Discovery

Detecting the influence of additives on the physical properties of asphalt binder

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ABSTRACT

The physical properties of Asphalt cement binder usually decline throughout its service life due to the environmental impact. The asphalt binder will lose the required flexibility, resilience, cohesion, and creep stiffness. Implication of additives can enhance the quality of the binder and extend its useful life. In the present investigation, two types of asphalt cement binder with a penetration grade of (40-50) and (60-70) have been modified by implication of (coal fly ash), and (hydrated lime) additives. The treated binders underwent determination of their physical properties. It was observed that for (60-70) and (40-50) binders, the penetration value declined by (69.7, and 16.6, 5) % and (66, and 22.7) % after implication of coal fly ash, and hydrated lime respectively. The softening point of (40-50) and (60-70) binders increased by (2, and 2) % and (6.2, and 4.1) % after implementation of coal fly ash, and hydrated lime respectively. It was observed that modification of binder with (coal fly ash) exhibits higher stiffness modulus among the control or lime-treated binder regardless of the binder type. For (40-50) and (60-70) binders, the creep stiffness increased by (5, and 32.5) % and (6.2, and 25) % after implication of coal fly ash, and hydrated lime into the binder respectively. It was concluded that modification of asphalt binder with coal fly ash had exhibited the highest stiffness modulus as compared to the control or lime treated binders regardless of the binder type.

Keywords: Asphalt binder, physical properties, penetration, stiffness modulus, additives, creep stiffness

1. INTRODUCTION

The influence of implication of fly ash into the asphalt cement binder was reported by Sarsam and AL-Azzawi, 2013) using different percentages. It was revealed that it causes poor adhesiveness, poor wetting, and the behaviour of the modified binder changes from hydrophilic to hydrophobic. Bhat and Mir, (2021) conducted a laboratory investigation on the physical properties of asphalt binders after modification with Nano-silica. It was revealed that Nano-silica is produced from rice husk and silica fumes while it is considered as eco-friendly additive, and costeffective asphalt modifier. The testing results of the study concluded that the incorporation of additives into the asphalt binder had exhibited an improved performance at elevated temperatures which enhanced the resistance against fatigue cracking.

Sarsam, (2015) had digested asphalt cement binder with two types of additives, (fly ash and silica fumes), and assessed the possibilities of improving mechanical, and physical properties of the asphalt binder. It was revealed that the additives exhibited a positive influence on the behavior of asphalt cement by reducing its temperature susceptibility, while it exhibited variable impact on the viscosity of the binder. It was detected that Silica fumes increase the viscosity, while fly ash reduces the values. However, Silica fumes increase the softening point of the binder significantly, while fly ash increases it marginally Golestani et al., (2012) assessed the performance of modified asphalts binder by additives.

The testing results showed improvement in the physical properties, and the stability of the bitumen. Hui et al., (2013) assessed the chemical bonding of modified asphalt binders after blending with Nano silica. It was found that implementation of Nano silica exhibits a positive influence on anti-oxidation, while it slightly decreased the viscosity of the control asphalt binder and maintained low dissipated work per load cycle. Jahromi and Khodaii, (2009) stated that various physical properties of asphalt binder such as tensile strength, stiffness, tensile modulus, thermal stability, and flexural strength could be enhanced when modified with small amounts of nano-clay.

The merit of implication of nano-silica as an anti-ageing additive into asphalt binder was assessed by (Zafari et al., 2014). The modified Asphalt binder was then exposed to short-term aging process. It was concluded that Nano-silica additive was able to improve the ageing resistance of the asphalt binder and significantly increases the viscosity and complex modulus of the asphalt binder. This in turn will improve the rutting resistance of the pavement. Sarsam, (2015) modified the Asphalt cement binder in the laboratory by adding of (silica fumes) and (hydrated lime). It was stated that the softening point increased while the penetration declined, and the control of the temperature sensitivity could be achieved after modification.

It was concluded that hydrated lime caused reduction in the penetration, ductility, while increased the elastic strain recovery, significantly, and increases the temperature susceptibility of the modified binder. Yao et al., (2013) investigated the applicability of nano-clay and carbon micro-fiber in asphalt cement binders. They evaluated the performance of the modified asphalt binders in terms of rheological properties. It was stated that the dynamic shear modulus of asphalt binder can be improved by the selected additives. Adding Nano-clay, Nanotubes, and Nano-silica to asphalt cement binder normally increases the viscosity of asphalt binders, as stated by (Yanga and Tigheb, 2013).

