SASSESING THE EFFECT OF VARIOUS CATEGORIES OF FILLER OF HIGH CONTENT ON HOT MIX ASPHALT MIXTURE

Saifa Summin Upoma[1], Mohei Menul Islam*[2] and Quazi Sazzad Hossain[3]

[1] *Graduate, Khulna University of Engineering & Technology, Bangladesh, e-mail: saifasumminupoma@gmail.com*
[2] *Assistant Professor, Khulna University of Engineering & Technology, Bangladesh, e-mail: m.mahir.116267@gmail.com*
[3] *Professor, Khulna University of Engineering & Technology, Bangladesh, e-mail: sazzad@ce.kuet.ac.bd*

***Corresponding Author**

ABSTRACT

Fillers strengthen cohesiveness and fill void in the mixture of asphalt, which affects engineering properties of this mixture. Ordinary Portland Cement (OPC), lime and stone dust are generally used in the asphalt mixture as fillers. The influence of different fillers of various contents on volumetric and mechanical properties (Marshall stability, quotient and moisture susceptibility) of asphalt concrete mixtures was analysed in this research. The mixing of aggregate and fillers (stone dust, OPC and/or fly ash) in different amounts with asphalt was done. Hot mix asphalt (HMA) specimens with filler (stone dust) and without filler were prepared to compare the OPC cement and fly ash-added HMA. A total of eight test specimen groups were prepared, utilizing various fillers in varying concentrations within the mixture. The investigation of volumetric characteristics of asphalt concrete mixtures revealed that HMA without filler had the lowest bulk specific gravity and voids filled with asphalt (VFA), and the highest voids in total mix (VTM) and voids in mineral aggregate (VMA) among all the HMA samples with different filler materials used in this study. Again, HMA with 7% OPC cement had the highest specific gravity, VFA, and lowest voids. On the other hand, for the mechanical characteristics of HMA, the mixture of a combination of 4% OPC cement and 4% fly ash filler had the highest Marshall stability and quotient values and the lowest flow value. The 7% cement filler-added mixture had the highest tensile strength ratio (TSR), which was 58.32%. The mixture with 7% cement filler had the maximum indirect tensile strength (ITS) value for both dry and wet conditions. Therefore, compared to stone dust and fly ash filler used in HMA separately, the OPC cement filler and its combination with fly ash filler used to the asphalt mixture showed a higher strength, and moisture susceptibility.

Keywords: *Stone dust, Cement, Fly ash, Marshall quotient, Tensile strength ratio*

IntroductioN

Asphalt concrete used as the top course of flexible pavement consists of aggregates (coarse and fine), asphalt and filler. The materials those sizes are finer than 0.075mm, is known as filler in the asphalt concrete. Filler has a major impact on the properties and performance of asphalt concrete. It often increases the viscosity flow of asphalt and slow down the aging process (Bianchetto et al., 2007). Conversely, flexible pavement's asphalt concrete serves as the structural framework due to the coarse and fine aggregate.

Asphalt mastic is produced by mixing mineral filler and asphalt binder, which is crucial in regulating the mixture's mechanical behaviour (Roman & García-Morales, 2017). This filler is act as the modifier of the characteristics of the mixture of asphalt. Prowell *et al.* (2005) concluded that adding filler in HMA can have the subsequent basic impacts: (i) stiffening the asphalt, (ii) extending the asphalt, (iii) increasing the volume of asphalt in HMA or (iv) stiffening as well as extending the asphalt at the same time. According to Aljassar *et al.* (2004), filler improves the durability and stability of the hot mix to reduce rutting and shoving issues whereas it reduces the moisture susceptibility. The application of specific mineral fillers also provides asphalt concrete with an improved chance to become stronger and stiffer (Benson & Martinez, 1984). By filling in the gaps in the asphalt mix and lowering permeability, coarser filler particles improve packing (Choudhary *et al.*, 2020). According to them, fillers' chemical makeup affects how they interact with bitumen and, in turn, how well mixes operate when exposed to moisture. Roberts *et al.* (1996) declared that the mineral filler is utilized in HMA to accomplish the following goals: (i) fulfill aggregate gradation requirements; (ii) lower the ideal amount of asphalt by occupying voids in the granular structure; (iii) improve stability of HMA; and (iv) strengthen the "bond" between the aggregate and asphalt system. Improved packing circumstances between the aggregates are mostly reliant on the filler and moreover it causes the ideal asphalt content to be reduced and asphalt concrete to become more stable (Likitlersuang & Chompoorat, 2016).

