LIFE NEREIDE: NEW LOW NOISE PAVEMENT SURFACES

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The Life NEREiDE project has the aim of evaluating the advantages of using crumb rubber and Reclaimed Asphalt Pavement (RAP) in construction of new Low Noise Pavement (LNP) surfaces, specifically designed to reduce rolling noise by optimizing surface texture. The new LNP surfaces are realized by using the Warm Mix Asphalt (WMA) technology that allows a significant reduction of mixing and compaction temperatures of asphalt concrete. The benefits of using WMA technology may include reduced fuel usage and pollution, and improved working conditions whilst the reuse of RAP allows to saving consumption of non-renewable resources in asphalt pavement industry. WMA technologies act on some characteristics of asphalt binders; the NEREiDE project will investigate the effects of the WMA additives in order to identify the most appropriate additives to be used to improve binder properties in terms of viscosity and coating properties; the work will be completed by determining the optimum mixing and compaction temperatures of the new LNP mixtures by using the selected WMA additive. These temperatures will be evaluated by measuring the internal resistance of the mix during compaction and this allows to evaluate resistance to compaction by using the Gyratory Load-cell and Plate Assembly (GLPA). A method to determine the allowable percentage of RAP that can be added in the new LNP mixtures has been proposed by the research team elsewhere and will be applied in the NEREiDE project. It is based on a new approach used to determine rheological properties of the RAP binder. From DSR frequency sweep tests carried out on mortars composed of RAP and fresh binder, the master curves of the RAP binder can be back-calculated by using the Modified Nielsen model and the Voigt model.

Keywords: crumb rubber, recycled asphalt pavement

1. The Life NEREiDE project

The LIFE NEREiDE project wants to demonstrate the use of new porous asphalt pavements and low noise surfaces composed by RAP and crumb rubber from scrap tires [1]. These materials will be mixed with binders at warm temperatures to produce WMA pavements with specific benefits in order to:

- reduce the disposal of waste materials and reduce the use of virgin materials;
- achieve better acoustical performance than those currently available, allowing a significant reduction of noise in urban areas and health improvement;
- improve safety in urban areas by obtaining draining and good textured surfaces;
- improve air pollution due to asphalt laying.

The experimental activities will lead to the development of specific guidelines to be used by Road Administrations in preparing specifications for the construction of new porous asphalt, low-noise and low carbon footprint road surfaces. Guidelines will be developed in order to upgrade and to improve the methods currently available to assess the effectiveness of low noise road surfaces in urban areas.

This article describes the experimental activities performed to date. These activities allowed to identify the more suitable WMA additive to use for reduction of mixing and compaction temperatures of a specific type of crumb rubber modifier binder (CRMB); moreover a new approach used to determine rheological properties of the RAP binder is presented.

2. The warm mix asphalt technology

Generally, mixtures containing crumb rubber are mixed and compacted at temperatures not lower than those of the traditional Hot Mix Asphalt (HMA). Evidently, this aspect conflicts with the actual needs of eco-efficiency and sustainability that require a reduction of energy consumption and pollution. In the perspective of reducing air pollution and the environmental impact related to the production of these mixtures at high temperature, it is necessary to make attempts to reduce their mixing and compaction temperatures.

WMA additives were developed and implemented as means to reduce environmental impacts by allowing for mixture production at least 30°C lower than conventional HMA with no premature failures [2]. Furthermore, results of numerous research studies have shown the potential for WMA to benefit performance in the following ways:

- the presence of more uniform mat compaction.
- an increased mixture durability.
- Higher Recycled Asphalt Pavement (RAP) contents in mixes.

Actually, there are various WMA additives available on the market, and they can be classified according to the type of product and the claimed mechanism as reported in Table 1 [2]. Table 1 provides a summary of some of the widely used WMA additives and the mechanisms by which they are known or claimed to operate. These technologies come with numerous potential benefits and risks related to both construction and performance.

