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Laboratory evaluation of Rediset modified bitumen based on rheology and adhesion properties

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HIGHLIGHTS

- Rediset reduces the surface energy of bitumen.
- Rediset increases the complex modulus and decreases the phase angle of the binder at high in-service temperatures.
- Rediset reduces the viscosity of bitumen which in turn decreases the mixing and compacting temperature.
- Rediset could improve the bonding strength between bitumen and aggregate in a limited value.

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ABSTRACT

Warm mix asphalt (WMA) could significantly reduce the production temperature of asphalt mixtures. Lower production temperature meaning reduced fossil fuel consumption and greenhouse gas emission which in turn avoid environmental pollution in the road construction process. This study aims to characterise the properties of bitumen with the addition of a type of WMA additive – Rediset. The influence of Rediset on bitumen surface energy was evaluated by using the Dynamic Contact Angle (DCA) test. Complex modulus and phase angle of bitumen were evaluated through frequency sweep test using Dynamic Shear Rheometer (DSR). The high-temperature viscosity of bitumen was measured using a corn and plate system which installed in the DSR equipment. Finally, the Pneumatic Adhesion Tensile Testing Instrument (PATTI) test was performed to measure the tensile strength and moisture susceptibility of aggregate-bitumen combinations. The results show that the Rediset reduces the surface energy of bitumen. Moreover, as seen in the DSR test, the complex modulus increased while the phase angle decreased at the low frequency range due to the addition of Rediset. The decreased bitumen viscosity because of the addition of Rediset demonstrating reduced mixing and compaction temperature of asphalt mixture. In addition, the addition of Rediset could improve the bonding strength of aggregate-bitumen combinations at medium and high service temperatures but has no influence at low temperature. Furthermore, the Rediset is able to increase the retained tensile strength which in turn reduces the moisture susceptibility of asphalt mixture.

1. Introduction

Asphalt mixture, as a widely used material, consists of aggregates and bitumen heated to high temperatures and mixed together followed by compaction to form asphalt pavement [1,2]. Due to growing concerns over global warming and air pollution, the area of pavement engineering has been steadily evolving over the last two decades [3]. Persistent efforts have been made by asphalt pavement researchers with aims of reducing the fossil fuel consumption and promoting sustainable development [4,5,6]. In this context, the WMA technology was developed and successfully applied by several countries due to its reduced energy consumption and pollution [7,8]. In general, the WMA is able to reduce mixing and compaction temperatures by 20–40 °C, but without significantly affecting the road performance [9,10].

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The use of a WMA technique offers many benefits to asphalt industries. Lower mixing temperature means fuel cost savings to the contractor [11]. Also, the emission of carbon dioxide (CO_2) and other greenhouse gases are reduced in comparison with hot mix asphalt (HMA) [8,12]. In addition, lower compaction temperature demonstrates increased haul distances and cold weather paving benefits [13]. Currently, WMA can be prepared by the addition of organic additives and chemical additives or through the foaming generation process with the view of improving the workability of mixtures at reduced temperature [12,14]. The organic additives could reduce the production temperatures by decreasing the viscosity of bituminous binders, while the chemical additives decrease the frictional forces at the aggregate-bitumen interface at high temperature range so as to reduce the production temperature [15,16,17]. The foaming technologies are based on the principle to expand the volume of bitumen by injecting water during the mixing process to make sure the mixture can be mixed and compacted at lower temperatures [18].

The focus of this paper is on the WMA additive – Rediset. Rediset is a multifunctional WMA additive which consists of surface active agents and anti-stripping agents. The addition of Rediset can improve the wettability of bituminous binders by reducing the surface energy at temperatures below its typical mixing temperature [19,20]. At the same time, the anti-stripping agents can encourage the aggregate-bitumen adhesion so as to improve the bitumen resistance to displacement by water. Its melting range is between 80 °C and 90 °C. The melting temperature is high enough to make Rediset maintains its solid mode at pavement service temperatures to produce stiffening effect. At temperatures above its melting point, Rediset decreases the surface tension of bitumen, reduces the interfacial friction between bitumen and aggregate and improve the wettability of aggregate by bitumen [21].

