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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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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.

Keywords: *Ash; Cellulose; Filler; Aging effect; Reduce; Asphalt*

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].

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 cellulose industry residues, these ashes are placed in an authorized ISW landfill, generating additional production costs [25–27].

The ash should be previously separated from other solid residues such as carbon, sand and woodchips; achieved by sifting ash with an N°200 sift, with an opening of 0.08 mm (Fig. 2).

The methodology used for ash characterization follows the Argentinian IRAM 1542 [23], where the real density is obtained from the medium density value in kerosene for a group of 30 test samples, meanwhile the critical concentration is obtained through sedimentation of the ash particles in kerosene by simple rest and using the formula [a]:

$$C_s = \frac{m}{(V\ x\ \rho)}$$

where
C_s: Critical ash concentration,
m: ash mass, (g),
V: sediment volume, (cm^3),
ρ: dry ash density, (g/cm^3).

Table 2 presents the values obtained by volumetric ash characterization.

2.3. Design of bituminous mixtures

The specimens are made from two types of bitumens (CA-14 and CA-24) a semi-dense type “IV-A-12” aggregate, following Volume N°5 of the Road Manuel (2015) [28], and different ash concentrations, so that the difference between mixtures is in the bitumen type and the proportions and quantities of relative fillers. Table 3 presents the maximum and minimum values of particle grading envelope. The bitumen content incorporated into the different mixtures corresponds to 5% bitumen of the total aggregate mass (1050 g) which corresponds to 52 gr of bitumen.

To maintain aggregate size and bitumen content constant, all the samples have similar porosity and binder film and therefore a surface exposed to similar aging conditions. Thus, this ensures that aging occurs only in function of the ash content and bitumen type, exclusively evaluating the effect of these variables in aging resistance and durability of bituminous mixtures [15].

On the other hand, when using a semi-dense mixture hardening vs aging of the mixture via the thickness of the thin film that covers the aggregates is completely dependent on the mastic bituminous, minimizing this effect as a result of the amount of voids in the mixture, due to increased exposition (open mixtures) to the effects of weather and air flow.

2.3.1. Volumetric dosage of the filler

Diverse studies indicate that treatment with contribution filler in different quantities generates small reductions in penetration and small increases in the bitumen softening point and viscosity; indicators that show a lower degree of mixture aging [2]; [22]; [29]; [30]; [31]. Based on this, it is expected that higher filler content produces decreased losses due to a protector effect provided against aging mechanisms, producing less bitumen hardening and increased mixture cohesion [3].

However, if an excessive amount of filler is incorporated, the biphasic bitumen-filler system stops being viscous and an internal structure with a network of non-Newtonian flow makes the mixture stiffen, worsening the required mixture characteristics such as flexibility, cohesion and durability [32]; [33]; [34]; [35]; [36]; [37].

The Argentinian IRAM 1542 regulation (1992) defined as the “critical concentration” at which the mastic begins to become rigid, and meanwhile, to conserve the viscous deformation capacity of the filler-bitumen system the filler volume concentration (Cv) must be equal or less than its critical concentration (Cs), i.e. Cv/Cs ratio ≤1 [23].

The formula for filler concentration volume (Cv) is the following [b]:

$$C_v = \frac{Filler\ Vol.}{Filler\ Vol. + Bitumen\ Vol.} = \frac{\frac{P_f}{\gamma_f}}{\frac{P_f}{\gamma_f} + \frac{P_l}{\gamma_l}}$$

where
Pf: Available filler mass in the mixture, (g)
Pl: Bituminous bitumen mass, (g),
γf: Specific weight of the filler, (g/cm^3),γl: Specific weight of the bitumen, (g/cm^3).

Limiting the dose and rationally decreasing the amount of filler in the mastic bituminous indicates the maximum proportion that can be added without sacrificing resistance to permanent deformation from over-filling, which quickly translates into depletion of the mixture resistance. Finally, 200 samples will be fabricated and tested in the experimental stage, for the amount necessary to obtain representative statistics of the results. Table 4 shows the total distribution of the samples for each selected bitumen and volume concentration (Cv/Cs).

