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Influence Of Filler on Asphalt Dispersions with Recycled Tire Rubber for Hot Asphalt Mix

Ignacio Zapata Ferrero[1*], Agustina Gelsi[1], Julián Rivera[1], Gerardo Botasso[1]

[1]LEMaC Centro de Investigaciones Viales UTN FRLP – CIC PBA
Universidad Tecnológica Nacional FRLP, Av. 60 y 124, 1900 La Plata, As. Bs., Argentina

***izapata@frlp.utn.edu.ar**

Abstract

Mineral filler additions change the rheological behavior of the asphalt binder, which has a big impact on the properties of asphalt mixtures like rutting resistance, fatigue resistance, and thermal susceptibility. There is currently no specification in Argentina that specifies the ideal filler content to be added to hot asphalts modified with recycled tire rubber (RTR). In the current study, an analysis of the behavior of asphalt dispersions with varying amounts of RTR—from 15% to 25% of the binder weight—is done when mineral filler is incorporated in various concentrations. By measuring how the dispersion reacts to the softening point test and temperature sweep using a dynamic shear rehometer (DSR), it aims to establish a standard for the ideal amount of filler to incorporate and show how the RTR residue and filler work together to produce the desired results. The amount of rutting resistance offered by the asphalt has been found to increase by up to 200 percent when measured with DSR for the highest contents of RTR and filler.

Keywords*:* Filler, RTR, Rheology, Hot asphalt mix

INTRODUCTION

The most common problems in asphalt pavements are rutting, fatigue failure, and thermal susceptibility, which arise because of incorrect dosages and/or forms of placement, mixing, and compaction of asphalt mixtures. Hot mix asphalt is composed of a combination of different materials, such as asphalt, either conventional or modified, together with aggregates and filler [1].

Its properties depend on the relative concentrations, by volume, of its components. These proportions are calculated during the design of the mixes to obtain a quality asphalt pavement suitable for its life in service. The service requirements that must be considered when designing an asphalt mix are durability, slip resistance, flexibility, stability, and compatibility. The quality of an asphalt pavement is directly related to its properties of flexibility, stability, and durability [2]. Generally, when a mix has more flexibility, its stability decreases. Over the years, in the design of asphalt mixes, it has been decided to increase stability at the expense of flexibility using mineral filler. Therefore, it is necessary to establish criteria to add mineral fillers to conventional asphalt mixes without excessively affecting either of these two properties. This criterion, developed by Ruiz (1960) [3],[4], is based on considering that dense mixes are made up of a granular skeleton of compacted coarse and fine aggregates, whose voids are partially filled by the dispersion of the filler in the asphalt. The incorporation of mineral filler modifies the relationship between stresses and strains, considering the constant time of load application and temperature.

It was shown that there is a relationship between the volume of filler and the volume of the asphalt-filler system, for which the addition of filler increases the resistance to deformation without modifying the viscous nature of the asphalt bitumen. This relationship is called volumetric concentration (Cv). The effect of the filler addition is beneficial up to a certain critical value; above this, the asphalt-filler system behaves like a rigid solid. This value is called critical concentration (Cs) [5].

In Argentina, for the design of hot, dense asphalt mixes, the addition of filler is limited so as not to exceed the value of Cs. In this way, it is possible to foresee the maximum amount of filler to add without affecting the mix resistance or the rest of its properties. The different proportions of filler in the matrix asphalt can be seen in Figure 1. The Technical Specifications Sheets of the" Vialidad Nacional Argentina" (Argentine National Roads, DNV) [6] indicate that, for mixtures made with conventional binders, the Cv of the mineral filler must not exceed its Cs, that is, a Cv/Cs ratio ≤ 1. For asphalt mixtures made with modified asphalt, the volumetric concentration Cv of the mineral filler must not exceed its Cs by more than 10%, that is, a Cv/Cs ratio ≤ 1.1. However, in the case of mixtures made with asphalt modified with Recycled Tire Rubber (RTR) powder, there are no regulations in this regard or studies that evaluate the influence of filler content. In another way, it can be seen visually in RTR asphalts that there is a proportion of the rubber that is not fully digested in conventional asphalt. That undigested fraction is expected to act as the filler does, which does not happen when another modifier is used, such as SBS or SBR. This aspect leads to the need to generate another study not addressed in the present work.

