Effect of Suspended Hydrated Lime Mineral Filler on the Physical Properties of Asphalt Binder

Lamya M. J. Mahdi
Civil Engineering Department, University of Technology, Baghdad, Iraq
40366@uotechnology.edu.iq (corresponding author)

Ruqaya M. Atif
Civil Engineering Department, University of Technology, Baghdad, Iraq
40354@uotechnology.edu.iq

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ABSTRACT

Although several studies have investigated the best additive to improve the properties of bitumen that contributes to asphalt pavement mixtures, selecting the best performing, cheapest, and most environmentally friendly material is not yet an easy task. Aging can be a chronic phenomenon that constantly threatens the durability and service life of asphalt pavement, and research efforts aim to mitigate its effects. Accordingly, this study selected a suspended and insoluble material as an additive to investigate its effect on the physical properties of asphalt binder before and after the aging process. Hydrated Lime Mineral Filler (HLMF) was added at different concentrations (2, 4, 6, 8, and 10 % by weight of asphalt) to investigate its ability to mitigate the effect of short-term aging. Penetration, softening point, and viscosity tests were performed on samples prepared under two conditions, short-term aging and non-aging. The results showed positive signs of improvement, with lower penetration values and higher softening point values achieved, as well as higher viscosity values measured at two standard elevated temperatures. The higher retained penetration values as well as the lower increment in Softening Point (SP), and Viscosity Aging Index (VAI) values showed that the suspended HLMF particles successfully enhanced the aging resistance of the asphalt binder. All AC-HLMF samples showed better performance than the unmodified AC asphalt sample. There were no significant performance variations for the selected HLMF concentrations, but AC-HLMF 6% was the best performer, recording a 9% RP and a 26% VAI improvement compared to base asphalt.

Keywords-suspended additive; hydrated lime; STA; RTFO; asphalt properties

I. INTRODUCTION

Since road pavement surfaces are directly exposed to weather conditions and traffic loads, deterioration will continue to threaten their performance and service life [1-3]. Using conventional asphalt mixture and pure asphalt for road paving makes rutting, moisture damage, as well as fatigue cracking just a few of the problems that will arise. For this reason, many researchers have strongly recommended modifying asphalt mixtures by improving their asphalt binder properties [4-6].

Fly ash, limestone, stone dust, ceramic waste, carbon fiber, and other fillers have been successfully used to enhance the properties of the asphalt binder and the mixture, recording desirable performance [7-12]. In terms of size, nanofillers have also shown remarkable improvement in various properties of modified asphalt binder [13-18].

A. Uses of Hydrated Lime (HL) with Asphalt

HL is a suspended material that has proved its efficiency as an additive to asphalt mixtures to enhance the adhesion between the asphalt binder and the aggregate. Several studies have proven its effectiveness in increasing durability, improving the mechanical properties of the mixture, and achieving a significant enhancement in its resistance to moisture damage and aging [19-27]. In addition, an improvement in the rutting resistance of the asphalt mixture was obtained when limestone dust was partially replaced by HL filler [28]. Particular improvement was achieved at high testing temperatures when HL was added to Hot Mix Asphalt (HMA) containing both polymer-modified asphalt and limestone aggregate [29].

HL is a white dry powder made mainly from limestone (Calcium Carbonate, $CaCO_3$) subjected to high temperatures of up to 900°C resulting in the production of quicklime (Calcium

Oxide, CaO), which is in turn hydrated by specific equipment [30]. HL is widely used around the world as an antistripping component. Using the surface free energy method, the effect of HL in Worm Mix Asphalt (WMA) and HMA was evaluated in [31] and [32], respectively, both concluding that the addition of HL to the asphalt mixture resulted in fewer stripping phenomena. Despite the role of HL in improving the properties of asphalt mixture and its success in achieving the desired objectives of controlling distress, or at least mitigating its effect, few studies have shed light in detail on its contribution to improving the properties of asphalt binder before using it in asphalt mixture. This study selected suspended HLMF additive to examine the effect of different proportions in improving the physical properties of the asphalt binder before and after the short-term aging process.

