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Effect of Coal Combustion Products on high temperature performance of asphalt mastics

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HIGHLIGHTS

- Coal Combustion Products (CCPs) enhance the performance of asphalt materials exposed to elevated temperatures.
- The effect of CCPs on rheological response of asphalt mastics is governed by physical and chemical properties of CCP.
- When used in asphalt CCPs can be considered as performance enhancing additives.

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ABSTRACT

For many years fly ash has been effectively used as a partial replacement of portland cement in the production of different types of concrete, as well as in embankments and soil stabilization. On the other hand, the use of Coal Combustion Products (CCPs) in asphalt pavements has been very limited. Few researchers investigated the application of CCPs in asphalt.

This research reports on the effect of CCPs on the high temperature performance of asphalt binders. In this paper 15 CCPs were identified, characterized and investigated for their compatibility with different types of asphalt cement and compared to control mineral filler. Furthermore, the study explored the effect of dosage, physical properties and chemical composition of CCP on the stiffness, phase angle and rutting behavior of mastics.

The investigation of the rheological performance of asphalt binders with different types of CCPs using Dynamic Shear Rheometer (DSR) confirmed the feasibility of using these by-products to improve the permanent deformation resistance of asphalt binders. Research data demonstrate that the effect of the CCPs is dependent on the dosage and physical and chemical properties of CCP. Based on the rheological response of CCP based mastics at high temperatures this study found a strong physical and chemical interaction between the CCP and the asphalt binder.

1. Introduction

The United States has more than 2 million miles of paved roads and highways, and 94% of those are surfaced with asphalt concrete. Each year, 4000 asphalt plants in the U.S. produce 500 to 550 million tons of asphalt pavement material worth in excess of $30 billion [1–7]. Increased traffic demands and factors such as escalating price of crude oil and rising energy costs, all contribute to increased production costs of asphaltic concrete. With continual repair of aging U.S. transportation infrastructure and increasing transportation volumes there is an urgent need for high-performance paving materials beneficially incorporating industrial by-products (e.g., waste glass, fly ash) with improved performance and extended service life that meet the sustainability objectives [7]. Improving asphalt performance can be achieved by means of additives to extend the application over a wide range of temperatures. The modification of the asphalt is commonly achieved through blending asphalt with synthetic products; such as polymers. The use of fly ash to enhance the performance of asphalt concrete was demonstrated; however, in spite of potential benefit, has not been adopted on a commercial scale [1–5,8–24]. The use of Class C ash has received most of the research focus. On the other hand, Class F and “off-spec” Coal Combustion Products (CCPs) were not thoroughly explored for the use in asphalt mixtures. This provides a great potential for research and future exploration.

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The blend of bitumen and particulate filler creating a dense mix is referred to as "mastic". Since the early 1900's [14] it was noted that the use of mineral fillers in asphalt increases the stiffness of the asphalt-filler mix. Fly ash in asphalt bitumen can be considered as effective filler in a viscoelastic matrix [18]. Fillers for asphalt pavement applications are defined by the AASHTO M 17 (ASTM D242) as finely divided minerals, such as rock dust (e.g., granite and limestone), slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter. The typical maximum particle size of fillers in asphalt is less than 75 μm. Although fillers, in general, usually represent less than 8% of Hot Mix Asphalt (HMA) by mass, the interactions of fillers with asphalt binder, and/or coarse and fine aggregates, affect the field performance of HMA.

Researchers have extensively investigated the use of by-products such as fly ash in the construction industry to improve the material properties [16]. Fly ash has been used extensively in concrete production; however, there are limited applications in which fly ash has been used in asphalt pavements [1,2,21,10,17,18]. However, in all these studies fly ash was viewed as a filler with the expectation of performance similar to mineral fillers. Sobolev et al. [18,19] reported that the incorporation of fly ash into asphalt mixtures (ASHphalt) improves the performance of asphalt at the levels compared to those achieved with polymer modification. This effect was attributed to unique spherical shape, beneficial size distribution and chemical properties of fly ash. The use of fly ash in bitumen materials is attractive as it improves performance and reduces costs and environmental impacts [21]. The advantages of fly ash in asphalt include improved mixing, placing and compaction, stability, resistance to water damage, rutting resistance, flexibility, and resistance to freeze–thaw damage [5,23,24,15,12,22,20,4,21].

This study explores the interactions and compatibility of Class C, Class F and Spray Dryer Absorber (SDA) materials with two types of asphalt binders at high temperatures. The effects of dosage, chemical composition and physical properties of CCP on the stiffness, phase angle and rutting behavior of mastics based on different grade asphalts were investigated. The detailed analysis was conducted to correlate the chemical and physical properties of CCP with rheological performance of mastics.

