the response variables: bulk density and Marshall stability. The individual factors or independent variables used for the analysis were binder type, additive content, and reductions in production temperature. ANOVA was carried out at 95% confidence level using SPSS software.

## RESULTS AND DISCUSSION

### Volumetric and Marshall Parameters of Warm Mixes

Bulk density of PMB and CRMB warm mixes with different additive dosages and production temperatures are depicted in Figure 2(a) and 2(b). Bulk densities of both PMB and CRMB warm mixes are found to be higher than their respective control HMA at standard production temperature. This shows that addition of organic WMA additive helps to increase the workability of mix by decreasing the internal resistance of mix during compaction. As production temperature decreases, the workability of warm mixes decreases due to increase in viscosity of binder which results in lower bulk densities. Bulk density of PMB and CRMB warm mixes with 2% and 3% dosage at 20°C reduction in production temperature are found to be greater than their respective control mixes. Hence, it can be inferred that mixes modified with organic additive can achieve desired density at lower production temperatures compared to their respective control mix.



(a)

(b)

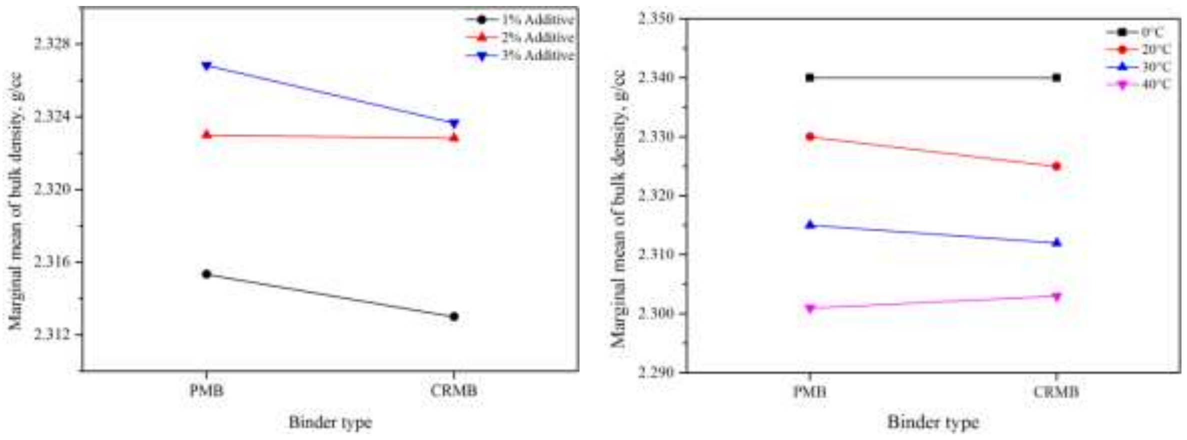
*Figure 2. Bulk density results of warm mixes: (a) PMB (b) CRMB*

Further, it is observed that increase in additive dosage actually improved bulk density of mixes at all production temperatures. An increase in additive content from 1% to 2% exhibited greater effect in improvement of bulk density values as compared to increase from 2% to 3%. This effect is found to be even more pronounced at reduced production temperatures. In regard to binder type, bulk densities of PMB warm mixes are found to be higher than CRMB warm mixes at all production temperatures at same additive content. This might be due to low viscosity of PMB binder compared to CRMB.

