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Research paper

Enhancement the Performance of Asphalt Pavement Using Fly Ash Wastes in Saudi Arabia

Mohammed Dahim [1]*

[1]*Vice president for project, King Khalid University, Abha, Saudi Arabia*
**Corresponding author E-mail: madahim2018@yahoo.com ; Phone: + 966 503 239 981*

Abstract

Saudi Arabia is the largest Arab country and is one of the most prolific producers of oil and energy consumption. The Kingdom uses heavy oil and diesel to generate electricity and desalinate seawater. This produces large amounts of ash, a toxic substance that is disposed of by landfill and may cause many environmental problems and contribute to pollution of groundwater, which is one of the most important sources of drinking water. This paper presents the possibility of using fly ash by-product waste from electric power generation plants to improve the properties of asphalt mixtures. This study investigates the use of two types of fly ash namely; class C and class F was used as a filler in two types of bitumen and asphalt material known as AC 40/50 and AC 60/70. The rheological performance of asphalt with different percentages of fly ash filler ranging from 0% to 10% with an increment of 2% was tested. The rheological properties of both asphalts modified using both types of ash were determined. The rutting factors of the modified asphalt with fly ash content were calculated using the rheological properties. The result indicates that rutting resistance of asphalt could be improved by both types of fly ash which can be lead to reduces the costs of repairing and rehabilitation of asphalt pavement and reduce environmental impacts of a significant amount of toxic waste fly ash. Class F fly ash shows higher rutting factor than class C. Also AC 60/70 asphalt possess higher rutting factor than AC 40/50 asphalt at both low and high temperature.

Keywords: *Asphalt; Fly as; Rheological performance; Ruttin; Saudi Arabia.*

1. Introduction

Kingdom of Saudi Arabia (KSA) is one of the largest Arab countries in West Asia with an area of 2149690 km2 and a population of 32.552336 million in 2017[1]. KSA is a high-income nation and is part of the Group of Twenty (G20) of major economies. According to the average per capita income, KSA ranked on the 18th position globally [2-3]. The larger the population of a country and the higher the income, the higher the demand for electricity, energy, and transport infrastructure such as roads and highway which consumes an enormous amount of energy and asphalt materials[4]. Development of paved and rural roads in the KSA in the last five years indicate that the number of paved road in year 1432H (2011) was 59143 roads and increased to 64632 roads in 1437H (2016) [5]. KSA is the world's leading oil exporter and plays a pivotal role in OPEC. The contribution of the oil sector in the Kingdom constitutes 45% of the annual budget revenues and GDP and 90% of the export revenues[6]. KSA has a mix of power and water desalination capacity, with more than 80.5 GW of power generation. KSA has the most significant installed capacity (including desalination) among Arab countries, and the total consumption of electric power in KSA during 2016 approximately was 300 terawatt hours [7].

KSA has more than 70 power plants which consumed more than 22 million metric tons of crude and heavy oil. These power plant produced a vast amount of fly ash waste. The total amount of fly ash waste in 2008 was about 0.25 million cubic meters, and it is expected to increase to half million cubic meters by 2016 [8]. This significant amount of waste ash mostly disposed of in landfill which contribute to several environmental problems.

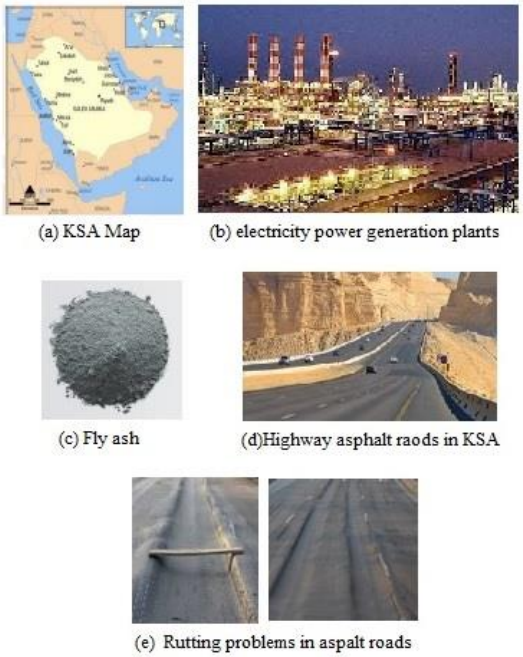

Fig. 1: Map of KSA and rutting problem in roads and pavement.