In the present work, we seek to establish a criterion to determine the influence of filler content to be incorporated into asphalt mixes modified with RTR.

INFLUENCE OF THE FILLER IN ASPHALT MIXES

Mineral filler or "Filler"

A finely subdivided product of mineral origin where no less than 75% passes the IRAM sieve 75 micrometers (N° 200) is called "filler". The mineral filler can come from the component fractions of the aggregate or from a material for this purpose (cement, lime, calcareous material, fly ash, etc.).

It allows for obtaining denser asphalt mixes without the need to incorporate a greater amount of asphalt. This is because the filler aggregate fills the gaps between the coarse aggregate particles. In this way, the filler increases the stability of asphalt mixtures, optimizing the rheological properties of the asphalt. When the asphalt is modified with filler, its complex modulus is increased [7]. This is possible when the volumetric concentration of the mastic is such that it allows an increase in the shear strength of the asphalt mixtures without affecting the viscosity of the asphalt. It reduces porosity and thus prevents the entry of external agents, thus increasing its durability.

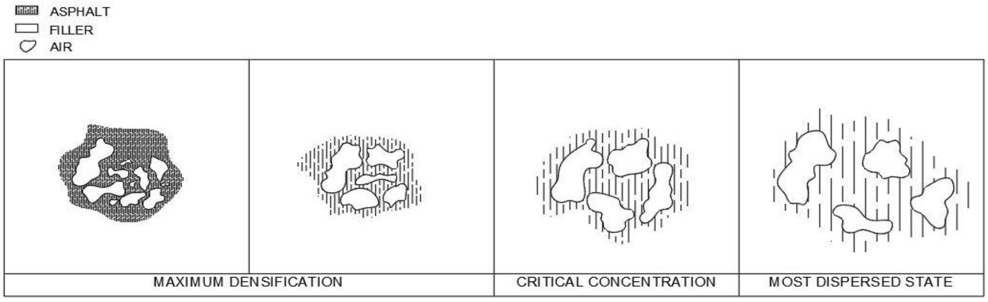

Figure 1. Asphalt dispersion in different proportions.

In conclusion, adding filler to asphalt mixes has many benefits because it changes the properties of the asphalt, making it more consistent, giving it a higher viscosity, and making it less sensitive to heat. That gives the mixture greater stability, greater resistance, and better adhesion between the aggregates and the asphalt binder [8],[9].

Rheological aspects of asphalt

Asphalt is a viscoelastic material that presents a very complex rheological behavior. The asphalt's response to stress depends on the temperature, magnitude, and time of load application. Asphalt then presents an intermediate behavior between Hooke's solid (elastic) and Newton's liquid (viscous). At low temperatures, it has an elastic behavior, while at high temperatures, it has a viscous behavior; at service temperatures, it presents both behaviors simultaneously [10].

To characterize the viscoelastic properties of asphalt, the dynamic shear rheometer (DSR) is used to determine two representative rheological parameters: the complex shear modulus (G*) and the angle of phase (δ). The complex shear modulus G* is a measure of the total resistance to deformation of a binder. It is defined as the quotient between the maximum stress applied (τ max) and the maximum deformation recorded (γ max), as can be seen in equation (1).

$$G^* = \frac{\tau_{max}}{\gamma_{max}} \tag{1}$$

The G* (Figure 2) is made up of an elastic component, called the Storage Modulus (G'), and a viscous component, called the Loss Modulus (G''). The storage modulus is related to the energy stored in the material while the loss modulus is related to the energy dissipated. These components are linked through the phase angle in a vector sum. The phase angle δ is the phase difference between stress and strain and represents an index of the viscoelasticity of the material. It is between 0°< δ<90° (Figure 3).

