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Reduction in the use of mineral aggregate by recycling cellulose ashes to decrease the aging of hot asphalt mixtures

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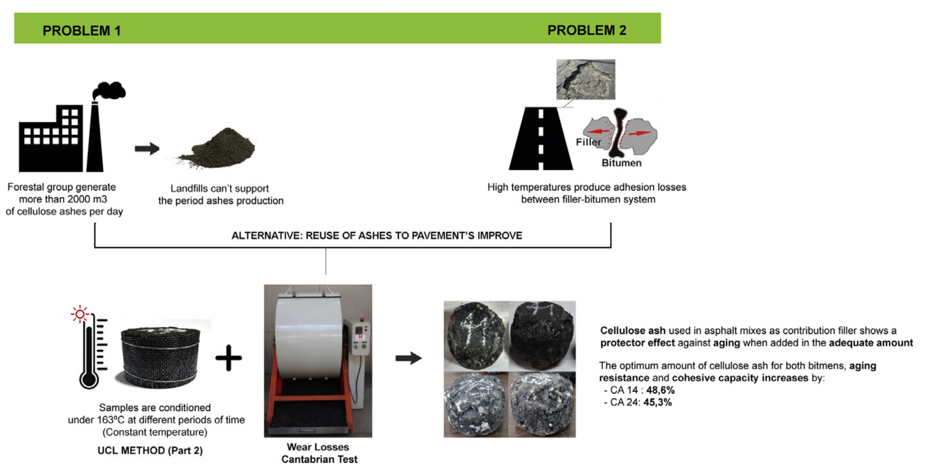
HIGHLIGHTS

- Aging at different times were considered during design phase of mixes.
- Cellulose incineration ash is useable as contribution filler in hot asphalt mixes.
- Excess cellulose ash in the asphalt mixes stiffens the bituminous mastic.
- Cellulose incineration ash as contribution filler in asphalt mixes reduces aging effect.

GRAPHICAL ABSTRACT



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ABSTRACT

The rapid development that our society is experiencing effects road management, therefore developing economical and efficient solutions, as well as extending road service life is indispensable. Aging is a problem associated to the majority of failures at the pavement surface layer (cracks, fissures, fatigue), including those produced by traffic solicitations. Diverse studies indicate that alterations to mixtures due to age can be decreased by incorporating a filler or mineral filler. Therefore, the present study incorporates cellulose ashes at different Cv/Cs concentrations as contribution filler in bituminous mastic, analysing its influence on aging resistance using the Cantabro wear test.

The results indicated that using cellulose ash as contribution filler allows promising results to be obtained in regards to aging resistance of asphalt mixtures, if they are incorporated in concentrations close to or equal to the critical concentration, with an increase in aging resistance from 45.3 to 48.6% depending on the type of bitumen used. Therefore, incorporating them into the design of asphalt mixtures could be an efficient and economical solution to the current problems of early cracking and pavements with a service life lower than the estimated, although a more thorough analysis of its behaviour in other tests and service conditions is required in bituminous mixtures.

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1. Introduction

The society is becoming more accelerated and more demanding with each passing day. This rapid development is also present in the productive and road management sector, an area which presents a growing demand for economical and efficient solutions which also care for the environment, guaranteeing user comfort and security without incurring increased costs and maintenance. Given these demands to modern road engineering, extending road service life is indispensable to minimize the use of economical and natural resources. However, this is not a simple task given that the bitumen is a material from petroleum distillation, of organic origin, making it practically impossible to avoid their susceptibility to aging, a factor that provokes changes to their initial properties and directly coincides with shortening pavement and bituminous mastic service life [1–3].

Aging (considered a functional failure at the surface level) is a problem associated to majority of the faults produced in surface layers made with bituminous mixtures, including those produced by traffic demands. Among these faults associated to aging are; fissures, loss of material at pavement surface, cracks due to fatigue from traffic loads and thermic demands and even total disintegration of the mixture (Fig. 1) [4–7].

