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TO REVIEW EVALUATION OF MOISTURE DAMAGES IN WARM MIX ASPHALT

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ABSTRACT

From last centuries, technologies of Warm Mix Asphalt have been used widely. Stakeholders have been motivated due to its benefits to implement this technology. The study of researchers raised concerned that WMA showedgood performance in field as compared to the performance in laboratory regarding moisture damages due to resistance .Thus it is important to know more about properties of warm mix asphalt. This article mainly focused on WMA various sources of aggregates, binders of asphalt and additives of WMA. In this study, test on conventional hot mix asphalt and WMA is conducted by using a dynamic mechanical analyzer. Various specimens are prepared to for testing purpose and test are conducted in dry and wet conditions, and at start and after 3 months in control temperaturei.e. 60^{0}C. The results of test are analyzed using approach of fracture mechanism. Fundamental properties of material are incorporated in this approach, including adhesive bond energy among asphalt binder and aggregates. The Study results showed that with aging performance of WMA is improved while improvement in overall WMA performance is optimized with materialselection (Sources of aggregates, asphalt binders and technology of WMA)based on their surface energy compatibility.More ever, few findings from mechanical testing are expanded by the results of surface energy related to moisture susceptibility of WMA.

Keyword's

Warm Mix asphalt, Stakeholders, moisture damages, dynamic Machinal analyzer, fracture mechanism, surface energy, sources of aggregates

I. INTRODUCTION

In the technology of warm mixed Asphalt (WMA, the allow production and compaction temperature is lower as compared to Hot mixed asphalt (HMA).Due to these properties and its economic and environmental benefits stakeholders implement this technology rapidly. In order to reduce mixing temperatures, consumption of energy, emissions, ageing of binding, season of construction, compaction and reclaimed asphalt pavement increase various techniques of WMA has been developed. The techniques included such as chemical additive incorporation (surfactants and viscosity reducers) and technologies of foaming. The WMA use mainly depend upon its ability of mixing with better or same durability and performance as compared to HMA(Button, Estakhri, & Wimsatt, 2007; Jones, 2004; Prowell, Hurley, & Frank, 2011).

Durability and performance of WMA remained under consideration due to low compaction and production temperatures. Asphalt binder with less stiffness was resulted due to WMA low production and compaction temperatures instead of HMA which directly led to pavement rutting at early stages (Bower,Wen,Willoughby,Weston, & DeVol, 2012). More ever, for aggregate drying in the technologies of WMA lower temperature of mixing was not sufficient. The adhesive bond was affected due to presence of moisture among asphalt binder and aggregate interface and moisture damage was promoted. Moisture damage is type of damage which must be evaluated and major concern for warm mix asphalt (Bennert, Maher, & Sauber, 2011; Goh & You, 2011; Gong, Tao, Mallick, & El-Korchi, 2012).

Study on WMA potential was conducted during laboratories tests to plasticly deform and accumulate damage under effect of retained moisture. According to (Buss, Rashwan, & Williams, 2011; Kim, Baek, Lee, & Bacchi, 2011) HMA performance was found better as compared to WMA as showed in laboratory studies of some moisture damage. While WMA performance in case of field monitoring was found better as compared to HMA (Epps Martin et al., 2014.,Estakhri, 2012; Jones, Wu, & Tsai, 2011).

According to past studies (Bonaquist,2011; Bower et al., 2012; Goh & You, 2011) WMA and HMA compared on the bases of fatigue performance. But it is essential to elaborate thecompatibility ofconstituents and effect of ageing on moisture susceptibilitybased on fundamental properties of WMA.

II. OBJECTIVES

The objectives of this article were as given under

- To give comprehensive and mechanical classificationof WMA mixtures and impact of WMA technologies on interaction of mixture constituents (e.g. binder and aggregate)
- To know the synergistic effects of moisture damage and ageing on WMA.

III. LITERATURE REVIEW

In this part past studies were summarized about WMA technologies, evaluation of contact among constituents and fracture in asphalt mixes characterization.