Practical applications of several forms of mineral fillers, with widely differing characteristics (physical and chemical), have been made in HMA: natural fillers like mineral dust derived from aggregate screening and crushing, as well as imported fillers like lime, OPC cement, fly ash, and slag (Roberts *et al.*, 1996). Particle size and shape, void content, surface area, qualities (mineral and chemical) and some physical attributes are the main characteristics that differentiate the fillers (Zulkati *et al.*, 2012). Adhesion in mixtures can be enhanced by the use of fillers such as OPC and hydrated lime (Aljassar *et al.*, 2004; Lesueur *et al.*, 2013). Sung Do *et al*. (2008) showed that using recycled lime as a mineral filler enhances asphalt mixture's resistance to enduring deformation, stiffness, and fatigue over a wide temperature range. Asmael (2010) used 5.8%, 7.8% and 9.8% Portland cement, silica fume and fly ash as filler and concluded that Portland cement and silica fume had more workability, tensile strength and better mechanical properties as a filler than those of fly ash. Al-Hdabi (2016) applied rice husk ash (RHA) and OPC as the filler in the asphalt mixture and compared to the control mixtures made with OPC as a mineral filler, there was a notable enhancement in the mechanical characteristics and a notable improving in durability of the asphalt concrete using RHA as a mineral filler. Tire-derived fuel (TDF) fly ash was compared to the fillers of stone dust, cement and hydrated lime with respect to Marshall stability, moisture susceptibility, dynamic immersion, and a wheel tracking test in the study of Choi *et al*. (2020). In highway construction, Abdel-Wahed and Rashwan (2016) utilized waste dust of cement as a cost-effective substitute for conventional limestone filler and used 2%, 2.5%, 3% and 3.5% limestone, OPC cement and cement dust as filler and found that OPC and cement dust filler increased the unit weight and Marshall stability of asphalt concrete and limestone filler enhances the total displacement value. Aschuri and Woodside (2007) used the Marshall Test to examine the behaviour of an asphalt concrete that included hydrated lime and fly ash at weights of 3%, 6% and 9% bitumen in a binder. According to test results, bitumen mixes with these materials performed better than the original bitumen mixes. Likitlersuang and Chompoorat (2016) investigated the influences of various categories fillers (fly ash, cement) of 1%, 3% and 5% and their combination of equal amounts on the volumetric properties, dynamic creep behaviour, resilient modulus, Marshall stability and moisture susceptibility in Thailand at 25ºC and 55ºC and compared them with those of HMA without filler and polymer modified asphalt (PMA), and used limestone aggregate with 12.5mm nominal maximum size and also used lower to moderate amount of fillers and C class fly ash. Again, for asphalt concrete, the Asphalt Institute suggests using a filler percentage of 4 to 8% (Rajitha & Koramutla, 2019). According to Sharma *et al.* (2010), fly ash can make up to 7% of the total amount of mineral filler used in HMA. Besides, for reduction the environmental pollution, materials such as fly ash and for increasing stability and durability of the HMA, cement can be used as the filler in the mix design of surface course of flexible pavement.