Table 1: WMA additives and claimed mechanisms

Product	Claimed mechanism	
	During coating/mixing	During compaction
Foaming by injection or mixing	Reduced viscosity	Increased film thickness
Foaming by water bearing minerals	Reduced viscosity	Reduced viscosity
Wax synthetic	Reduced viscosity	Reduced viscosity
Chemical surfactant/wax combination	Viscosity/surface tension	Reverse micelle formation
Chemical surfactant	Reduced surface tension	Reverse micelle formation
Chemical functionalized poly-olefins	Reduced surface tension	Internal lubrication

Recent research studies reported that the reduction in production temperature due to the use of WMA additives predicted using conventional viscosity based methods underestimates the workability and the densification behaviour observed in the field [3], [4]. As a result of these shortcomings current test methods and mix design methodologies are unable to quantify the effects of WMA additives. Potentially, mastic viscosity can be a first estimate for workability but at this time there is no substitute for compaction of total mixture. Asphalt mixture workability and sensitivity to compaction temperature are strongly influenced by gradation, therefore the need for WMA additives and proper dosages should be selected on the gradation used [5].

In the following sections a new procedure to evaluate effect of WMA additives on binder viscosity and on mixture workability and to facilitate the mixture design and temperature selection process is presented.

2.1 Identification of the most suitable WMA additive

In order to identify the most suitable WMA additive to use for reduction of mixing and compaction temperatures of a specific type of CRMB, 4 different types of WMA additives have been analysed. The CRMB used is composed of 50-70 penetration grade bitumen (80% by weight) and CRM (20% by weight). In Table 2 are shown the different types and quantities of WMA additives used.

Table 2: Types of WMA additives used

WMA additive	Type of additive	Quantity* [%]
SW	Synthetic wax	3.0
F	Foaming	0.6
SA	Surfactant agent	0.5
C	Chemical	1.0
* additive content as percentage by weight of the CRM		

2.1.1 Effects of WMA additives on binder viscosity

The dynamic viscosity of the CRMB before and after mixing with the selected additives was evaluated in order to choose the more appropriate additive to achieving the specific aims: low viscosity at the desired mixing and compaction temperatures. The more appropriate additive was selected by considering the additive that at lower temperatures has the same viscosity of the CRMB at 175°C, that is the usual mixing temperature of CRMB (ASTM D6114/D6114M 2009).

Dynamic viscosity of binders has been measured by a Brookfield Viscometer at a constant shear rate of 10 s^{-1} according to ASTM D4402 standard procedure. Isotherm viscosity curves at T=175°C and the viscosity curves versus temperature were determined in order to evaluate the variation of viscosity after adding the different types of WMA additives (Figure 1).

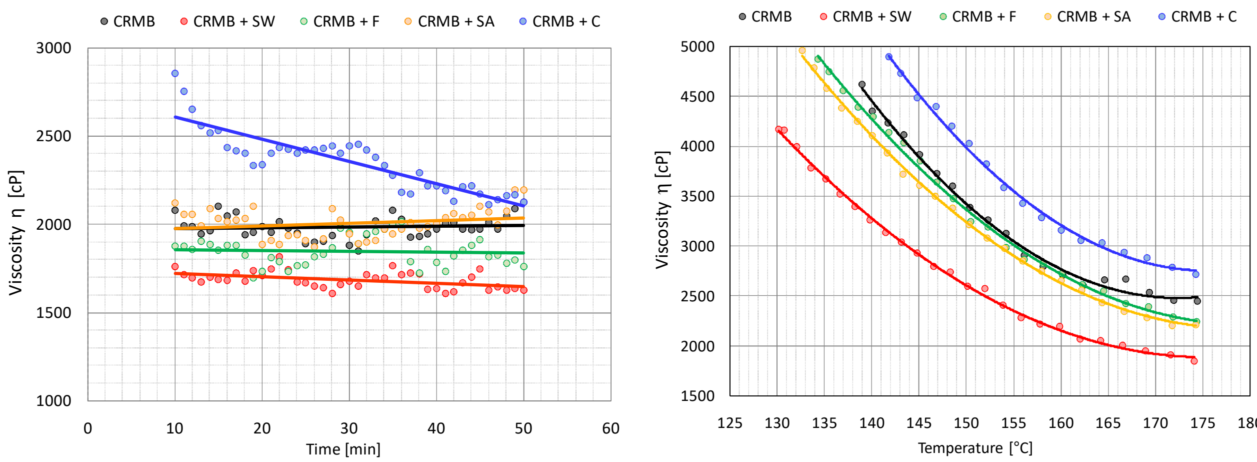

Figure 1: Isotherm viscosity curves at T=175°C and the viscosity curves versus temperature.