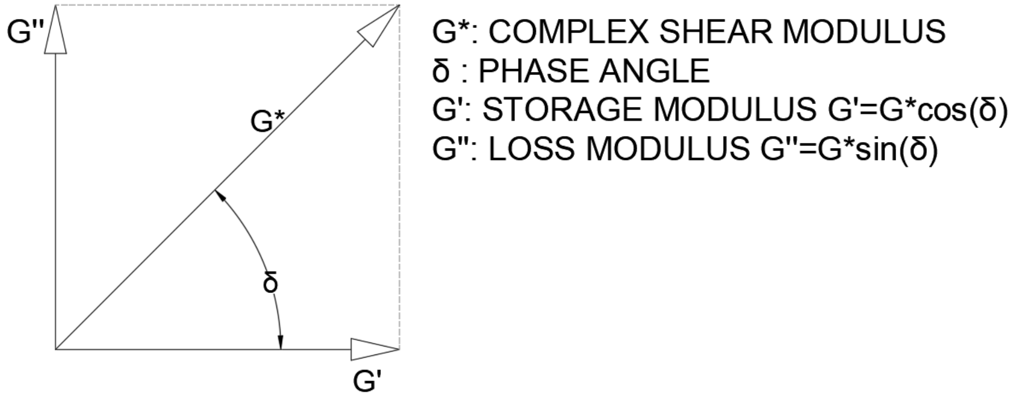

Figure 1. Shear modulus and phase angle.

When a material is elastic, stress and strain are in phase, so δ=0°. In these cases, G*≃G'. When a material is viscous, the applied stress and the resulting strain are out of phase, so δ=90°. In these cases, G*≃G''.

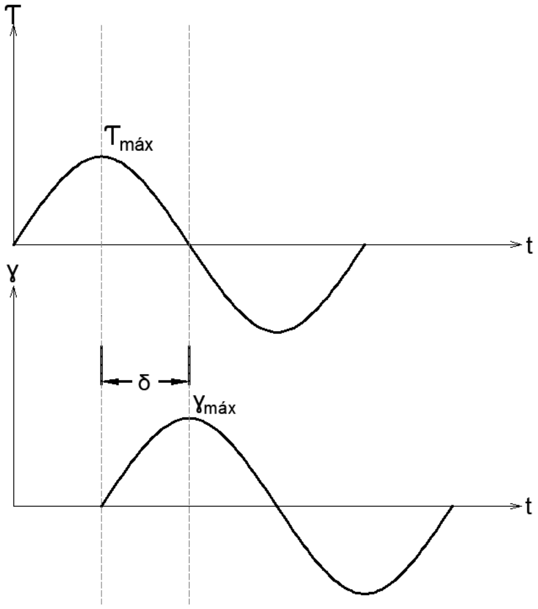

Figure 3. Viscoelastic behavior. (0°< δ < 90°).

Jiang et al. (2020) study the influence of the mastic film that covers the aggregates. It determines that for small specific deformations of around 0.1% in the DSR, the influence of the incorporation of the filler within the mastic considerably improves the resistance to fatigue [11]. Zhang et al. (2019) analyse the behaviour of asphalt mastic using the DSR and with discrete element methods. It determines that there is a good correlation between both methods for low proportions of filler within the mastic [12]. Faheem & Bahia (2010) study the incorporation of different kinds of filler into the asphalt mastic to arrive at a regression model and obtain the complex shear modulus of the asphalt with the addition of filler, based on simple obtaining parameters [13].

SUPERPAVE

SUPERPAVE (Superior Performing Asphalt Pavement) [14] is a design program for high-performance asphalt and asphalt mixes that differs from traditional methods by considering the direct dependence of the binder resistance on temperature and aging over time its useful life [15]. Regarding asphalt design, this method defines three types of failures: rutting, fatigue cracking, and thermal cracking.

In the binder specification, SUPERPAVE sets the rutting parameter G*sin δ. This parameter is specified with a minimum value of 1 kPa for virgin asphalt and 2.2 kPa for the Rolling Thin Film Oven Test (RTFOT) residue for temperature evaluation [16-19] using rutting limitations. This determines the performance grade (PG) of the binder, which is specified at 64 °C, 70 °C, 76 °C, 82 °C, and 88 °C. In this research work, the influence of filler lime in modified asphalt dispersions with increasing rates of RTR is evaluated by means of the softening point and the parameter G*/sin δ to quantify the increase in stiffness that presents the samples.