KSA also has a very huge of asphalt paved roads and highway. These asphalt pavement suffer from the rutting problems due to heavy truck loads and hot, arid weather in KSA. Billions of dollars spent every year to overcome this problem and repair the asphalt

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pavement roads. Fig. 1 show the map of KSA and rutting problem in roads.

Fly ash has been used to improve the performance of construction materials such as concrete [9-11]. Despite the extensive research conducted to use fly ash in cement concrete industry, limited research conducted to investigate the use of fly ash to enhance asphalt material. Several studies conducted to evaluate the effect of using fly ash in asphalt materials. A sample of these studies includes improvement of asphalt to moisture resistance[12-13], enhancement of mechanical performance of asphalt [14], the effect of fly ash on the rheological properties[15].

This paper presents the investigation of the use of two types of fly ash supplied by electricity power plants in KSA to enhance the rutting resistance of asphalt material. Two types of bitumen AC 40/50 and AC 60/70 were used. The rheological performance and rutting factors of these types of bitumen incorporated different percentage of fly ash content were evaluated and reported

2. Material and Test

In this study, two bitumen binder were used. These binders were AC 40/50, and AC 60/70 and the specification of these binders are given in Table 1. The binder was mixed with two types of fly ash class C and class F as filler.

The chemical analysis, X-ray fluorescence (XRF) and scanning electron microscope (SEM) of each type of fly were conducted, and the result is presented in the next section.

Table 1: Specification of bitumen asphalt binder AC 40/50 and AC 60/70.

Font Size	Standard Test	Bitumen (asphalt type)	
		AC 40/50	AC 60/70
Density	ASTM D7	1.01-1.06	1.01-1.06
Penetration @25°C, 10/mm	ASTM D5	40-50	60-70
Softening Point (°C)	ASTM D36	52-60	49-56
Ductility at 25°C (cm)	ASTM D113	Min 100	Min 100
Flash Point (°C)	ASTM D92	Min 250	Min 250
Solubility in Disulfide % wt	ASTM D4	Min 99.5	Min 99.5
Strain Test	AASHTO 102	Negative	Negative
Weight Loss by Heating % wt	ASTM D6	Max 0.2	Max 0.2
Penetration Loss by Heating %	ASTM D5	Max 20	Max 20

Sample from each binder (AC 40/50 and AC 60/70) was used to prepare asphalt with 0%, 2%, 4%, 6%, 8%, and 10% from each type of fly ash (class C and class F) by weight. Both binder and ash were mixed using a standard mixer for 6 min at temperature 160°C.

The mixing procedure was repeated three times to produce a homogeneous product of original and modified asphalt. To evaluate the rheological properties of the modified asphalt was determined using AASHTO T315 standard.

The complex modulus (G*)and phase angle (δ) was calculated from the rheological results such as the maximum applied stress, the resulting maximum strain, and the time lag between these. Rutting factor of each asphalt sample was calculated by:

$$Rutting\ Factor = G^*/(\sin\delta) \quad (1)$$

3. Results and Discussion

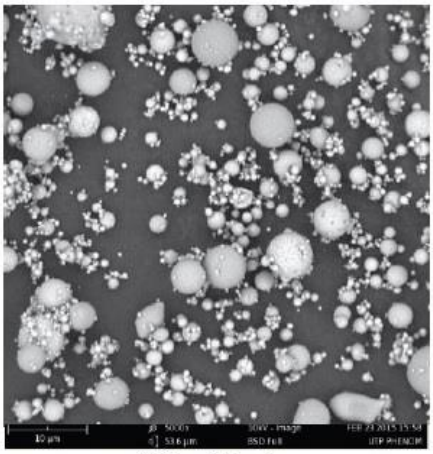
The result obtained in this study are presented in the next two subsections. The first section includes the properties of fly ash samples used in this study while the second section explains the result obtained from the rheological test of modified asphalt material using the two types of ash. The rutting factor was determined from the rheological properties of the asphalt with and without ash were compared.

3.1. Fly Ash Material

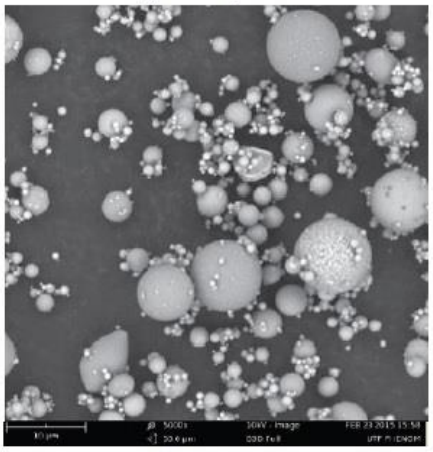
This research was conducted to investigate the use of two types of fly ash. The two samples of fly ash were taken from power plants of Saudi Electricity Company in KSA. The chemical composition of both samples of fly ash is shown in Table 2. The results indicate that fly ash used in this study could be classified as class F fly ash and class C fly ash according to the ASTM 618 standards requirements. The analysis shows that class F fly ash has more Si and Al content compared to class C fly ash.