B. Asphalt Aging

Aging can be a chronic phenomenon that negatively affects the performance of asphalt pavements and influences their service life. Aging caused by temperature and oxygen has a significant impact on the durability of asphalt by seriously changing its structure and composition, resulting in harder and more brittle bitumen [33]. It is known that the mechanisms of bitumen volatilization and oxidation are mainly responsible for its aging, or even accelerating its aging process [34-36].

Three critical stages were selected by the Superior Performing Asphalt Pavements (SUPERPAVE) method to test and specify the life cycle of both the modified and unmodified asphalt binder: (i) short-term aging that occurs during transportation, storage, and handling, which is represented by unaged bitumen, (ii) short-term aging that occurs during the HMA production and construction process, simulated by aged bitumen using a Rolling Thin Film Oven (RTFO) according to ASTM D2827, and (iii) long-term aging after a long service life in a mixed pavement while exposed to various environmental and other factors, simulated by aged bitumen (previously subjected to RTFO testing) using a Pressure Ageing Vessel (PAV) according to ASTM D6521 [37]. This study adopted some physical tests for asphalt binders, including the RTFO test, to simulate the short-term age, considering an important stage that affects the life of the mixture.

The severity of aging due to exposure to high temperatures during the production and construction of the asphalt mixture is believed to indicate short-term aging. For this reason, the RTFO test was adopted to simulate the short-term aging process and evaluate the possibility of using the suspended HLMF to mitigate the aging of the modified binder at this important stage.

II. MATERIALS USED

A. Bitumen Content

This study chose bitumen with a penetration grade of 80/100 because it is free from additives and, therefore, the properties affected by the addition of any additive can be better investigated. In general, this grade of bitumen lacks adequate performance to resist fatigue, rutting, and pavement support under heavy loads. Table I shows the required properties of 80/100 penetration-grade bitumen.

TABLE I. PROPERTIES OF 80/100 PENETRATION GRADE BITUMEN

Properties	Result	Specification	Requirement
Penetration @ 25°C, 100 g,5 s, (0.1 mm)	83	ASTM D5	80-100
Softening point, (°C)	46	ASTM D36	> 45
Specific gravity, @ 25°C	1.02	ASTM D70	1.01 -1.06
Solubility in trichloroethylene, (wt. %)	99	ASTM D2042	99 - 100
Ductility @ 25°C. (cm)	>100	ASTM D113	>100
Flash point (°C)	230	ASTM D92	225 min.
Mass loss on Heating, RTFO (%)	0.1	ASTM D6	1 max.
Viscosity @ 135°C (cP)	355	ASTM D4402	3000 max.
Viscosity @ 165°C (cP)	110	ASTM D4402	-

B. Hydrated Lime Mineral Filler (HLMF) as a Suspended Additive

This study used HL as a suspended mineral filler, which is a dry powder made from limestone as a raw material. It is widely available around the world and has the properties shown in Table II.

TABLE II. PROPERTIES OF HYDRATED LIME MINERAL (HLM)

Property	Result
Physical appearance	Dry white powder
Primary ingredients	$Ca(OH)_2$
Specific gravity	2.34
Passing sieve No.200	92% (min)

III. EXPERIMENTAL METHOD

A. Blending Protocol

Five groups of asphalt binder were prepared by adding five different selected proportions of HLMF (2, 4, 6, 8, and 10% by weight of asphalt binder) to bitumen with a penetration grade of 80/100. 500 g of bitumen was first heated to the specified mixing temperature of 154°C using a hot plate and slowly stirred using a high-shear mixer. This mixing temperature was measured from the viscosity chart, plotting the viscosity value of bitumen at two standard temperatures of 135°C and 165°C as shown in Figure 1. This value varies depending on the different proportions of HLMF added to the modified asphalt binder. At 500 rpm, the first proportion of well-dried HLMF was gradually added until the specified amount was completed to ensure that there was no agglomeration and that the HLMF particles did not fly away during the addition process. Then the speed was increased to 1500 rpm for one hour to ensure the homogeneity and consistency of the mixture. The same process was repeated for all the selected proportions. After the process of preparing the required quantities of each group of modified asphalt binders was completed, each group was separated into two parts, one of which was prepared for the required laboratory tests and labeled as unaged samples, and the other was subjected to the RTFO test to simulate the short-term aging process. The resulting samples were also prepared for the required laboratory tests and labeled as aged samples.

