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Study of the thermal stress development of asphalt mixtures using the Asphalt Concrete Cracking Device (ACCD)

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HIGHLIGHTS

- Binder grade and type of modification showed notable effects on thermal stresses.
- The addition of RAP and RAS resulted in an increase in thermal stress development.
- Increase in air void content resulted in a reduction in thermal stresses.
- Increase in the CTE of aggregates and mixtures resulted in higher thermal stresses.
- Increasing the binder content increased the magnitude of thermal stresses.

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ABSTRACT

Asphalt pavements exposed to colder temperatures may crack when higher thermal stresses are induced in them. The Asphalt Concrete Cracking Device (ACCD) is a test method developed as a simpler alternative to the thermal stress retrained specimen test (TSRST) for cracking temperature determination. This study was conducted to investigate asphalt mixture properties influencing thermal stress development within the ACCD. Asphalt mixture properties investigated included: asphalt binder grade, the addition of recycled materials (RAP and RAS), air void content, aggregate/mixture thermal expansion coefficient (CTE) and binder content. The aforementioned mixture properties investigated were all found to influence thermal stress development.

1. Introduction

Thermal cracking is a prevalent pavement distress experienced by asphalt pavements within colder regions of the world. When asphalt pavements are subjected to very cold temperatures thermal stresses are induced which may cause transverse cracks to develop when the induced stresses exceed the tensile strength. A great deal of research have been conducted to investigate the thermal cracking potential of asphalt mixtures using test methods such as the thermal stress retrained specimen test (TSRST) and the IDT creep and strength test. Other testing methods include fracture tests such as the Semi-Circular Bending (SCB) test and Disk-Shaped Compact Tension Test (DC(T)) [1,2]. The current AASHTO M320 PG low temperature grading of asphalt binder utilizes the creep stiffness and relaxation rate of stiffness (m-value) obtained from the bending beam rheometer (BBR) for characterizing cold temperature performance of asphalts. For a given thermal contraction and cooling rate, the thermal stress increase is proportional to the stiffness of the asphalt mixture which is, in turn, a function of binder stiffness. There are however other factors such as binder modification, aggregate properties, mixture properties, climate, traffic, and pavement structure which have significant influence on the low temperature performance of asphalt pavements [1].

The Asphalt Concrete Cracking Device (ACCD) is another testing method developed as a simpler alternative to the TSRST device [3]. The ACCD ring is an Invar ring with a 60 mm (2.4 in.) outer diameter, a 24 mm (0.94 in.) inner diameter, and 64 mm (2.5 in.) in height. The ACCD ring works on a principle that a large difference in CTE between a cored asphalt mixture slid around the ring will cause the asphalt mixture to shrink and therefore be subjected to tensile stresses when the temperature of the asphalt mixture-ACCD ring assembly is lowered. Ultimately, the stress in the asphalt specimen exceeds its tensile strength and the sample cracks. This crack is evident by a sudden increase in strain rate of

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the Invar ring. ACCD test results have been found to correlate with TSRST results for 5 asphalt mixtures at a correlation coefficient of 0.86 [3]. There are number of test equipment that require the use of cored or hollow Superpave gyratory compacted specimens for the characterization of asphalt mixture performance. Notable among them is the hollow Cylinder Tensile Tester (HCT) which utilizes a hollow cylindrical asphalt mixture specimen to measure creep compliance and tensile strength at low and intermediate temperatures [15]. The fundamental principle in running both the HCT and the ACCD tests is to apply internal pressure to hollow cylindrical specimens which results in hoop strains. Based on finite element modelling of the HCT, Buttlar et al. [15] observed that the presence and distribution of voids on the surface of HCT specimens may influence the modulus and hence tensile strength of asphalt mixtures tested. Such analysis has not been done in the ACCD test but may be needed for further development of the device.

The magnitude of thermal stress development is as important as the cracking temperature and failure strain in road pavements because it affects the durability of asphalt pavements subjected to thermal loading. This may become critical when considering stresses due to thermal loads together with stresses due to traffic loads. Waldhoof et al. [4] reported that traffic loads applied during critical cooling events resulted in a substantial increase in tensile stresses in pavements. It is therefore important for pavement engineers to determine how asphalt mixture properties can affect the magnitude of thermal stress generation in the pavement during cooling. The accumulation of thermal stresses within asphalt mixtures is also important in analyzing thermal fatigue cracking of asphalt mixtures. For example, the magnitude of thermal stress increase in an asphalt mixture can influence the number of cycles required to cause thermal fatigue cracking. This is critical under milder cold temperature conditions where several cooling cycles are required for cracks to propagate through the entire asphalt pavement layer. In thermal fatigue cracking, an increase in the magnitude of thermal stress development will reduce the number of cycles required to cause the asphalt mixture to crack [5]. Bazin and Saunier [6] also reported that a material subjected to repeated stresses may crack even when the applied stress is considerably lower than that required to break the material. Vinson et al. [5] also identified asphalt mixture properties as an important input parameter for the determination of the number cycles to failure in thermal fatigue cracking.

