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EVALUATING THE EFFECTS OF MINERAL FILLER ON THE VOLUMETRIC PROPERTIES OF HMA MIXTURES BASED ON SUPERPAVE MIX DESIGN SPECIFICATIONS

Al-Bayati, Hanaa Kh[1,3], Tighe, Susan[2]

[1] PhD Candidate, Centre for Pavement and Transportation Technology (CPATT), Department of Civil and Environmental Engineering, Faculty of Engineering, University of Waterloo, Waterloo, Canada

[2] PhD, PEng, Deputy Provost and Associate Vice-President Integrated Planning and Budgeting, Canadian Society for Civil Engineering, Norman W. McLeod Professor in Sustainable Pavement Engineering, Department of Civil and Environmental Engineering, Faculty of Eng., University of Waterloo, Canada

[3] halwan@uwaterloo.ca

Abstract: Volumetric properties of hot mix asphalt (HMA) are necessary requirements to ensure good performance for asphalt mixtures. However, volumetric properties appear to be directly influenced by various factors including the mixture grading, aggregate surface characteristics and compaction energy. This research is conducted to evaluate the influence of mineral filler on the volumetric properties of HMA. Two types of mineral fillers with three filler percentages were chosen to examine the effect of filler on various volumetric properties including voids in mineral aggregates (VMA), voids filled with asphalt (VFA), dust to binder ratio (Dp), and others. The obtained results indicated that the optimum asphalt binder content, VMA, and VFA decrease as the filler content is increased. Compared to other volumetric properties that were reduced when filler content increased, Dp proportion behaved inversely for both filler types in which Dp proportion increases when the filler content is increased. HMA mixtures that includes dust plant filler had the higher values of VMA, VFA, and optimum asphalt content (OAC) compared to the hydrated lime. The addition of filler with 2.5% percentage is very successful for both filler types due to satisfying all Ministry of Transportation Ontario (MTO) requirements for volumetric properties of HMA. Based on MTO specifications, the addition of 2.0% filler seems to be unsuccessful for both filler types due to lowering the Dp ratio. Mix design with 3.0% filler was also unsuccessful because of the lower value of OAC meaning that the mix is dry and there is insufficient asphalt binder to coat the aggregate particles.

1 INTRODUCTION

It is generally accepted that asphalt concrete (AC) is a heterogeneous material that is fundamentally composed of various constituents: asphalt cement, natural or artificial aggregate, mineral filler, additives, and air voids. To achieve a desirable performance for the asphalt mixtures, the volumetric properties of pavement mixes are utilized. Currently, the volumetric properties of asphalt mixtures can be categorized into two main groups: primary and secondary volumetric parameters (Dos Santos et al. 2013). While the primary volumetric parameters are directly related to the relative volumes of the individual constituents of asphalt mixtures: aggregates volume (Vs), air voids (Va), and asphalt binder volume (Vb), secondary volumetric parameters commonly referred to as volumetric properties of mixtures are Void Volume (Vv), Voids in Mineral Aggregates (VMA), and Voids Filled with Asphalt (VFA). Depending on the primary volumetric parameters, secondary volumetric parameters can be determined. The terminology of volumetric properties for the components of a compacted asphalt mixture can be found in Figure 1.