The obtained results show appreciable benefits from the use of the wax, where it is possible to obtain, at a temperature of about 150 °C, viscosity values comparable to those obtained on the CRMB at usual mixing temperatures (175 °C); in particular, it can be observed the gain increases as the temperature decreases.

2.1.2 Effects of WMA additives on mixture workability

The results obtained from viscosity measurements show that the synthetic wax is the additive assuring the best performance; it was used in an amount of 3% by weight of the CRMB to determine the optimum range of mixing and compaction temperature for a gap graded asphalt concrete with 8.0 mm maximum aggregate size and with optimum binder content equal to 8%.

The optimum mixing and compaction temperature was determined by comparing the volumetric characteristics at different temperatures (155, 145 and 135 °C) with those determined on the CRMB mixed and compacted at T= 175 °C; this latter is assumed as the control mixture. The volumetric characteristics of the mixes have been carried out on specimens compacted by the Superpave Gyratory Compactor (SGC) at N_{design}=50. The Figure 2shows the volumetric characteristics of the mixes in terms of volume of air voids (AV) and bulk density (G_{mb}).

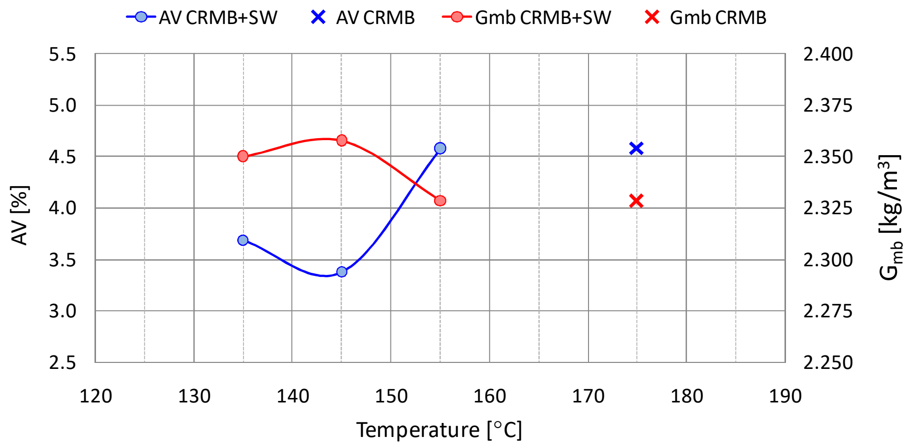

Figure 2: Volumetric characteristics of the mixes.

In order to evaluate the effects produced by the reduction of mixing and compaction temperatures on the mixture workability, the friction resistance should be measured by the Gyratory Pressure Distribution Analyzer (GPDA) during compaction. The GPDA is a device for the measurement of the shear resistance of hot-mix asphalt mixtures. The GPDA can be inserted in SGC to measure the moment applied by SGC loading ram on mixture to keep the tilting angle constant during gyrations. The results from the GPDA give a continuous measure of the resistance of asphalt mixtures to shearing under gyratory loading at a fixed angle. The study [6] has proposed that the bulk shear resistance estimated from the GPDA is a good indicator of the workability of asphalt mixtures. In the study [2] the parameters $N_{92}$and CFI have been proposed to evaluate asphalt mixture workability using volumetric data routinely collected during current mix design and quality control testing. The $N_{92}$is defined as the number of gyrations required to reach 92% G_{mm} corresponding to 8% air voids (G_{mm} is the theoretical maximum density of mixture). The CFI is defined as the Construction Force Index, which is the area under the resistive effort curve from $N_{initial}$ to 92% G_{mm}. A mixture with higher N_{92} and CFI needs higher amount of energy to reach the 92% G_{mm} in construction, instead a mixture with lower N_{92} and CFI is characterized by better performance in terms of volumetric characteristics and workability. The values of these parameters was determined at different temperatures, particularly at 155, 145 and 135 °C for the mixes with CRMB+WMA additive and at 175°C for the mix with CRMB.

The results confirm the better internal structure is obtained by compacting the mix at 145°C which results the optimum compaction temperature to achieve better results in terms of volumetric characteristics and workability (Table 3, Figure 3).