So, in the current study, high amount of fly ash of class F and OPC cement and these fillers combination of different proportions and stone chips of 9.5mm nominal maximum aggregate size were applied in HMA and volumetric analysis, Marshall stability, quotient, and moisture damage resistance (moisture susceptibility) of these fillers added HMA were investigated. These characteristics of these HMA were also compared to those of the HMA with stone dust filler and HMA without any kind of fillers. The volumetric analysis and moisture susceptibility test, and Marshall stability test were conducted at 25ºC, and 60ºC temperature, respectively.

methodology

Several works were conducted to investigate the influences of various kinds of filler and fractions on the qualities of HMA. The whole procedure can broadly be divided into three parts: materials properties, preparation of HMA and experimental program.

1.1 Materials

60/70 grade asphalt was used in the present study as this grade of asphalt in the surface courses of flexible pavements in Bangladesh are mostly used. Stone aggregate of nominal maximum size of 9.5mm was collected from the Taltala, Noapara, Jashore, Bangladesh. Fly ash of class F, ordinary Portland cement (OPC) and stone dust from aggregates after sieving were used as filler. Among these, fly ash was collected from the Seven Rings Cement Industry, Khulna.

1.2 Materials Properties

1.2.1 Grain Size Distribution of Aggregate

The sieving procedure of grain size distribution of aggregate was performed according to ASTM C136 standard. Here, the nominal maximum aggregate size was 9.5mm and the upper and lower range of gradation was followed the range stated in the study of Shen *et al.* (2006). Total eight sieves from 1.5” to #200 were used for sieving and the gradation curve of aggregate is shown in Figure 1.

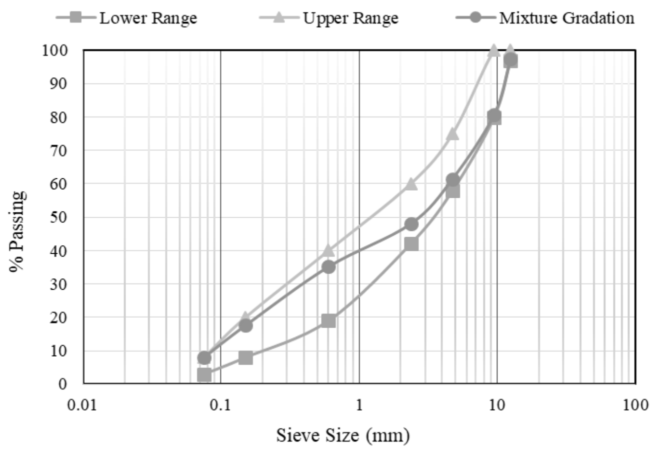

Figure 1: Gradation Curve of Aggregate

1.2.2 Physical Properties of Materials

Physical properties of aggregate, OPC and fly ash were measured according to the ASTM and BS standards and stated in Table 1. Again, the physical and rheological properties of asphalt are shown in Table 2.

Table 1: Physical Properties of Aggregate, OPC and Fly Ash

Name of the Properties	Materials Type	Value of Properties	Name of the Standard
Specific Gravity	Aggregate	2.74	ASTM C127 ASTM C128
	Stone Dust	2.81	ASTM D854
	Fly Ash	2.60	ASTM C311
	Cement	3.17	ASTM C188
Flakiness Index (%)	Coarse Aggregate	18	BS 812:105.1
Elongation Index (%)	Coarse Aggregate	23	BS 812:105.2
LA Abrasion Value (%)	Coarse Aggregate	12	ASTM C131
Soundness (%)	Coarse Aggregate	14	ASTM C88
	Fine Aggregate	9	ASTM C88
Aggregate Impact value (%)	Coarse Aggregate	17	BS 812:112
Aggregate Crushing Value (%)	Coarse Aggregate	14	BS 812:110

Table 2: Physical and Rheological Properties of Asphalt

Name of the Properties	Value of Properties	Name of the Standard
Specific Gravity	1.02	ASTM D70
Softening Point (ºC)	44	ASTM D36
Penetration (0.1mm)	63	ASTM D5
Ductility (cm)	110	ASTM D113
Solubility (%)	99.4	ASTM D2042
Flash Point (ºC)	320	ASTM D92
Fire Pont (ºC)	355	ASTM D92
Loss on Heating (% wt loss)	0.07	ASTM D6