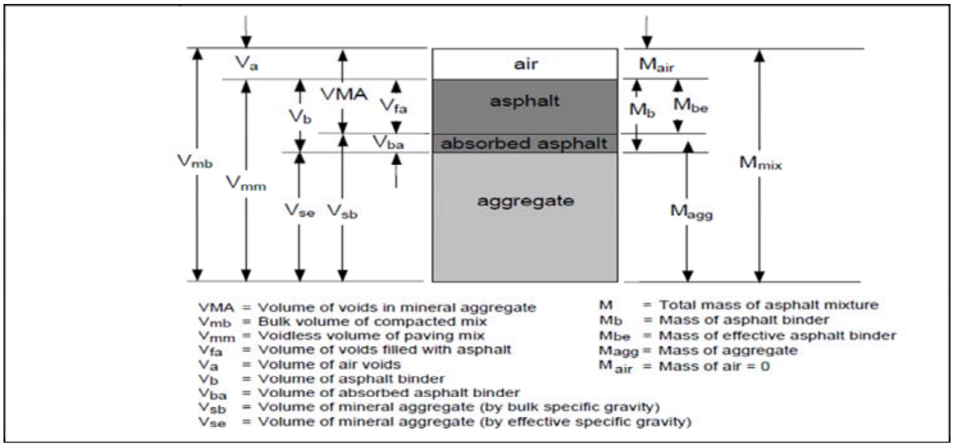

Figure 1: Components of a compacted HMA specimen (Hislop 2000, Huner & Brown 2001)

Marshall and Superpave methods are the common methods used in asphalt mixture design and incorporate volumetric criteria that mathematically calculated from the volumetric proportions of the constituent materials of the mixtures. In detail, the methods determine the optimum asphalt binder using HMA volumetric properties (Vv, VMA and VFA). Additionally, Superpave method can evaluate the filler content in the mixture and the percentages of initial and maximum compaction as a function of the number of gyrations in the Superpave Gyratory Compactor (SGC) (Dos Santos et al. 2013). In Superpave, a volumetric mix design protocol was established with limits on all three volumetric parameters (Hislop 2000). Depending on the mixture's nominal maximum size (NMS) and traffic volume, Superpave method establishes minimum values of VMA, and minimum and maximum values of the VFA as shown in Table 1.

Table 1: Superpave HMA volumetric properties (OPSS 1151 2007)

Traffic* Category (Note 1)	% of Theoretical Maximum Specific Gravity			Voids in Mineral Aggregate (VMA) % Minimum						Voids Filled with Asphalt (VFA)	Dust to Binder Ratio (Note 3)	Minimum Tensile Strength Ratio %
				Nominal Maximum Aggregate Size mm								
	$N_{initial}$	N_{design}	N_{max}	3.75	25	19	12.5	9.5	4.75			
A	91.5	96.0	98.0	11.0	12.0	13.0	14.0	15.0	16.0	70-80 (Note 4)	0.6-1.2	80.0
B	90.5									65-78		
C	89.0									65-75 (Note 5)		
D												
E												

Notes:

1. Traffic category as specified in the Contract Documents.
2. For Traffic Categories C, D, and E Superpave 9.5 mixes shall have a VFA range of 73 to 76%, while Superpave 4.75 mixes shall have a VFA range of 75 to 78%.
3. For Superpave 4.75 mixes, the dust-to-binder ratio shall be 0.9 to 2.0. Superpave mixes with gradation that pass beneath the PCS Control Point in Table 4, the dust-to-binder ratio shall be 0.8-1.6.
4. For Traffic Category A, Superpave 25.0 mixes shall have a VFA range of 67 to 80%
5. Superpave 37.5 mixes shall have a VFA range of 64 to 75%.

*The design equivalent to a single-axle load ranged (ESALS) for: A= Less than 0.3 million, B= 0.3 to 3 million, C= 3 to 10 million, D= 10 to 30 million, E= > 30 million.

2 LITERATURE REVIEW

It is generally agreed that a portion of aggregate that is suspended and freely discrete from aggregate particles in an asphalt binder can be known as a mineral filler. Based on this, it is reasonably postulated that mineral filler cannot be considered as aggregate or as a single component in a mixture; therefore, it is equitably counted as an integral component of mastic which is generally described as an actual binder for a mixture (Anderson & Bahia 1997, Remisova 2015). Additionally, due to its very small size, a filler is viewed as a fine material that has an ability to modify and enhance the properties of the asphalt-concrete mixture; and therefore, the filler appears to be a modifier and is not considered as a part of aggregate gradation (Zulkati et al. 2011).

