Construction and Building Materials 160 (2018) 268–277

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Thermal suspectability analysis of the reuse of fly ash from cellulose industry as contribution filler in bituminous mixtures

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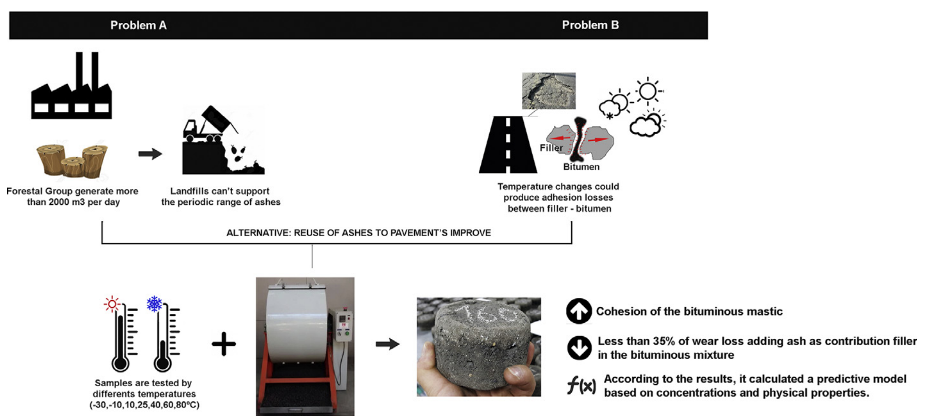
HIGHLIGHTS

- Mixture properties at different temperatures were considered during design phase.
- Cellulose incineration ash is useable as contribution filler in hot asphalt mixes.
- Addition of cellulose incineration ashes reduces thermal susceptibility of asphalt mixes.
- Relation between experimental results and statistical predictive values was found.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 August 2016
Accepted 11 November 2017

Keywords:
Cellulose ashes
Highway pavements
Temperature
Filler
Recycled materials

ABSTRACT

The increased population has accelerated pavement deterioration of and boosted production of residues, generating a constant environmental problem. One of the main problems of pavements is a failure to develop union between bituminous mastic ligand and aggregate. The following study evaluates the use of ash from cellulose incineration as a contribution filler to improve thermal susceptibility of pavements in different climatic zones. The applied methodology for dosage was based on volumetric criteria and state curves. The obtained results showed that reusing this residue in determined conditions ($C_v/C_s \leq 1$) offers lower wear loss to 35% of temperatures between −10 and 60 °C, due to the $C_v/C_s = 0.75$ ratio that maximizes the cohesive properties of the mixture. Therefore, we showed that this type of industry residue can be reused without complication in zones of certain climatic criteria and that it provides improved properties to the asphalt mix compared to conventional mixes.

1. Introduction

Constant population increase and the ease of transportation have led to a parallel and gradual increase in transport demand. This growing demand leads to accelerated deterioration of road pavements, making improvements to roads and asphalt mixes with a longer service life essential. On the other hand, intensification of human activity has generated a progressive increase in dangerous substance and residue production, provoking an incessant environmental problem [1,2].

One of the main problems of asphalt pavements produced by climatic and environmental conditions is union failure between the ligand and surface aggregate [3]. These problems are mainly

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https://doi.org/10.1016/j.conbuildmat.2017.11.046
0950-0618/

due to insufficient cohesion and adhesion characteristics which translate into cracks and pavement surfaces with loss of material [4–6]. One of the external agents that most affects asphalt mixture cohesion is the temperature of its service conditions. Asphalt mixes under extreme temperature conditions have features comparable to a fragile, elasto-plastic or sticky body [7]. The variation of mixture state with temperature can be controlled through cohesion characteristics and the low susceptibility supplied by bituminous mastic [8–11].

The concept of 'filler' has long been known, however, over the last years the use of this material in asphalt mixes has increased: lime and cement are the most widely used fillers. Within the mastic nucleus, it is common that studies and pavement jobs centre their attention on the ligand, given its absolute responsibility as a binding agent [12,13]. However, since the type of filler is the most variable mastic component (filler and bitumen), in charge of filling gaps in the mineral skeleton as well as waterproofing, densifying and modifying asphalt mix viscosity, it is of vital importance to evaluate and define the characteristics, composition and quantity of filler to use when protecting or providing a higher mixture cohesion capacity against external agents such as water and temperature variations [5,6,8–10,14–16].

Numerous studies have evaluated the potential use of different materials as contribution fillers in asphalt mixtures. These materials include cement, calcium hydroxides, ash, recycled powder from building material, calcium carbonate, vegetable filler, among others [3,17–19]. Diverse authors such as Chuanfeng et al. (2014) [16] and Ke-Zhen et al. (2013) [20] evaluated the influence of the filler's characteristics on cohesive resistance at different temperatures and found that specific surface is a fundamental parameter when choosing a material, such as contribution filler, for the mixture [16,20]. Among the range of fillers, ash from industrial processes acquires added value due to its potential environmental contamination. Currently, solid industrial residues (SIR) constitute a critical environmental problem in the modern industrial society, making their management and valorisation essential [2,4,11,21].

