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Viscosity criteria and methodology for estimating the optimum compaction temperatures of polymer modified asphalt binders in hot mix asphalt design

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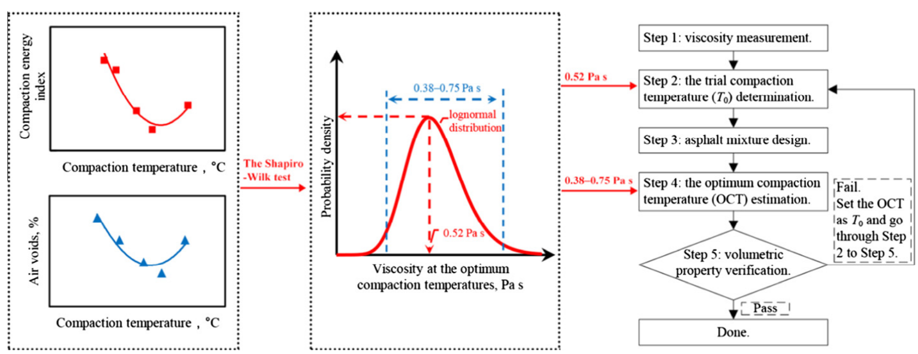
HIGHLIGHTS

- Viscosity values at the OCTs came from a lognormal distribution.
- A mode of 0.52 Pa s was suggested to determine a trial temperature for HMA design.
- A range of 0.38–0.75 Pa s was suggested as the criterion for estimating the OCTs.
- The quadratic fit method provided a rational means to estimate the OCTs.
- The CEI increased 7.7% on average at the temperatures of 10 °C off the OCTs.

GRAPHICAL ABSTRACT



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ABSTRACT

The viscosity criteria and methodology to estimate the optimum compaction temperatures (OCTs) of polymer modified asphalt binders were studied by statistical analysis. Results showed that the viscosity corresponding to the OCTs came from a lognormal distribution. A mode of 0.52 Pa s and a range of 0.38–0.75 Pa s were suggested as the viscosity criteria. A quadratic fit method was proposed, which provided a rational means to estimate the OCTs. Comparing to the compaction temperatures of 10 °C off the OCTs, compaction energy can be reduced by 7.7% on average by compacting the asphalt mixtures at the OCTs.

1. Introduction

A change in compaction temperatures is one of the most significant influence factors on particle mobility and pavement performance in hot mix asphalt [1–6]. During compaction, there is an OCT at which the viscosity of mastic is low enough for lubrication, but high enough to provide sufficient film thickness at aggregate contacts and prevent mixture locking at the early stages of compaction [1]. In this paper, the OCT of an asphalt mixture is defined

Abbreviations: AV, air voids; HMA, hot mix asphalt; OGFC, open-graded friction courses; PMAB, polymer modified asphalt binder; CEI, compaction energy index; OCT, optimum compaction temperature; PG, performance grade; SMA, stone matrix asphalt.

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as the temperature at which the minimum friction at aggregate contacts is achieved during compaction. At the OCTs, compaction energy tends to the minimum and the asphalt mixture specimen density tends to the maximum due to sufficient lubrication. Nevertheless, rutting resistance of an asphalt mixture specimen compacted at the OCTs tends to its best due to the maximum aggregate contact number in skeleton [1,7].

For neat asphalt binders, the viscosity criteria of 0.28 ± 0.03 Pa s are recommended for estimating the OCTs in hot mix asphalt design, at which the maximum density is achieved during compaction [8,9]. For PMABs, the estimation of the OCTs shows more complexity, as most of PMABs exhibit shear thinning non-Newtonian behavior at their compaction temperatures, whose viscosity decreases with an increase in shear rates [10,11], both shear rates and viscosity criteria should be included for optimizing the compaction temperatures of PMABs. According to Bahia's research, a zero shear viscosity of 6.0 Pa s was suggested as the criterion for optimizing the compaction temperatures of PMABs [12]. Li recommended a shear rate of 60 s^{-1} and a criterion of 0.28 Pa s for estimating the OCTs [13]. Yildirim recommended a shear rate of 500 s^{-1} and a criterion of 0.55 Pa s for estimating the OCTs [14,15]. According to Reinke's research, viscosity approaches a steady state at the shear stresses around 500 Pa. The compaction temperatures corresponding to the steady state viscosity of 0.35 ± 0.03 Pa s match well to the compaction temperature ranges successfully used in practice [16].