Due to the diverse influence of filler addition on asphalt mixtures, numerous studies have investigated various aspects related to this influence and these aspects can be fundamentally classified into two main categories. The first category mainly includes the influence of filler addition on the asphalt mixture's performance. It was found that the addition of higher filler concentrations leads to strong mixtures. This was mainly attributed to better asphalt cohesivity and good stability that was obtained from a good packing distribution of the filler (Zulkati et al. 2011). The addition of lime as a filler can improve the resistance of hot mix asphalt mixtures to moisture damage, reduce oxidative aging, improve the mechanical properties and resistance to fatigue and rutting, and enhance the asphalt-aggregate bond (Dos Santos et al. 2013, Epps & Little 2001, National Lime Association 2006, Sutradhar et al. 2015). The second category is extensively focused on the influence of filler on the asphalt binder or mastic properties. It has been previously concluded that the presence of filler is highly related to a reduced optimum asphalt content (Tayebali et al. 1998, Muniandy et al. 2013, Brown et al. 1989, Kandhal et al. 1998). Mineral filler in hot mix asphalt plays a significant role in stiffening and toughening an asphalt binder. It seems to be responsible for improving adhesion of bitumen to aggregate (Sutradhar et al. 2015). In the perspective of volumetric properties, (Dos Santos et al. 2013) explored the influence of filler type and content on HMA volumetric parameters. The findings of the research revealed that VMA and VFA decrease as the filler content increases. It was concluded that lower values of VMA and VFA generally refer to the existence of thin asphalt film.

While comprehensively scanning the literature related to the filler addition into the asphalt mixtures, it should be noted that investigation of its impact on the volumetric properties of the asphalt mixtures is rarely found in the relevant literature. As many investigations were primarily limited in assessing the performance of asphalt mixtures that included mineral filler proportions, only one characteristic; namely, optimum asphalt content that can be counted as a volumetric property was evaluated (Muniandy et al. 2013, Patil et al. 2016). Additionally, as a part of the Marshall mix design, the relationship between asphalt binder content and some volumetric properties such as VMA and VFA were examined (Rahman et al. 2012, Kar et al. 2014, Sutradhar et al. 2015, Priyanka et al. 2015, Patil et al. 2016). To the best of the authors' knowledge, none of the literature studies mentioned above have ever explored the effect of filler on the volumetric properties according to the Superpave mix design. Therefore, this paper is a comprehensive study that mainly aims to investigate the influence of filler types with various proportions on various volumetric properties based on the Superpave mix design of HMA. Based on Superpave specification standards, asphalt mixtures were designed with 19 mm nominal maximum aggregate size (NMAS) and one binder type; namely, PG 64-28. To achieve this goal, two different types of mineral fillers that commonly utilized for preparing asphalt mixtures were used; namely, dust plant (DPt) and hydrated lime (HL) of various proportions (2%, 2.5%, and 3%) were chosen to examine the influence of mineral fillers on various volumetric characteristics including VMA, VFA, dust to binder ratio (Dp), and others.

3 MATERIALS AND METHODS

3.1 Materials

Natural aggregate (NA), and hydrated lime (HL) and dust plant (DPt) that are used as fillers in HMA were obtained from Miller Group company. The obtained sieve analysis of NA, targeted mix design, and MTO specifications are given in Figure 2. Table 2 shows some physical and mechanical properties of NA. The optical images of NA, DPt, and HL are shown in Figures 3-5, respectively.