This study focuses on analysing the influence of temperature on semi-dense asphalt mixture properties (functional and mechanic) through the sensibility or susceptibility concept. The evaluated mixtures were fabricated with ash, from cellulose incineration, as a contribution filler. Ash dosage was based on its volumetric concentration (Cv), with special attention to parameters such as specific weight and critical concentration (Cs). This procedure is performed using the Argentinian standard IRAM 1542 (1983) [22–24]. Finally to obtain the results we used the universal ligand characterization method, UCL® [7]. Comprehension of functional and mechanical properties of asphalt mixtures is essential at different temperatures, given the influence of this variable directly on the visco-elastic behaviour of materials.

2. Materials & methods

In this study we prepared 7 types of asphalt mixtures. Two of these corresponded to Semi-dense mixtures, according the standard [25]. In the other 5 mixtures the mineral filler was completely replaced using ashes at different concentrations.

2.1. Aggregates and bitumen

The employed aggregate for this research was arid obtained by crushing natural gravel in the south of Chile, specifically in the Los Rios Region. The different fractions of arid used for mixture doses were combined so that particle size of the test samples adjusted to the "IV-A-12" type band, specified by the standard [25]. This particle size allowed obtainment of mixtures that can be used both in intermediate layers, such as asphalt layers, the reason for which these mixtures are the most widely used throughout Chile. Table 1 contains the values of the selected particle size bands.

Bitumen ligands or asphalt cements (AC) are presented as a bright and black mass with a consistency that varies with temperature. The Road Manual (2015) classifies AC according to their absolute viscosity at 60 °C, not allowing projects to specify the use of classification of asphalt cements by penetration [26]. The ligands used for this research were the CA-24 ligand and an elastomer ligand "Stylink" modified with polymers. Table 2 contains the characteristics and specifications of the used ligands.

2.2. Filler

For thermal susceptibility analysis, this study centres its attention on the cohesive properties that bituminous mastic transfers to the mixture when it is subjected to temperature variations. The ash used as bituminous mastic filler come from the production process of the cellulose plant. Mainly, they are the residues from burning bark and wood-chips for the generation of energy from high pressure vapor generated by biomass boilers, where combustion occurs [21]. Currently, theses ashes are disposed in RSI authorized landfills [27]. The ash used was sifted through a sieve N°200 (0.08 mm) since by nature this is mixed with other solid residues such as carbon, sand and wood-chips (Fig. 1) [21].

2.3. Material dosage

Due to the importance of filler selection and dosage for a bituminous mixture, material dosage for fabrication of the sample mixtures was based on a volumetric concentration (Cv) of the filler in regards to the ligand [23,28].

It is important to obtain and characterize in detail the ash to be used as filler. The methodology used to characterize ash meets the Argentinian standard IRAM 1542 [22]. To evaluate exclusively the effect of ash on asphalt mixture cohesion under variable temperatures, without taking into account the effect of nature, the quantity and type of arid and ligand, the retained material in each sieve, as well as ligand contents, these remained at fixed values during the fabrication processes, therefore the nature and ash content of the mixture were the only variables.

The bitumen content corresponds to 5% (aprox.) of ligand in the mixture (5% bS/M). Fig. 2 contains the arid particle size used in the mixtures.

2.3.1. Real density of the filler

To determine ash density in kerosene, we performed a total of 30 tests with 50 gram samples, following a previously described method from the Argentinian standard [22]. Once the results of kerosene density were obtained for each of the 30 samples, we calculated the average.

2.3.2. Critical concentration of the filler

To calculate filler volumetric dosage (Vc), we must first determine critical concentration (Cc). This value relates intrinsic characteristics of the analysed filler, since it depends (among others) on fineness and surface characteristics of the filler [13,24].

The critical concentration, in theory, assures mastic viscosity behaviour, a fundamental characteristic when evaluating mixture cohesion. This value is obtained by accomodation and sedimentation of filler dispersion particles at rest. The continuous medium used for this purpose is kerosene due to its chemical similarity with the ligands [22,23]. The calculation for ash critical concentration is determined by the following expression (a):

$$Cs = m/(V \times \rho) \tag{a}$$

where:

Cs: Ash critical concentration,
m: Ash weight, (gr.),
V: Sediment volume, (cm^3),
ρ: Dry ash density, (gr./cm^3).

Table 3 shows the values obtained from ash characterization.

2.4. UCL method

The universal characterization method of ligands or simply UCL method, development by Dr. Miró Recasens and Dr. Pérez Jiménez (1994) is based on the study and assessment of the functional properties that the binder provides the mixture [7]. Among these properties are cohesion and thermic susceptibility; the first is related to binder and material disintegration capacity, meanwhile the second is related to mechanical behaviour variability of mixtures at different temperatures [29].

To assess these properties, the method will evaluate the disintegration resistance of samples submitted to different conditions (dry, after immersion, at different temperatures and time periods) through the Cantabrian test of wear loss at 25 °C [30].