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The Influence of Coal Fly Ash on the Mechanical Properties of Hot Mix Asphalt Mixture

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Abstract. Coal is one of the most important sources of energy, providing for over 40% of global electricity generation. Coal fly ash (CFA) is the by-product of thermal generation of energy in coal-fired power plant. CFA has been widely employed in the construction of concrete; however, there are only a few cases in which asphalt pavements have employed coal fly ash. This paper aims to determine the performances of CFA as filler in hot mix asphalt (HMA) mixture. This study used four CFA contents as filler by weight of aggregate in the dry method, namely CFA-0, CFA-2, CFA-4, and CFA-6. The mixtures were tested for stability, flow, stiffness, moisture damage, and Cantabro loss test. The findings indicated that the stability values of asphalt mixtures containing CFA were higher than conventional mixture. In addition, incorporating CFA also improved resistance towards moisture damage and durability. As a result, it can be inferred that CFA can be employed as filler substitute in HMA mixtures.

1. Introduction

This day, one of the primary global concerns in waste management is the vast amount of waste material created on a daily basis. Concerns about the environment and a limiting number of disposal sites are prompting countries to find new ways to recycle waste [1]. The use of waste and alternative materials in concrete and asphalt pavements has been studied extensively to conserve natural resources. Fly ash, a by-product of the thermal generation of energy in coal-fired power plants, is among the most promising from these materials. The annual global production of coal fly ash is approximately a billion tonnes [1]. The possibility of using it in asphalt mixtures was investigated in the mid-nineteenth century as part of efforts to contribute to sustainable engineering, to obtain mixtures with satisfactory properties, minimising the negative effects of landfilling, and conserving natural resources [2]. For many years fly ash has been widely used in concrete studies because of its pozzolanic activity; however, it has only a limited number of applications in asphalt pavement. Since 1988, seven of Malaysia's power plants have used coal as a raw material to generate electricity [3]. Coal power stations create two forms of ash: coal fly ash (CFA) with an ash content of 80% and coal bottom ash (CBA) with an ash content of 20%. Malaysian electricity production generates a massive 6.8 million tons of CFA and 1.7 million tons of CBA [4]. The use of coal fly ash in mineral-asphalt mixtures has not been extensively investigated. Only a few research have shown that fly ash can improve the performance of asphalt concrete [1]. The studies by Mistry and Kumar [5] have showed that fly ash as filler can give reduced deformation and improved strength compared to hydrated lime as filler replacement in hot mix asphalt (HMA) [6]. The purpose of this research was to determine the effect of CFA on the mechanical properties of HMA. CFA was obtained from the coal thermal plant in Tanjung Bin in Johor. It was compared to the control mixture to evaluate the feasibility as filler in an optimum proportion.

2. Materials and Methods

2.1. Material

The 60/70 PEN asphalt binder was acquired from Kemaman Bitumen Company (KBC). The asphalt binder properties are shown in Table 1 and all properties met the requirement. The aggregate was collected from the inventory of Hanson Quarry in Kulai, Malaysia and met all of the requirements by Malaysia Public Work Department (2008) [7]. Table 2 show the aggregate properties. Hot mix asphalt (HMA) mixture was designed according to the AC14 aggregate gradation as listed in Table 3. The conventional fillers used in this research were fine aggregates and hydrated limestone. Coal fly ash (CFA) with Class-F category was collected from Tanjung Bin coal power thermal plant Johor, Malaysia. It contains a high percentage of SiO2 (65.9%), Al2O3 (19.7%), and a little amount of CaO. (3.29%) as shown in Table 4. The above-mentioned fillers were preheating before being sieved on a 0.075 mm sieve, with the material finer than 0.075 mm being utilised in this research Table 5.

Table 1. The properties of the asphalt binder.