Hui et al., (2013) reported that with the addition of nano-silica as an additive to the asphalt binder, the viscosity values of the modified asphalt binder decline slightly. This may indicate that lower energy consumption and lower compaction temperature of the construction process could be achieved. The mechanism of nano ZnO on the moisture damage resistance of asphalt mixtures was assessed by (Hamedi et al., 2015). The testing results exhibited that the tensile strength ratio of (wet/dry) values of indirect tensile strength for the mixtures containing nano ZnO for two types of aggregate was higher than that of the control asphalt concrete mixtures.

Li et al., (2017) reported that nanomaterial additives exhibit specific characteristics due to their large surface area and small size, compared to the common material applied in the field of asphalt pavement as an additive. Some conventional test results including dynamic modulus, viscosity, and rheological properties have been employed to characterize the performances of the modified asphalts binder. It was concluded that the addition of such additives could dramatically enhance the properties of an asphalt material such as the resistances to aging, visco-elasticity, and performance at high temperature. Shafabakhsh et al., (2020) reported that the modification of asphalt binder with Nano-SiO_2 exhibited reduced ductility, increased elastic modulus, increased viscosity, and increased softening point.

According to a recent investigation by Farag et al., (2014), the addition of calcium oxide (CaO) in asphalt cement binder produces a reduction of the penetration value, which is directly related to its resistance to high temperature, and an increase of softening point's value while the resilience modulus value increased as compared with that in the control binder. Raufi et al., (2020) investigated the impact of modification of asphalt binder with $CaCO_3$, nano-Bentonite, and Zyco-Therm. Conventional tests on asphalt binders have been conducted to verify the influence of modification.

The testing results revealed that such additives can enhance the high-temperature susceptibility resistance of asphalt binder samples. The present assessment aims to assess the influence of modification of asphalt binder with additives (coal fly ash and hydrated lime) on the physical properties. The variation in penetration, softening point, resilience, creep stiffness, and the predicted stiffness modulus of asphalt concrete will be monitored after implication of additives and compared with those of the control binder.

2. MATERIALS AND METHODS

The implemented additives (coal fly ash and hydrated lime) are locally available; Figure 1 demonstrates the implemented additives.

Hydrated Lime

Hydrated lime is a derivative of burnt lime, it is produced by reacting burnt lime with water in a continuous hydrator. Hydrated lime is light and fluffy with a chemical formula of Ca (OH)2 and has a 4404 m^2/kg specific surface area and a specific gravity of 2.211. This material was obtained from the local market and the portion used is 75-micron maximum size. Its chemical compositions are listed in (Table 1).

Fly Ash

The fly ash of class F is obtained as a by-product of coal combustion from local market, this fly ash has specific surface area of 600 m^2/Kg and a specific gravity of 2.016. The portion used is 75-micron maximum size. The chemical components of fly ash are listed in (Table 1).

Figure 1 The implemented additives

Table 1 Chemical Components of additives

Additives	Oxides percentages					Loss on Ignition
	SiO2	**Fe2O3**	**Al2O3**	**CaO**	**MgO**	
Hydrated lime	0.74	0.19	0.5	64.23	1.17	29.94
Coal fly ash	61.95	2.67	28.82	0.88	0.34	0.86

Asphalt Cement Binder

Two types of Asphalt cement binder of penetration grade (40-50) and (60-70) have been obtained from the Dourah oil refinery. Such types of binder are implemented in asphalt pavement construction in Iraq. Table 2 presents the physical properties of asphalt binders.

Preparation of Modified Asphalt Binder

The modified asphalt binder was prepared in the laboratory by using the wet process. In the wet process, asphalt cement was heated to 150 °C and then blended with the additives with the specified percentage. The blending was conducted at a blending speed of 1300 rpm and constant for 30 minutes to promote the possible chemical and physical bonding of the components. The degree of dispersion of the additives into the asphalt binder was controlled by the blending duration and blending speed. Similar precautions were followed by (Li et al., 2017).

Table 2 Physical Properties of Asphalt Cement Binders

Property	(ASTM, 2015) specification	Asphalt cement (40-50)	Asphalt cement (60-70)
		Test results	Test results
Penetration at 25°C,100gm,5sec, (0.1mm)	D-5	44	66
Softening Point, °C	D-36	50	48
Ductility at 25 °C, 5cm/min, (Cm)	D-113	+100	+100
Resilience (ball strain recovery) %	D-5329	98	99
Specific gravity	D-70	1.042	1.030
After the thin film oven test			
Penetration at 25°C, 100gm, 5sec, (0.1mm)	D-5	33	51
Loss in weight	D-1754	0.17	0.24
Ductility at 25 °C, 5cm/min, (Cm)	D-113	73	90
Softening Point, °C	D-36	54	51

The range of treatment with additives was (5-20) % with a 3 % increment. The optimum percentages of additives content were selected based on the significant change in physical and rheological properties of the modified binder as compared with the control binder. Details of mixing and obtaining the optimum additive could be referred to (Sarsam, 2013; Sarsam, 2015; Sarsam and Lafta, 2014; Sarsam, 2016). The summary of the optimum additives content for Micro and Nano size is listed in (Table 3).