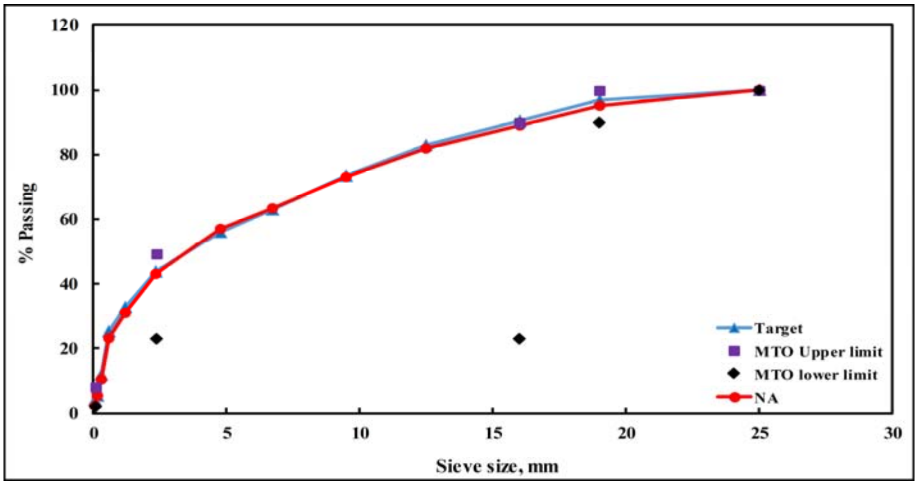

Figure 2: Particle size gradations of NA

Table 2: Physical and mechanical properties of NA

Aggregate type	Bulk relative density (BRD) (ASTM C 127)	Absorption wt.% (ASTM C 127)	Micro-deval abrasion loss, wt.% (ASTM D6928)	Fractured particles, wt.% (ASTM D5821)	Aggregate crushing value test (ACV) (BS 812-110)	Flat & elongated, wt.% (LS-608)	Freezing & thawing (LS-614)
NA	2.658	0.85	15.89	95.5	19.48	0.95	17.4

Figure 3: Optical image of NA

Figure 4: Optical image of HL

Figure 5: Optical image of DPt

3.2 Methods

3.2.1 HMA Superpave Mix Design

HMA Superpave mix design was performed according to AASHTO R 30-2 2010. A 19-mm Superpave® gradation designed for a road volume ranged between 10 and 30 million was utilized with an unmodified Performance Grade (PG) 64-28 binder. The main characteristics of the design procedure can be simply explained in the following brief descriptions. The design gyration level (N_{des}) was 100, whereas the maximum gyration level (N_{max}) was 160. The viscosity of 1.7 Poises and 2.8 Poises were established to define the mixing and compaction temperatures, respectively. The mixing temperature was 163°C, whereas compaction temperature was 150°C. Compaction was performed by using a Superpave gyratory compactor as shown in Figure 6. An optical image for the samples after compaction is presented in Figure 7.

Figure 6: Superpave gyratory compactor

Figure 7: Samples after compaction

4 RESULTS AND DISCUSSION

4.1 Aggregate Blends with Filler

As mentioned earlier, Superpave mix design was performed according to AASHTO R 30-2 2010. For filler addition, three proportions (2%, 2.5%, and 3%) were used to determine the mix blend. The mix blend that included two filler types with various proportions is given in Table 3.

Table 3: Mix design blend with filler

Filler content, %	Aggregate type, %			
	CA#1, HL8 stone	CA#2, ¼ chip	FA#1, Manufactured sand	FA#2, Blend sand
2.0	40	12	36	10
2.5	40	12	35.5	10
3.0	40	12	35.0	10

CA = Coarse aggregate, FA = Fine aggregate

4.2 Volumetric Properties of Asphalt Mixtures Including Filler

The laboratory data on the volumetric characteristics for HMA mix design with filler addition is tabulated in Table 4. More details on the results of the volumetric properties are discussed in the following sections.