Material	Characteristics	Unit	Test Method	Requirement	Value	Check
Asphalt binder 60\70 PEN	Density	gm/cm^3	ASTM D70	1.01-1.05	1.02	√
	Penetration at 25°C	mm	ASM D5	60 – 70	64.5	√
	Softening Point	°C	ASTM D36	48 – 56	51	√
	Ductility at 25°C	cm	ASTM D113	Min. 100	117	√
	Viscosity @ 135 ºC	(mPa.s)	ASTM D4402	-	3500	√
	Viscosity @ 165 ºC	(mPa.s)	ASTM D4402	-	700	√

Table 2. Aggregate properties.

Aggregate Testing	Standard method	Results	value
SG. Coarse	ASTM C 128	2.863	-
SG. Fine	ASTM C 127	2.681	-
Aggregate Impact Value (%)	BS EN 1097-2	13.37	< 30
Aggregate Crushing Value (%)	BS EN 1097-2	17.1	< 30
Los Angeles Abrasion (%)	AASHTO T96	17.4	< 45
Flakiness (%)	BS EN 933-3	18.4	< 25
Elongation (%)	BS 812	22.19	< 25

Table 3. Aggregate gradation for AC 14.

Sieve Size (mm)	Passing %
20	100
14	95
10	81
5	56
3.35	47
1.18	26
0.425	18
0.150	10
0.075	6
Pan	0

Table 4. The chemical component of CFA from (XRF).

Component	CFA %
Al_2O_3	19.7
SiO_2	65.9
Fe_2O_3	5.82
TiO_2	1.21
Na_2O	1.28
MgO	0.958
SO_3	0.322
K_2O	1.52
CaO	3.29

Table 5. Fine material utilised.

Samples	Hydrated Lime	Fine Aggregate	CFA
CFA-0	2	4	-
CFA-2	2	2	2
CFA-4	2	-	4
CFA-6	-	-	6

2=24g, 4=48g, 6=72g

2.2. Samples Preparation

The Marshall mix design method was used to design the HMA mixture. The aggregate and CFA were heated in the oven at 150 °C before mixing with asphalt binder. While 60/70 PEN asphalt binder was kept in the oven at 110 °C before mixing with the aggregate. The samples were placed in a pre-heated mould and compacted by applying 75 blows on each face according to ASTM: D6926 [8] having five different bitumen content between 4 and 6% by total weight of aggregate at 0.5% increments for control mixture as well as a mixtures containing CFA-2, CFA-4 and CFA-6 as filler. In this study, a 5.05% optimum asphalt content was utilized for all four mixtures to maintain consistency throughout the research for comparison purposes.

2.3. Tests

Marshall stability and flow tests were performed on ASTM D6927-compliant control and modified asphalt mixes. The stiffness value was then calculated using the stability and flow correlation. Then, using ASTM D4867 [9], the indirect tensile strength (ITS) and tensile strength ratio (TSR) were evaluated. Finally, a Cantabro loss test was performed in compliance with Texas Department of

Transportation (TxDOT) Tex-245-F in order to determine the mixture's resistance to disintegration induced by traffic load.

3. Result and Discussion

3.1 Marshall Properties

Table 6 summarises the Marshall properties results for the control and modified mixes. It can be observed that the stability value increases linearly and the flow decreases with the increase in the CFA content. The regular shape of FA particles (usually spherical) may act as rollers, allowing for less friction in the mastic during compaction, resulting in tighter packing [10]. A stiffer mixture was represented by a higher value of stability divided by a lower value of flow. The high values of the stability and the low value of the flow in the CFA mixtures all comply with the Malaysia Public Work Department (2008) specification [7].

In addition, the void in total mix (VTM) of the control mixture was 3.6% where the value was decreasing as the CFA content increased. These results can be explained by the addition of CFA to the mixtures increased the surface area, which decreased the air voids in the specimens. According to Likitlersuang & Chompoorat [11], the larger the surface area, the more asphalt is required to coat the aggregates. Thus, it will increase the void filled with asphalt (VFA) and decrease the void in total mix (VTM) in the mixture.

