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Evaluation of RAP binder mobilisation and blending efficiency in bituminous mixtures: An approach using ATR-FTIR and artificial aggregate

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HIGHLIGHTS

- Parameters to assess RAP binder mobilisation and blending efficiency using ATR3 FTIR were evaluated.
- Glass beads were used as artificial aggregate.
- The effects of temperature and WMA additives were evaluated.
- Certain additives increased RAP binder mobilisation to comparable levels of HMA mixes prepared at higher temperature.

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ABSTRACT

The undetermined extent of reclaimed asphalt pavement (RAP) binder mobilisation is a major apprehension in the design and construction of bituminous mixtures with RAP. This study proposes a new method to quantify the degree of mobilisation of RAP binder and subsequent blending efficiency of RAP mixtures by utilising attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy as an assessment tool. Binders were recovered from laboratory bituminous mixtures with different percentages of RAP prepared under different mixing conditions using glass-based aggregates as tracers. Parameters for assessing the relevant properties were then developed and validated through the means of dynamic shear rheometer (DSR) and gel permeation chromatography (GPC) tests. Lastly, the study was extended to the use of various warm mix additives (WMA) in RAP mixtures. The results indicated that RAP binder mobilisation is highly dependent on temperature and the usage of WMA additives can enhance the mobilisation at lower mixing temperatures. It was also observed that certain chemical additives increased RAP binder mobilisation and blending efficiency to comparable levels of that in hot mix asphalt (HMA) mixtures.

1. Introduction

The use of reclaimed asphalt pavement (RAP) in pavement mixtures has been widely encouraged around the word due to economic and environmental benefits [1]. Nevertheless, the field implementation of RAP is a challenge for practitioners as the nature of aged binder in RAP introduces several difficulties such as decreased workability of mixtures and increased stiffness of binders. It is now increasingly common that mixtures with RAP are used in combination with warm mix asphalt (WMA) technologies to better address these concerns and help reduce construction temperatures [2,3]. However, one of the main limitations that still lingers in mix design is the limited understanding on the mobilisation of the aged RAP binder and the subsequent blending efficiency of the aged and new binders with or without WMA additives. Quantitative information of mobilised RAP binder is critically important, as the extent of the RAP binder that blends with the new binder can substantially alter the design criteria and overall mixture performance. The initial research on RAP mobilisation assumed that the RAP binder completely mixes with the virgin binder or rejuvenator to form a new mixture with intended properties [1]. Thereafter, the degree of this blending between the binders has been a matter of much deliberation and debate [4,5]. Another effect considered earlier was the "black rock" effect which suggests the likelihood of a binary coat of aged and virgin binder when RAP is used [6]. Due to these uncertainties, many regulatory frameworks specify caution when defining targets for RAP mixing and

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blending [7]. Specifically, the extent of RAP binder mobilisation and blending of RAP mixtures have been studied by many researchers in the past using various rheological and chemical techniques [8–11]. Some rheological approaches involved using models, such as the Hirsch model, to predict the effective dynamic modulus (E^*) of blended binders using the master curves of plant produced mixtures [12,13]. Regarding the chemical methods, gel permeation chromatography (GPC) and Fourier transform infrared (FTIR) spectroscopy have been the main tools used to assess the extent of blending and RAP mobilisation. Several studies have been conducted using GPC which has consistently showed a near linear relationship between the percentage of LMS (large molecular size) and percentage of RAP mobilised [9]. FTIR on the other hand, has been used to a lesser extent but also proven to be effective in determining the blending efficiency of recycled asphalt mixtures [14]. Most of these studies have indicated that full mobilisation and blending of RAP binder is unlikely, although it occurs to a substantial level. For RAP mixtures with WMA additives, it is unclear whether RAP and virgin binders blend completely during WMA production. On one hand, the level of blending and mobilisation occurring during production might be lower due to the reduced production temperature. But on the other hand, the increase in workability brought about by using WMA additives might increase binder mobilisation during mixing, as reported by some previous studies [14,15]. One of these studies, which specifically looked at the effect of WMA using GPC as an analysis tool, showed that WMA additives yielded higher blending ratios as compared to the virgin mixes [15]. But in many of these previous studies, characterizing the extracted binder required the separation of RAP and virgin aggregate. Hence, a gap gradation or certain aggregate type was usually used. This represented the best-case scenario as the gradation of the mixtures might also impact RAP mobilisation. Most significantly, there is no tangible consensus regarding RAP mobilisation and exists an imperative need to validate prior results using various methods under different laboratory conditions. To address this need, this study aims to investigate the effect of temperature and WMA usage on RAP mobilisation and blending efficiency by using attenuated total reflectance FTIR (ATR-FTIR) and artificial aggregates as suitable methods of evaluation.