Warm Mix Asphalt:

The changes in WMA design and procedures related to quality control was proposed in past studies because of its fast implementation. While for short term oven ageing protocols current literatures investigated the effect of temperature and conditioning time of loose mixtures of WMA (Laboratory and plant mixed). The study noted substantial effect on test results of laboratory due to WMA temperature and conditioning times ((Estakhri, 2012; Jones et al., 2011). Methods of development have been focused by some of researchers for WMA production in laboratory which simulate field performance of different stages various stages and mixtures of testing at that stage(Yin et al., 2013; Yin, Garcia Cucalon, Epps Martin, Arambula, & Park,2014). Considering filed ageing for mixtures of WMA evaluation (Yin et al., 2014) recommended at 85 °C a long-term oven ageing protocol of 5 days. To know comparison between HMA and WMA based on past studies ,the studies conducted by previous researchers were. The many researchers study showed that HMA performed well as compared to WMA in laboratory while in field the performance of both HMA and WMA found satisfactory. The Previous studies comparison between HMA and WMA was shown in Table 1.

Table.1 Past studies conducted on Performance of WMA

S.No	Titles	Conclusions	References
1	Laboratory evaluation, moisture susceptibility	HMA was found less moisture susceptible than WMA	Wasiuddin et al. (2008) Austerman et al. (2009)
		More ever moisture susceptibility increased at less temperature by production of WMA.	Goh and You (2011) Alavi et al. (2012)
		In addition, Resistance of WMA increased with inclusion of RAP to moisture induce damage.	Mogawer et al. (2011), Solaimanian, Milander, Boz, and Stoffels (2011)

		Best results were obtained from mixture constituents i.e. additives of WMA, type of binder and aggregates, optimization.	Prowell, Hurley, and Crews (2007), Garcia Cucalon et al.(2015)
2	Laboratory evaluation, rutting potential	It was concluded that rutting potential has increased with WMA.	Rashwan and Williams (2012), Bower et al. (2012)
		More ever it was also observed that rutting potential improved with addition of anti-stripping agents, polymers, or RAP.	Hurley and Prowell (2006), Mogawer, Austerman,Kluttz, and Roussel (2012)
3	Laboratory evaluation, fatigue, WMA versus HMA	It was noted that fatigue resistance improved with WMA	Goh and You (2011) Caro et al. (2012
		Equal fatigue resistance was revealed with WMA	Bonaquist (2011)
		WMA revealed decrease in fatigue resistance	Bower et al. (2012)
4	Performance in Field	it was observed that WMA performance in filed found satisfactory.	Diefenderfer and Clark (2011), Jones et al. (2011), Kim et al. (2011),Estakhri (2012) Epps Martin et al. (2014)

IV. Research methodology

To achieve above mentioned objectives following research methodology was adopted during this study.

In this paper, methodology composed of fundamental survey for compatibility of essential materials using surface free energy experimental measurements. More ever, in this article a model based on fracture mechanics was used for materials of viscoelastic. The method of dynamic analysis was used to process the mechanical testing results. The materials and tests used during this research are as under

Materials:

Experimental work conducted in laboratory composed of four various technologies of WMA such as foaming, wax organic and two chemical additives in addition to control HMA. Foaming obtained by mixing aWirtgen laboratory foamer with one percent of injection of water in laboratory. Organic wax used to reduce production temperature while purpose of chemical additives was to minimize binder surface tension and for improving coating and low temperature. For evaluation purpose two numbers of aggregate sources and binders were utilized. The combinations of constituents and conditions were evaluated and showed as doted in table 2. The experimental plan adopted during this research was shown in table 2.

Table 2. Experimental Plan

			DMA FAM					
Test methods			Unaged		Three months at 60°C		Surface free Energy	
Materials			Dry MC	Moisture Conditioned	Dry MC	MC	Original Binder	Pressurized Ageing Vessel (PAV)
Gabbro	PG 64-22	HMA	●	●	●	●	●	●
		Foaming	●	●	●	●	–	–
		Sasobit	●	●	●	●	●	●
		Evotherm	●	●	●	●	●	●
		Rediset	●	●	●	●	●	●
	PG 76-22	HMA	●	●	●	●	●	●
		Foaming	●	●	●	●	–	–
		Sasobit	●	●	●	●	●	●
		Evotherm	●	●	●	●	●	●
		Rediset	●	●	●	●	●	●
Limestone	PG 64-22	HMA	●	●	●	●	●	●
		Foaming	●	●	●	●	–	–
		Sasobit	●	●	●	●	●	●
		Evotherm	●	●	●	●	●	●
		Rediset	●	●	●	●	●	●
	PG 76-22	HMA	●	●	●	●	●	●
		Foaming	●	●	●	●	–	–
		Sasobit	●	●	●	●	●	●
		Evotherm	●	●	●	●	●	●
		Rediset	●	●	●	●	●	●