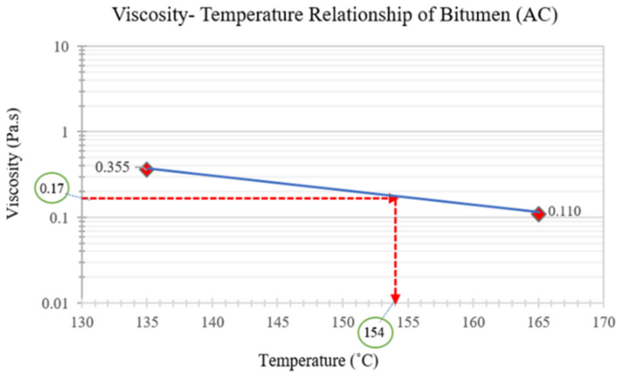

Fig. 1. Mixing temperature measurement of base bitumen (AC).

B. Short-Term Aging (STA) Process

RTFO was adopted to simulate the Short-Term Aging (STA) process. Following ASTM D2872 specifications, the base and the modified asphalt binder with the selected proportion of HLMF were exposed to STA at 165°C for 85 minutes. After the STA, each sample was prepared for the required laboratory tests and labeled as aged samples.

IV. RESULT AND DISCUSSION

A. Test Results for Unaged Samples

The effect of suspended HLMF on the physical properties of asphalt binder, including penetration, softening point, and viscosity, was tested using traditional tests using a Penetrometer, a Ring and Boll apparatus, and a Brookfield viscometer. Table III presents the results.

TABLE III. PHYSICAL PROPERTIES OF UNAGED BASE AND MODIFIED ASPHALT BINDER WITH SELECTED PROPORTIONS OF SUSPENDED HLMF

Sample Code	Physical properties' test results of unaged samples			
	Penetration (0.1mm)	Softening point (˚C)	Viscosity at 135°C (cP)	Viscosity at 165°C (cP)
AC	83	46	355	110
AC-HLMF 2%	73	47.3	399	115
AC-HLMF 4%	65	48.7	476	122
AC-HLMF 6%	60	50.5	468	125
AC-HLMF 8%	62	49.4	462	120
AC-HLMF 10%	60	48.9	463	120

The consistency of the asphalt binder can be well measured by penetration testing. According to the penetration test results, it appears that the presence of the suspended HLMF particles in the medium of asphalt binder has successfully strengthened it by significantly reducing the penetration value of the modified binder. This improvement was found to be associated with an increase in the concentration of HLMF in asphalt binders, which helped to increase their stiffness to some extent. Each of the asphalt binder samples prepared with different selected concentrations of suspended HLMF showed an improvement in penetration results compared to the base asphalt, but the 6% HLMF asphalt binder (AC-HLMF 6%) recorded the highest improvement, as shown in Figure 2. It should be noted that the process of preparing the asphalt binder and adding the suspended additive to the mixture plays a major role in obtaining more reliable results [13-16].

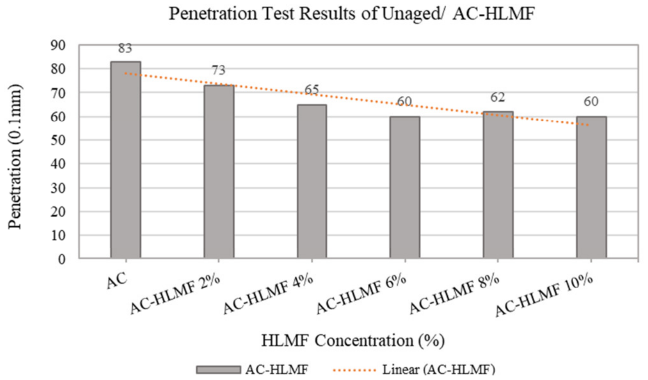

Fig. 2. Penetration test results of unaged base and modified asphalt binder with selected proportions of suspended HLMF.