Table 3 Optimum Additives Content

Additives	
Coal fly Ash	**Hydrated Lime**
5 %	10 %

Testing of Modified Binder

The prepared asphalt binder samples were subjected to some of the traditional physical properties' determination such as (Cone penetration, ring and ball softening point, resilience %, creep stiffness, and predicted stiffness modulus of asphalt mixture SM). The various testing was conducted following the recommended testing procedures by ASTM, (2015), AASHTO, (2013), Shell International Petroleum Company, (1978) and other procedures recommended by the literature.

3. RESULTS AND DISCUSSIONS

Influence of Additives on Physical Properties of the Binder

Figure 2 demonstrates the influence of additives on physical properties of asphalt binder. It can be stated that the consistency of the binder, as indicated by the penetration test, is significantly influenced by implication of additives regardless of the binder type. The penetration value declines after implementation of (fly ash and hydrated lime) by (69.7, and 16.6) % for (60-70) binder, while it declines by (66, and 22.7) % for (40-50) binder. Such behaviour may be attributed to the increase in viscosity and reduction in the consistency of the modified binder that occurred due to the physical and possible chemical reaction between the binder components and the implemented additives.

Higher impact of additives on penetration could be detected for binder of (60-70) penetration grade as compared to the (40-50) grade binder. Such behaviour may be attributed to the higher volatiles content, which can enhance the chemical reaction for (60-70) grade binder. Similar findings were reported by (Norhidayah et al., 2021). The softening point is defined as the temperature at which the asphalt binder is converted from solid state to semisolid state, and it is implemented to evaluate the temperature susceptibility of asphalt cement. It can be noticed from Figure 2 that the softening point of the binder increases after digestion with additives regardless of the binder type as compared with the control binder.

The softening point of (60-70) binder increases by (6.2 and 4.1) % for (fly ash and lime) modified binder, while for (40-50) binder, it increases by 2 % for both additives. A high softening point is usually recommended for paving work to control the temperature susceptibility of the binder; this can be achieved by implementing coal fly ash and hydrated lime for modification of the asphalt binder. The additive particles can change the viscosity of the binder significantly in addition to the possible chemical reaction with the binder's components. Such a finding agrees with (Jahromi and Khodaii, 2009).

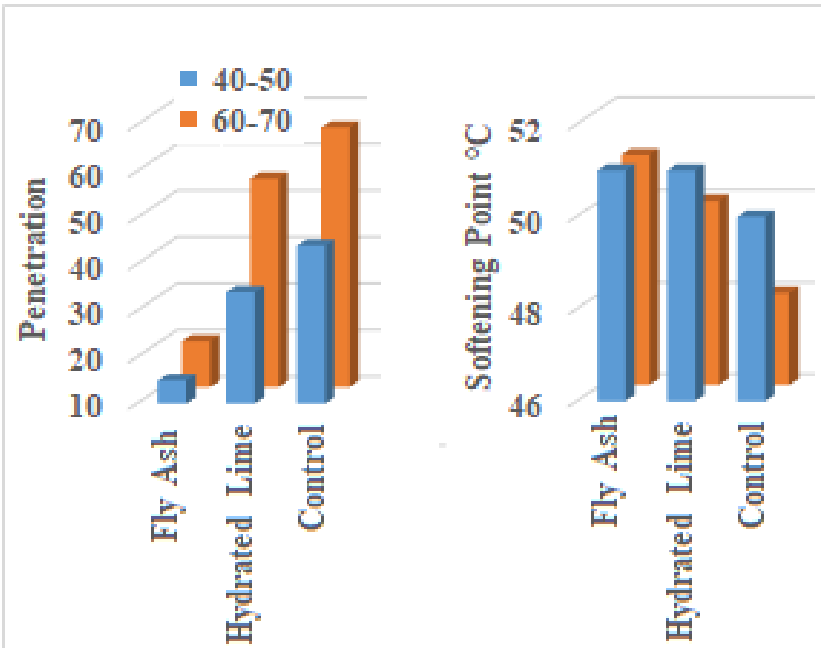

Figure 2 Influence of additives on the physical properties of the binder

Influence of additives on resilience and predicted stiffness modulus of Asphalt Concrete Mixture

