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Polymer Modified Bitumen Using Sewage Sludge Ash (SSA)

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Abstract

Sewage sludge (SS) is a waste material produce by sewage treatment plant and its amount increase over the year. Normally, sewage sludge will sent to landfill for disposal. However, disposal of sewage sludge in landfill can cause problem to the soil due to leachate that contains of high potentially toxic heavy metal. Reuse the sewage sludge in construction and paving industry should give the best alternative not only in reducing the amount of sewage sludge, but it also can alleviate the impact of this waste material on the environment and human health. In this study, an attempt has been done to investigate the feasibility of using sewage sludge ash (SSA) to modify the bitumen. Besides, this study also attempt to investigate the effect of blending temperature and blending time on modified bitumen using SSA. Physical properties; ductility, softening point, penetration and penetration index (PI) of the modified bitumen were considered to determine the best SSA content, optimum blending temperature and optimum blending time. From the result, it can be concluded that SSA can be utilized to modify bitumen and improve the physical properties of modify bitumen. The results also show that the blending temperature and blending time does not have any significant effect on the rheological properties of modified bitumen. However, it is suggested that the blending temperature and blending time to be used to prepare SSA-modified bitumen were 160 ºC and 30 minutes respectively.

Keywords: *Sewage sludge ash, modified bitumen, waste material, physical properties*

1. Introduction

Due to the global encouragement of sustainable development and stringent standard set by the government, many countries try to find an alternative environmentally friendly method to dispose sewage sludge. One of the best methods is to combust sewage sludge (SS) in incinerator before the residue deposited in landfill. Combustion of sewage sludge at high temperature in incinerator will produce sewage sludge ash (SSA), an inert and odourless fine material. However, this method will not solve the problem associated with the increasing amount of sewage sludge and sewage sludge ash produce every year all over the world. According to Spanish National Sludge Registry, 1.2 million tons of sewage sludge were generated annually and part of this sludge is incinerated to produce 0.2 million tons of SSA [1]. In 2011, 221,000 tons of SSA were produced in Japan [2]. In Switzerland, seven mono-incinerators fed solely with sewage sludge are in operation producing about 35,000 tons of SSA annually that is disposed of [3]. Therefore, reuse the sewage sludge and sewage sludge ash in construction and paving industry should give the best alternative not only in reducing the amount of sewage sludge and sewage sludge ash, but the most important thing, it also can alleviate the impact of this waste material on the environment and human health.

In recent years, an investigation has been done extensively regarding the use of sewage sludge and sewage sludge ash in construction and pavement industry. From the result of the research, it shows that both materials (sewage sludge and sewage sludge ash) have a potential to be used in concrete and asphalt mix. The replacement of cement in concrete with 5% SSA has lower the water absorption and increases the compressive strength of concrete up to 10% compared to control samples. However, replacement of cement with SSA more than 5% has reduced the compressive strength of the concrete [4]. Moreover, mortar samples with 10% cement replacement of 800 °C burnt SSA improves the compressive strength up to 1.14% and 5.06% at the ages of 28 and 90 days, respectively [5]. Antonio et al (2015) in his study prove that, the usage of SSA as mineral filler in asphalt mix produce better results when compare to the asphalt mix used limestone as fillers [1]. In a study conducted by Sato et al (2013) the used of pulverized SSA can improve the paving materials properties and increased the amount of reusable materials (SSA) [2].

Based on the current research, most of the study on the usage of SS and SSA in pavement industry used SS as a fine aggregate replacement in asphalt mix or use SSA as filler in asphalt mix. The wide range of uses SSA as filler in asphalt mix may be due to its chemical properties where its major components are quartz, aluminum oxide, iron oxide and phosphorus oxide which is more similar to cement component [5]. When compared to Palm Oil Fuel Ash (POFA), which it is normally used to modified bitumen, SSA contains almost similar to POFA chemical components. The use of POFA as a bitumen modifier has proven that it can reduce the aging effect on the physical and rheological properties of bitumen as indicated by the reduced aging

index viscosity [6]. Besides POFA, fly ash also has been used widely to modify bitumen. Sobolev et al (2013) has proven that substitution of 10% of bitumen binder with fly ash did not impair the workability and compactability ofhot mix asphalt (HMA) [7]. Lin and Weng (2001) in his study mentioned that incinerated sewage sludge ash possesses good pozzolana characteristics and has similar properties to fly ash [8]. Since SSA's chemical component is similar to POFA and fly ash, therefore this study was conducted to investigate the feasibility of using sewage sludge ash (SSA) to modify the bitumen. Besides, this study also attempt to investigate the effect of blending temperature and blending time on modified bitumen using SSA.

2. Experimental Program

2.1 Raw Materials

2.1.1 Bitumen

Bitumen is a main material used for road construction. It is a binding agent that hold the aggregates together. Nowadays, most of the bitumen is a by-product of refined crude oil. In this study, the conventional bitumen grade 80/100 was used and it was supplied by Atlas Setayesh Mehr (ASM) Co. Table 1 show the physical properties of the bitumen.