Laboratory Test Methods:

Surface Free Energy: Wilhelmy plate and Universal Sorption Device

The plate apparatus of Wilhelmy was used to measure the asphalt binder which is component of surface free energy.To know the various component of surface free energy of asphalt binders contact angle among slides having coating of asphalt binder and various different probe liquids was measured.In asphalt binder SFE measurements five numbers of probe was used i.e. glycerol, water, formamide, ethylene glycol and diiodomethane. For calculation of SFE components of aggregates universal sorption device (USD) was used. From the maximum mass adsorption of a probe liquid at various pressure spreading pressure was calculated. For 3 various probe liquids same procedure was repeated, and 3 replicates per probe liquid.

Testing Process Dynamic Mechanical Analysis (DMA):

A Bose electroforce DMA was used for conducting the testing of Fine mixtures. Figure 1 shown a Bose Electroforce DMA. The specimen used was gripped carefully into DMA and loading was applied (Figure 2), While figure 3 showed failure of sample after loading. For every material obtaining relaxation modulus in DMA testing sequence was first step. Tensile strain with constant ratio was applied on fine aggregate matrix (FAM) sample having level of 200με for this purpose. To prevent damage to FAM sample small starin was enough.For ten minutes keep constant the strain and then noted both strain and load. The strain was held constant for 10 min, and both load and strain were measured. The relaxation modulus was defined using following formula.

$$E(t) = \frac{\sigma(t)}{\varepsilon_0}, \quad (1)$$

$$E(t) = E_\infty + E_1 t^m.$$

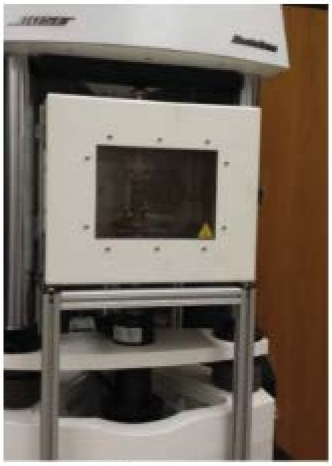


Fig.1 Bose Electroforce (DMA)

Fig.2 Sample Gripping

Fig.3 Sample after failure

V. Results

Surface Free Energy:

Results of SFE was shown in this section. More ever WMA performance at various stage of ageing in wet and dry conditions was discussed. Evaluation of asphalt binders SFE was conducted at original and PAV -Aged condition. For determined the SFE components of asphalt binders experimentally table 3 showed standard deviation and avg values for this purpose.

Table 3. Asphalt Binders SFE Components

Binder type		SFE Components				Standard Deviation		
		LW	Acid	Base	Total	LW	Acid	Base
Unaged binders PG 64-22	HMA	40.5	0.4	28.6	47.4	0.9	0.1	1.3
	Sasobit	40.0	0.1	29.3	44.0	0.5	0.0	1.1
	Evotherm	44.7	0.1	24.3	48.5	0.9	0.1	0.8
	Rediset	40.0	1.4	8.9	46.9	0.6	0.1	0.7
PG 76-22	HMA	45.9	0.1	33.0	49.4	0.8	0.0	1.4
	Sasobit	41.8	0.0	30.0	43.6	0.6	0.0	1.1
	Evotherm	43.0	0.3	25.9	48.1	0.7	0.1	1.0
	Rediset	43.9	1.1	12.5	51.4	0.6	0.1	0.8
PAV Aged Binders PG 64-22	HMA	40.5	0.4	7.9	44.2	0.6	0.1	0.6
	Sasobit	41.5	0.4	9.1	45.1	0.7	0.1	1.0
	Evotherm	40.2	0.2	19.0	44.2	0.7	0.1	1.9
	Rediset	40.1	0.3	10.5	43.6	0.7	0.1	0.8
PG 76-22	HMA	43.9	0.5	15.7	49.7	0.6	0.1	1.0
	Sasobit	40.5	0.4	11.7	44.8	0.6	0.1	0.6
	Evotherm	43.5	0.4	21.0	49.5	0.6	0.1	1.3
	Rediset	45.2	0.5	22.8	52.2	1.0	0.1	1.3

The figure 4 and 5 clearly showed control asphalt (PG 64-22 and PG 76-22) and WMA binders adhesive bond energies with aggregates of limestone and gabbro.