The resilience % of the binder provides an idea about the changes in elastic properties of the binder, it can be observed from Figure 3 that the resilience declines significantly after implementing the hydrated lime additive for (40-50) binder, while the coal fly ash additives exhibit lower decrease in the elastic property. The reduction in the resilience property may be attributed to the increase in the viscosity of the binder. The resilience percentage for (60-70) grade binder declines by (12.1, 5) % for Fly ash, and lime modified binder respectively. However, for (40-50) binder, the resilience declines by (2, and 6.1) % for Fly ash, and lime modified binders respectively. Such a finding agrees with (Raufi et al., 2020).

Figure 3 also exhibits the influence of additives on the predicted Stiffness Modulus of asphalt concrete with the aid of (Shell International Petroleum Company, 1978). It can be noticed that the implication of additives increases the predicted Stiffness Modulus regardless of the binder or additive type. For (40-50) binder type, fly ash exhibits higher stiffness Modulus of asphalt concrete than control or lime treated additive. Such behavior may be attributed to the possible chemical reaction of the additive with the component of the binder. The Stiffness Modulus increases by (400, and 25) % when fly ash, and hydrated lime were implemented as compared with the control binder. For (60-70) binder type, the Stiffness Modulus increases by (780, and 200) % when fly ash, and hydrated lime were implemented as compared with the control binder. A similar finding was reported by (Sarsam, 2016).

Influence of additives on the creep stiffness of asphalt binder

Creep stiffness measures the impact of thermal stresses in the asphalt binder resulting from thermal contraction. If these stresses are significant, cracking will occur. A higher creep stiffness value indicates higher thermal stresses. To determine the stress relaxation properties of an asphalt binder, creep stiffness calculations are made after 8, 15, 30, 60, 120 and 240 seconds of loading with the aid of bending beam rheometer BBR. These loading periods were chosen because they are equally spaced on a logarithmic time scale. For each time, the asphalt binder creep stiffness is calculated and plotted. The creep stiffness measured at 60 seconds should be equal to or less than 300 MPa for regular asphalt binder.