Table 1: Physical Properties of Bitumen

Grade	SP (ASTM D36-95) [9]	Ductility (ASTM D113-99) [10]	Penetration (ASTM D5-97) [11]
80/100	47 ºC	>150 cm	96 dmm

Explanation. SP: Softening Point

2.1.2 Sewage Sludge Ash (SSA)

Sewage sludge ash (SSA) is a by-product of combustion of sewage sludge in incinerator at high temperature ranging from 550˚C to 900˚C. Different research uses different temperature to produce SSA. Study conducted by Siew et al, (2016) showed that the sludge burnt at 600˚C exhibited needle-shaped particles whereas a smooth structure was found in sludge burnt at 800°C due to the pozzolanic reaction which filled the void and pores in the mortar [5]. Moreover, sludge burnt at 800°C also provides additional strength to the mortar where the compressive strength has increased after 28 and 90 days [5].

Investigation done by Doh et al, (2016) found that the SSA produce at the temperature of 600˚C for the duration of three hours has the potential to be used as partial cement replacement in concrete since there are high similarities in major chemical component of SSA compared to cement [4]. Sharif and Attom, (2000) used burned sludge ash as soil stabilizing agent [12]. They burned the sewage sludge at 550˚C and mix with the different type of clay soil. From the test result, they suggested that the burned sludge ash can be used as a soil stabilizer [12]. Carriona et al, (2014) in his study on using SSA to manufacture pre-cast concrete block burned the SS at 800˚C to produce fine SSA. This fine SSA material then was found out apt to be used in pre-cast concrete block manufacturing [13]. Jamshidi et al, (2010) used 650˚C temperature in his study to investigate the mechanical performance of concrete with partial replacement of sand by SSA [14]. However, Kazberuk, (2011) used two different temperatures of furnace chamber where in bottom section the temperature is above 600 ºC and the upper section is more than 850˚C to produce sewage sludge ash [15].

Fig 1: Sewage sludge ash out from the furnace (Left), pulverized sewage sludge ash (Right)

Based on the previous research and for the purpose of this study, SSA was produce by incinerate the dewatered sewage sludge collected from Indah Water Konsortium (IWK) treatment plant in a furnace at 800 ºC for one hour. After it was burnt and cooled down at room temperature, SSA was pulverized and sieved through the sieve size of 0.425 mm to ensure that only fine particle of SSA will be used to modify bitumen. Table 2 show the chemical components of SSA that was used in this study.

Table 2: Chemical Component of Sewage Sludge Ash

Component	Concentration	Unit
Si	1.43	%
Fe	57.15	%
Ca	0.38	%
Al	0.81	%
Mg	0.18	%
S	0.87	%
Zn	771.24	mg/kg
K	1.46	%
Na	0.11	%
Pb	355.95	mg/kg

Ti	0.14	%

2.2 Preparation of SSA-Modified Bitumen

The SSA-modified bitumen was prepared using a high shear mechanical mixer. Initially, bitumen was heated at a temperature of 160 ^{o}C for 30 to 40 minutes to ensure it melt enough to be mixed with the SSA. The SSA was then added into bitumen at different percentage ranging from 1 – 9 % of the total weight of bitumen content. After that, physical properties test of bitumen (softening point test and penetration test) has been conducted and penetration index (PI) has been calculated

Fig 2: Mechanical mixer used to blend SSA with bitumen

3. Results and discussion

3.1 Determination of Optimum SSA Content

The amount of SSA used in this study was varied from 1 to 9 in weight percentage with an increment of two percent for each blend except for the 2 percent blend; with an increment of 1 percent SSA. At the beginning, the blending time, blending temperature and blending velocity of 10 minutes, 160 ºC and 250 rpm were used to determine the best SSA content that could be added to prepare the SSA-modified bitumen. Physical properties (ductility, softening point, penetration and penetration index (PI)) of the modified bitumen were considered to determine the best SSA content and it is shown in Table 3.

From the result, it can be seen that, SSA-modified bitumen has lower softening point compare to unmodified bitumen. However, softening point of SSA-modified bitumen increased as the SSA content increase up to 5 percent SSA where the softening point is 45 ºC. After that, the softening point of SSA-modified bitumen was decreased as the SSA content increased. Based on the result where SSA-modified bitumen has lower softening point compared to unmodified bitumen, this phenomenon may happen due to the condition of SSA. The fine particles of SSA tends to soften the bitumen and hence reduce the softening point of modified bitumen.

Contrary to softening point result, ductility value of SSA-modified bitumen decrease as the percentage of SSA increase. The ductility value decreases to 103 cm with the addition of 1 percent SSA and it achieved the minimum ductility value of 71 cm at 5 percent of SSA. After that, at higher SSA content (7 and 9 percent), ductility value increased again to 73 and 95 cm respectively. The decrease of ductility value might be due to the excess SSA content whereby it will affect the homogeneity of the mixture, thus reduce the ductility value.