The mechanisms that intervene in the aging process are associated to chemical, physical, mechanical and rheological changes to the mixture and in particular their organic component (bitumen). The aging process starts during fabrication at the factory and continues during its transfer and construction of roads, extending throughout its service life [5,8,9]. Aging that appears during road construction is known as "short term aging" and it is more aggressive according to the aging curve by Read & Whiteoak (2003) [10]. This type of aging is mainly caused by the loss of volatile bitumen components when these are hot. On the other hand, aging that occurs during the pavement's service life is known as "long term aging" and is produced essentially by climatic and environmental conditions generated by progressive oxidation of the mixture [11,12].

In general, these chemical alterations such as volatilization, oxidation and polymerization produce readjustment of the bitumen molecular structure which translates into hardening of the mixtures; increasing their rigidness which slowly converts them into a fragile material susceptible to cracking [13–18]. The consequence of these changes is the appearance of cracks, loss of cohesion and moisture damage, leading to general deterioration of asphalt pavements. Based on these aging mechanisms and the inevitable fact of aging, studies should obtain pavements with increased durability, which is of vital importance to optimize resistance to mixture deterioration (aging). Diverse studies indicated that these mixture alterations can be decreased and/or stalled by the characteristics and properties of the mixture mastic [2–4,6,19]. Incorporating contribution filler generates changes in the properties of bituminous continuous medium making the bitumen a thicker with the aim of modifying its vicious flow and improving adhesion between the aggregate-binder. This provides thickening of the film that covers the aggregates, decreasing volatilization and oxidation processes and supplying increased cohesion, slowing the mixture aging process [3,20,21]. Another benefit and/or filler action that contributes to mixture aging resistance is the "obstacle effect" established by Gubler et al. (1999). This mechanism describes that when adding filler, its particles function as an obstacle for oxygen diffusion within the bitumen, slowing the mixture hardening process [22].

The present study proposes to analyse and quantify the influence and benefits obtained when adding ashes from the cellulose incineration process (at different concentrations) such as bituminous mastic contribution filler, against damage as a result of thermic aging. Incorporation of ash aims to increase aging resistance of asphalt mixtures and is performed using volumetric dosage of the filler in regards to the bitumen and design Cv/Cs ratios. This procedure is described by the Argentina IRAM 1542 regulation (1992) [23].

Finally, given both the intrinsic variables (bitumen, aggregates, gaps, etc.) and external (temperature, radiation, humidity, traffic loads and time) that intervene in the aging processes, valuation of mixture cohesion properties was performed using universal bitumen characterization UCL [3,5]. This procedure is used by a method that evaluates the functional properties of the mixture as a whole, unlike the most common aging analysis methods (TFOT, RTFOT, Rotovapor) which analyse a layer of thin bitumen film, not considering for example aggregate-bitumen interactions, the influence of mineral filler nor other eventual additives that could significantly alter the qualities of the bituminous phase [4,7,19].

Fig. 1. Wear losses on pavements by aging effect.

2. Materiales and methods

Experimental development of this research is based on evaluating the cohesion grade of mixtures that incorporate cellulose ash at different concentrations and how the quality changes when faced with thermic aging parameters.

2.1. Binder

The binder used in this study are classified according to their absolute viscosity at 60 °C as stipulated by the Roads Guide (2015) [24]. Table 1 presents the characteristics and specifications of two bitumen used in this study.

2.2. Mineral and contribution filler

For this research, two types of mixtures have been fabricated, one with mineral filler (traditional mixture) and another with cellulose ashes as contribution filler, in order to know the difference in the behaviour against the aging of a traditional mixture and one made with industrial by-products. The ash used as contribution filler came from pulp mill production processes, mainly from burning bark and chipping wood to generate energy for biomass boilers. Due to its nature as the residue with the second greatest contribution to total industrial solid waste (ISW), it is considered a potential environmental contaminant waste product. Currently, and due to the terminal strategy management (end of pipe) of cel-