2.4. Production of Marshall samples

The simple fabrication process starts with previous conditioning of the materials that will compose this mixture. These materials should be washed and dried in an oven until they reach a constant mass to remove impurities and other materials that could decrease the final properties of the mixture. Once the material is prepared, the aggregate and filler fractions are weighed separately (1100 gr. aprox) according to the selected grain size of the bituminous mixtures in the design stage. Mixture processing is performed in the laboratory following the UNE-EN 12697-35 [38]. For this, the aggregate and filler mixture, moulds and Marshall accessories required to make the samples, are introduced into an oven at 170 °C for a minimum of 8 h. The bitumen is conditioned during 2 h at the temperature indicated by the providers (150 °C for the CA-14 bitumen and 152 °C for the CA-24 bitumen). Once the time is up, the aggregate and bitumens are mixed until the mixture is totally homogenous and particles are completely covered in bitumen. The filler is then incorporated (Fig. 3) to the mixture as it continues to be mixed, maintaining the temperature constant at all times (150 °C aprox).

For mixture compaction, this is introduced into moulds of 101.6 mm in diameter and 63.5 mm high, which are then introduced into the Marshall impact compaction machine applying 75 blows per side during the time defined by the UNE-EN 12697-30 [39]. This number of blows is used given that the mixture is destined to be used as a pavement for heavy traffic. Once compacted, the samples are left to cool to room temperature (25 °C) and then demoulded (Fig. 4).

2.5. UCL Method

This research is based on the Universal Bitumen Characterization Method (UCL Method) developed by Dr. Miró Recasens and Dr. Pérez Jiménez (1994) [15]. The information provided by the UCL method is more precise and complete than that provided by conventional assays, since this is based on the deterioration of cohesive properties of the mixture as a whole and not on the relative variations of certain bitumen properties, which do not always match the practical solution. Valuation of functional mixture properties is performed using the Cantabro wear loss test of sample disintegration resistance after being submitted to different deterioration conditions (humidity, different temperatures and aging periods) and how these vary in function of the aggregate filler concentration added to the mixture under the Cv/Cs design ratios. The Cantabro wear loss test was performed under UNE-EN 12697-17 [40].

2.5.1.Sample aging

Sample aging lies in the acceleration of aging in a forced air oven during different time periods. Circulation of warm air in the interior of the oven ensures that aging is produced uniformly over the sample contact surface, guaranteeing gradual and homogenous aging [5]; [7]; [8] ; [13]. The aging conditions consist in maintaining the samples at a constant temperature of 163 °C during 0, 5, 20, 40 and 72 h respectively to obtain different degrees of aging. The longer samples stay in the oven, thermic oxidation of the mixture will be higher simulating a longer aging time. Previous to the aging process, the samples are laterally confined using a metallic fabric (Fig. 5) to avoid possible crumbling and/or loss of material as a result of the elevated temperature to which they will be exposed (well above the bitumen softening point) which would make it impossible to perform the Cantabro wear loss test [15].

Also, to avoid possible bitumen runoff towards the inferior zone of the samples during aging (due to elevated temperature), these are manually inverted toward the interior of the oven every 2, 4 or 8 h (depending on the degree of aging). This way, we invert the direction of the run off, avoiding bitumen accumulation in one zone that would provoke higher disintegration resistance compared to the rest of the sample [15].

2.5.2. Cantabro test

The Cantabro test is performed following the UNE-EN 12697 (2006) [40]. This assay consists in submitting Marshall Samples to wear using the machine from Los Angeles without an abrasive charge and a normalized velocity of 3.1 and 3.5 rad/s (30–33 rpm), during 300 rounds. During the assay the most superficial stone aggregates of the sample become detached due to abrasion and impact (Fig. 6), allowing disintegration and resistance of each sample to be evaluated [15].

Sample weight loss is calculated according to the formula [c]:

$$P_c = (P_1 - P_2)\ x\ \frac{100}{P_1}$$

where
P_C: Cantabro loss, (%),
P_1: Initial simple weight, (g),
P_2: Final sample weight, (g).

The results of the Cantabro test (by a state curve graph) allows changes in bituminous mixture cohesion to be analysed parametrically according to the amount of ash incorporated, the type of bitumen used and the degree of aging. This is because increased aging results in less cohesive power and therefore higher Cantabro losses.

3. Results and discussion

3.1. Wear loss as a result of different aging periods

With the aim of evaluating how cohesion of bituminous mixtures is affected by mastic aging, Table 5 presents the average value obtained from the Cantabro test for each degree of aging and volumetric filler concentration.