Table 3: Workability parameters

Type of mix	N_{92}	CFI
	n*	kPa·n*
CRMB at T=175°C	40	288.0
CRMB+3% SW at T=155°C	39	307.8
CRMB+3% SW at T=145°C	30	194.2
CRMB+3% SW at T=135°C	31	211.2
* number of gyrations		

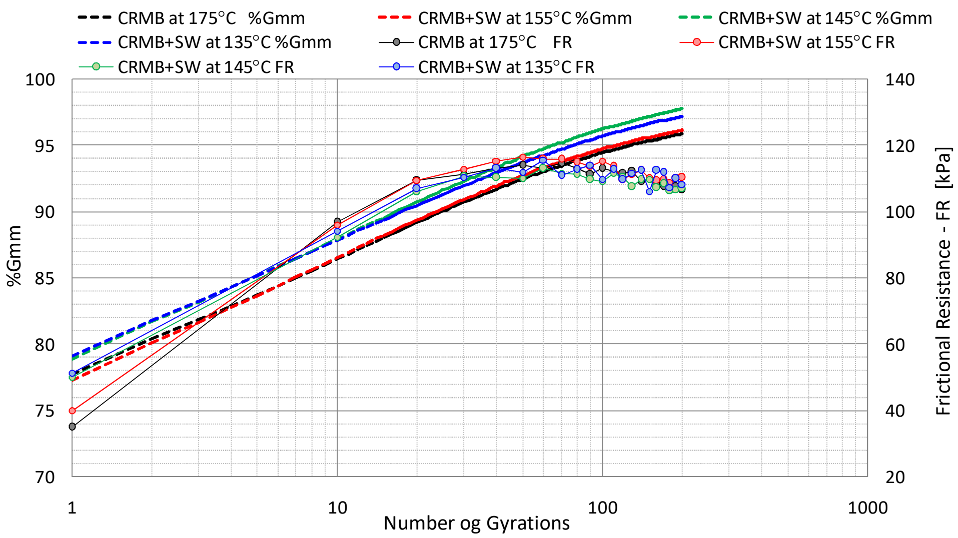

Figure 3: GPDA results.

3. Estimation of the rheological properties of RAP binder

The use of RAP in HMA mixtures has increased in recent years. When the residual service life of asphalt pavements is approaching the end [7], the materials composing the structure still retain considerable value. In addition, the use of RAP in LNP surfaces is not common practice. LNP surfaces are mixture with enhanced surface properties (acoustics and friction performances) [8], superior fatigue and rutting resistance, and considerable durability obtained through a highly stable aggregate skeleton and the selection of appropriate and high quality materials. Due to the high performance levels required and to the premium materials needed for such a mixture, LNP surfaces may be significantly more expensive than conventional HMA. The use of RAP in LNP surfaces would potentially reduce the production costs and make this material environmentally sustainable, when the superior fatigue performance is preserved [9].

In the following sections, a new procedure to estimate the rheological properties of RAP binder and of bituminous blends composed with RAP binder, avoiding the extraction and recovery method is presented [10]. Furthermore, a procedure to determine the maximum amount of RAP that can be added to a LNP mixture without compromising its performance is proposed [11].

3.1 Description of the research approach

The approach used is based on the evaluation of rheological properties of two different mortars composed of fresh binder and RAP material passing 0.15 mm sieve:

- Selected RAP mortar(SRAP), composed by the selected RAP material passing 0.15 mm sieve and fresh binder;
- Burned Selected RAP mortar (BSRAP), composed of the resulting aggregates, after the SRAP was burned in the ignition oven, and the fresh binder.

The proposed research approach is based on a combination of Dynamic Shear Rheometer (DSR) tests on asphalt binders and on asphalt mortars, and on rheological modelling.

3.2 Determination of the rheological properties of the RAP binder

The proposed methodology is summarized in Figure 4. First, SRAP and BSRAP mortars are produced; then, DSR tests are performed on SRAP and BSRAP mortars. Finally, in order to back-calculate the effective complex modulus and the phase angle of the blends of virgin and SRAP binders, a new approach based on the Nielsen model and on the Voigt model for composite materials is used.