By testing the softening point, the temperature at which the asphalt binder changes from solid to liquid state can be measured, which greatly affects the consistency of the asphalt binder and the mixture. Figure 3 shows the relationship between the softening point values of the asphalt binder containing different selected concentrations of HLMF. The histogram clearly shows the increase in temperature with the addition of HLMF compared to the base asphalt and the varying improvement with increasing concentrations. According to ASTM D36, both AC and AC-HLMF, containing all specified HLMF concentrations, met the requirement by achieving a softening point higher than 45°C. The variation in the softening point temperature between AC-HLMF groups with different concentrations was not significant, but AC-HLMF 6% recorded a slightly higher value of 51°C, which was 4.5°C above the softening point of the base asphalt.

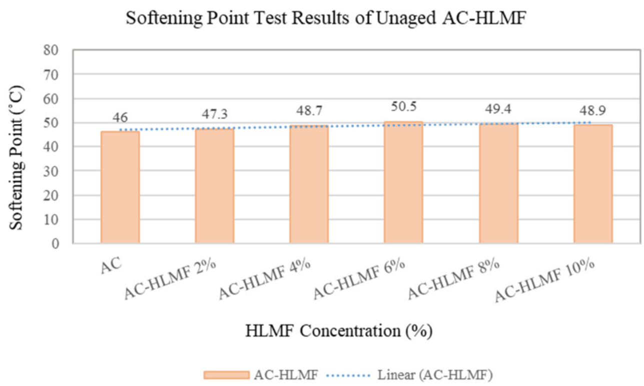

Fig. 3. Softening point test results of unaged base and modified asphalt binder with selected proportions of suspended HLMF.

It is desirable to have an increase in the softening point temperature of the asphalt binder, as an asphalt binder with a high softening point appears to be less susceptible to high temperatures and thus to permanent deformation [14, 15].

The flow characteristics of the asphalt binder can be determined using a viscosity test, as the flow resistance can indicate consistency and provide some assurance about how the asphalt binder will be pumped and handled in the hot mixing facility. This approach has been widely adopted by many researchers [13-16]. The higher viscosity value corresponds to the higher resistance of the asphalt binder. The viscosity of the base and the modified asphalt binders were measured at two standard testing temperatures of 135°C and 165°C, as shown in Table III and Figure 4. The addition of suspended HLMF successfully enhanced the resistance of the modified binder to flow at the two standardized elevated temperatures, resulting in higher viscosity values. Compared to base asphalt, the modified asphalt binder with different concentrations of suspended HLMF showed higher viscosity values. Again AC-HLMF 6% was found to perform better when exposed to elevated temperatures of 135°C and 165°C.

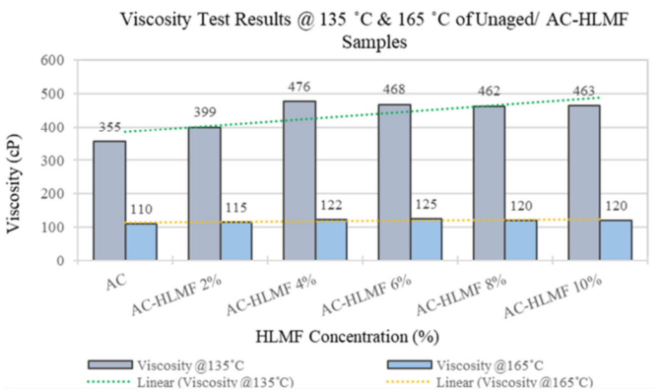

Fig. 4. Viscosity test results of unaged base and modified asphalt binder with selected proportions of suspended HLMF.