Tricalcium silicates (C_3S), dicalcium silicates (C_2S), tricalcium aluminate (C_3A), tetracalcium alumino ferrite (C_4AF), and calcium sulfate in the form of gypsum ($CaSO_4.2H_2O$) make up ordinary Portland cement (OPC) (Singh, 2019). According to American Coal Ash Association (2003), Table 3 lists the chemical makeup of OPC and fly ash from class F.

Table 3: Chemical composition of OPC and Fly Ash (class F) (American Coal Ash Association, 2003)

Filler	Amount of Chemical Ingredients (%)					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
OPC	23	4	2	64	2	2
Fly Ash	55	26	7	9	2	1

1.3 Preparation of HMA

The asphalt concrete mixture specimen was designed according to ASTM D6926 in which Marshall apparatus was used. A total of eight types of specimens were made in which six categories of HMA were made with various percentage of cement and fly ash, and rest types of specimens were HMA with filler (stone dust) and HMA without any kind of filler. Here, 8% stone dust was applied as filler in HMA, and OPC and fly ash were used with the same amount (7% and 8%). Also 3.5% OPC + 3.5% fly ash and 4% OPC + 4% OPC combinations were used in HMA. The optimum asphalt of 5.5% was applied to prepare each category HMA. Three samples were prepared for each type of specimen for one test. So, total 84 samples were prepared for determining the optimum asphalt content, volumetric analysis, Marshall stability, Marshall quotient, ITS (both dry and wet) and TSR. The HMA with stone dust filler and Hot Mix Asphalt without filler are symbolized as HMA (fi) and HMA (wo-fi), respectively. The other HMA specimens with OPC and fly ash filler were symbolized with Ce and Fi, respectively and the numerical number that follows this letter indicated the amount (%) of filler. The symbols of all specimens are given in Table 4.

Table 4: Symbols of all HMA

Amount of filler (%) in HMA	Symbols of HMA
8% stone dust	HMA (fi)
no filler	HMA (wo-fi)
7% OPC	Ce7
8% OPC	Ce8
7% fly ash	Fi7
8% fly ash	Fi8
3.5% OPC + 3.5% fly ash	Ce3.5+Fi3.5
4% OPC + 4% fly ash	Ce4+Fi4

Total 1228.5 gm aggregates after gradation with filler for each sample were kept at 110°C for drying in an electric oven. The asphalt was also heated by a heater to turn it into liquid form. The aggregates and asphalt were mixed properly at 150°C. Before the mixtures were placed into the mold of 102 mm (4in) diameter and 64 mm (2.5in) height, it was heated at 110ºC. The samples were compacted by the hammer of Marshall compactor at 50 blows per side for medium traffic and hammer was also heated at the same temperature of mold before compaction. After compaction, the specimens were brought out from the mould and kept in the room temperature for cooling for 24 hours. After that, the specimens were ready for test.

1.4 Experimental Program of HMA

The experimental tests: Marshall stability and the moisture susceptibility test were performed according to ASTM D6927 and ASTM D4867, respectively. From Marshall Stability test, the volumetric properties of HMA and Marshall quotient (MQ) and from moisture susceptibility test, ITS (both for dry and wet condition) and TSR were found out.

1.4.1 Volumetric Analysis of HMA

Volumetric properties such as; bulk specific gravity, VTM. VMA and VFA were determined according to ASTM D6927. After the preparation of specimens, the height, air weight and the submerged weight of sample were recorded to calculate specific gravity for the volumetric measurement. Again, specific gravity of materials was also important to calculate these volumetric properties.

