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Back-calculation method for determining the maximum RAP content in Stone Matrix Asphalt mixtures with good fatigue performance based on asphalt mortar tests

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ABSTRACT

This paper presents a simple method to determine the amount of Reclaimed Asphalt Pavement (RAP) that can be added to Stone Matrix Asphalt (SMA) mixtures without compromising the fatigue resistance. Dynamic Shear Rheometer tests (DSR) on binder and mortars composed with fine RAP particles, called Selected Recycled Asphalt Pavement (SRAP) are used together with the Nielsen model to back-calculate the norm of the complex modulus of the bituminous blend of fresh and RAP binder. Fatigue properties are derived from parameter $G^{*}\sin\delta$ and Linear Amplitude Sweep tests. The analysis indicates that a limiting SRAP binder content of 23% can be included in SMA mixtures with satisfactory fatigue performance.

1. Introduction

The use of recyclable materials is currently encouraged and commonly accepted in the construction of road infrastructures for technical, economical, and environmental reasons [13,14,39]. Specifically, Reclaimed Asphalt Pavement (RAP) has received significant support and attention both in Europe form road authorities [47] and in US from departments of transportation [24] with the aim of increasing asphalt pavements sustainability by reducing the use of new asphalt binder and virgin aggregates, as well as, by limiting RAP disposal.

RAP binder is an aged and oxidized material; nevertheless, when mixing new and recycled binders the blending occurring between the two materials can significantly decrease the overall aging effects while presenting specific properties to be successfully used in Hot Mix Asphalt (HMA) [44]; for example, the stiffer RAP binder can improve the pavement rutting resistance. On the other hand, the use of RAP may become critical and sometimes detrimental for phenomena such as fatigue and thermal cracking [10,13,9,15].

Currently, higher percentage of RAP (up to 40%) are used in base and binder layers [18], while this material is not always allowed in surface layers or its amount is limited [34,42]. In addition, the use of RAP in specific mixtures such as Stone Matrix Asphalt (SMA) is not common practice [36]. SMA is a gap-graded HMA with enhanced surface properties [32], 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, SMA may be significantly more expensive than conventional HMA. Combining SMA technology with RAP would potentially reduce the production costs and make this material environmentally sustainable, when the superior fatigue performance is preserved [28].

Estimating the effect of RAP on the final material performance requires an accurate evaluation of RAP constituents. Extraction and recovery process is commonly performed to tests and characterize RAP binder [6]; however, this process is not fully accurate. Different research studies [33,13] consistently showed that it alters the binder properties and, in spite of solvent action, a significant amount of RAP binder still remains on the aggregate surface. An additional drawback associated to the extraction process is asphalt binder hardening [11,26]. SHRP research demonstrated that hardening occurs with all commonly used solvents, such as toluene,