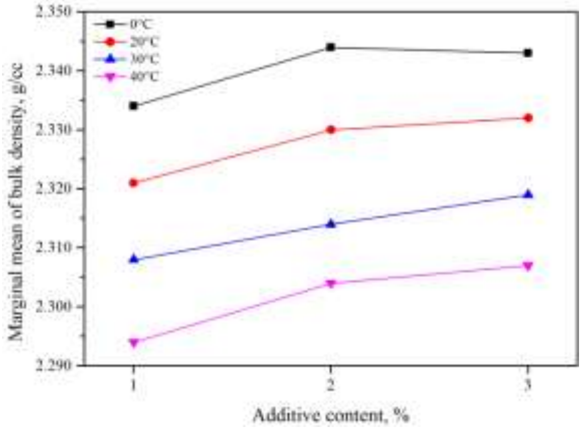
Results of statistical analysis performed on bulk density values are presented in Table 5. The main effects of all three individual factors (binder type, additive content, and reduction in production temperature) are found to be statistically significant at 5% significance level. This implies that all three factors have substantial effect on the bulk density results. Among all the interactions, interaction between binder type and reduction in production temperature is found to be statistically significant. This implies that effect of reduction in production temperature on the bulk density results is governed by the type of binder used in the study and vice-versa. The interaction plots between any two independent factors are also presented in Figure 3 to understand the effects of interaction on the bulk density results. A non-significant two-way interaction between binder type and additive content shows that the effect of additive dosage has been the same for each binder type, as it is observed that PMB bulk densities are consistently higher than CRMB bulk densities. Further, the effect of additive content remains the same at each reduction in production temperature, which is seen from non-significant two-way interaction between additive content and production temperature. However, from the Figure 3, it can be clearly state that increase in the additive content and production temperature increases the bulk density values with both binders.

***Table 5. Results of ANOVA***

| Factor | Bulk density | Marshall stability |
|---|---|---|
| | p-value, S/NS | p-value, S/NS |
| Binder type | 0.019, S | <0.001, S |
| Additive content | <0.001, S | <0.001, S |
| RPT | <0.001, S | <0.001, S |
| Binder type * Additive content | 0.278, NS | 0.260, NS |
| Binder type * RPT | 0.003, S | <0.001, S |
| Additive content * RPT | 0.512, NS | 0.349, NS |
| Binder type * Additive content * RPT | 0.388, NS | 0.066, NS |
| Adjusted $R^2$ | 0.956 | 0.957 |
| Note: 'RPT'—*Reduction in production temperature;* 'S'—*Significant difference*; 'NS'—*Non-significant difference* | | |



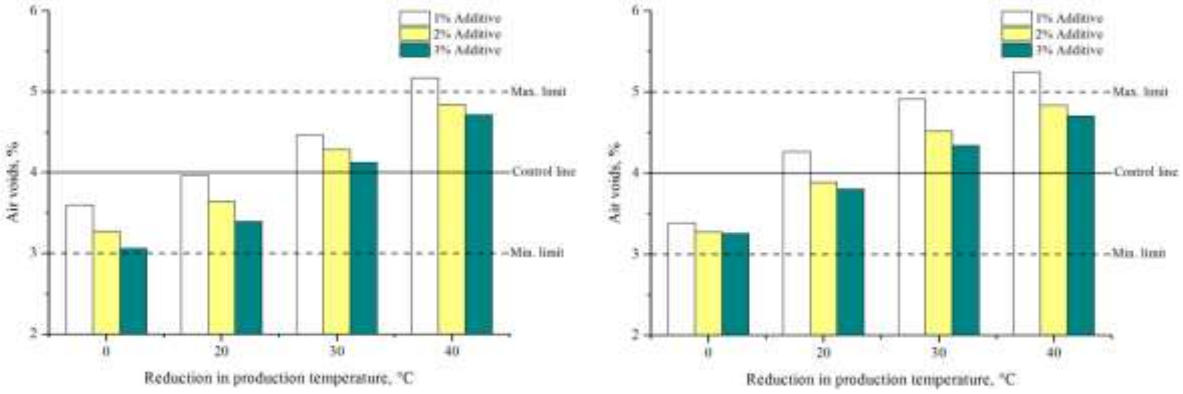
(a) (b)



(c)

*Figure 3. Interaction plots for bulk density (a) binder type vs. additive content; (b) binder type vs. RPT; (c) additive content vs. RPT*