In this study, a type of solid Rediset pellet was blended with base bitumen with the view to understand the contribution of Rediset to related bitumen properties. As the Rediset containing surface active agent, the influence of Rediset on bitumen surface energy was obtained by using the DCA test. The visco-elastic behaviour of bitumen (including complex modulus and phase angle) from low to high service temperatures was evaluated through frequency sweep test using DSR. In addition, the high-temperature viscosities of bitumen were measured using a developed corn and plate system which installed in the DSR equipment. Furthermore, the PATTI test was used to measure the strength of aggregate-bitumen bond at different temperatures. Finally, the moisture resistance of different aggregate-bitumen bonds were evaluated through the PATTI test. The retained tensile strength, which is the ratio of wet bonding strength to the dry bonding strength, were used to assess the moisture susceptibility.

2. Materials

2.1. Bitumen

The bitumen used in this research was a 40/60 penetration grade base bitumen with the detailed parameters showing in Table 1.

Table 1
Empirically properties of 40/60 pen bitumen.

Property	Values
Penetration at 25 °C (0.1 mm)	42
Softening point (°C)	51.2
Density at 25 °C (kg/m^3)	1035
Flash point (°C)	230
Solution in Xylene (%)	99

Table 2
Physical properties of Rediset.

Property	Result
Appearance at 25 °C	Brown pastilles
Melting range (°C)	80–90
Bulk density (g/cm^3)	0.55
Flash point (°C)	>150

2.2. WMA additive – Rediset

In this study, a type of WMA agent named Rediset was used as the WMA additive. Rediset is a composite material which contains both surface active agents and organic additives. The surface active agents could improve the wetting of aggregate by bitumen by reducing the surface energy of bituminous binders and reduce the interfacial frictions between bitumen and aggregate. The Rediset also contains anti-stripping agent which promotes the adhesion between aggregate and bitumen which in turn improves the moisture resistance of asphalt mixtures. Table 2 shows the basic properties of Rediset.

2.3. Aggregates

In this paper, two types of aggregates named limestone and granite were used to investigate the influence of Rediset on the moisture susceptibility of aggregate-bitumen combinations. As from different quarries, these two aggregates must have different mineral compositions and surface properties and these differences must influence the bonding strength between aggregate and bitumen. So, the mineral properties of aggregates which including mineral composition, surface texture and grain size were analysed by using a mineral liberation analyser (MLA). In this research, an FEI Quanta 600 SEM was used to evaluate the mineral properties of aggregates with the detailed testing procedures could be seen elsewhere [1].

The MLA scans with the summaries of mineral compositions, as determined by MLA, are provided in Fig. 1. The results show that these two aggregates have significantly different mineral composition with the predominant phase of limestone is calcite (99.33% by weight). In terms of the granite, it is made up of several different minerals with the predominant phase being albite (73.17% by weight), followed by significant quantities of chlorite and anorthite with the content of 15.58% and 10.75%, respectively.

3. Experimental procedures

3.1. WMA binder preparation

Before evaluating the influence of Rediset on bitumen properties, it is of importance to prepare well blended WMA binders. In this study, a high speed shear mixer was used to prepare the WMA binders, as shown in Fig. 2. The detailed procedures for sample preparation are given as follows [23]:

- Heat the base bitumen to 130 °C until it has melted;
- The WMA Rediset was added with the weight percentage of 1%, 2% and 3%, respectively;
- The bitumen container was placed into an oven at a temperature of 130 °C for 10 min;
- High speed mixer was applied at the speed of 2500 rpm for 10 min to decrease the particle size of Rediset and achieve a good homogeneity.
- The well blended binders are named Rediset modified binders and stored for further tests.

3.2. Surface energy of bitumen

A Cahn Model DCA analyser, as shown in Fig. 3, was used to measure the contact angles of probe liquids on bitumen surface and the results were then used to calculate the surface energy of bitumen. Because there are three unknown surface energy parameters for bitumen, this study selected three probe liquids included water, glycerol and di-iodomethane with their surface energy components showing in Table 3 [22].

In this test, the microbalance measured and recorded the weight of the slide during the advancing and receding process.