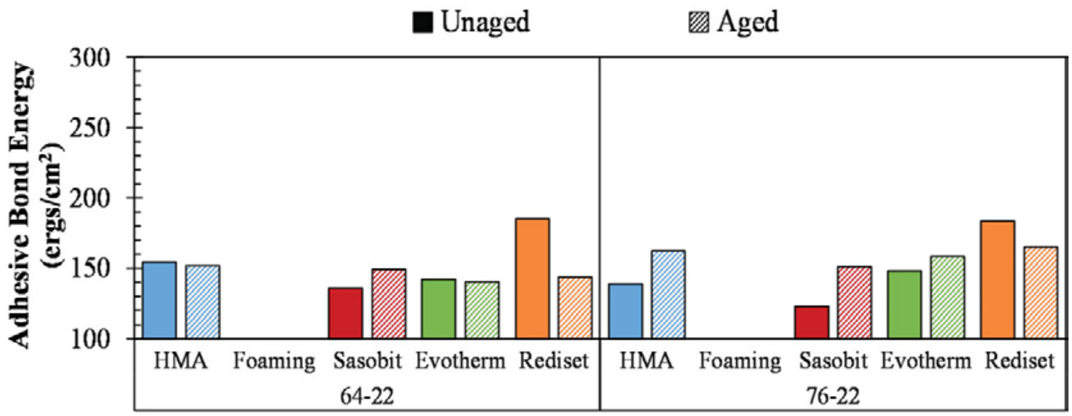


Fig.4 Limestone-Adhesive Bond energy

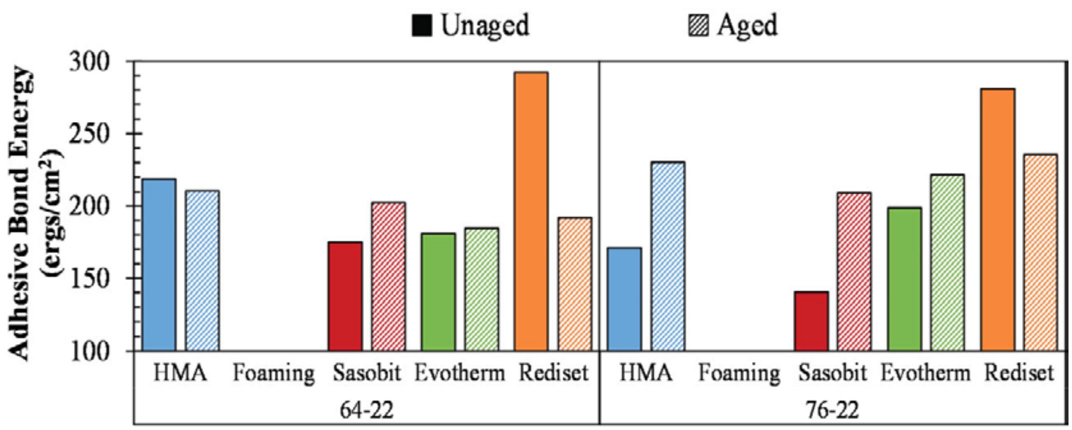


Fig.5Gabbro-Adhesive Bond energy

Based on comparison of figure 4 and 5 it was clearly showed that using gabbro aggregates technology of WMA, type of binder and ageing condition having high impact on adhesive bond energy as compared to limestone aggregates. Higher energy ratio (ER) showed that combination of binders was less susceptible to moisture damage. ER results shown in figure 6 a and b for limestone and gabbro. From figure 6a it was shown that higher ER value was given by WMA Rediset which mean more resistance to moisture damage when compared with other Additives of WMA before aging. While all other Additives of WMA increase but decrease in Rediset was noted after ageing. The value of ER for WMA additive was found higher in case of limestone as compered to gabbro. By comparing both figures, it was noted that WMA mixture with limestone provided good resistance to moisture damage against gabbro. With ageing or time WMA resistance improved to moisture damage.

