Comparison of binder and mixture aging characteristics in binders from different sources

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ABSTRACT: Laboratory simulation of RAP is essential to minimise the variability in the characterization of RAP. Different binder/ mixture aging procedures are available to age bituminous binder/ mixture in the laboratory. The mixture aging is more representative of the field conditions but involves considerable variability associated with the aging, extraction, and recovery processes. On the other hand, binder aging is more repeatable but does not capture the thin film aging observed in mixtures. The aging behaviour is thus different in a binder and mixture aging. Scarcely has any study quantified the magnitude of variability associated with such aging and ascertained the influence of parameters such as the type of base binder and the aging temperature. In this study, bituminous binder and mixtures prepared with two types of base binders were aged in a forced draft oven at two temperatures, namely, 100 and 120°C. The binder extracted from the aged mixture and the binders aged in the oven were compared through their rheological properties. It was observed that the mixture aging exhibited much higher stiffness compared to the binder aging. Also, the properties of the base binder, especially the history associated with the production process, were seen to influence the rate of aging. This was verified through the master curve generated for these binders.

1 INTRODUCTION

The use of Reclaimed Asphalt Pavement (RAP) in a new pavement construction is considered a sustainable measure as it utilizes valuable materials such as binder and aggregates. To utilise RAP in a fresh mix, quantification of the properties of the RAP binder is essential. The RAP available from field possesses considerable variability in terms of binder content and the rheological properties of the binder among many other properties. To minimise the influence of these variables during characterisation of RAP material, it is advantageous to simulate RAP mixes in the laboratory. Currently, there is no specific procedure available to simulate RAP mixes in the laboratory. The standard binder and mixture aging procedures available to simulate long term aging are used to obtain aged binder or mixture.

The long-term aging in the binder is simulated using a Pressure Aging Vessel (PAV) (ASTM D6521-19) and for the mixture, it is aged in oven as per the procedure specified in AASHTO R 30 (2012). Also, different oven aging procedures have been used to simulate long-term aging in binders (Bonaquist et al., 2021; Behera et al., 2013) and mixtures (Steiner et al., 2020; Elwardany et al., 2017; Paul et al., 2017). For mixture aging also, the mix is aged in the form of a loose mixture or a compacted sample.

The mixture aging is considered to represent the aging behavior in field wherein the binder is in the form of a thin film coating the aggregates (Sirin et al., 2018). The degree of binder coating on the aggregates depends on the mix properties, especially the aggregate size (Hamzah et al., 2015). The major limitation with respect to mixture aging is the considerable variability associated with the binder coating influenced by the aggregate gradation, the binder extraction and recovery processes. On the other hand, the binder is aged in an oven in trays of specified thickness varying from 650 µm to 3 mm (Behera et al., 2013). The binder aging is said to possess much better repeatability when compared to mixture aging. However, the thickness of the binder film and the interaction with aggregate during aging may not be present here. Thus, the aging behavior of a binder in oven and the binder coating the aggregates in the mixture are completely different.

The aging behavior also significantly depend on the characteristics of the base binder. Generally, the characteristics of the base binder vary depends upon the crude source and processing methodology. Two production processes are commonly adopted in India for bitumen production. One is component blending, wherein the vacuum residue from the refinery is mixed with propane in a deasphalting unit to separate the deasphalted oil and the asphaltene rich pitch called as Propane Deasphalted Pitch (PDA pitch). The PDA pitch is further blended with heavy oil to comply with the specification requirement (Nivitha et al. 2019). The other is the air rectification process, wherein the binder is subjected to a continuous air supply at elevated temperatures. Hence a certain degree of aging is expected to occur in these binders during the production process itself and this is expected to reduce the susceptibility of the binder to subsequent aging. The degree of difference in aging between these two types of binders should be quantified. Many studies have shown that binders falling under the same grade will exhibit different aging characteristics depending on the crude source and processing methodology (Nivitha et al., 2019). Understanding the sensitivity of base binder on the aging characteristics of binders and mixtures is necessary as this will highlight the influence of production process of base binder in the simulation of RAP binders/ mixtures. The type of base binder and its properties also influence the interaction of the aggregate with the binder. The influence of such interactions will however be captured only when the binder is aged in the mixture form.