In agreement with the previous table, this indistinctly confirms the amount of ash incorporated into the mixture, as well as the nature or type of bitumen used, that produces higher losses as aging time increases, showing that bituminous mixtures are materials prone to aging.

From the state curve graph for mixtures made with the CA-14 bitumen (Fig. 7) it can be observed that mixtures with a Cv/Cs ratio equal or superior to 0.25 are more susceptible to aging due to their low performance in the Cantabro test. These mixtures present the highest losses of all the considered aging degrees, reaching losses 48.6% higher than other mixtures at 40 h of aging, where losses of close to 60% were recorded. This increase of losses compared to the other produced mixtures is mainly due to the scarce ash content that these mixtures possess (7.27 gr of ash) which impedes that they develop the protector filler effect when faced with mixture hardening, volatilization and oxidation; effecting this fragile material, susceptible to cracking with quick depletion of the resistance response to abrasion and impacts.

On the other hand, minor losses occur in mixtures with a Cv/Cs equal to 1 (35.21 gr of ash), minimizing these losses between 16.5 and 48.6% for all the considered aging times. The behaviour of the mixtures with this Cv/Cs is similar to that obtained with the traditional mixture (Cv/Cs equal to 0), with differences close to 3% between them, showing a better behaviour in the mixtures with ashes for aging times between 20 and 40 h.

In regards to the performance of mixtures fabricated with the CA-24 bitumen represented in Fig. 8, an instable behaviour can be observed, with Cantabro losses that are more disperse and discontinuous, in particular at 40 h of aging. In this period a marked decline in losses is produced, which could be explained by a sudden change in the rheological properties of the bituminous mastic, causing an increase in mixture cohesion which is later impaired; phenomenon that requires a more profound analysis. However, despite the discontinuity of the results the trend described above is still observed, where larger losses occur in mixtures with a Cv/Cs ratio different from the critical point (between 0.75 and 1.0). As in the case of CA-14, the losses of the traditional mixture are similar to those obtained in the mixtures with Cv/Cs equal to 1.0, with slightly better results for the traditional mixture for a short-term aging (between 20 and 40 h), and an evident improvement in the mixture with cellulose ashes at the end of the aging period (72 h).

At 0 and 72 h the lowest losses were obtained with a Cv/Cs ratio equal to 1, reducing losses by up to 45.3% compared to the mixture with the lowest performance. For aging at 20 and 40 h, the minimum losses occur in Cv/Cs mixtures equal to 0.75 (24.67 gr of ash), where losses are reduced by 26.1%. Lastly, the Cv/Cs mixture equal to 1.1 that incorporates 39.86 grams of ash is the mixture with the best performance for the aging period of 5 h, obtaining a 26.9% of Cantabro wear loss, translating into a reduction of losses by 31.2%. For all the previously analysed periods, the mixture with the lowest performance for each of the analysed aging degrees was considered the reference point.

Despite the lowest losses obtained for the different volumetric relations, these did not differ by more than 3 points (6.7%) compared to the Cv/Cs mixture equal to 1.00, which presents the best behaviour of the mixtures made with the CA-14 bitumen. Therefore, without committing a miscalculation, it can be argued that the best behaviour for mixtures with the CA-24 bitumen is with the Cv/Cs ratio equal to 1.0.

Finally, from the state curve graph of both bitumens, Fig. 7 ; Fig. 8, all mixtures that incorporate cellulose ash as a contribution filler to the bituminous mastic have similar behaviour, in particular those made with the CA-14 bitumen, where a gradual increase of Cantabro losses can be clearly appreciated as the mixture ages, affecting short term aging periods (of 0–5 h). This phenomenon is reflected by the slope of the curve in this interval, as a result of the loss of oils and volatile bitumen components produced during the mixture fabrication process and first stages of the life; an effect that disappears over the long term since this loss of components is almost completely produced during the first stage [10]. Also, in this interval the Cantabro losses are larger for the CA-14 bitumen than for the CA-24 bitumen due to the rheological characteristics of this bitumen, which possesses a lower penetration degree than the CA-24 bitumen, making this (CA-14 bitumen) a harder bitumen due to the short term aging processes. On the other hand, given the shifting of the curves towards higher or lower losses, according to the Cv/Cs ratio, it can be determined if the filler content is one of the factors with increased influence on the aging resistance of bituminous mixtures, since its wear resistance is directly related.