B. *Test Results for STA Samples*

The same assessments carried out to evaluate the physical attributes of unaged asphalt and modified asphalt were once again applied to all STA samples to analyze the impact of adding specific concentrations of suspended HLMF on their physical attributes, utilizing the RTFO test to mimic the STA phenomenon that takes place during the HMA production and construction phases. Table IV and Figures 5, 6, and 7 illustrate the outcomes of the penetration, softening point, and viscosity assessments conducted on the base and modified asphalt binders at five distinct selected concentrations after the STA procedure, respectively.

TABLE IV. PHYSICAL PROPERTIES OF BASE AND MODIFIED ASPHALT BINDER WITH SELECTED PROPORTIONS OF SUSPENDED HLMF

Physical properties test result of STA samples				
Sample code	**Penetration (0.1 mm)**	**Softening point (°C)**	**Viscosity at 135 °C (cP)**	**Viscosity at 165 °C (cP)**
AC	52	51.5	560	146
AC-HLMF 2%	46	52.1	612	170
AC-HLMF 4%	43	53.0	691	173
AC-HLMF 6%	41	54.9	667	165
AC-HLMF 8%	40	53.6	700	166
AC-HLMF 10%	38	53.0	690	163

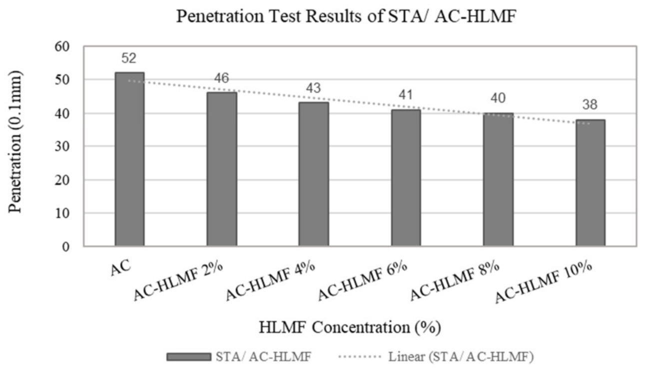

Fig. 5. Penetration test results of STA base and modified asphalt binder with selected proportions of suspended HLMF.

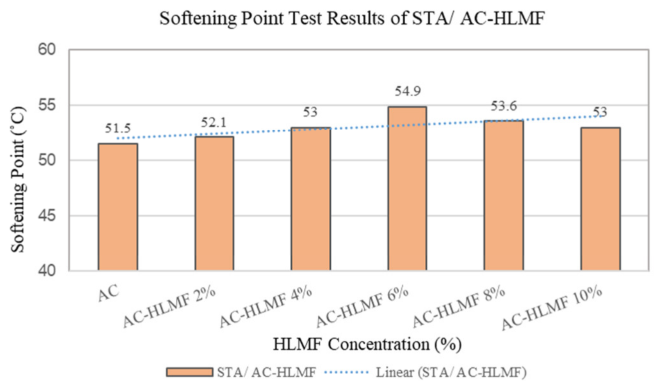

Fig. 6. Softening point test results of STA base and modified asphalt binder with selected proportions of suspended HLMF.

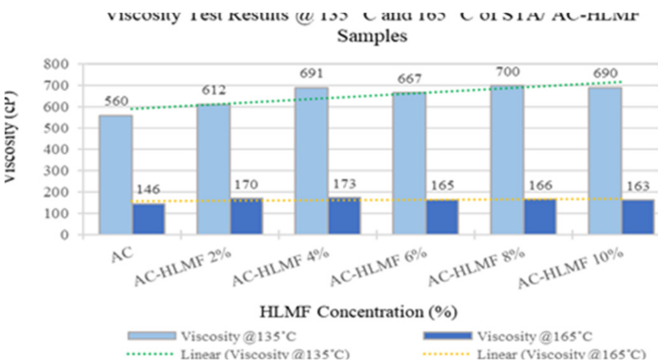

Fig. 7. Viscosity test results of STA base and modified asphalt binder with selected proportions of suspended HLMF.