1.4.2 Marshall Stability Test of HMA

For Marshall stability test, at first HMA samples after cooling of 24 hours were immersed in water bath at 60ºC±1ºC for 30 minutes. Then the soaked samples were taken to the Marshall stability testing equipment as soon as possible and testing load at constant rate of 2in/min was incorporated to HMA samples. The load at which the specimen was failed to resist that load was the stability of that sample. Flow value was recorded in 0.25mm unit from the dial gauge attached to the equipment during loading (from zero to maximum load of failure of sample). Then, MQ was found by dividing the Marshall stability by the flow of specimen.

1.4.3 Moisture Susceptibility Test of HMA

The goal of this test was to determine how water affected the paving mixture's tensile strength. TSR is the measurement index for the moisture susceptibility of specimens and both ITS (dry and wet condition) are needed for determination of TSR. ITS was conducted according to ASTM D6931. Two sets of samples were necessary in which one set's condition was dry while the other set was in wet condition. To perform this test the specimens were prepared according to Marshall method. For the dry specimens the temperature was adjusted by soaking these in water bath throughout 30 min at the temperature of 25°C. The height of the HMA samples were recorded before the test. The sample was put into the equipment of loading, and the strips of loading were arranged so that they were parallel and centered on the vertical diametric plane, in order to calculate the ITS of the dry-conditioned specimen. Until the maximum load was achieved, a diametric load was given at a rate of 2 in/min. Then the maximum load was noted. Then this load was divided by the contact area to get strength. For moisture condition the HMA specimens were soaked in water bath at the temperature of 60°C throughout 24h. After 24h the temperature was adjusted by soaking in water bath for 1h at the temperature of 25°C and then the ITS of wet conditioned was determined according to the procedure stated above for dry conditioned. TSR was determined by dividing the ITS (wet) by ITS (dry).

Results and Discussion

Volumetric properties, marshall stability, flow value, quotient and moisture susceptibility were determined for the hma of different fillers (stone dust, opc and fly ash) and hma without filler. Its (dry and wet) and tsr were determined for knowing about the moisture damage resistance of these hma. The results of these properties are stated and discussed in below.

1.4.4 Volumetric Properties of HMA

Table 4 provides an overview of the volumetric property results for each sample design.

Table 4: Volumetric Properties of HMA

HMA sample	Bulk specific gravity	VTM (%)	VMA (%)	VFA (%)
HMA (fi)	2.14	8.2	23.6	65.3
HMA(wo-fi)	2.08	10.3	24.9	58.6
Ce7	2.17	5.2	21.8	77.4
Ce8	2.14	5.3	22.1	76.7
Fi7	2.16	6.5	22.2	70.2
Fi8	2.11	7.9	22.4	68.8
Ce3.5+Fi3.5	2.15	7.7	22.8	66.2
Ce4+Fi4	2.16	7.3	22.4	67.4

From Table 4, it is seen that HMA (wo-fi) has the lowest bulk specific gravity (=2.08) and VFA (=58.6%), and on the other hand, highest VTM (=10.3%) and VMA (=24.9%) are found. This is because of the absent of filler and so, void spaces in the asphalt mixture are not filled up with it. As there are more void spaces, bulk specific gravity is lower. Again, the specimens with OPC and/or fly ash (class F) filler have more specific gravity and VFA than those of HMA (fi) and HMA (wo-fi). For VTM and VMA, the results are totally opposite because of more density and specific gravity. According to Likitlersuang and Chompoorat (2016), by filling the void, the filler can raise the mixture's density and decreasing VMA leads to decrease VTM indirectly. Among all the specimens, Ce7 has the highest bulk specific gravity (=2.17) and VFA =77.4%), and lowest VTM (=5.2%) and VMA (=21.8%). Specimen with higher OPC filler have more specific gravity and VFA, and lower VTM and VMA than those of fly ash added mixtures. This result's pattern is similar as stated in the study of Asmael (2010). According to him, because fly ash has a low specific gravity, a given weight percentage of fly ash will often take up more volume than a traditional filler material.