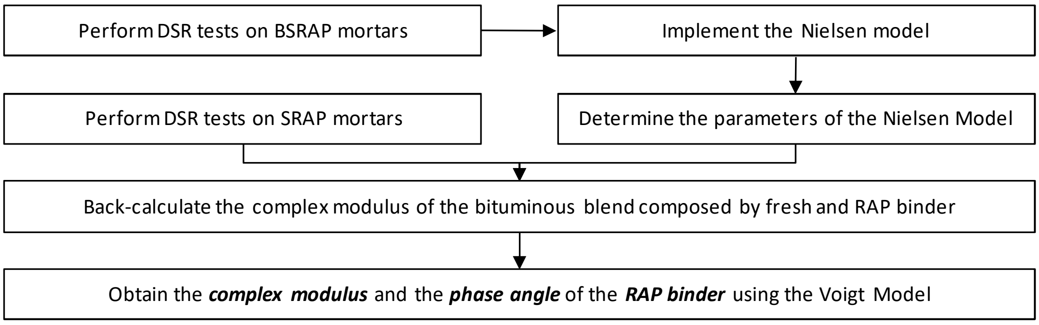

Figure 4: Research approach flow chart.

The original formulation of the Nielsen model, adapted to the specific case of bituminous mortars, is expressed by the equation:

$$\frac{\left|G_m^*\right|}{\left|G_b^*\right|} = \frac{1 + A \cdot B \cdot V_P}{1 - B \cdot \Psi \cdot V_P}. \tag{1}$$

where $\left|G^*_m\right|$ is the norm of the complex modulus of the mortar; $\left|G^*_b\right|$ is the norm of the complex modulus of the binder; V_P is the volume fraction of fine aggregate particles calculated as the ratio of the particle volume over the composite (mortar) volume in percentage; and A, B and ψ are dimensionless model parameters.

The DSR tests performed on the BSRAP mortars are used to determine the parameters of the Nielsen model. The stiffening ratio $\left|G^*_m\right| / \left|G^*_b\right|$ is calculated using the results of DSR tests performed on fresh binder and on BSRAP mortar.

Once the complex modulus of the bitumen compound is estimated, it has been demonstrated that the complex modulus of the RAP binder can be calculated by using the Voigt model:

$$G^*_{RAP\,binder} = \frac{\left(G_b^*\right)_{SRAP} - G_F^* \cdot V_F}{V_{RAP\,binder}}. \tag{2}$$

Where G_F*, $G^*_{RAP\ binder}$ and $(G^*_b)_{SRAP}$ are the complex modulus of the fresh binder, of the RAP binder, and of the blend of the fresh and RAP binder, respectively; and V_F and $V_{RAP\ binder}$ are the percentages of the fresh and of the RAP binder.

According to studies by Christensen [12]12 and Hashin [13], the phase angle of a composite material is theoretically equal to that of the material matrix. Based on this consideration, the phase angle master curve of the SRAP mortar can be used also for estimating the phase angle of a blend of fresh and RAP binder. The phase angle of the artificially RAP binder can then be obtained through this equation:

$$\left(\tan\delta_b\right)_{SRAP} = \frac{V_F \cdot \tan\delta_F + V_{RAPbinder} \cdot \frac{G'_{RAPbinder}}{G'_F} \cdot \tan\delta_{RAPbinder}}{V_F + \frac{G'_{RAPbinder}}{G'_F} \cdot V_{RAPbinder}}. \tag{3}$$

where $(\tan\delta_b)_{SRAP}$, $\tan\delta_F$ and $\tan\delta_{RAPbinder}$ are the loss tangent of the bituminous blends (fresh and RAP binder), of the fresh binder and of the RAP binder, respectively; $G'_{RAPbinder}$ is the real part of the complex modulus of the RAP binder equal to ($G^*_{RAPbinder} \cdot \cos\delta_{RAPbinder}$); and G'_F is the real part of the complex modulus of the fresh binder. In Figure 5 the predicted rheological properties of RAP binder using previous equations are reported versus the measured values.