MATERIALS AND METHODS

Materials

To make the samples, an ordinary asphalt binder with the viscosity number AC-30 and recycled tire rubber powder (RTR) from old tires were mixed together to change the base asphalt. Table 1 shows the particle size distribution of RTR powder. The RTR powder is added at increasing rates of 15%, 20%, and 25% with a high-speed disperser until a homogeneous mixture is obtained, and a total of four binder samples are obtained. These samples are characterized by the softening point test and temperature sweep. Hydrated lime is used as a mineral filler, and an apparent specific weight and concentration test are carried out for its characterization. The sample denomination is BASE for the conventional AC-30 and BASE+15RTR, BASE+20RTR, and BASE+20RTR for the asphalts modified with 15%, 20%, and 25% of RTR, respectively.

Table 1. Particle size distribution of RTR.

Sieve (ASTM E11)	Aberture [mm]	Mass passing [%]
10	2.000	100.00
12	1.680	100.00
14	1.410	100.00
25	0.707	98.42
35	0.500	59.04
60	0.250	16.58
120	0.125	2.19
230	0.063	1.40
270	0.053	1.05

Apparent specific weight [20] is the relationship between the dry weight of the material and the displaced volume. It is calculated with equation (2).

$$P.E.A = \frac{P}{V_D} = \frac{P}{V_F - V_I} \tag{2}$$

Where:

P.E.A. = Apparent specific weight.

P = Dry weight of the material introduced into the volume meter.

V = Volume of anhydrous kerosene displaced by the sample.

On the sample of lime, the critical concentration is calculated with equation (3).

$$C_s = \frac{P}{V * P.E.A} \tag{3}$$

Where:

Cs: Critical concentration.

P: Weight of mineral filler.

V: Volume of the mineral filling.

P.E.A: Apparent specific weight of the mineral filler determined according to VN - E15 – 89.

Softening Point

The softening point (Figure 4) is the temperature at which the material in the rings softens enough to allow each sphere to fall and touch the brass plate below. This test is used to determine the consistency of the asphalt bitumen and, in conjunction with the penetration test (IRAM 6576), to establish its thermal susceptibility and then classify it by means of the penetration index.

Temperature sweep

The dynamic shear rheometer is used to carry out the temperature sweep test in a range of 58°C to 88°C for BASE sample and from 64°C to 88°C for the rest of the samples. This test is used to determine the dynamic shear modulus and phase angle when an oscillatory shear stress is applied at a constant oscillatory frequency of 10 rad/s. The geometry used is in the form of parallel plates of 25 mm in diameter, including a 1 mm-thick pad.

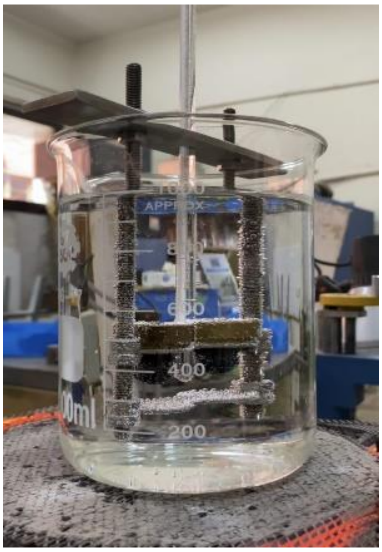

Figure 4. Softening Point Test.

Sample preparation

Limes filler dispersions are made in different concentrations in the binder samples. Four Cv/Cs ratios from 0 to 1 are chosen (limit ratio established for conventional binders according to the DNV): 0.00; 0.40; 0.80; 1.00. Together with the critical concentration value obtained, the amount of filler, by volume, to be added for each dispersion was determined. To make the samples, the mineral filler is sieved through sieve N° 40 and dried in an oven until it reaches a constant weight. Then the asphalt is heated to a temperature of 160°C until the desired consistency is obtained, and it is placed in cylindrical containers of approximately 90 mm in diameter, as seen in Figure 5.

Figure 5. Asphalts samples

RESULTS AND DISCUSION

Table 2 shows the results of the specific weight and critical concentration performed on the filler used.