3.2. Wear losses in function of ash loss

Filler protection against aging provides increased cohesion to the mixture and decreased bitumen hardening; moreover, it produces an increase in bituminous mastic consistency since this contains a higher mineral content, thus determining the optimum ash content to be added is essential. Fig. 9 shows Cantabro losses for the mixtures made with the CA-14 bitumen with increasing ash content. As shown, mixture behaviour up until 40 h of aging is similar, where the curve moves in a parallel manner towards the zone of increased losses as the aging degree becomes more sever. At 72 h of aging, the losses are practically invariable, with a difference of approximately 10 points between higher and lower losses (61.4 and 51.3% of losses). This sudden increase in Cantabro losses compared to the CA-24 bitumen at the same degrees of aging (Fig. 10) is due to the fact that this bitumen possesses a higher susceptibility to aging due to its higher initial hardness.

On the other hand, incorporation of deficient cellulose ash in mixtures with CA-14 bitumen becomes more pronounced as the mixture ages. This can be appreciated in the slope of the curves in Fig. 8, because at first (0 h of aging), the losses do not present significant differences between consequent volumetric relations, however, as the aging degree increases, the slope of the curve becomes more pronounced; presenting an increased difference between the samples with low filler concentrations and those that have a Cv/Cs ratio equal to 1.0. The largest difference between the mixtures with a Cv/Cs ratioequal to 0.25 and 1.0 are found precisely at 40 h of aging, with losses of 59.7% and 30.7% respectively.

On the contrary, the mixtures fabricated with the CA-24 bitumen (Fig. 10), where excess ash in the mixture produces a more pronounced Cantabro loss as the mixture ages, given the increased slope of the curves where Cv/Cs is equal to 1.0 and 1.1. The previous behaviour makes losses in mixtures made with softer bitumen more sever when insufficient ash content in added ("subfill").

Fig. 11 compares the two types of bitumens at 0 and 72 h of thermic aging. The analysis of this graph, Cantabro losses vs volumetric Cv/Cs ratios of both bitumens, allows us to visualize how disintegration losses decrease as the mixture ash content increases, an event that occurs over all the considered aging degrees, as observed in Fig. 9 ; Fig. 10.

The previous effect or tendency thrives to achieve a Cv/Cs volumetric ratio equal to 1.00 which is where minimum losses are obtained, losses of 51.3% for the CA-14 bitumen and 42.6% for the CA-24 bitumen at 72 h of aging. The losses obtained with the Cv/Cs equal to 1.0 are equivalent to those obtained by the traditional mixture, both in the cases of 72 and 0 h of aging time. The major difference is observed with the CA-24 binder at 72 h aging, where the Cv/Cs ratio of 1.0 reduces in 20% the losses compared to the traditional mixture. However, this filler protector effect when faced with aging mechanisms begins to slowly revert when the ash content surpasses its critical value (Cv > Cs), producing a more accentuated influence on bituminous mastic rigidness than the decrease of bitumen hardening, making the Cantabro losses increase once again. The increased loss for mixtures with a Cv/Cs = 1.10 indicates that this relation begins to produce "overfilling" of the filler-bitumen system, which translates into a reduction of the mixture's resistance properties.

Mixtures with a Cv/Cs equal to 1.00 are those that have lower losses at 0 and 72 h of aging for both bitumens, which suggests that these are more resistant to aging, favouring mixtures made with the CA-24 bitumen, which obtains an improvement in losses up to a 16.9% compared to the CA-14 bitumen at 72 h of aging. On the other hand, the results for Cv/Cs ratios equal to 0.25 and 0.50 were opposite for both the considered times (0 and 72 h), even so, the differences between losses at 72 h are close to 3 and 5%, which indicates that their final behaviour is similar for low ash concentrations for both types of bitumens.

According to the Spanish Standard [41] for a medium temperatures zone the recommended ratio filler/bitumen in terms of weight of the semi-dense mixtures is between 0.9 and 1.1, the weight ratio being obtained. In this case, the best results were obtained for a Cv Cs = 1, which equals 40.6 g of ash, obtaining a weight ratio of 0.68, which would be out of standard. However, in order to optimize the behaviour of the asphalt mixtures, consider the different contribution fillers, the ratio f/b must be performed with respect to the specific density of the filler.