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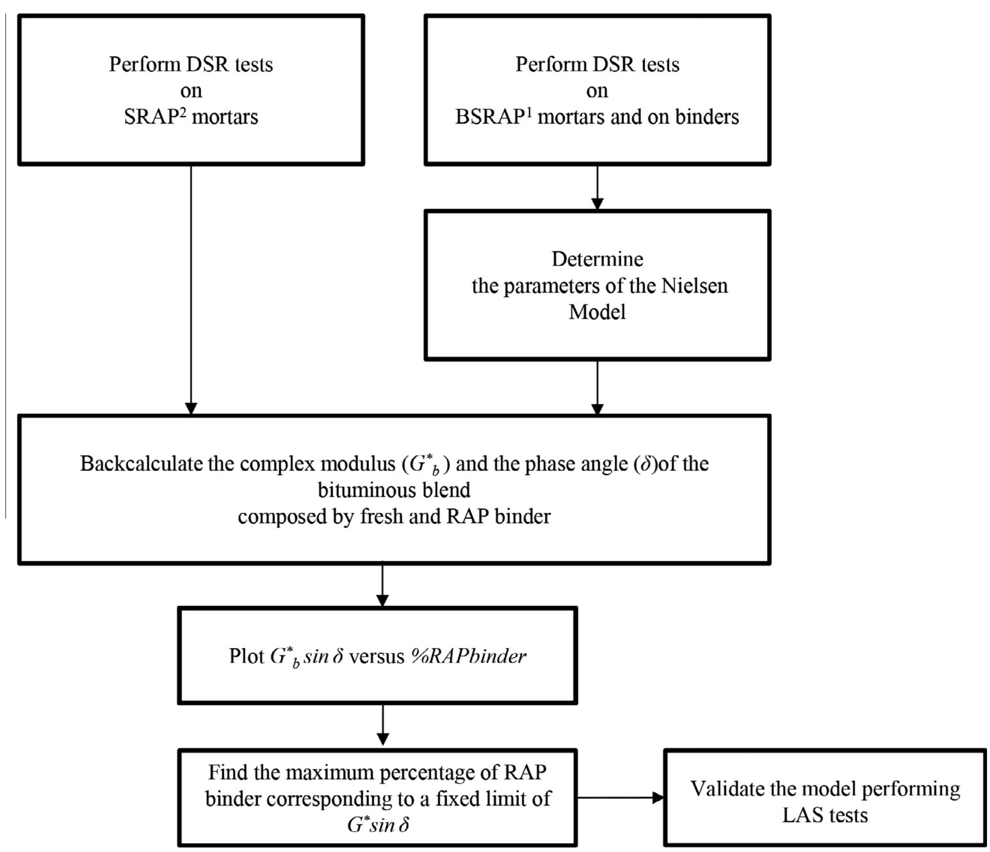
ethanol, n-propyl bromide, trichloroethylene, and that this phenomenon is significant also for lower temperature extraction methods [45]. Further concerns are associated to the presence of residual solvent after recovery and to the aging of binder by the high temperature required during the process. For example, researches indicated that even 0.5% residual solvent could cause a 50% decrease in viscosity [38].

An extensive literature is available on the methodologies for studying the effect of RAP binder as well as the blending process between aged and virgin asphalt binders by using mechanical testing on asphalt mixture and back calculation of binder properties [46,49,12,16]; however, these methods are computationally complex and, sometimes, time demanding. Therefore, an alternative and practical procedure [29,40] for a simple and accurate evaluation of the RAP binder properties at intermediate temperature avoiding the extraction and recovery method is used in the present study. This procedure is based on Dynamic Shear Rheometer tests [8] on asphalt mortars and on the Nielsen model [27].

2. Objective and research approach

The main objective of this study is to identify the maximum percentage of RAP that can be added in a SMA mixture without compromising its good fatigue resistance. The proposed research approach (Fig. 1) is based on a combination of DSR tests [8] on asphalt binders and on asphalt mortars, and on rheological modeling.

First, a selected fine fraction of RAP, obtained from the milling process of a pavement and named SRAP, is prepared by separating the material smaller than 0.150 mm through sieving. Then, SRAP aggregates (Burned Selected Reclaimed Asphalt Pavement – BSRAP) are extracted by ignition and mixed with virgin binder in order to produce BSRAP mortars. DSR tests are performed on BSRAP mortars and on asphalt binders, and the results are used to find the parameters of the Nielsen model [27,40]. This model expresses the stiffening ratio between the mortar and the binder as function of four physical constants: maximum volumetric packing fraction φ, volume fraction of aggregate particles V_p, generalized Einstein coefficient K_E, reduced frequency (see Section 4.1). Then, this model is used to back-calculate the norm of the complex modulus of the blend composed of virgin and RAP binder from DSR test results on SRAP mortars. Finally, based on the back-calculation results and on the Superpave criterion ($G^*\sin\delta$) [1] for a standard modified binder (Styrene-Butadiene-Styrene, SBS, polymer modified binder) used for preparing SMA mixtures, the fatigue resistance is evaluated and, the maximum percentage of RAP binder that can be added without compromising the fatigue resistance is found. The viability of this value is also validated through Linear Amplitude Sweep Tests (LAS) [3].



[1] BSRAP: Burned SRAP consists of the aggregate particles contained in the recycled material and obtained through ignition

[2] SRAP : Selected RAP consists of the aggregate fraction passing the # 100 sieve (0.15 mm)

G^*_b: Complex modulus of binder

Fig. 1. Flow chart of the research approach.