Complex modulus Phase angle

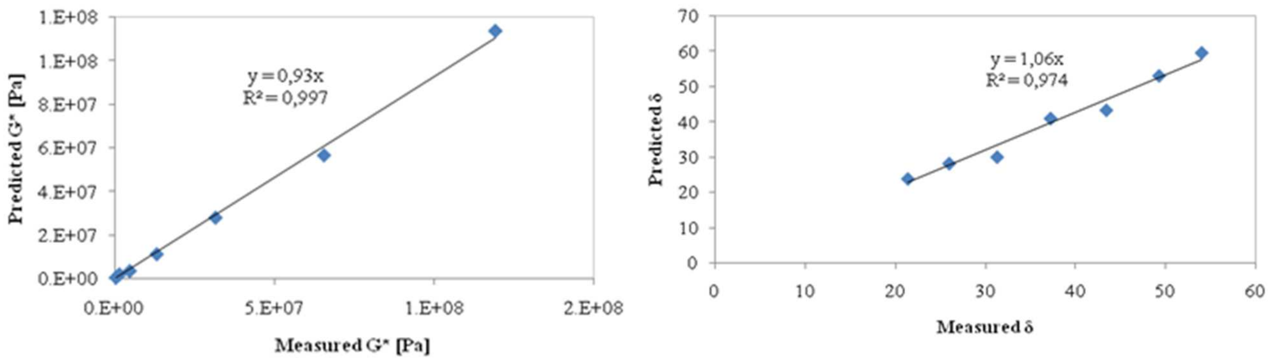

Figure 5: Predicted versus measured rheological properties of RAP binder

3.3 Analytical procedure to determine the maximum amount of RAP

In order to determine the allowable RAP binder which can be included in the design of LNP mixtures while preserving good fatigue properties, the fatigue parameter $|G_b^*|\cdot\sin\delta$ of the bituminous blend of fresh and RAP binder back-calculated from the Nielsen model.

A 50/70 Pen grade binder with good fatigue performance can be used as a reference material and the value of $|G^*|\cdot\sin\delta$ = 2201 kPa, measured at 25°C and at 10 rad/s can be kept as benchmark. Therefore, plotting the parameter $|G_b^*|\cdot\sin\delta$versus different percentage of RAP binder (6%, 16%, 36%) is possible to determine the maximum percentage of RAP that can be added in a LNP mixture. For the specific SRAP material a maximum content of 23.3% of RAP binder was calculated. When considering the entire RAP fractions, this value corresponds to a percentage of 33.5% of RAP that can be added to a LNP mixture with an optimum binder content equal to 7.5%, considering a percentage of RAP binder in the total mixture of 5%.

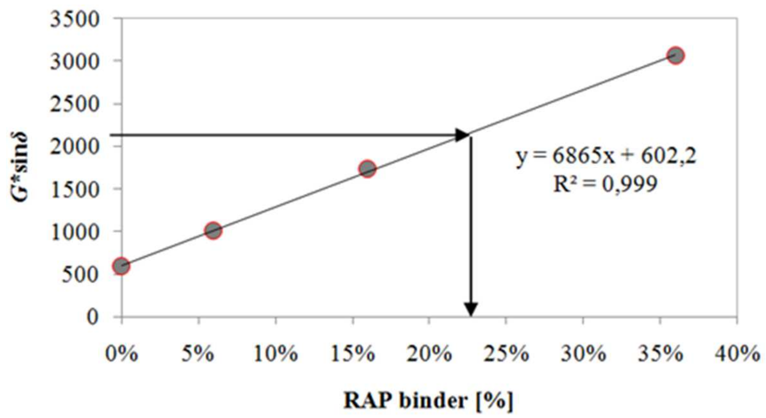

Figure 6: $|G^*|\cdot\sin\delta$ versus RAP binder percentage

4. Conclusions

The aim of this research is to identify the most appropriate WMA additive able to reduce the mixing and compaction temperature of CRMB and to determine the allowable percentage of RAP that can be added to LNP mixtures without compromising the fatigue resistance. The following conclusions can be drawn:

- The addition of 3% of wax produces the greater reduction of viscosity of the CRMB and it assures the workability up to the temperature of 145°C.
- The assessment of volumetric and workability characteristics of the CRMB+WMA additive (3% of synthetic wax), by a SGC equipped with the GPDA, show a significant improvement in workability at T=145°C and at T=135°C; the workability at T=155°C is still comparable with that of the CRMB at T=175°C. In particular, the better workability is obtained at T=145°,

that has been considered the optimum compaction temperature for this mix. This result allows a reduction of 30°C of the mixing and compaction temperatures of CRMB, with a significant benefit in terms of pollution and energy consumption.

- From DSR frequency sweep tests carried out on mortars composed of RAP and fresh binder, the master curves of the complex modulus and of the phase angle of the RAP binder can be back-calculated by using the Modified Nielsen model and the Voigt model, by this way avoiding the extraction and recovery method to characterize the properties of the RAP binder.
- A limiting amount of RAP binder of 23.3%, corresponding to 33.5% of RAP material, was estimated for LNP mixture without compromising the superior fatigue performance when a typical 50/70 pen grade binder is used.

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