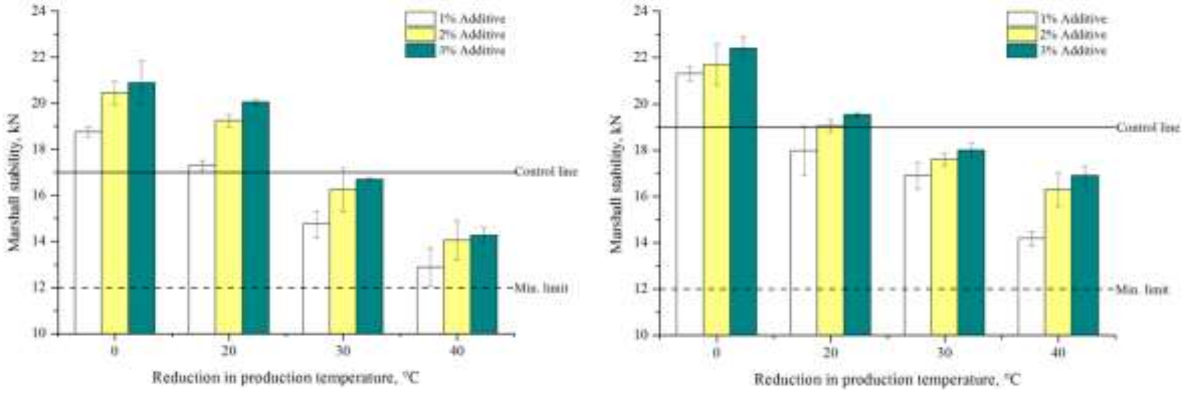
Air void content of PMB and CRMB warm mixes are illustrated in Figure 4. Air void content of warm mixes increases with decrease in mixing temperature. This is expected as the increase in viscosity of binder due to reduced production temperature will reduce compactability of mixes. A similar trend was observed by Akisetty [16] for the air voids of mixes containing Aspha-min and Sasobit WMA additives. Air voids of warm mixes are found to decrease with increase in organic additive content, nonetheless meeting the criteria of 3-5% required as per MoRTH [7], except the warm mixes produced with 1% additive at 40°C reduction in production temperature. From the trends of air voids values of warm mixes with 2% and 3% additive, it can be identified that designed air void content (4%) for control mix can be achieved for warm mixes after reducing the production temperatures in between 20°C to 30°C. This shows that addition of organic additive helps in enhancing the compactability of mixes with the same compaction effort even at lower production temperatures.



(a) (b)

*Figure 4. Air voids results of warm mixes: (a) PMB (b) CRMB*

Marshall stability of PMB and CRMB warm mixes obtained with different dosages of organic additive at different production temperatures are shown in Figure 5. In general, it is observed that stability values of both warm mixes decrease with decrease in the production temperatures and increases with increase in additive percentage. The reduction in the Marshall stability can be explained by weakening of mass viscosity of aggregate–bitumen mix due to reduced stiffness of binder at lower production temperatures; and may be also due to reduction in bulk density of mixes which can be observed from Figure 2. Moreover, addition of small amount of organic additive (1%) resulted an increase in the Marshall stability at 0°C reduction in production temperature, with a value of 18.8 kN for PMB warm mix and 21.3 kN for CRMB warm mix against with their corresponding control mix values of 16.9 kN and 19.3 kN respectively. The increase in the Marshall stability can be described by the formation of lattice crystalline structure in the binder, which add-on extra stability to binder at pavement service temperature (typically at 60°C).

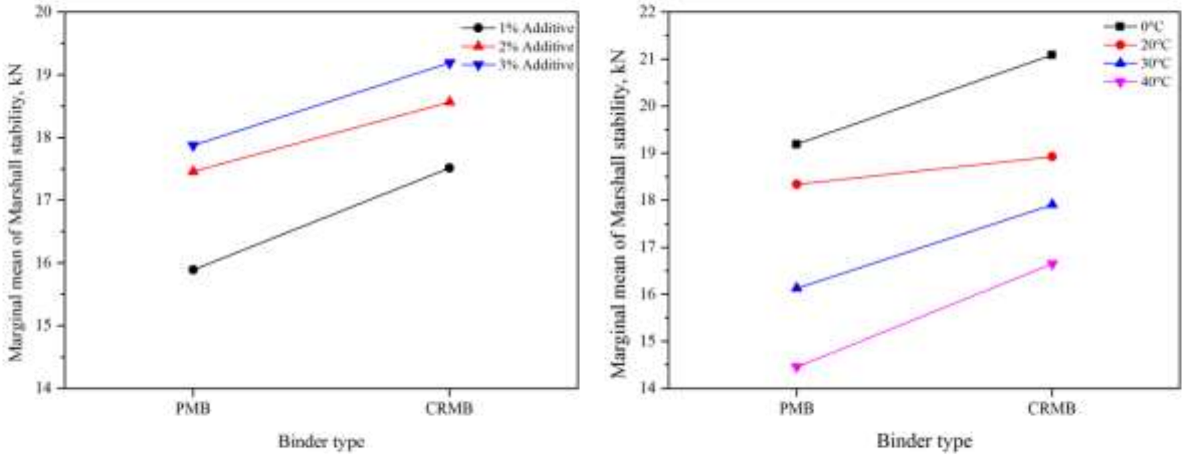


(a) (b)