Although the OCT of an asphalt mixture should be unique, at least four compaction temperatures can be obtained according to these criteria. A possible explanation for this phenomenon is that the viscosity values corresponding to the OCTs of PMABs vary in a wide range. The difference in binder sample selection for each specific research results in several different viscosity criteria for optimizing the compaction temperatures of PMABs. If this assumption is established, how to determine the viscosity criteria becomes the focus for estimating the OCTs of PMABs. Also, the wide viscosity criteria broaden the temperature range within which the OCTs locate. How to estimate the OCTs according to the wide viscosity criteria becomes another challenge for estimating the OCTs of PMABs in hot mix asphalt design.

2. Objectives

The main objective of this research is to establish the viscosity criteria and corresponding method for estimating the OCTs of PMABs in hot mix asphalt design.

3. Experimental

3.1. Materials

3.1.1. Asphalt binders

In this study, eight PMABs including four SBS modified asphalt binders, one rubber modified asphalt binder, one high viscosity modified asphalt binder and two commercial modified asphalt binders were studied.

A shear rate of 25 s^{-1} was selected for viscosity measurement, as in the shear rate measuring range of commonly used Brookfield viscometers (0.279–25 s^{-1}) the viscosity values at 25 s^{-1} exhibited the best correlation with the CEI at the OCTs according to the results of the authors [17]. Viscosity was measured at 135, 160 and 185 °C. The viscosity value at a specific temperature was estimated according to the viscosity versus temperature relationship shown in Eq. (1) [18]. The performance grades of asphalt binders and the parameters of the viscosity-temperature relationships including the R square (R^2) are shown in Table 1.

$$\log_{10}(\log_{10}(\eta_{25})) = b_1 - k_1 \times \log_{10}(273.15 + T) \quad (1)$$

where

T = temperature, °C;
η_{25} = viscosity value at 25 s^{-1}, mPa s;
b_1, k_1 = regression coefficient.

3.1.2. Asphalt mixtures

Asphalt mixtures including Superpave, SMA and OGFC with the nominal maximum aggregate sizes of 12.5 and 19.0 mm were prepared. The gradations, asphalt content and air voids are shown in Table 2.

3.2. Optimum compaction temperatures

3.2.1. Compaction energy index

The change in contact friction results in the change in compaction effort. The authors assumed that the typical paver compaction effort is represented by a constant applied energy equivalent to initial number of gyrations (N_1). Asphalt mixtures are compacted to a required density at the end of rolling with a gyration number of N_2. The energy expended in compacting the mix from its initial density behind the paver to the required density at the end of rolling is estimated by the area under the compaction curve between N_1 and N_2 shown in Fig. 1, which is defined as compaction energy index (CEI) [19]. The CEI value is calculated using Eq. (2).

$$\mathrm{CEI} = \int_{N_1}^{N_2} f(N) - (N_2 - N_1) \times f(N_1) \quad (2)$$

where

N_1 = initial number of gyrations;
N_2 = gyration number corresponding to the desired density at the end of rolling;
$f(N_1)$ = percentage of theoretical maximum specific gravity (G_{mm}) at N_1,%;
$f(N_2)$ = the desired percentage of G_{mm} at the end of rolling, %.

For Superpave and SMA mixtures, the pavement is compacted to 92.0% of the theoretical maximum specific gravity (G_{mm}) for

Table 1
Performance grades and parameters of the viscosity-temperature relationships.

No.	Binder type	PG	b_1	k_1	R^2
B1	SBS modified binder	70–22	8.139	2.938	1.000
B2	SBS modified binder	70–22	7.815	2.816	1.000
B3	SBS modified binder	70–22	7.291	2.607	0.976
B4	SBS modified binder	76–16	7.518	2.688	1.000
B5	Rubber modified binder	76–16	6.469	2.276	0.997
B6	High viscosity modified binder	88–16	7.904	2.807	0.986
B7	Commercial modified binder	76–22	9.349	3.367	0.994
B8	Commercial modified binder	82–22	6.887	2.441	0.999