4. Conclusions

Incorporation of cellulose ash to the bituminous mastic shows a protector effect in asphalt mixtures against aging when added in the adequate amount, although this does not mean that the mixture is not prone to aging. On the other hand, due to the sieve in the curve of Cantabro losses, as the Cv/Cs volumetric ratio increases it can be observed that the filler content (ash) is the most influential factor when improving aging resistance in bituminous mixtures.

Due to the pronounced slope of the curves in the Cantabro loss graphs vs the volumetric ratios (Cv/Cs) between 0 and 5 h of aging, aging is more accelerated in the early stages of life (fabrication, transport and placement) due to the volatilization and oxidation of the bitumen at high temperatures, an effect that is attenuated over time.

In regards to the samples made with bitumen CA-14, the results of the state curves indicate that the mixtures that contain a Cv/Cs ratio equal to 1.00 have lower wear losses; therefore this ratio is exhibited as the optimum ash content to be used to obtain the maximum resistance to aging without sacrificing resistance to permanent mixture deformation.

For mixtures fabricated with the CA-24 bitumen the results in regards to losses were variable, presenting lower losses for different ash concentrations. However, despite the disintegration of the results, the differences between concentrations with lower losses and a Cv/Cs ratio equal to 1 did not surpass 7%, which can be considered the optimum ash content in mixtures prepared with the CA-24 bitumen, corresponding to a Cv/Cs ratio equal to 1.0. The mixtures that contained a Cv/Cs ratio ≤0.50 were more susceptible to aging with both bitumens, presenting increased Cantabro losses. This is due to accelerated hardening of the mastic according to the age of these mixtures due to the lack of ash, which makes the material more fragile and susceptible to cracking.

When adding cellulose ash as a contribution filler at Cv/Cs concentrations equal to 1.00, the optimum amount of ash for both bitumens, aging resistance and cohesive capacity increases by 48.6% for the mixtures made with the CA-14 bitumen and 45.3% for the mixtures made with the CA-24 bitumen compared with the lowest performing mixture in the different aging degrees studied.

From the volumetric ratio Cv/Cs >1.00 the increase of Cantabro losses can be appreciated due to the mastic stiffening state which predominates over the filler protector state. This effect of "overfilling" endorses that indicated by the Argentinian regulation IRAM 1542 and manifests the importance of volumetric dosage of the filler in regards to the bitumen.

In regards to the performance of both bitumens, lower losses occurred with the CA-24 bitumen, therefore we can conclude that the aging resistance of the mixture that incorporates cellulose ash as contribution filler is improved with the use of softer bitumens since these have a lower aging degree compared to slightly harder bitumens under the same aging conditions. On the other hand, the mixtures prepared with softer bitumens (CA-24), present more accentuated losses between the consecutive volumetric ratios as the mixture ages when overfilling is produced, i.e., the slope of the curve increases between the Cv/Cs ratios equal to 1.00 and 1.10 as the mixture ages, meanwhile in the mixtures made from a harder bitumen (CA-14) the changes in the losses become more sever with time (increased slopes) when incorporating a deficient amount of ash or "subfiller" to the mixture.

For the design of asphalt mixtures, it is more appropriate to use a filler-bitumen ratio based on the specific weight of the filler, rather than the weight ratio. In this way, a correlation with the Cv/Cc parameter can be established to ensure the correct behaviour of the mixture and consider the variations in the densities of the materials that can be used as contribution filler.

In regards to the UCL Method, the Cantabro wear loss test evaluates not only mixtures with open granulometry submitted to thermic aging, but it is also sensitive enough to detect variations of the mastic with age and ash content of semi-dense mixtures.

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

Fig. 2. Cellulose ashes used as contribution filler.

Fig. 3. Hot mixture and filler contribution after the first envelope.

Fig. 4. Marshall samples fabricated in the laboratory.

Fig. 5. Marshall lateral confinement before aging process.