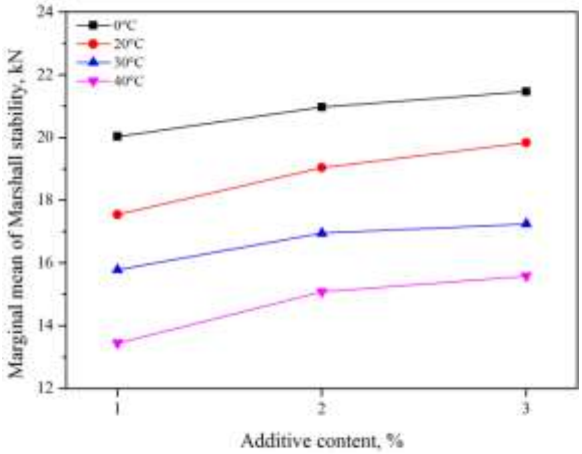
*Figure 5. Marshall stability results of warm mixes: (a) PMB (b) CRMB*

An increase in additive content from 1% to 3%, increased the Marshall stability of PMB and CRMB warm mixes by 11% and 19% respectively, even at maximum reduction in production temperature (40°C). This effect is due to increase in stability of binder drawn from the crystalline lattice structure developed inside the binder, which is more prominent with increase in organic additive dosage. In regard to binder type, Marshall stability of CRMB warm mixes are greater than PMB warm mixes due to higher viscous nature of CRMB binder. Also, Figure 5 indicate that Marshall stability of all warm mixes satisfy the minimum requirement of 12 kN set forth by MoRTH [7], at all production temperatures.

Results of statistical analysis performed on Marshall stability values are presented in Table 5. A strong statistical evidence (p-value <0.001) showed that all the main effects of all factors have significant effect on the test results of Marshall stability. Among all the interactions, interaction between binder type and reduction in production temperature is found to be statistically significant. This finding reveals that effect of binder type on the Marshall stability results values is governed by the level of reduction in the production temperature considered and vice-versa. Interaction between binder type and additive content, and additive content and reduction in production temperature is found to be statistically insignificant, which can be also observed from the interaction plots shown in Figure 6(a) and 6(c). This shows that the organic additive behaves similarly with any type of binder and level of reduction in production temperature used in the study. From Figure 6, it can be clearly observed that increase in the additive content and production temperature increases the Marshall stability values with both binders.



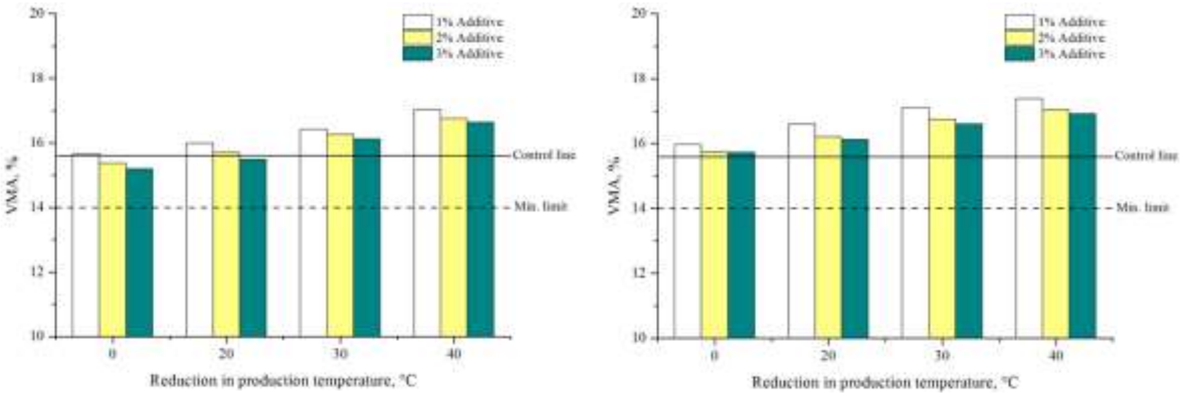
(a) (b)