Table 2. Specific weight and critical concentration results

Sample	Specific weight [g/cm3]	Critical concentration
Lime Filler	2.529	0.171

In Table 3, the results of the softening point test of all the samples BASE, BASE+15RTR, BASE+20RTR, and BASE+25RTR in function of the addition of filler are presented. The results are expressed in terms of centigrade degrees. All samples were tested in water except for those that gave results above 80 °C. These samples were tested on glycerine to avoid boiling the material and generating a non-linear flow over the samples to be tested.

Table 3. Softening point results

Cv/Cs	BASE	BASE+15RTR	BASE+20RTR	BASE+25RTR
0.0	53.0	59.6	62.2	67.5
0.4	56.0	65.5	67.0	73.0
0.8	58.6	68.7	75.5	87.3
1.0	61.1	72.7	90.5	100.9

From the softening point tests, it is observed that the BASE sample and the sample BASE+15RTR present similar behavior. The parallelism between the slopes of both curves indicates an approximately linear variation of the softening points as the filler content increases, as can be seen in Figure 6. It can be observed that for Cv/Cs concentrations greater than 0.8 in the BASE+20RTR and BASE+25RTR samples, the addition of filler generates a greater increase than for the rest of the samples, and the parallelism in the BASE and BASE+15RTR samples is no longer noticeable. For concentrations greater than 15% of RTR, the incorporation of filler generates an interaction with the rubber particles, triggering higher values of softening points.

In the rest of the modified asphalt samples, greater slopes are observed with increasing filler content. which suggests a more intensive effect of lime that modifies the consistency of the binder.

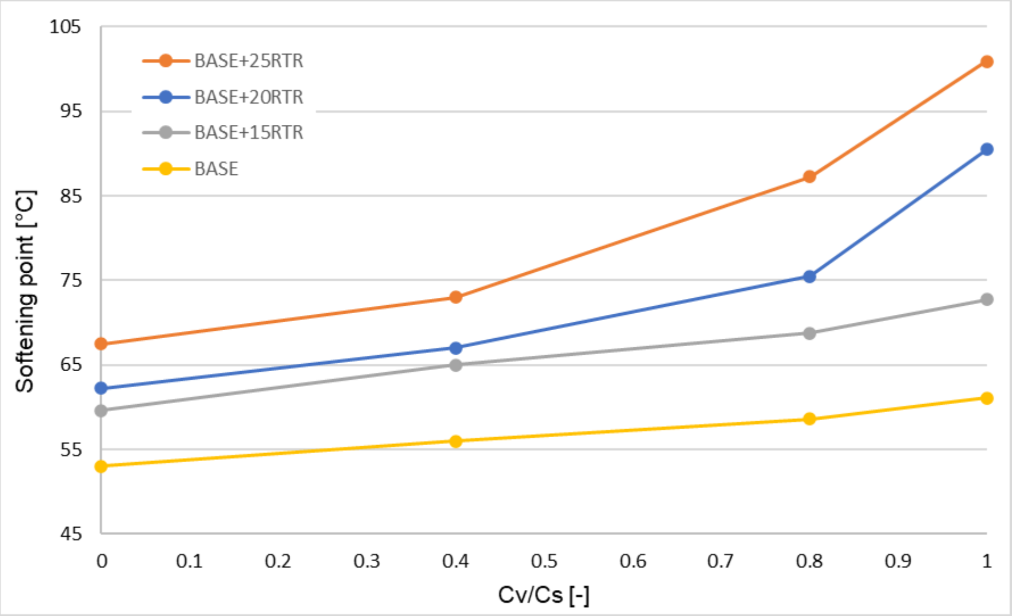

Figure 6. Variation of softening points in function of Cv/Cs

The temperature sweep test can be seen in Figures 7, 8, 9, and 10 of the samples BASE, BASE+15RTR, BASE+20RTR, and BASE+25RTR, respectively, with increasing content of filler. Sample BASE with Cv/Cs=0 was not evaluated beyond 70 degrees because the low consistency would cause the geometry of the sample to be lost. Although several samples do not reach the value of 1 kPa, the test is not continued because there are no SUPERPAVE classifications for asphalts higher than 88 °C.