Table 4: Mix design volumetric for different filler percentages

Filler type / Property	Dust plant, %			Hydrated lime, %		
	2.0	2.5	3.0	2.0	2.5	3.0
OAC (%)	4.9	4.83	4.54	4.81	4.79	4.26
VMA (%)	14.65	14.5	13.4	14.5	14.2	13.2
VFA (%)	72.69	72.50	70.10	72.30	72.00	69.50
Dp	0.43	0.6	0.8	0.47	0.6	0.8
Gmm N initial (%)	88.56	88.60	88.30	88.01	88.02	88.03
Gmm Ndes (%)	96.0	96.0	96.0	96.0	96.01	96.0
Gmm Nmax (%)	97.3	97.10	97.19	97.21	97.22	97.00
G_{mb}	2.398	2.40	2.425	2.401	2.407	2.423
G_{mm}	2.498	2.50	2.526	2.501	2.507	2.524

4.2.1 Optimum asphalt content

The optimum asphalt binder content in HMA with two different filler types is graphically analyzed in Figure 8. The obtained results revealed that a comparable performance that can be represented as an exponential equation for both filler types is registered. It is observed that the optimum asphalt binder content decreases when the filler percentage is increased. This behaviour can be mainly attributed to the fact that an increase in the filler amounts can lead to filling the voids that generally exist between aggregate particles, resulting in a reduction of the voids in the mineral aggregate. Therefore, the available space for asphalt binder is decreased (Mehari 2007). However, it is noteworthy that a considerable decrease in the optimum asphalt binder content is highly noticeable when filler content is increased from 2.5% to 3% for both filler types. Additionally, the results demonstrated that the HL with different percentages have a lower OAC than the DPt.

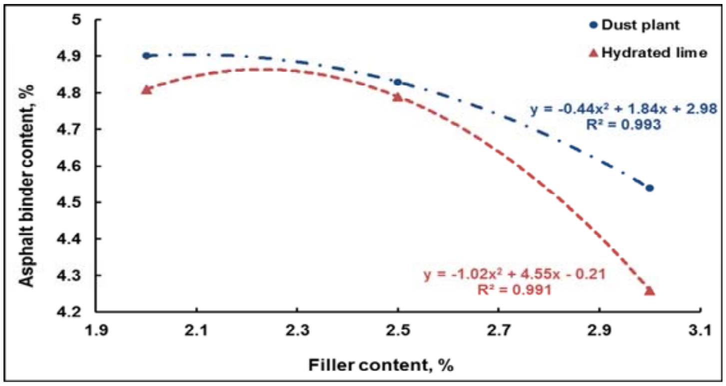

Figure 8: Optimum asphalt content

4.2.2 Voids in mineral aggregates (VMA)

Figure 9 illustrates the effect of filler types with different percentages on VMA of HMA mix design. It was demonstrated that an increase in filler content can lead to a decrease in VMA of the mixture for both filler types. The lowered VMA value could possibly indicate the existence of a thin asphalt film around the aggregate particles. It has been previously found that the utilization of high amounts of filler produces a thin asphalt film which could be more likely to be a detrimental factor with regards to mixture durability (Dos Santos et al. 2013). The findings also indicate a slight variation between two different filler types on VMA. This could be possibly attributed to the size of particles. During the compaction, the large particles of HL can work as rollers that provide less friction in the mastic, which leads to more compact packing and lowers

VMA (National Lime Association 2006). However, compared to the required percentage of the minimum VMA to MTO specification that is typically accounted as 13 for this category of the HMA mix design, the obtained outcomes were higher than the required percentage, resulting in a highly successful filler addition for both different types.

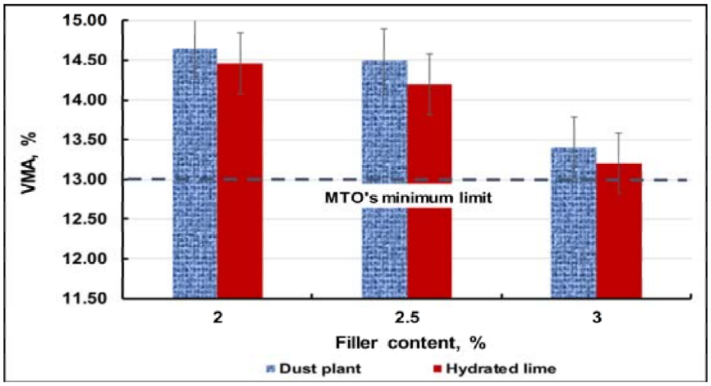

Figure 9: Voids in mineral aggregates (VMA)