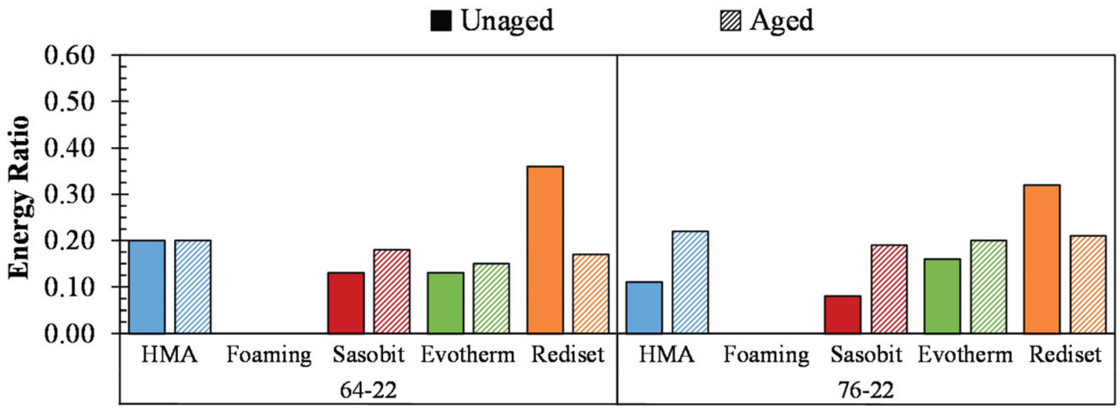


Fig 6a. Gabbro-Energy Ratio

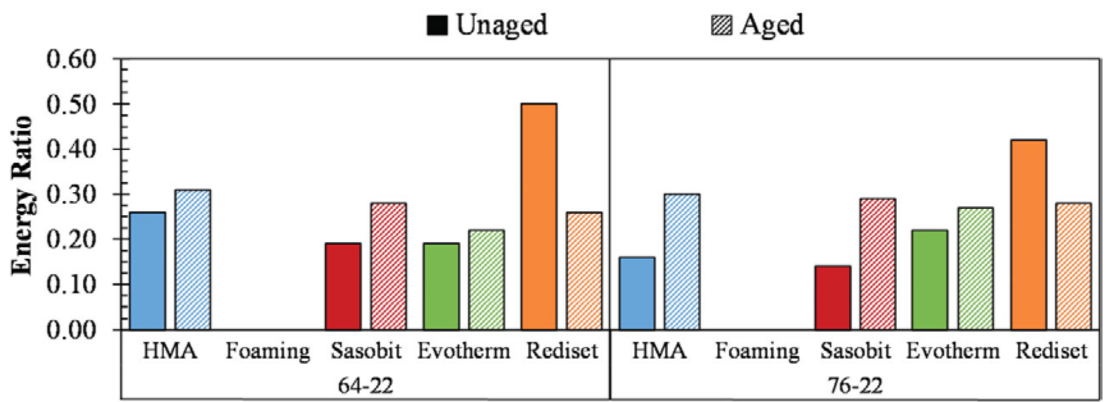


Fig 6b. Limestone- Energy Ratio

Moisture susceptibility evaluation using DMA:

In table 2, for all samples crack width index was determined by researcher under various conditions. Crack growth index change examples was shown (Figure 6) in wet and dry conditions having increase in load cycles numbers.