Table 2: The chemical composition of the two fly ash samples

Chemical composition	Fly ash type	
	Class C	Class F
SiO_2	20.5	55.17
Fe_2O_3	32.1	11.27
Al_2O_3	9.11	24.82
CaO	26.9	1.42
K_2O	2.61	1.71
Na_2O	1.10	1.48
SO_3	1.50	0.14
MgO	2.16	0.29
LOI	2.95	5.13



(a) Class C fly ash



(b) Class F fly ash

Fig. 2: SEM of the two types of fly ash, (a) class C fly ash and (b) class F fly ash.

The SEM and XRF were used to determine the chemical composition of both fly ash types. Figures 2 and 3 shows the result of XRF and SEM respectively.

The results of SEM indicate that there are no significant differences in morphology and elements between class C and class F fly ashes. The particle shape of both fly ash is amorphous sphere and sleek which have over 50% chemical proportions of aluminum

(Al), silica (Si) and oxygen (O) which they are in strong signal intensities. Therefore both ashes is called amorphous alumina silicate sphere.

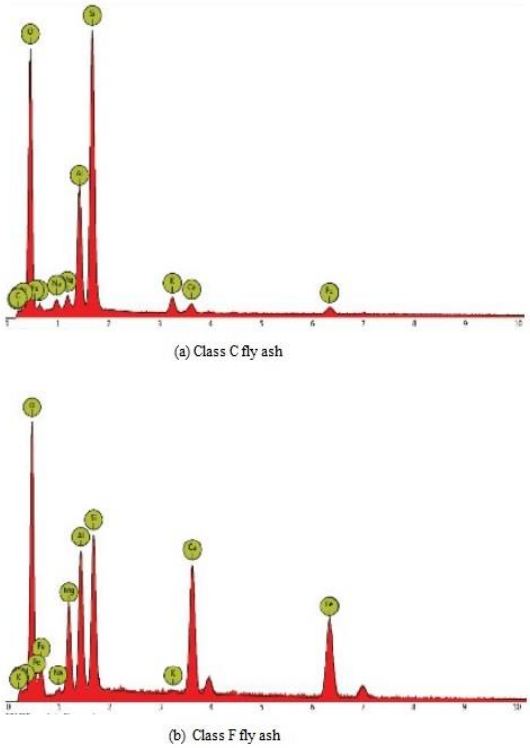


Fig. 3: XRF test of the two types of fly a, . (a) class C fly ash and (b) class F fly ash.

3.2. Rheological Result and Rutting Factor

The result of rheology and rutting factor for the two types of bitumen AC 60/70 and AC 40/50 with two type of filler fly ash class C and fly ash class F at various filler content tested at two temperature 60°C and 70°C are shown in Fig. 4 and Fig. 5.

The result indicates clearly that both types of fly ash improve the rutting factor. Rutting factor increase with increasing fly ash content in asphalt material. This may lead to improve the performance of road in KSA and reduce deterioration problems result from rutting and could save a significant amount of money every year. Class F fly ash show a high rutting factor in compare with fly ash class C. Also, the rate of improving rutting factor of asphalt incorporated class F fly ash is higher than the rate of improvement observed for class C fly ash. The result also indicates that bitumen AC 60/70 has higher rutting factors than bitumen AC 40/50 at both testing temperatures. The results obtained and presented is in good agreement with the research conducted by other researchers in the literature[15-17].

A regression analysis shows that a linear model could be used to determine the rutting factor of asphalt material for all fly ash type and at temperature 60°C and 70°C. The linear model with the corresponding correlation factor is given in Fig. 4 and Fig 5.

Class F fly ash shows higher rutting factor than class C. Also AC 60/70 asphalt possess higher rutting factor than AC 40/50 asphalt at both low and high temperature.