For increasing contents of Cv/Cs concentration, increasing values of G*/sin δ are obtained. This trend is observed in the same way for the rest of the samples. It is observed that the curves of the parameter G*/sin δ of all the samples decrease with the increase in temperature in the range tested from 64°C to 88°C.

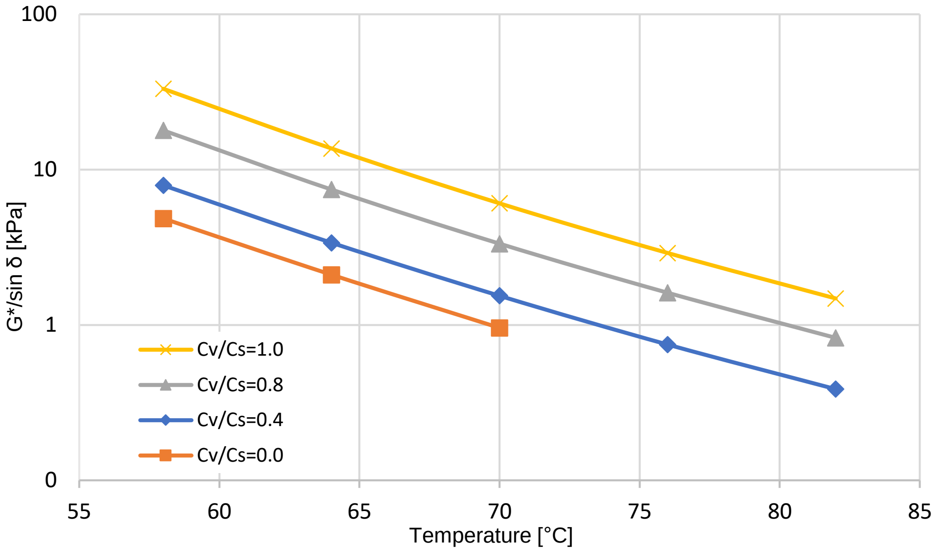

Figure 7. Temperature sweep curves from BASE samples at different Cv/Cs concentration

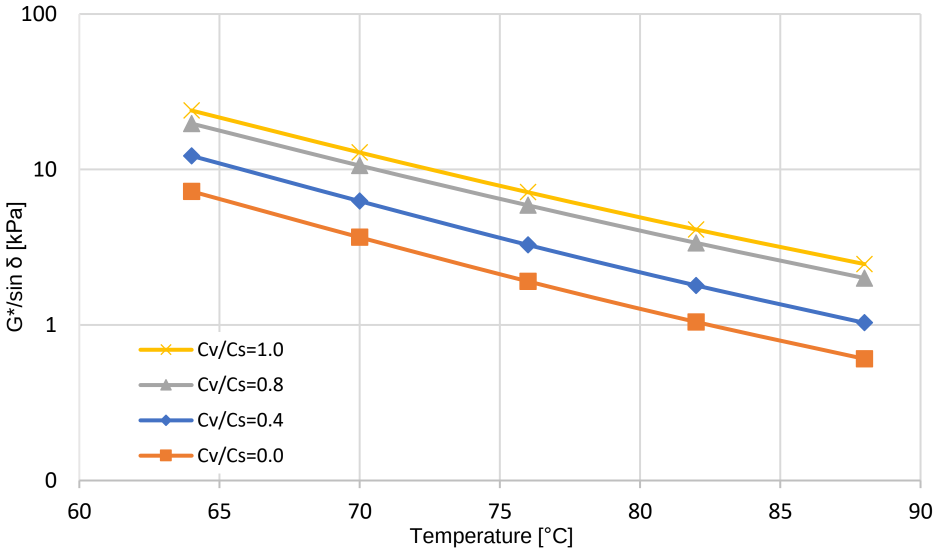

Figure 8. Temperature sweep curves from BASE+15RTR samples at different Cv/Cs concentration