Many studies have analysed binder and mixture aging individually but scarcely any study has compared and quantified the same for different types of base binders and aging temperatures. The objective of this paper is to obtain the RAP binder through simulation of binder and mixture aging in the laboratory forced draft oven. The simulation is carried out through binder aging and binder extracted from mixture aging. The binders will be extracted from RAP mixtures and compared with that of RAP binders obtained from binder aging. RAP binder and mixture aging is carried out in the laboratory for two different types of base binders and aging temperatures. The influence of base binder, aging temperature and binder/mixture aging will be quantified through this exercise.

2 METHODOLOGY

Two binders were selected in this study. One binder was produced by air rectification method and procured from Visakhapatnam refinery (VR). The other binder was produced by component blending method and procured from Mumbai refinery (MR). The properties of base binder are shown in Table 1. Since, the base binders are of different properties the bituminous mix prepared with same aggregate can age differently. The aggregates used for preparation of the bituminous mix was obtained from a single source and corresponded to Bituminous Concrete (BC) grade II specification (MoRTH, 2015). The bituminous mix was prepared by heating the aggregates and binder at 165°C. The two base binders (MR & VR) and the corresponding mixtures were aged at 120 & 100°C in force draft oven by varying the aging durations as 2, 4 & 10 days. The test matrix is shown in Table 2. The binders were aged in a tray with 3 mm film thickness and the mixture was aged in loose state. The thickness of the mixture was kept as 3 cm.

The binder was extracted from aged mixture using centrifuge extractor (ASTM D2172-17) and recovered using rotary evaporator (ASTM D5404-21). The recovered binder was placed in oven for 24 hours to remove the residual solvent.

Table 1 Properties as per IS 73:2018

Characteristics	Result	
	VR	MR
Penetration at 25 °C, 100 g, 5 s, 0.1 mm, Min	56	38
Absolute viscosity at 60°C, Poises	2485	3898
Kinematic viscosity at 135°C, Min, cSt	541	589
Softening point (R&B), Min, °C	50	52
Test on residue from rolling thin film oven test		
Viscosity ratio at 60°C	2.2	
Ductility at 25°C, Min, cm	100+	

Table 2 Test Matrix

Aging		Binder	Aging	
Condition	Method		Temperature (°C)	Duration (Days)
Mixture (Loose state)	Oven (3 cm thich)	MR	100	2, 4 & 10
			120	2, 4 & 10
		VR	100	2, 4 & 10
			120	2, 4 & 10
Binder	Oven (3 mm thick film)	MR	100	2, 4 & 10
			120	2, 4 & 10
		VR	100	2, 4 & 10
			120	2, 4 & 10

Frequency sweep test was performed using Dynamic Shear Rheometer (ASTM D7175-15) on the recovered binders from aged mix and aged binders for test temperatures in the range of 40 to 82°C in increments of 6°C and frequency range of 0.1 to 50 Hz at the rate of 0.1 Hz per second. The dynamic modulus for extracted/aged binders were compared to analyse the effect of base binder on the rheological response of laboratory simulated RAP binder/mixture.

3 RESULTS AND DISCUSSION

The frequency sweep test results at 64°C for VR and MR binders at different aging durations are shown in Figure 1. These binders were aged at 120°C. While the stiffness of the binders increased with aging duration successively from unaged to 10-day aged condition for both the binders, the degree of aging was seen to depend on the type of base binder. It was seen that the MR binder was stiffer than the VR