As shown in the figures above, under the same aging conditions using RTFOT, suspended HLMF at different concentrations successfully contributed to improving the physical properties of modified asphalt binders exposed to STA, compared to the unmodified base asphalt. The experimental results of the aged samples showed that with an increase in HLMF, the penetration value decreased, the softening point increased, and the viscosity increased at 135°C and 165°C compared to the base asphalt. There was a slight variation among asphalt binders with HLMF concentrations more than 4%, especially for the softening point and viscosity tests, but their performance was definitely better than that of the base asphalt. The observed variation in results with varying concentrations of suspended HLMF in the asphalt binder can also be attributed to the tendency of the suspended material to settle at the bottom of the sample container. Therefore, it is very important to pay attention to this point and to emphasize that the modified asphalt binder is stirred well before sampling and before starting any testing, if possible, to ensure proper dispersion of the additive particles within the asphalt binder. This improvement can be attributed to the proper distribution of suspended HLMF particles in the STA asphalt binder samples, which made them stiffer and less susceptible to permanent deformation at elevated temperatures, in addition to the fact that the dispersion of HLMF reduced the chemical reaction of some asphalt components with oxygen [1]. The suspended particles positively strengthened and hardened the modified asphalt binder by reducing its flowability and achieving the required resistance to the aging phenomena compared to the base asphalt, which is significantly affected by aging.

Three different aging index measurements were adopted to characterize the effect of suspended HLMF on modified asphalt binder samples before and after exposure to STA: Retained Penetration (RP), Increment in Softening Point (ISP), and the Viscosity Aging Index (VAI), as shown in Figures 8, 9, and 10, respectively. RP was calculated according to the penetration test values of all unaged and short-term aged AC-HLMF asphalt binder samples at different concentrations. The variation in RP, shown in Figure 8, indicates that there is an obvious improvement in the penetration value, represented by the retained penetration values after adding suspended HLMF to the asphalt binder. The addition of this substance can improve the consistency of the asphalt binder by dispersing suspended particles more effectively and enhancing its resistance to aging by limiting the reaction of its chemical components with atmospheric oxygen. These particles are thought to form a strong bond, making it difficult for the testing needle to penetrate the sample. As expected from the previous results, AC-HLMF 6% achieved the best results, with an improvement of 9%.

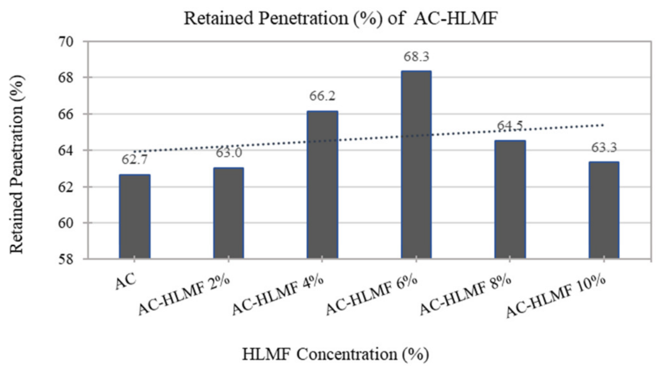

Fig. 8. Retained penetration in the percentage of AC-HLMF at different selected concentrations.

For the SP test, the ISP concept was adopted to provide a high degree of confidence in the test results. The addition of suspended HLMF to the asphalt binder contributed to the reduction of ISP, which is a good indicator compared to the base or unmodified asphalt. The presence of suspended particles in the asphalt binder made it somewhat difficult to flow at high temperatures and thus could be resistant to permanent deformation. Figure 9 shows a clear variation in ISP values corresponding to the variation of HLMF concentration in the asphalt binder, where all AC-HLMF samples recorded better performance than the base asphalt at elevated temperatures, with slight variations between them.