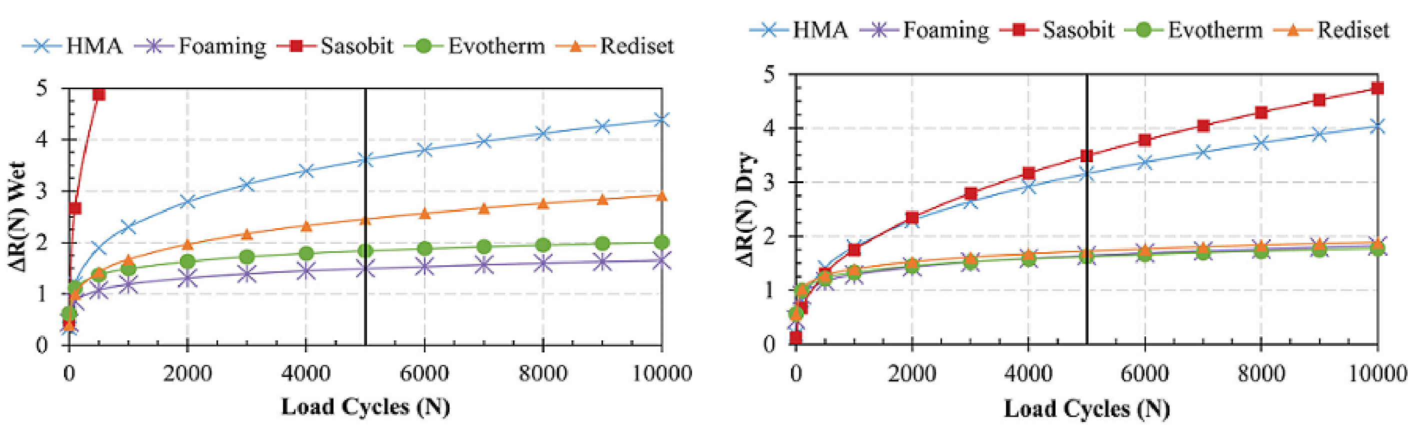
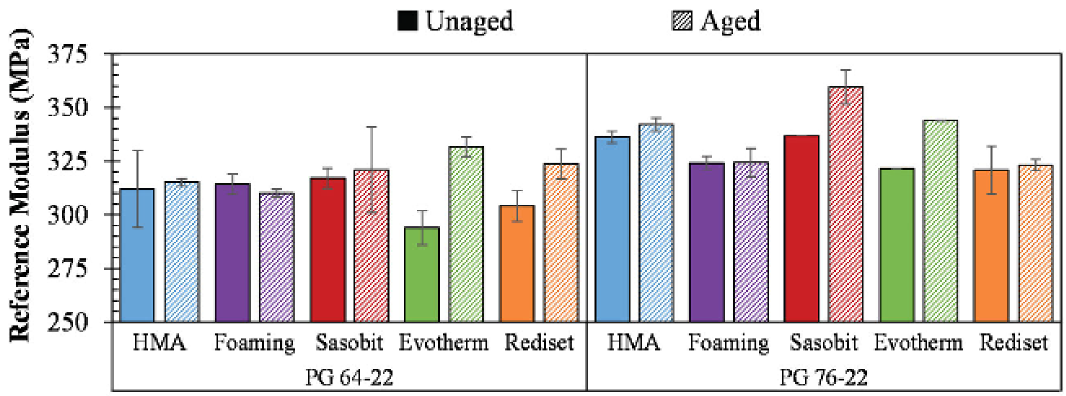


Fig 7Example results limestone aged: crack radius versus load cycles

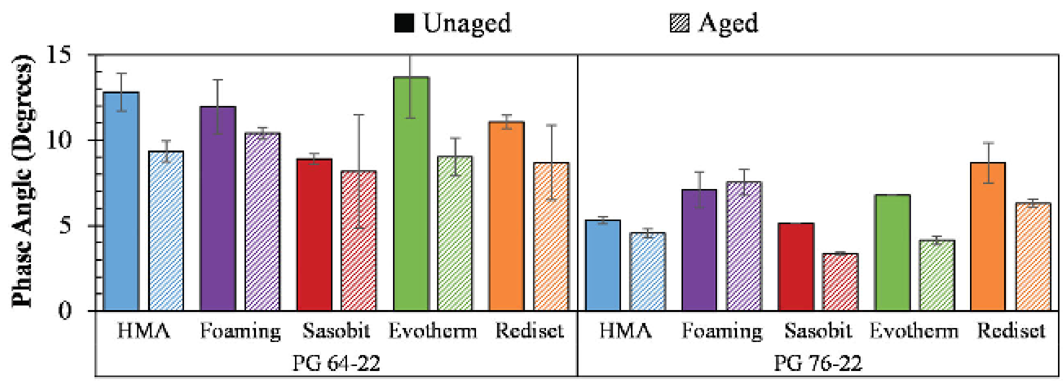
From figure 7 it was clearly revealed that Crack width growth in dry condition was less (less damage) as compared to wet condition.

Effect of ageing on mixture performance:

Asphalt mixture ageing is composite phenomenon which included changes in physical and chemical way to mastic and binder which is linked with increase in stiffness ,ductility loss, decrease phase angle, and less resistance to fatigue cracking with mechanical prospective. Mixture stiffness and phase angle decrease were evident when loading applied within range of non-destructive linear (Figure.7 and 8) visco-elastic(LVE) range for both type of aggregates (gabbro and limestone) along with both type of binders (PG 64-22 ,PG 76-22).