The purpose of this study was to determine the effect of five asphalt mixture properties on the thermal stress accumulation in the ACCD as the temperature of the mixture decreases. Asphalt mixture properties investigated included asphalt binder grade, the addition of recycled materials (Recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS)), air void content (compaction effort), aggregate/mixture coefficient of thermal expansion (CTE) and asphalt binder content. Asphalt mixtures were prepared and tested using the ACCD to investigate how various mixture properties influence thermal stress variation. The CTE of the asphalt mixture was also determined using a newly developed simple test device.

2. Experiment

2.1. Materials

Twenty three laboratory prepared Superpave asphalt mixtures were used for this study. The asphalt mixture samples were short-term and long-term aged before and after compaction in accordance with AASHTO R30. Asphalt binder grades used in the study included PG 64-22, PG 64-28, PG 70-22, PG 76-22 and PG 88-22. The PG 64-28 is a polyphosphoric acid (PPA) modified binder predominantly used in intermediate courses in the state of Ohio. The PG 64-22 was an unmodified base asphalt whereas the remaining binders were polymer modified. The PG 70-22 and PG 76-22 are Styrene-butadiene-styrene (SBS) modified binders whilst the PG 88-22 is modified with SBS and Elvaloy. The ACCD test was conducted on all mixture samples, and the effect of asphalt mixture properties on the variation of thermal stresses investigated. Two ACCD test specimens were prepared from each mixture sample and the average of the test results obtained from the 2 specimens reported as the results of the particular mixture sample. Table 1 summarizes the properties of all the asphalt mixtures used in this study.

2.2. Determination of the CTE of asphalt mixtures

The CTE of the asphalt mixtures was determined using a newly developed testing device referred to here as the Ohio CTE Device (OCD). The OCD consists of 2 Linear Variable Transducers (LVDTs) with flat tips fixed at the top sides of an aluminum frame ash shown in Fig. 1. The LVDTs were fixed in such a way that they were mutually perpendicular and coincided with the diameter of the test specimen. Each 150 mm diameter superpave gyratory compacted specimen was cut into 2

Table 1
Summary of asphalt mixture properties.

Mix property studied	Binder grade	BBR test results at −18 °C, 60 s		Aggregate type and size	Binder content (%)	Design air void (%)
		Creep stiffness (MPa)	m-Value			
Effect of Binder grade	PG 64-22	400	0.263	12.5 mm Limestone	5.7	4.0
	PG 64-28	260	0.303	No RAP	5.7	4.0
	PG 70-22	407	0.272		5.7	4.0
	PG 76-22	338	0.282		5.7	4.0
	PG 88-22	180	0.310		5.7	4.0
Effect of Recycled Material	PG 64-22	400	0.263	12.5 mm Limestone & 15% RAP	5.7	4.0
	PG 70-22	407	0.272		5.7	4.0
	PG 64-22	400	0.263	12.5 mm Limestone & 15% RAS	5.7	4.0
	PG 70-22	407	0.272		5.7	4.0
Effect of Air Void (Compaction Effort)	PG 70-22	323	0.278	12.5 mm Limestone & 15% RAP (PT1)	5.7	4.0
	PG 70-22	323	0.278		5.7	8.0
	PG 70-22	287	0.276	12.5 mm Gravel & 15% RAP (PT2)	5.9	4.0
	PG 70-22	287	0.276		5.9	8.0
Effect of Aggregate and Mixture CTE	PG 64-22	400	0.263	12.5 mm High CTE limestone	5.7	4.0
	PG 76-22	338	0.282		5.7	4.0
	PG 64-22	400	0.263	12.5 mm low CTE limestone	5.7	4.0
	PG 76-22	338	0.282		5.7	4.0
Effect of Binder Content	PG 70-22	287	0.276	12.5 mm Latham	5.3	4.0
	PG 70-22	287	0.276	Limestone	5.8	4.0
	PG 70-22	287	0.276	15% RAP	6.3	4.0
	PG 70-22	287	0.276	12.5 mm Mulzer	5.3	4.0
	PG 70-22	287	0.276	Limestone	5.8	4.0
	PG 70-22	287	0.276	15% RAP	6.3	4.0

Note: PT1 and PT2 are loose mixture samples obtained from Shelly and Sands, Incorporated Asphalt Plants 1 and 2 respectively.