4.2.3 Voids Filled with Asphalt (VFA)

The influence of various filler types with different proportions on VFA for HMA is presented in Figure 10. The findings showed that a similar behaviour for both filler types is obtained. It is noted that the VFA value proportionally decreases depending on an increase in the filler content. As explained in VMA property, the existence of a thin film appears to be the main reason behind the reduction in the VFA values. For the influence of different filler types on VFA, an insignificant variance between various fillers on this volumetric property is observed. The VFA values required for the MTO specification range between 65% and 75%. It is found that the research findings were higher than the lower limit percentage. This indicates that there is no impact of a filler type with various proportions on this volumetric property.

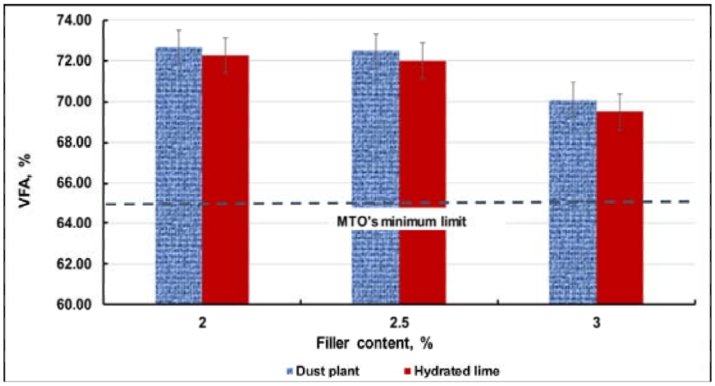

Figure 10: Voids filled with asphalt (VFA)

4.3 Dust to Binder Ratio (Dp)

Figure 11 demonstrates the Dp ratio (also known as the dust proportion) that represents another mixture design criterion. Dp can be defined as the ratio of aggregate fines expressed as a percent by weight that can pass through the 0.075 mm sieve (#200) to the effective asphalt content or optimum asphalt binder accounted as a percentage by weight. The findings of the investigation indicated that the Dp ratio seems to be directly proportional to filler content for both different filler types. The Dp proportion increases when the filler content is increased; therefore, it can be concluded that the Dp proportion behaves inversely compared to other volumetric properties for both filler types. The outcomes also revealed that the Dp values at 2% filler content are 0.43 and 0.47 for dust and lime filler types, respectively. It is interesting to note that the experimental values of Dp with filler content 2% were 0.6 for the dust and lime filler types, whereas the obtained values of Dp with filler content 3% were 0.8 for both different filler types. Depending on the MTO specification that requires an acceptable range for Dp between 0.6 and 1.2, it can be concluded that the obtained values of Dp for the mix design with a filler content of 2% are lower than the minimum required values, resulting in the mix design that is unacceptable for both filler types whereas the experimental values of Dp for mix design with filler content 2.5% and 3% were within the acceptable range of MTO specifications for both filler types. It has been previously reported that low Dp values generally indicate unstable mixtures, whereas high Dp values could possibly refer to a lack of sufficient durability (FHWA). An increase or decrease the air voids are affected by controlling the quantities of material passing the No. 200 sieve in the HMA. The increase addition of fine material leads to lower the air voids and vice versa. The durability of an asphalt mixture generally correlates with the air void. While the too high content of air void can provide passageways for the entrance of more air and water, resulting in a HMA damage, the too low percentage of air void results in a flushing and squeezing the excess binder out to the surface of HMA.