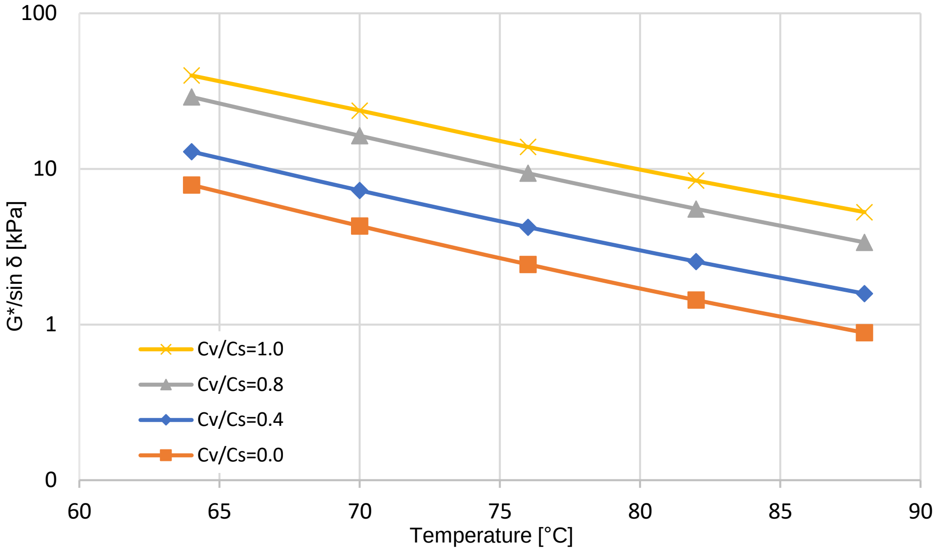

Figure 9. Temperature sweep curves from BASE+20RTR samples at different Cv/Cs concentration

Consequently, the tendency for rutting to increase with an increase in temperature can be seen. It is noted that, for modified asphalts, at increasing rates of RTR, the value of the parameter G*/sin δ is greater with respect to conventional asphalt, which translates into better performance against permanent deformations.

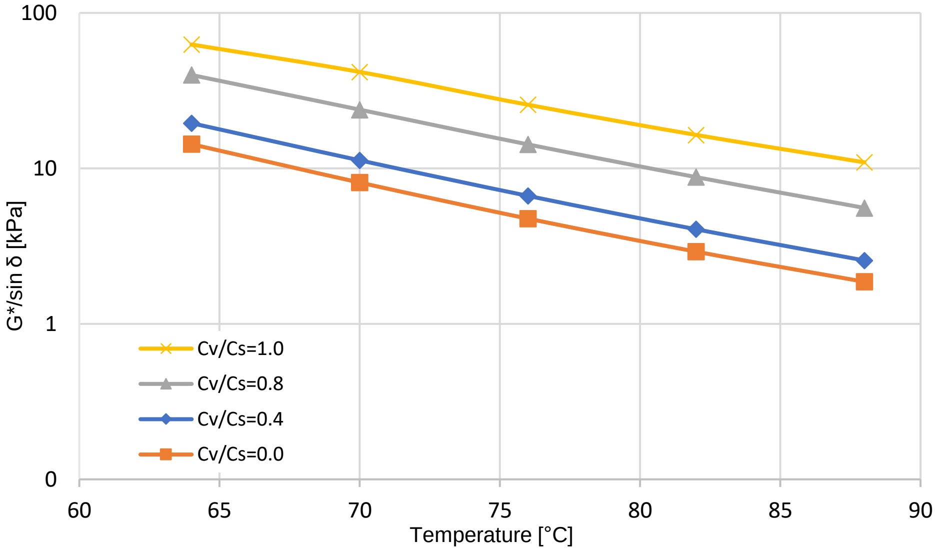

Figure 10. Temperature sweep curves from BASE+25RTR samples at different Cv/Cs concentration

For all samples with RTR, increasing the Cv/Cs ratio from 0 to 1 raises the G*/sin δ parameter to values of 200%. This confirms the even greater influence of the filler on samples that contain a high RTR rate.

Figure 8 shows that for BASE asphalt the SUPERPAVE specifications are met in relation to the limit value of the parameter G*/sin δ ≥1 kPa, for a temperature of 64°C for a relationship Cv/Cs = 0 that it is possible to predict an optimal behavior for its use in the pavement up to a temperature below 64°C. In the rest of the BASE samples, it is observed that as the Cv/Cs ratio increases, the higher the failure temperature. A similar trend is observed with the remaining asphalt dispersions with RTR. Although the incorporation of NFU increases the failure temperature due to rutting of asphalt, the incorporation of filler allows the temperature to be raised by one or even two PG degrees.