Table 3: Physical properties of modified bitumen with different SSA content

Run	% of SSA	SP (ºC)	Ductility (cm)	Penetration	PI
1	0	47	>150	86	-0.648
2	1	42	103	120	-1.075
3	2	43	95	111	-1.142
4	3	44	75	91	-1.471
5	5	45	71	78	-1.648
6	7	43	73	85	-1.913
7	9	43	95	108	-1.490

Explanation. SP: Softening Point, PI: Penetration Index

In terms of penetration, overall results shows that SSA-modified bitumen has higher penetration value compare to unmodified bitumen. The addition of 1 percent SSA causes the penetration value to increase from 86 to 120. At 2 and 3 percent SSA content, the penetration value tends to decrease from 120 to 111 and 91 respectively, and it achieved the minimum penetration value of 78 at 5 percent SSA content. After that, the addition of more SSA content (7 and 9 percent) increased the penetration value from 78 to 85 and 108 respectively. Again, these penetration results have shown that, excess SSA content tends to softer the modified bitumen which is indicated by the higher penetration value.

Temperature susceptibility is defined as the change in the consistency parameter as a function of temperature and it can be calculated in terms of penetration index (PI), using the results obtained from the penetration and softening point tests [16]. The penetration index (PI) shows the sensitivity of asphalt to temperature change. Higher PI values indicate lower thermal susceptibility. Table 3 reveals that the PI value was decreased from -0.648 to the lowest value of -1.913 with the increase in SSA content.

Based on the result shown in Table 3 and for the purpose of this study, 5 percent of SSA content was selected as the maximum useful amount of polymer that could be added to the prepared SSA-modified bitumen. Using 5 percent SSA content, the modification of bitumen was continued using different blending temperature and blending time.

3.2 Determining the Optimum Blending Temperature

Using 5 percent SSA content and blending time of 10 minutes, the study was continued to determine the optimum blending temperature. The blending temperature was varied from 150 ºC to 200 ºC. Physical properties of the SSA-modified bitumen were considered to determine the best blending temperature and the results are shown in Table 4.

Table 4: Physical properties of SSA-modified bitumen using different blending temperature

Run	Blending Temperature (ºC)	SP (ºC)	Ductility (cm)	Penetration	PI
1	150	44	79	86	-1.600
2	160	45	71	78	-1.648
3	170	43	104	88	-1.831
4	180	44	107	88	-1.483
5	190	43	119	99	-1.415
6	200	44	130	102	-1.242

Explanation. SP: Softening Point, PI: Penetration Index

The result shows that, the blending temperature does not have a significant effect on the softening point and the value is almost constant throughout the test. However, the ductility value and penetration value tends to increase with increasing blending temperature. Generally, it can be seen that, the blending temperature does not have any significant effect on the rheological properties of SSA-modified bitumen. However, for the purpose of this study, the blending temperature of 160 ºC was selected as the best blending temperature.

3.3 Determining the Optimum Blending Time

In order to determine the optimum blending time, the blending time was varied from 10 to 90 minutes with an increment of 10, 15 and 30 minutes respectively. Physical properties of the SSA-modified bitumen were considered to determine the best blending time and the results are shown in Table 5.

Table 5: Physical properties of asphalt emulsion residue using different blending time

Run	Blending Time (minute)	SP (ºC)	Ductility (cm)	Penetration	PI
1	10	45	71	78	-1.648
2	20	43	76	106	-1.295
3	30	44	>150	106	-0.976
4	45	44	>150	103	-1.025
5	60	44	>150	100	-1.135
6	90	44	>150	99	-1.145

Explanation. SP: Softening Point, PI: Penetration Index

Overall, it can be seen that blending time has no significant effect on softening point and penetration result of SSA-modified bitumen. However, ductility value shows an increasing trend as the blending time increase. At the blending time of more than 30 minutes, the ductility results were more than 150 cm. According to Jabatan Kerja Raya (JKR) specification, the ductility requirement should not be less than 100 cm for Grade 80/100 bitumen. Therefore, SSA-modified bitumen can be used for pavement construction based on JKR requirements for ductility.

From the result in Table 5, it is suggested that the optimum blending time is 30 minutes based on the ductility value. Even though, blending of more than 30 minutes give the result of ductility of more than 150 cm, the longer the bitumen exposed to the heat, it not only can alter the morphology of the polymer, but it also can damage the rheological properties of the bitumen.

4. Conclusions

Based on the result, it can be concluded that sewage sludge ash (SSA) can be utilized to modify bitumen and improve the physical properties (ductility and penetration) of modify bitumen. 5 percent of SSA content was the maximum useful amount that could be added to the prepared SSA-modified bitumen. The results from the experiment show that, the addition of 5 percent SSA could increase the softening point value and reduce ductility and penetration value. These properties can indicate that the hot mix asphalt using SSA-modified bitumen could have more strength and durability than using a non-modified bitumen. The results also show that the blending temperature and blending time does not have any significant effect on the rheological properties of modified bitumen. However, it is suggested that the blending temperature and blending time to be used to prepare SSA-modified bitumen were 160 ºC and 30 minutes respectively.

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