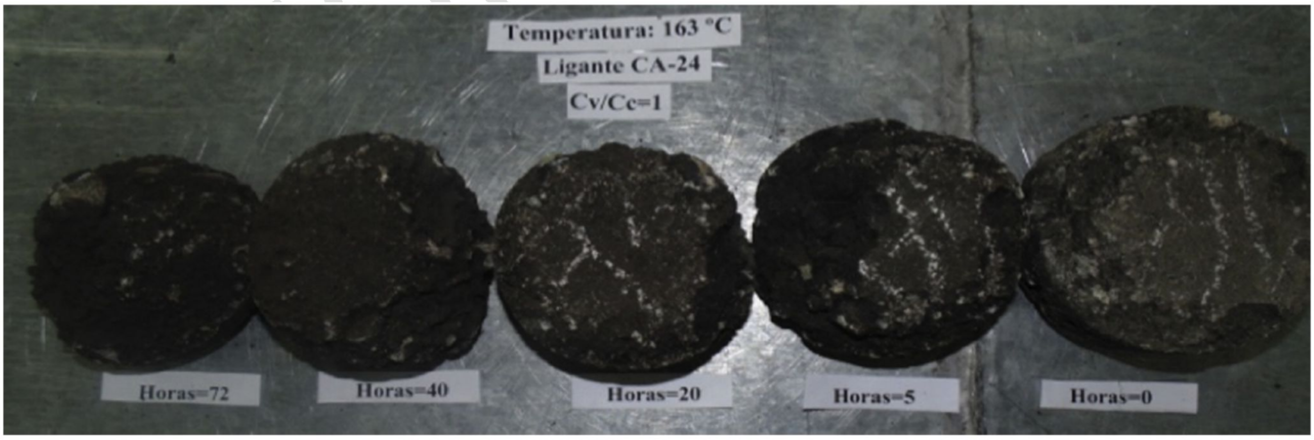

Fig. 6. Samples under Cantabro test by different periods of aging effect.

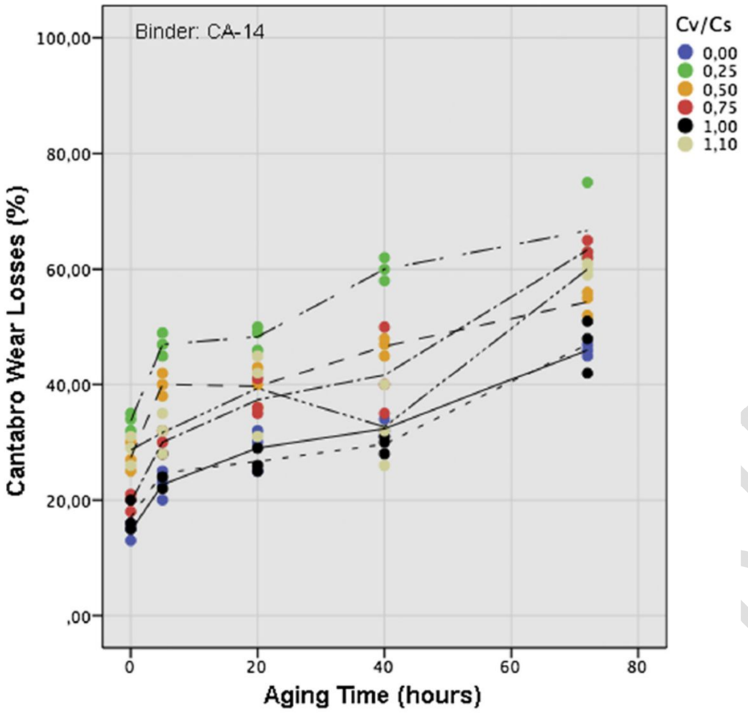

Fig. 7. Wear losses by Cantabro Test vs. Aging times – Bitumen CA-14.