From the comparison of the softening point and temperature sweep results, both tests follow the same trend. In Figure 11, it can be seen the variation of G*/sin δ at 70 °C for the four samples. The results are like those obtained from the softening point. These results indicate that for concentrations of Cv/Cs greater than 0.8, the increasing content of RTR considerably increases the parameter G*/sin δ.

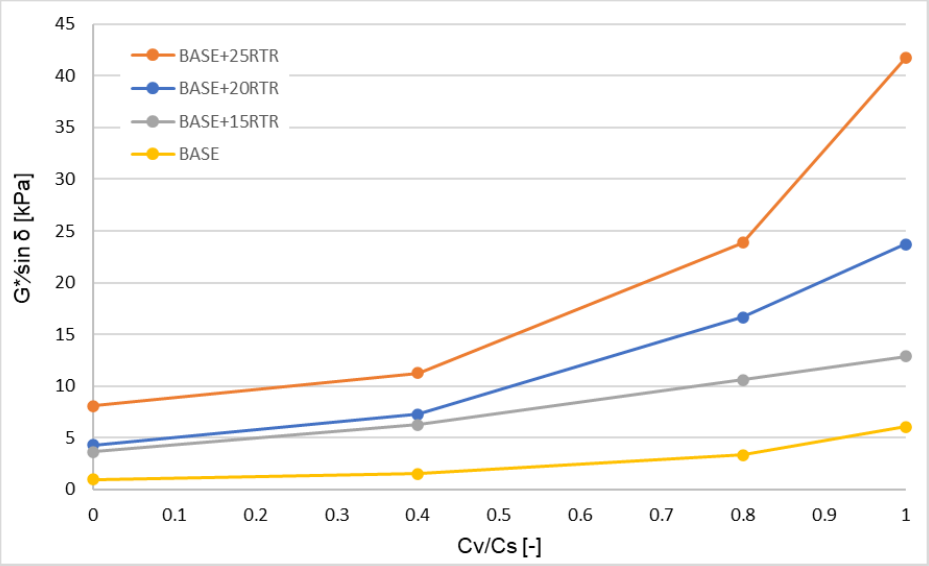

Figure 11. G*/sin δ at 70° C for different Cv/Cs concentration.

CONCLUSION

In this study, we investigated four types of asphalt mix with four different amounts of filler lime (0%, 40%, 80%, and 100% of the concentration critical) using the softening point test and temperature sweep with DSR. One of the asphalts is the original type, and the other three are changed with increasing rates of RTR. This methodology allows the preparation of rutting parameter curves versus temperature. From the analysis of the rheological curves, it is observed that the incorporation of lime filler produces an increase in the rutting parameter G*/sin δ, which implies less permanent deformation in the pavements. Although it is a situation at the limit of specifications, the combination of both factors (25 RTR and Cv/Cs = 1) can provide the asphalt mixture with the combined properties of adequate flexibility, as well as good resistance to permanent deformations and a lower susceptibility to temperature changes.

It is evident that to find the optimal filler content to be incorporated into asphalts modified with RTR, it is necessary to evaluate more parameters with performance tests on asphalt mixtures, which provide information on the real incidence of the lime filler in the variation of the properties of the asphalt. It is suggested to carry out an evaluation of other rheological parameters such as G*sin δ, glower, or the LAS test to characterize the fatigue failure of asphalt. also using different types of asphalt and mineral filler, either filler or material from the recovery of aggregates, to make a comparison of the effect caused by each one of them. In turn, evaluate dispersions of binder aged in the RTFO and PAV (pressure aging vessel) and characterize their medium- and long-term behavior through routine tests such as softening point and advanced tests such as viscosity and rheology. Although it is known that the addition of RTR powder as a modifier of asphalt base has a beneficial effect on the rheological properties of the binder, it is proposed as a future research project to quantify the critical concentration of mineral filler in asphalt mixes modified with RTR, discriminating the effect of the modifier.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interests associated with this publication.

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