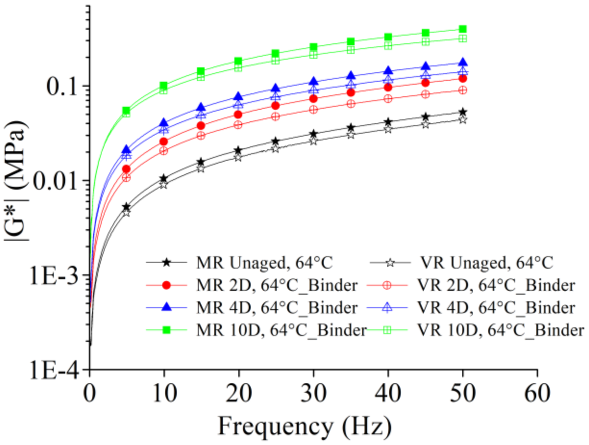

Figure 1. Dynamic modulus of binders aged at 120°C and tested at 64°C

binder in unaged condition and at all aging conditions as shown in Figure 1. A similar behavior was observed for the binder aging simulated at 100°C also (not shown here).

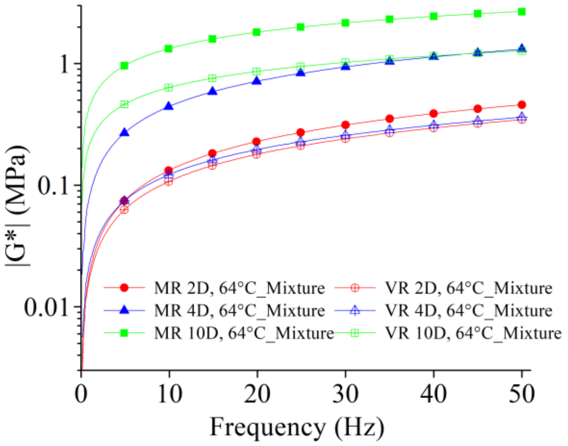

Figure 2. Dynamic modulus of binder extracted from aged mixture at test temperature 64°C

Figure 2 shows the results of the binder extracted from mixture aged at 120°C. For the extracted binders also, the MR binder was observed to be stiffer compared to VR binder at all aging conditions. The corresponding phase angle plot is shown in Figure 3. It can be seen that the phase angle plot clearly distinguishes the effect of aging. If the magnitude of dynamic modulus from binder and mixture aging are compared from Figures 1 and 2, it could be seen that the dynamic modulus of binder extracted from the mixture is higher when compared to the binder almost by a decade. This could be attributed to the thin film coating the aggregates in the case of mixture aging when compared to the binders aged in thickness of 3 mm.

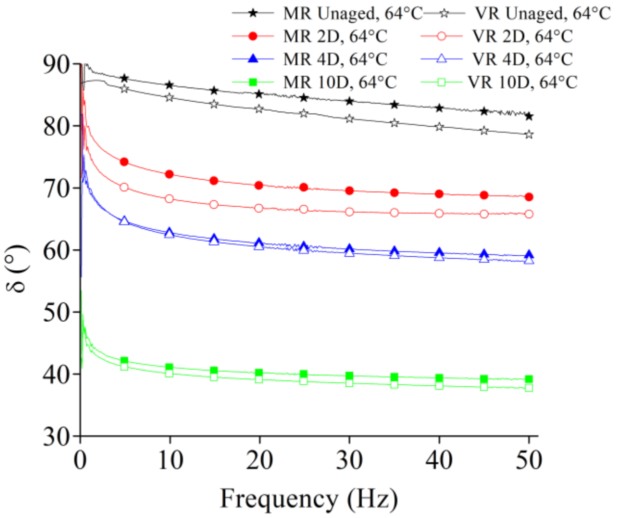

Figure 3. Phase angle of binder extracted from aged mixture at test temperature 64°C

In order to correlate the rate of aging among mixture/binder, VR/MR and 120/100°C, the dynamic modulus for all combinations at 10 Hz frequency is compared as shown in Figure 4. It can be seen that the rate of aging is higher for 120°C in comparison to 100°C, for MR binder compared to VR binder and for extracted binder when compared to aged binder.