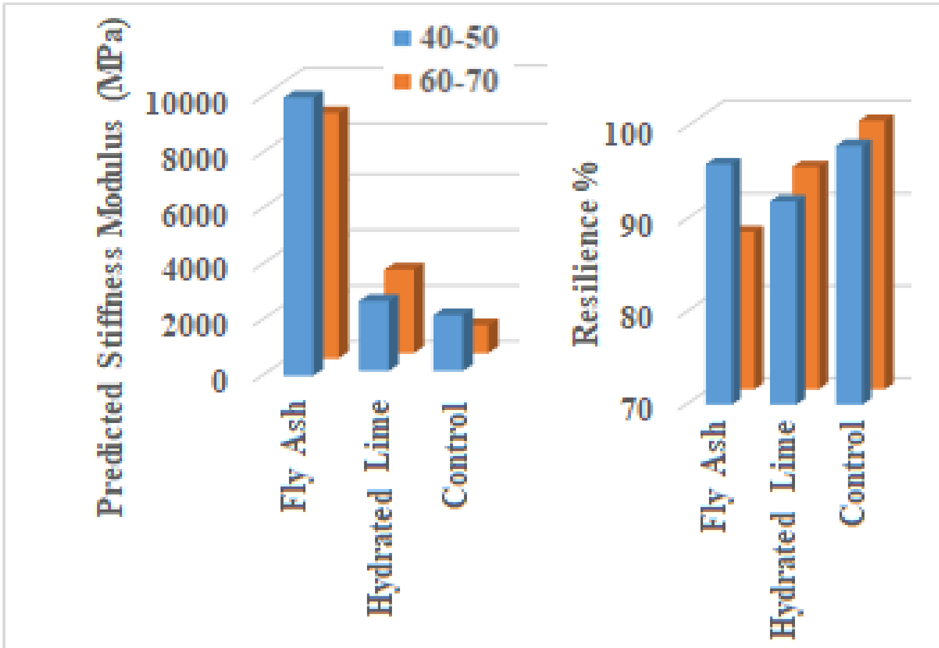

Figure 3 Influence of additives on resilience and predicted stiffness Modulus

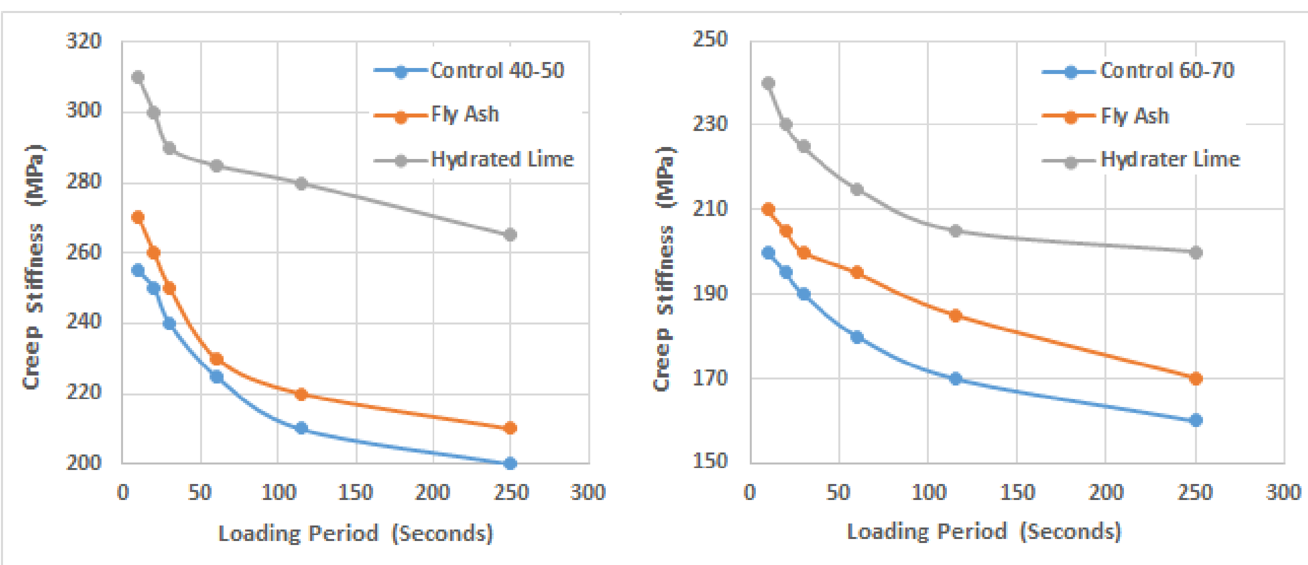

Figure 4 Influence of additives on the creep stiffness

As demonstrated in Figure 4, the creep stiffness declines with the loading period regardless of the binder or additives type. For (40-50) binder type, implications of additives into asphalt binder exhibits an increment in the creep stiffness compared to the control binder. A sharp reduction in the creep stiffness could be noticed after the start of loading, while the rate of reduction changes to gentle after 120 seconds. The creep stiffness increases by (5, and 32.5) % when coal fly ash, and hydrated lime were implemented. For (60-70) binder type, implementation of additives also exhibits an increment in the creep stiffness compared to the control binder.

A sharp reduction in the creep stiffness could be noticed after the start of loading while the rate of reduction changes to gentle after 120 seconds. The creep stiffness increases by (6.2, and 25) % when coal fly ash, and hydrated lime were implemented. It can be stated that implementation of additives exhibits higher creep stiffness when compared with the control binder. Similar findings were reported by (Sarsam and Lafta, 2014; Ashish and Singh, 2019).

4. CONCLUSIONS

Based on the limitations of testing and materials, the following conclusions may be addressed. For (60-70) and (40-50) binders, the penetration value declines by (69.7, and 16.6,) % and (66, and 22.7) % after implementing coal fly ash, and hydrated lime respectively. The softening point of (40-50) and (60-70) binders increased by (2 and 2) % and (6.2, and 4.1) % after implementing coal fly ash, and hydrated lime respectively. The resilience for (60-70) binder declines by (12.1, and 5) % for coal fly ash, and hydrated lime respectively. However, for (40-50) binder, the resilience declines by (2, and 6.1) % for coal fly ash, and hydrated lime respectively. It can be revealed that the implementation of additives exhibits higher stiffness modulus for (40-50) binder when compared with that of (60-70) binder. Coal fly ash modified binder exhibits the highest stiffness modulus compared to the control or lime treated additive regardless of the binder type. For (40-50) and (60-70) binders, the creep stiffness increases by (5, and 32.5) % and (6.2, and 25) % when coal fly ash, and hydrated lime were implemented respectively.

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Author Contributions

Contribution to this work was made by the author.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable.

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Data and materials availability

All data associated with this study are present in the paper.

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