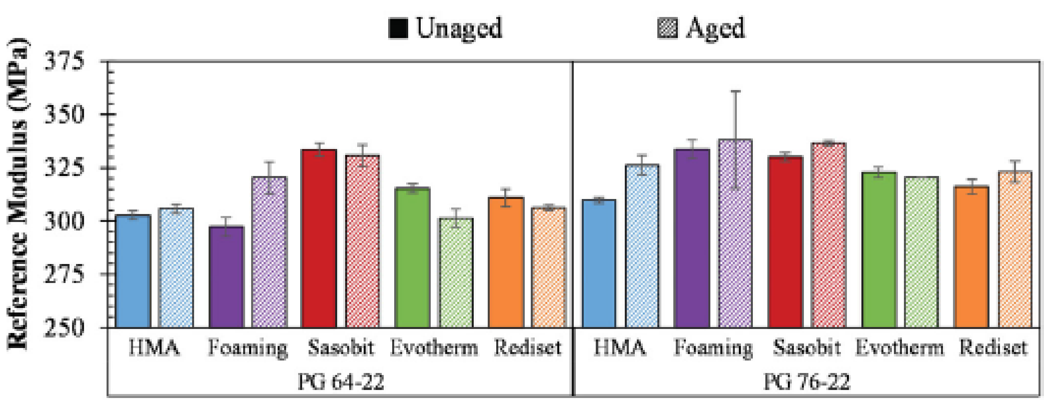


(a) Reference Modulus

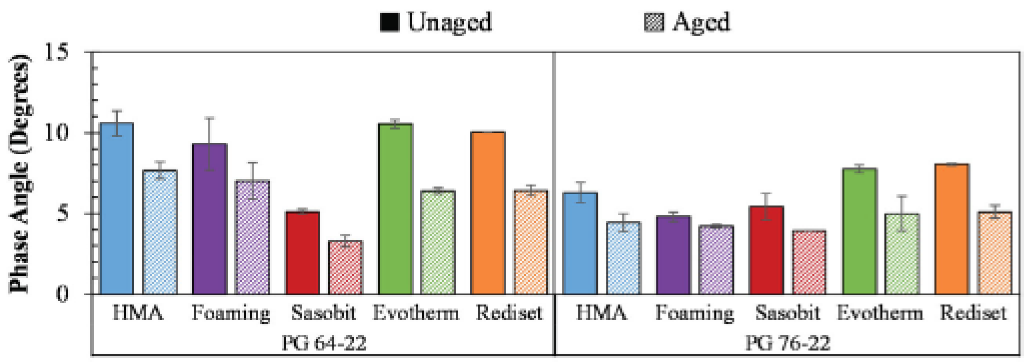


(b) Phase Angle

Fig.7 LVE properties changes with ageing -Gabbro



(a) Reference Modulus



(b) Phase Angle

Fig.8 LVE properties changes with ageing -Limestone

It was clear from above figure that sample prepared from Evotherm affected more, the process of ageing as compared to other samples. More ever, using PG 76-22 prepared test sample was found more stiffer because of lower phase angle and high reference modulus instead of sample prepared from PG 64-22.

Conclusions

In this article , investigator used mechanical testing and SFE parameters to find WMA various combinations and compared them with control HMA. Based on results it was found that at various condition, various combination (type of aggregate, binder and additive of WMA) gave various performances.To select and optimize constituents of WMA this study is very helpful. This paper helped pavement engineer to work WMAs various combination showed different results in dry condition as compared to wet condition. Similarly, ageing condition having also significant effect on combination performances as compared to others. In addition to this the maid conclusion of this paper are given below.

- Resistance to moistures damage due to WMA ageing was found increased based on measurement of Surface free energy and FAM mechanical testing.
- Mixtures composed of limestone found less liable to moisture damage as compared to mixture prepared with aggregates of gabbro from evaluations of DMA and SFE.
- Adhesive bond energy and energy ratio(SFE parameters) found more effective in resistance to moisture damage.
- Improvement in gabbro, moisture sensitivity can be achieved if binder types or additive of WMA are combined.
- Technologies of WMA which are available can also improve or reduced the effect on performance of mixtures.
- For Sample of FAM, asphalt binder PAV Ageing was utilized in this paper as ageing protocol and oven ageing of 3 months at 60°C.After this FAM and binder engineeringproperties determined. Complex and synergistic reactions occur during and following the ageingprocess that impact binderand FAM properties .i.e. due to oxidative ageing stiffening influenced which increased fracturestrength. This can also reduce potential of plastic deformation which occurs beyond critical stress level.

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