(c)

***Figure 6. Interaction plots for bulk density (a) binder type vs. additive content; (b) binder type vs. RPT; (c) additive content vs. RPT***

Figure 7 and 8 explain the trends of VMA and VFB of warm mixes. It is observed that reduction in production temperature increases the VMA. However, VMA is found to reduce with increase in additive dosage at any production temperature. This might be due to improved compactability achieved and consequent denser configuration attained by the aggregates with the increase in additive content. The minimum VMA requirement of 12% is met for all warm mixes. An increase in air voids with decrease in production temperatures should decrease VFB, which is indeed observed in Figure 8. VFB values of warm mixes produced at 30°C and 40°C are able to lie within the required range of 65 – 75%.



(a) (b)

***Figure 7. VMA results of warm mixes: (a) PMB (b) CRMB***

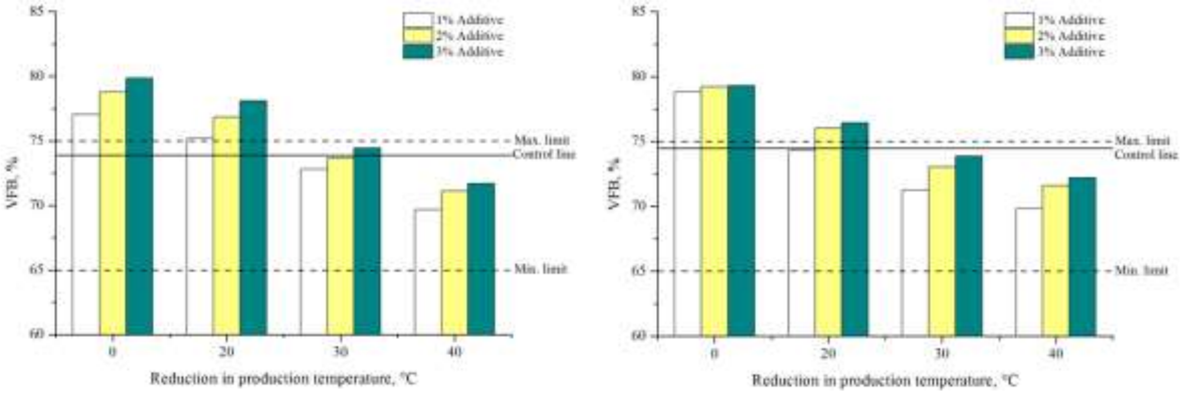
## CONCLUSION

The present study was conducted to investigate the effect of an organic WMA additive content and production temperature on the Marshall mix design parameters and properties of bituminous mixes with two types of modified binders. Mix volumetrics and Marshall parameters of warm mixes were evaluated and compared with control mix. Based on results, the main conclusions drawn from the study are:

1. Bulk density and Marshall stability of warm mixes were found to increase at standard production temperature with the addition of organic additive.
2. Design air void content (4%) for control mix can be achieved for warm mixes containing 2% and 3% additive after reducing the production temperatures by 20°C to 30°C.
3. Marshall stability of warm mixes were comparable to those of control mix after reduction in production temperature up to 20°C. Moreover, Marshall stability of warm mixes with both modified binders were higher than minimum specified value of 12 kN at all production temperatures.
4. An increase in the additive content improved the bulk density and Marshall stability at all production

temperatures.

5. WMA mixes with both PMB and CRMB produced at 30°C and 40°C were able to satisfy all the requirements set forth by MoRTH [7] specifications for BC mixes.
6. Statistical analysis showed that the factors considered in the study (binder type, additive content, and reduction in production temperature) had significant effect on bulk density and Marshall stability of the mixes.
7. Interaction between binder type and reduction in production temperature significantly affect bulk density and Marshall stability of the mixes. This finding shows the importance of careful selection of binder type and reduced production temperature for a given WMA additive and its content.



(a) (b)

*Figure 8. VFB results of warm mixes: (a) PMB (b) CRMB*

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