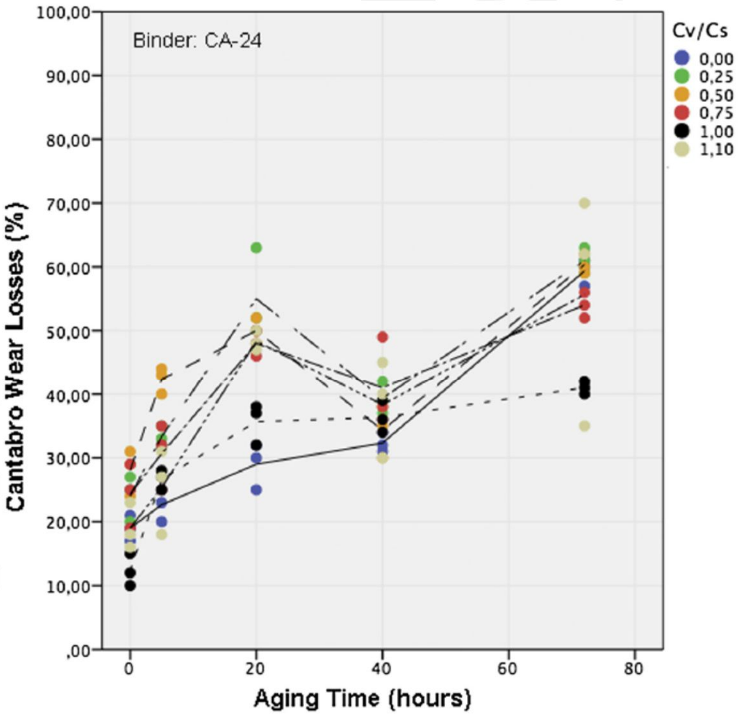

Fig. 8. Wear losses by Cantabro Test vs. Aging times – Bitumen CA-24.

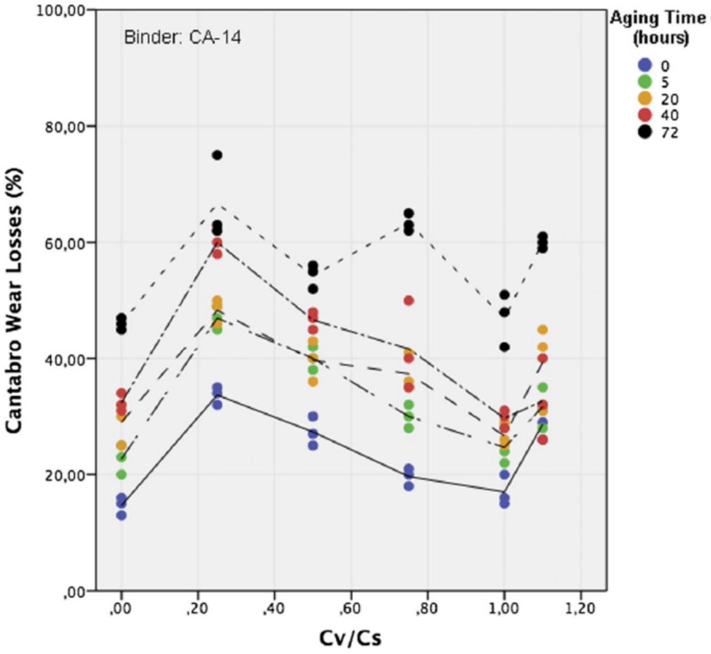

Fig. 9. Wear losses by Cantabro Test vs Volumetric relations Cv/Cs – Bitumen CA-14.

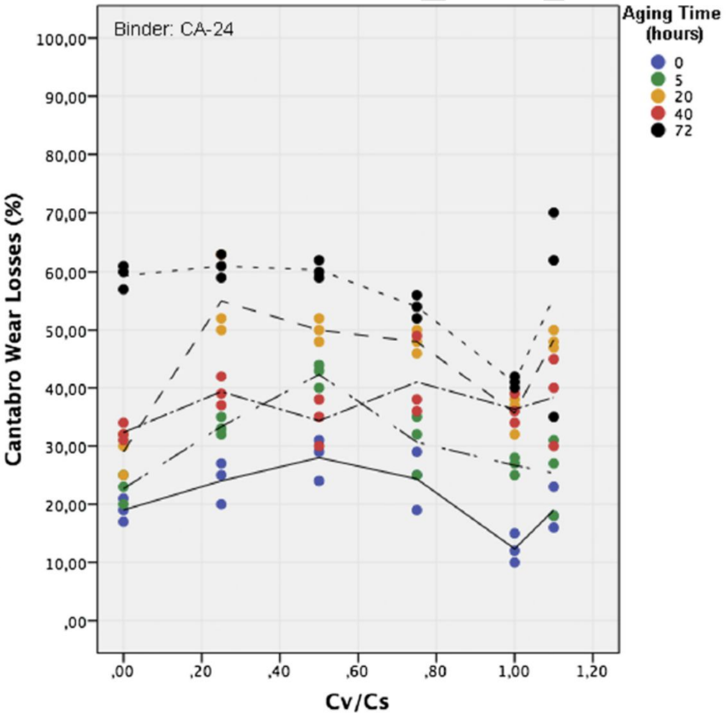

Fig. 10. Wear losses by Cantabro Test vs Volumetric relations Cv/Cs – Bitumen CA-24