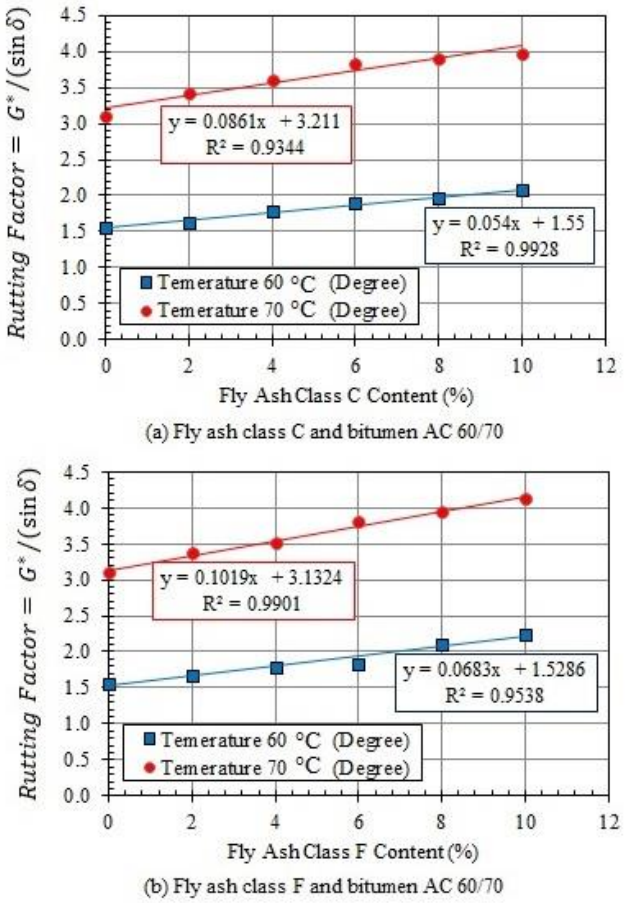


Fig. 4: Rutting factor G*/sin(δ) for bitumen AC 60/70 incorporated fly ash filler.

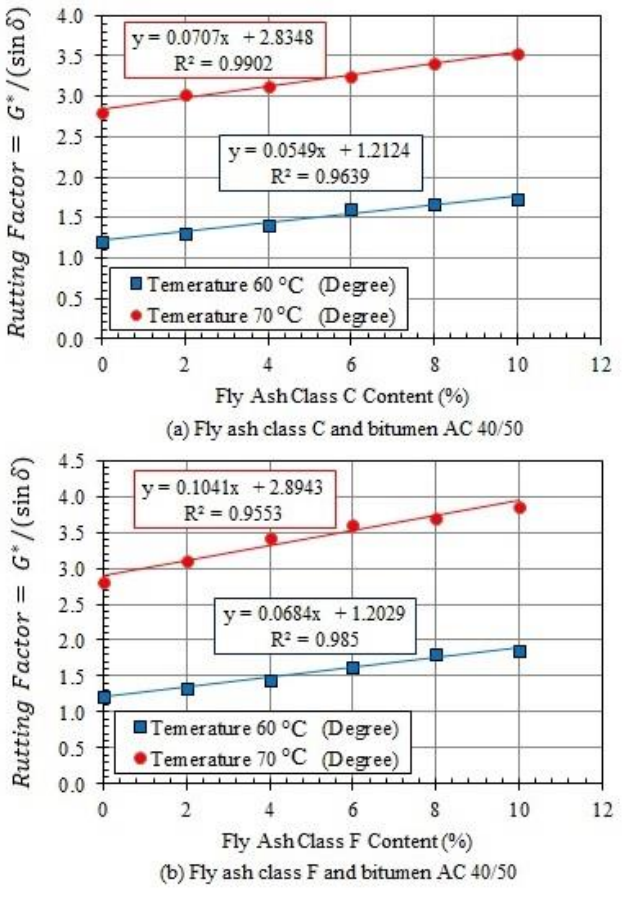


Fig. 5: Rutting factor G*/sin(δ) for bitumen AC 40/50 incorporated fly ash filler.

4. Conclusion

Based on the results obtained from this study the following conclusion could be made:

(1) A significant amount of fly ash by-product waste could be used to enhance the performance of asphalt material which leads to sustainable development and green environment,
(2) Both types of fly ash class C and class F could be used as a filler in the asphalt material and pavement design which could help in reducing road problem such as rutting,
(3) Both fly ash types could be used for enhancing the rheological performance of asphalt material,
(4) Class F fly ash shows higher rutting factor than class C fly ash, and
(5) AC 60/70 asphalt type possess higher rutting factor than AC 40/50 asphalt type at both low (60°C) and high temperature (70°C).

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