1.4.5 Marshall Quotient (MQ) of HMA

Marshall quotient (MQ) was derived by using the stability and flow value of specimens. It is a measure of material's stiffness, stress (shear) resistance, enduring deformation resistance and rutting resistance (Likitlersuang & Chompoorat, 2016; Mistry & Roy, 2020). The variations of Marshall stability, flow, and quotient of HMA specimens with different fillers of various amounts are demonstrated in the Figure 2, and Figure 3, respectively.

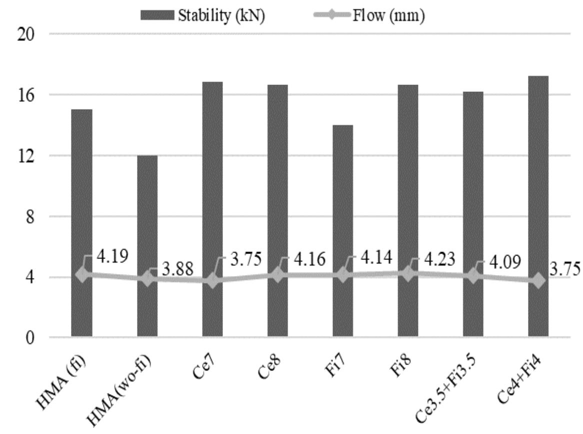

Figure 2: Marshall Stability and Flow of HMA

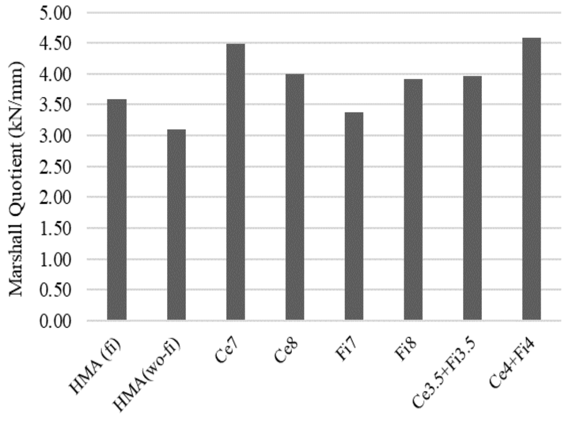

Figure 3: Marshall Quotient values of HMA

The results stated in Figure 2 indicates that OPC cement added mixture gives higher Marshall stability and quotient than those of fly ash (class F) added HMA as the density or specific gravity of fly ash added HMA are lower and voids are higher as stated in Table 4. Marshall stability (=17.2kN) and quotient value (=4.59kN/mm) are the highest for the specimen of Ce4+Fi4. But, HMA (wo-fi) has the lowest stability and MQ value among all the specimens and OPC and fly ash improves the MQ and stability value of asphalt mixture in this study. Ce7 specimen also gives better stability (=16.8kN), flow value (=3.75mm) and MQ (=4.48kN/mm) values and this MQ value is closed to the highest value (=4.59kN/mm). There are no significant changes of flow values among the samples. In the comparison of the study of (Likitlersuang & Chompoorat, 2016), MQ values are increased when more OPC and fly ash are added in the asphalt mixture. So, more OPC and fly ash added filler have more stiffness and resistance to shear stress, enduring deformation and rutting, and only OPC and OPC + fly ash filler added mixtures have better these properties with respect to only fly ash and stone dust added HMA. Samples without filler have low MQ value, stability and flow.

1.4.6 Moisture Susceptibility of HMA

To find out the moisture resistance properties of asphalt concrete, ITS (both dry and wet condition) are necessary. Then from these strengths, TSR are determined which is act as the moisture susceptibility index of HMA. The results of ITS (both dry and wet) and TSR are demonstrated in the Figure 4 and Figure 5, respectively.