The rate of aging was quantified through the slope of dynamic modulus vs. aging duration plot calculated for all these cases. The highest rate of aging (slope = 0.1856) was observed in the case of extracted MR binder aged at 120°C and the slowest rate of aging was observed in the case of VR binder aged at 100°C (slope = 0.0523). The higher rate of aging for MR binders can be attributed to two reasons: one is the initial higher stiffness of the MR binder when compared to VR binder as shown in Table 1. The other is the production process used to obtain these binders as discussed earlier. The VR binder with prior exposure to oxygen during the continuous air blowing processes exhibits relatively lower rate of aging when compared to the MR binder, especially when aged as a mixture.

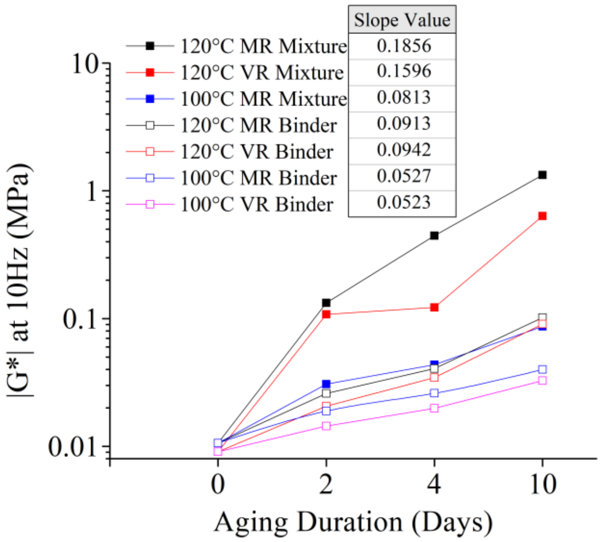

Figure 4. Rate of aging for MR & VR binder in mixture & binder aging conditions at test temperature 64°C

Dynamic modulus master curves are constructed at a reference temperature of 50°C. Figure 5 shows the master curve of frequency sweep test results of aged binder and binder extracted from the aged mixture of MR binder and VR binders respectively. The difference between the binder and mixture aging can be clearly distinguished from these plots. For both VR and MR binders, it was observed that the stiffness was higher for mixture aging when compared to binder aging.

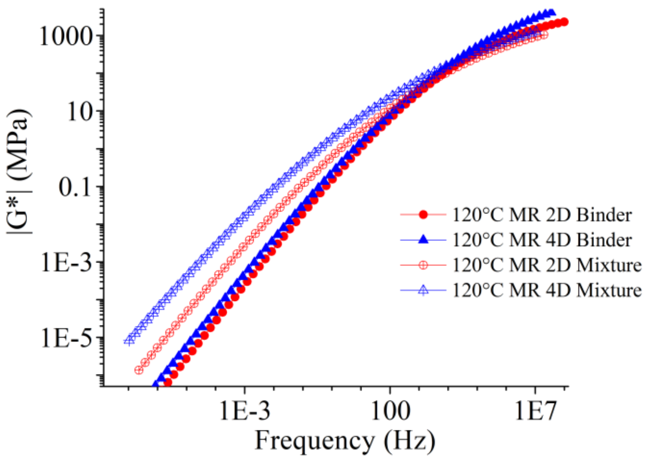

Figure 5. Master curve for MR binder in different aging durations

4 CONCLUSION

Identification of a suitable laboratory aging procedure is necessary to simulate RAP mixes in the laboratory. Such simulation can be carried out on aged binders or binders extracted from aged mixtures in the laboratory. While each of them have their own advantages and limitations, the aging behavior associated with both the aging procedures are completely different. The extent of variability in the rheological properties of the binder observed in the two types of aging has been scarcely compared and quantified. In this study, the aging behavior of binder and mixture aging were compared for two different types of base binders, VR and MR aged at two temperatures, 120 and 100°C. It was observed that the mixture aging exhibited substantial increase in stiffness when compared to the binder aging. This was also verified through the master curve constructed for these binders. Also, the rate of aging was observed to be different between the two binders. The MR binder due to the history associated with the production process, exhibited higher rate of aging when compared to the VR binder.

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