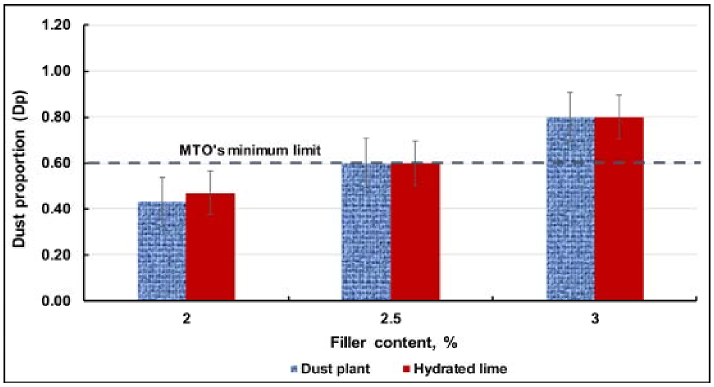

Figure 11: Dust proportion (Dp)

4.4 Maximum Theoretical Specific Gravity (Gmm) & Bulk Specific Gravity (Gmb)

It is generally known that Gmm simply refers to the ratio of the mass of the asphalt and aggregate mixture to the volume that does not include the air voids, whereas Gmb generally indicates the ratio of the mass of the asphalt and aggregate mixture to the volume that includes the air voids. The behaviour of the properties Gmm and Gmb for HMA using different filler types is displayed in Figure 12. It was observed that there is a comparable behaviour to Gmm and Gmb for different filler types with various percentages, indicating that there is no influence of filler type on these properties. When the filler content is increased, there is an increase in the Gmm and Gmb values for both filler types.

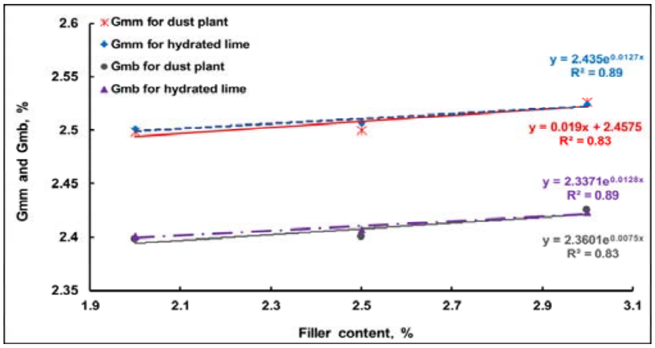

Figure 12: Gmm and Gmb of mix at different filler percentages and types

5 CONCLUSION

Based on the laboratory experiments that related to the application of various filler types in HMA, the following conclusions can be drawn:

- The optimum asphalt binder content for both filler types decreases when the filler percentage is increased. However, a significant decrease in the optimum asphalt binder content is observed when filler content is increased from 2.5% to 3% for both filler types.
- It is seen that an increase in filler content decreases VMA of the mixture for both filler types. A slight difference between two different filler types on the VMA property is noticeable. Compared to MTO specifications, the obtained results are higher than the required proportion.
- VFA values are proportionally reduced depending on an increase in the filler content. An insignificant variance between various filler effects on this volumetric property is found. Based on MTO requirements, it is indicated that the study findings are higher than the lower limit.
- Compared to other volumetric properties, Dp proportion behaves inversely for both filler types in which Dp proportion increases when the filler content is increased. The obtained values of Dp for the mix design with filler content 2% are unacceptable for both filler types due to lower values whereas the experimental values of Dp for mix design with filler content 2.5% and 3% were acceptable for both filler types based on the MTO specifications.
- Similar behaviour for the Gmm and Gmb properties with respect to different filler types with various proportions is observed. When the filler percentage increases, the values of Gmm and Gmb are increased for both filler types.
- The addition of filler of 2.5% is very successful for both filler types due to satisfying all MTO requirements for volumetric properties of HMA. Based on MTO specifications, the addition of 2.0% filler appears to be unsuccessful for both filler types due to lowering the dust to asphalt binder ratio. Mix design with 3.0% filler was also unsuccessful because of the lower value of OAC meaning that the mix is dry and there is insufficient asphalt binder to coat the aggregate particles.

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