Table 6. Marshall properties of asphalt mixtures.

Marshall properties	**Type of Mixture**				**Requirement**
	0% CFA	**2% CFA**	**4% CFA**	**6% CFA**	
Stability (N)	15225	16848	17148	18243	> 8000
Flow (mm)	3.22	3.12	2.80	2.37	2.0 – 4.0
Stiffness (N/mm)	4728	5400	6124	7697	> 2000
VFA %	75.5	76.1	76.9	78	70 – 80
VTM %	3.60	3.54	3.23	3.1	3.0 – 5.0

3.2. Moisture Damage

The findings of indirect tensile strength (ITS) for all of the mixtures tested at temperatures of 25°C and 60°C are shown in Figure 1. Generally, it can be seen that the ITS values of the unconditioned samples are higher for the control and modified compared to those of wet conditioned. In the case of a wet condition, it shows that moisture had a minor impact on the tensile strength of the CFA mixtures. A higher TSR value indicates that asphalt mixtures are more resistant to moisture damage [11]. It is clear that all of the combinations evaluated in this study met or exceeded the AASHTO TSR minimum criterion (> 80%) as shown in Figure 2. CFA-6 mixture had the highest TSR value of all the mixtures, indicating that the inclusion of CFA in the asphalt mixture reduces moisture damage susceptibility.

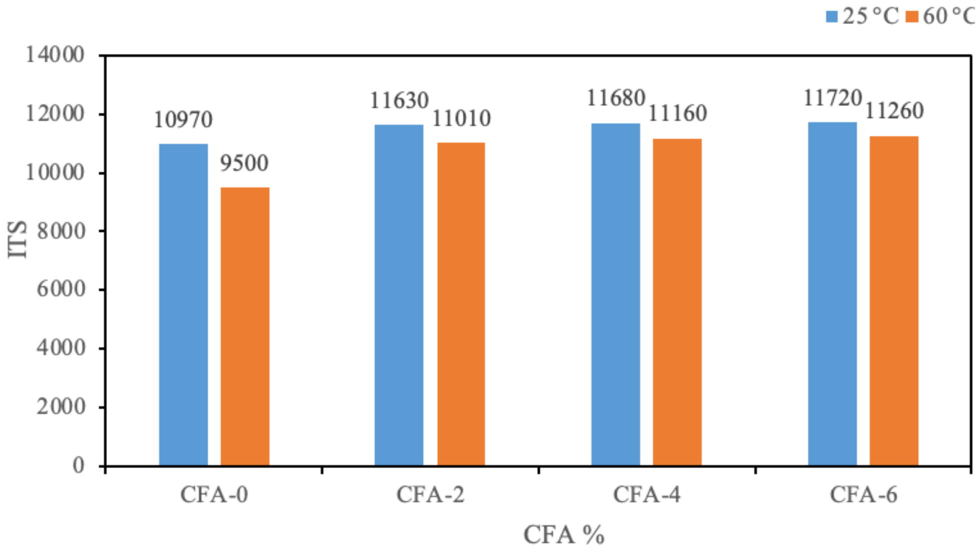

Figure 1. ITS of asphalt mixtures.