2. Experimental mix design and materials

The Marshall mix design was used to prepare the mixtures in this study. The virgin binder used was of penetration grade 60/70 (PEN 60/70) which is a common type of bitumen used locally. The specific gradation of the mixture is presented in Table 1. The coarse aggregates (greater than 5 mm) and fine aggregates (smaller than 5 mm) were local granite rocks. The RAP was obtained locally from wearing course milling. The RAP binder was extracted as per AASHTO T164 and analysed through Saturate, Aromatic, Resin and Asphaltene (SARA) fractionation as represented in Table 2. The SARA fractionation was conducted as per ASTM D2007. The softening point and penetration tests were conducted as per ASTM D5 and ASTM D36, and the obtained values are presented in Table 3. A mechanical mixer was used to mix all the samples for a period of 2 min to reduce variability and discrepancies between samples with regards to preparation [16]. As RAP contains aged binder, the mixtures prepared in this study were designed with consideration of the total contribution of the recycled binder. The binder content of the RAP was determined as per AASHTO T308 and found to be to 5%. For all the mixtures with 0%, 15%, 30% and 50% RAP materials, a total binder content of 5% was chosen.

Table 1
Mixture Composition.

Sieve Size (mm)	Mixture Gradation	RAP gradation
	Pass ratio (%)	
14	100	100
10	85.0	94.1
5	58.0	87.8
2.36	38.0	70.0
1.18	26.0	50.2
0.6	17.9	32.7
0.3	11.0	19.2
0.15	3.4	9.7
0.075	3.0	3.4

Table 2
SARA Fraction of RAP.

RAP	Composition %
Asphaltene	15.80
Saturate	24.23
Aromatics	19.53
Resin	40.45

Four different types of commercially available WMA additives were chosen in this study including wax based, foaming and chemical additives. The details of the additives used are presented in Table 4 and Fig. 1.

As the primary objective of this study is to examine the amount of RAP binder mobilisation, the blend of mobilised RAP binder and virgin binder coating the fresh aggregates is of specific interest. In a real blending scenario, it is visually impossible to distinguish between RAP aggregate and virgin aggregates after mixing. Thus, in this study artificial aggregates in the form of borosilicate glass beads were employed. Beads of diameter 12 mm, 10 mm and 7.5 mm were used to make up approximately a 2% fraction of the overall gradation of the mixes by weight by adjusting the original fresh aggregates. Such a small fraction was chosen so that the effect of the glass beads in the mixing process and aggregate interaction would be negligible. The chemical composition and the proportion of glass beads used are shown in Table 5 and Table 6, respectively. Fig. 2 shows illustrative images of the glass beads and glass beads dry blended with RAP. Prior studies have successfully used similar types of glass beads to characterise the mobilisation of RAP binder to virgin aggregates [17]. The consistent dimensions of glass beads make them useful for such studies. However, it does have the drawback of its relatively smooth surface as compared to the naturally rough surface of normal aggregates. To minimise this, the glass beads were initially blended with fresh aggregates to roughen the surface.

3. ATR-FTIR to evaluate RAP mobilisation and blending

Previously, chemical methods such as GPC and FTIR have been used to characterise oxidative ageing and its significance on the chemical composition of bituminous binders. FTIR is particularly interesting for researchers and engineers because of its repeatability, practicality, and the fact that it does not require a large or controlled lab space in comparison to GPC. There is a prospect that with advancing FTIR research, parameters for mix design and optimisation could be derived from FTIR results of bituminous binders. Attenuated total reflectance (ATR) is generally the preferred FTIR testing mode for binder characterisation as it offers faster sample

Table 3
Softening Point and Penetration of RAP.

Softening Point (°C)	Penetration (0.1 mm)
75.5	29