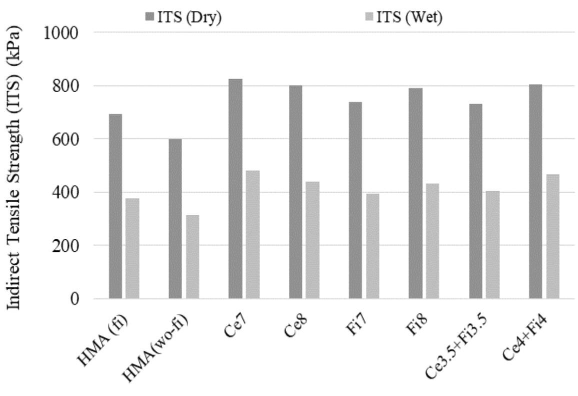

Figure 4: Indirect Tensile Strength of HMA

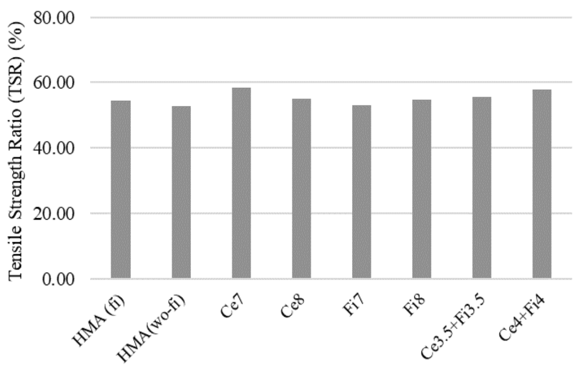

Figure 5: Tensile Strength Ratio of HMA

ITS (both dry and wet condition) of Ce7 is the maximum (=823kPa for dry and =480kPa for wet) and of HMA (wo-fi) is the minimum (=597kPa for dry and =315kPa for wet) among all the specimens. This is because of the amount of void spaces in the asphalt mixtures. Again, Ce7 asphalt mixture has shown better moisture damage resistance and its TSR value is 58.32% that is also the highest among all the specimens. Combined used of OPC and fly ash filler (Ce4+Fi4) in HMA also give good TSR value (=57.76%) that is much closed to 58.32%. With respect to ITS and TSR, specimens with OPC cement, fly ash and combination of OPC-fly ash have better performance than those of HMA with conventional filler (stone dust) and without any filler. In the comparison of the study of (Likitlersuang & Chompoorat, 2016), ITS (dry) at 25ºC of the OPC and fly ash filler added HMA are higher in this study because of the high amount of filler (7% and 8%) used in asphalt mixture.

CONCLUSIONS

Filler improves the physical and functional characteristics of asphalt concrete as it provides the stiffening, volume increasing, asphalt extending and void filling in the mixture. In this study, different fillers (stone dust, OPC, fly ash) were used in various amounts. Their effects on the volumetric properties, Marshall quotient and moisture susceptibility of HMA were analysed and these effects are concluded in the following section.

- HMA without filler is lighter (less bulk specific gravity) and has more voids (VTM and VMA) than HMA with any kind of filler. Again, HMA (wo-fi) has poor Marshall stability, quotient and moisture damaged resistance properties.
- Cement and fly ash both improves the asphalt mixture’s structure with respect to volumetric properties rather than stone dust filler. OPC cement filler increases the specific gravity and VFA, so VTM and VMA are automatically decreased. These increasing and decreasing trend is higher than those of fly ash filler.
- Ce7 and Ce4+Fi4 give higher stability, MQ, ITS and TSR, and low flow value than those of HMA with only stone dust (HMA (fi)) or fly ash filler.
- So, high OPC cement (7%) filler and its combination with fly ash (4% OPC + 4% fly ash) provides good stiffness, and shear stress, moisture damage, permanent deformation and rutting resistance capacity to asphalt mixture rather than fly ash and stone dust filler. These properties are improved with the amount of filler (OPC, fly ash or stone dust).

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