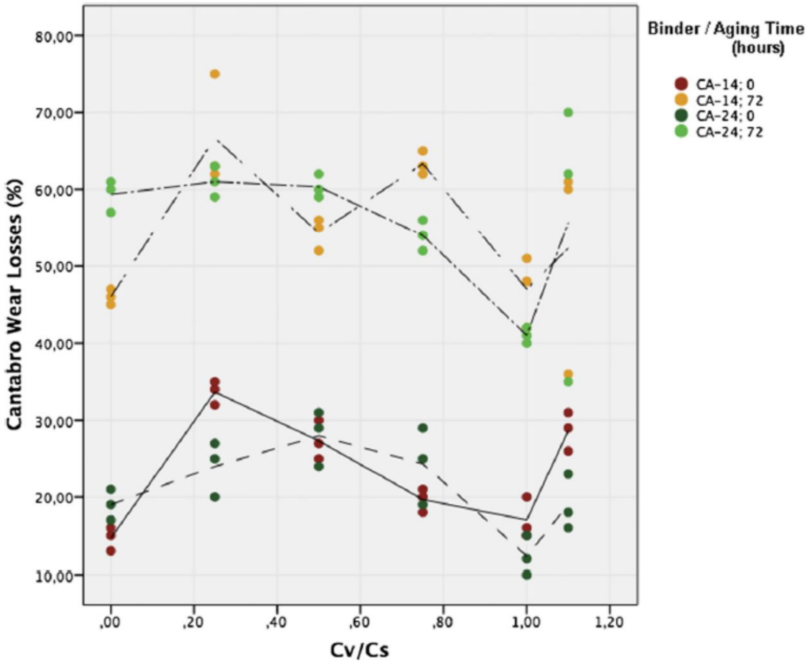

Fig. 11. Wear losses by Cantabro Test for asphalt mixtures fabricated with CA-14 and CA-24 bitumen in based to the ash content (0 and 72 h of aging effect).

Table 1
Specific characteristics of bitumen.

Characteristic	Units	Method	Results	
			CA-14	CA-24
Penetración 25 °C, 100 g, 5 s.	0.1 mm	MC 8.302.3*	44	59
Softening point	°C	MC 8.302.16*	50	50
Relative density	gr./cm3	281-2	1033	1033
Absolute viscosity 60 °C	Poise	MC 8.302.15*	1572	3039

* MC: Roads Guide (2015).

Table 2
Volumetric properties of the filler.

Filler	Specific density (gr./ cm3)	Critical concentration (Cs)
Cellulose ash	2.48	0.22

Table 3
Granulometric analysis used for IV-A-12 mixture.

Sieve (mm)	% Pass
20	100
12.5	80–95
10	70–85
5	43–58
2.5	28–42
0.63	13–24
0.315	8–17
0.16	6–12
0.08	4–8

Table 4
Distribution of samples.

		Aging time (hrs.)				
Bitumen	Cv/Cs	0	5	20	40	72
CA-14	0.25	4	4	4	4	4
	0.50	4	4	4	4	4
	0.75	4	4	4	4	4
	1.00	4	4	4	4	4
	1.10	4	4	4	4	4
CA-24	0.25	4	4	4	4	4
	0.50	4	4	4	4	4
	0.75	4	4	4	4	4
	1.00	4	4	4	4	4
	1.10	4	4	4	4	4

Table 5
Cantabrian wear losses under different aging effects (300 rev.).

Aging time (hours)	Mixture (Cv/Cs)									
	CA-14					CA-24				
	0.25	0.50	0.75	1.00	1.10	0.25	0.50	0.75	1.00	1.10
0	31.9	28.8	21.5	20.5	26.8	23.8	26.5	23.5	14.5	16.6
5	45.9	39.4	30.9	27.3	30.2	31.4	39.1	33.9	27.1	26.9
20	48.5	41.0	38.7	28.2	40.9	51.7	47.9	38.2	39.2	47.7
40	59.7	47.0	42.1	30.7	33.6	37.5	34.6	33.3	35.7	36.3
72	60.8	55.5	61.4	51.3	54.4	62.9	58.8	54.0	42.6	53.7