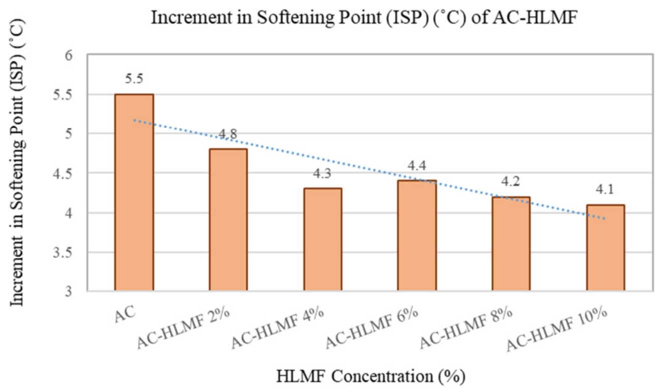

Fig. 9. Increment in softening point in Celsius degrees (°C) of AC-HLMF at different selected concentrations.

VAI was also used as an aging measure. This concept was designed based on the data of the viscosity test at an elevated temperature of 135°C before and after the STA process for AC and AC-HLMF asphalt binder samples. A lower VAI value indicates that the asphalt binder has better aging properties and is more resistant to aging. According to Figure 10, the decrease in VAI values showed that the HLMF particles gained significant improvement in aging resistances compared to base asphalt despite the difference in concentrations resulting in a noticeable variation in the heights of the histogram columns. AC-HLMF 6% exhibited better resistance to STA by 26% than base asphalt.

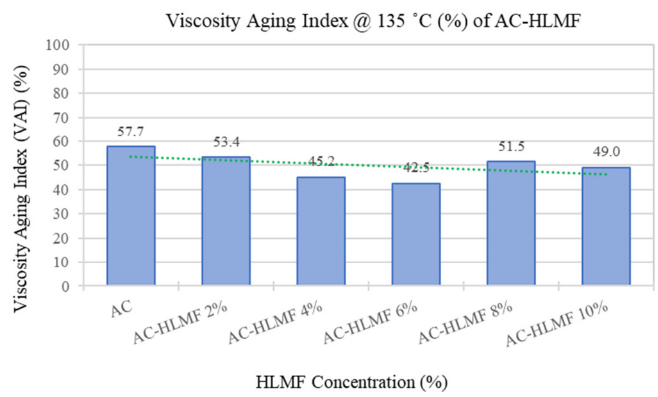

Fig. 10. VAI percentage of AC-HLMF at different selected concentrations.

V. CONCLUSION

The following conclusions were reached based on the results obtained from the laboratory experiments.

A. Unaged AC and AC-HLMF Samples

Lower penetration values as well as higher softening point, and viscosity values were achieved for AC-HLMF samples compared to AC samples, indicating that the addition of suspended HLMF to the asphalt binder successfully improved each of the stiffness, consistency at moderate temperatures, susceptibility to high temperatures, and flow resistance at elevated temperatures.

B. AC and AC-HLMF Samples Subjected to STA

Compared to unaged samples, aged samples showed lower penetration values, as well as higher softening point and viscosity values, regardless of whether the sample was modified or not. Aged AC-HLMF samples showed better performance than aged AC samples under the same aging conditions, indicating that the appropriate dispersion of suspended HLMF particles successfully reduced the chemical reaction of asphalt components with atmospheric oxygen, making the binder stiffer, less susceptible to temperature, and more aging resistant.

C. Aging Indices

This study adopted RP, ISP, and VAI as aging indices to describe the severity of the aging effect. Higher RP values and lower ISP and VAI values proved that the suspended HLMF particles improved aging resistance.

D. HLMF Concentrations

Although there were slight variations in the results with different HLMF concentrations, the performance of the AC-HLMF samples was definitely better than that of the AC sample under the same test conditions. In terms of concentration performance among the five selected concentrations, AC-HLMF 6% was the best, achieving improvements of 9% RP and 26% VAI compared to the base asphalt.

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