2. Experimental program

2.1. Materials

Two types of asphalt binders of different grades and sources were used and mixed with different CCPs. The binders used are PG58-28 and PG64-28, where PG stands for "Performance Grade" and the first number refers to maximum working temperature during summer and the second number refers to the lowest working temperature during winter. Therefore, the binders used in this study are suitable for temperature ranges from 58 °C to −28 °C and from 64 °C to −28 °C for PG58-28 and PG64-28, respectively.

Different types of CCPs were collected at power plants across the United States and used in the experimental program as received. A total of 15 CCPs and 2 reference fillers were tested and reported in this study. The Scanning Electron Microscope (SEM) images of fly ash illustrate the predominant round shape of the ash of Class C and F type (Fig. 1). Tables 1 and 2 report on the chemical composition and physical properties of the investigated CCPs. Further details of CCPs characterization were reported elsewhere [11].

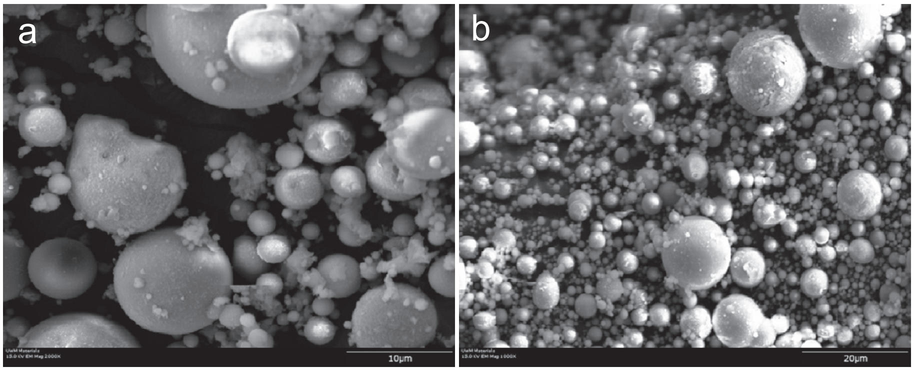

Fig. 1. The SEM images of a representative fly ash (a) Class F (b) Class C.

Table 1
Chemical composition of CCPs.

Materials ID	Class	Al_2O_3	CaO	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	TiO_2	P_2O_3	SO_3	SAF*	LOI**
FAC 05	C	22.3	24.6	5.4	32.9	6.3	2.8	0.5	1.3	1.6	1.8	60.6	0.3
FAC 08	C	23.9	23.1	4.5	34.4	5.3	2.2	0.6	1.3	1.5	2.1	62.8	0.4
FAC 02	C	19.7	26.4	7.0	27.8	6.6	3.1	0.8	1.1	2.7	3.4	54.5	15.3
FAC 06	C	23.4	22.9	5.4	34.3	5.7	2.1	0.6	1.2	1.6	1.4	63.1	0.2
FAF 07	F	27.2	5.0	14.0	45.6	1.0	0.7	1.8	1.1	0.5	2.7	86.8	2.1
FAF 09	F	26.0	13.4	4.5	45.1	3.5	2.1	1.2	1.2	1.2	1.3	75.6	7.9
FAF 10	F	26.3	12.1	4.7	47.8	2.9	1.9	1.2	1.1	0.9	0.8	78.8	4.3
FAF 11	F	24.5	13.0	9.0	42.9	3.2	1.5	1.4	1.2	0.8	2.0	76.4	1.9
FAF 12	F	23.2	8.0	12.5	47.7	1.2	0.9	2.0	0.9	0.4	2.7	83.4	1.0
FAF 13	F	30.9	1.4	7.0	53.1	1.2	0.6	2.8	1.3	0.3	0.9	91.0	3.5
FAF 14	F	26.0	2.8	16.9	46.3	1.3	0.8	2.8	1.0	0.3	1.5	89.2	2.0
SDA 01	SDA	14.2	34.8	4.5	20.2	3.1	1.4	0.4	1.0	1.0	18.5	38.9	2.9
SDA 03	SDA	15.8	30.0	4.5	23.9	4.2	1.3	0.5	1.0	0.9	17.1	44.2	1.7
SDA 15	SDA	17.5	28.1	4.4	25.2	4.7	2.5	0.5	1.0	1.0	14.2	47.1	2.7
SDA 16	SDA	4.7	51.0	1.2	5.8	2.2	0.4	0.2	1.0	0.4	33.3	11.7	7.2

* SAF = $SiO_2 + Al_2O_3 + Fe_2O_3$.
** LOI = Loss on Ignition.