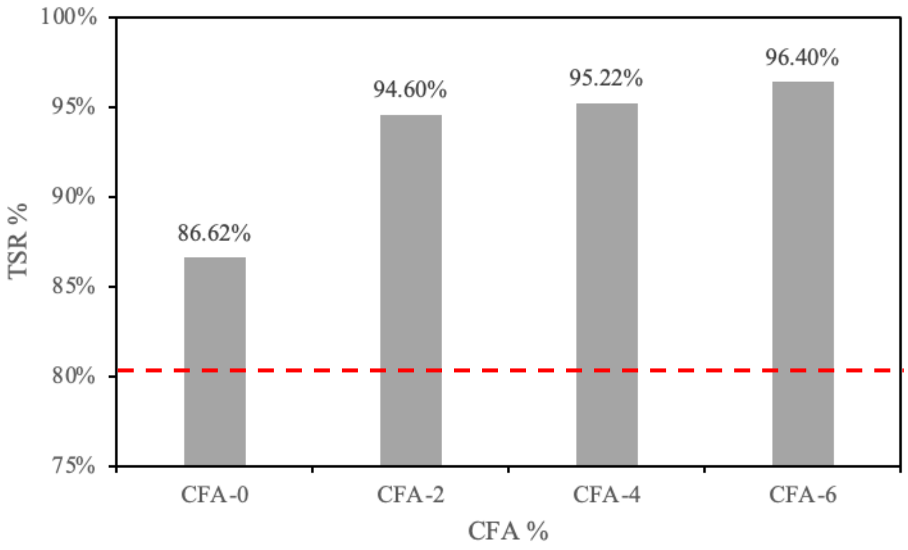

Figure 2. TSR for the asphalt mixtures

3.3. Cantabro Loss

Figure 3 depicts the mass loss test results for mixtures, showing that adding CFA could reduce mass loss as CFA content increases. As a result, the mixture showed more resistance to disintegration. This improvement was caused by the enhancement in adhesion and cohesion properties with the addition of CFA [12]. It's worth noting that the proportion of air voids in the specimen is strongly connected with Cantabro mass loss. The CFA, also known as bitumen extender, can provide a partial replacement of bitumen [13], reducing the air void of HMA. The addition of CFA reduces the percentage of air voids in the mixtures. As a result, mass loss was reduced.

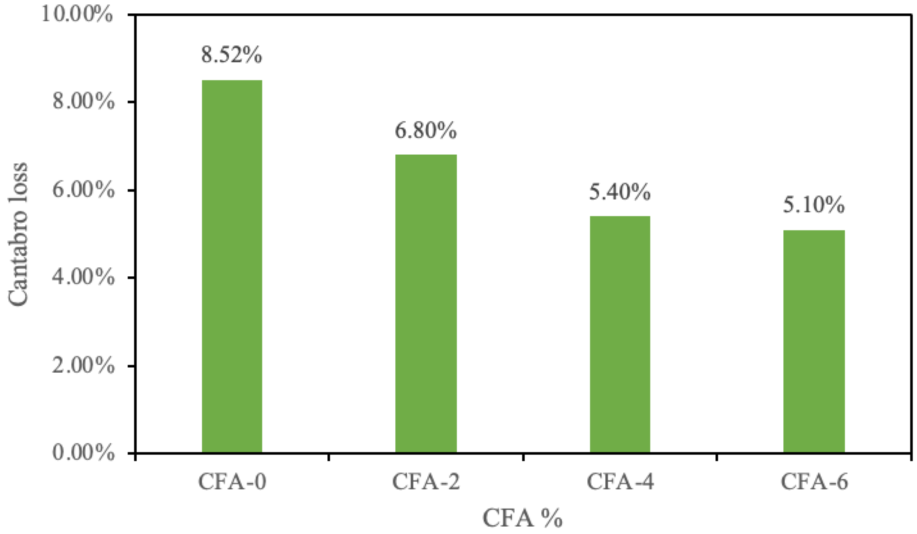

Figure 3. Cantabro loss for asphalt mixtures.

4. Conclusion

The main findings are summarised follows:

- Incorporating CFA in the asphalt by weight of aggregate increases the Marshall properties of the mixtures. It increases stiffness, thereby increasing the stability and decreased the flow
- The ITS and TSR values of modified mixtures with CFA have dramatically risen, showing that the CFA mixtures are the more resistant to moisture damage compared to the conventional mixture.
- Incorporating CFA into the mixture showed a reduction in the Cantabro loss, indicating an improvement in term of durability of the mixture.

5. References

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