Damage Mechanism of Asphalt Concrete under Low Temperatures

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ABSTRACT

Low temperature associated damage mechanism is not well known for asphalt concrete. Many studies have related the thermal cracking of pavement in the roadway in cold region with overall shrinkage of the pavement surface under assumption of homogeneous material. This study, however, was initiated based on the assumption that thermal incompatibility of materials (heterogeneous) in asphalt concrete mixture would be the primary cause of the damages. Acoustic emission technique and microscopic observation were employed to evaluate damage mechanism of asphalt concrete due to low temperature. The first method showed the sufficient evidence that asphalt concrete could be damaged by lowered temperature only. The second method showed that the damage by temperature resulted in micro-cracks at the interface between asphalt matrix and aggregate particle. It was concluded that these damage mechanisms were the primary cause of major thermal cracking of asphalt pavement in cold region.

INTRODUCTION

Many studies have revealed that there are distinct cracks appeared on asphalt pavement surface in cold climate regions. This low temperature damage described in many literatures in Canada, the United States, and many European countries including Germany and Norway, focuses mainly on transverse cracks. The damage mechanism they described is related to overall shrinkage of the pavement surface, considering it to be a homogeneous material. Based on the assumption of the material's homogeneity, elastic analysis has been used for distress analysis. This approach neglects thermal incompatibility of composed materials, asphalt cement and mineral aggregates. An analytical investigation (El Hussein and Halim1993) has shown that differential thermal contraction (DTC) takes place as a result of the large difference in the coefficients of thermal contraction of asphalt cement and aggregate. The asphalt matrix, defined as the mix of asphalt cement and mineral filler, tends to contract more than aggregates as a results of having coefficient of thermal contraction which is more than 20 times higher than that of coarse aggregates. Since contraction of the matrix is restricted by that of mineral aggregates, pressure will develop on aggregate walls leading to stresses in the asphalt matrix. A study showed that strength properties of asphalt concrete enhanced by lowering temperature down to a certain level and then deteriorated below that temperature (Kim and El Hussein 1994). This is an indication that there is a certain damage mechanism created in association with low temperatures.

At low temperatures asphalt cement behaves as a brittle elastic material and internal stress may continue to build up exceeding the strength of the matrix and leading to failure. Therefore, this study was designed to investigate the occurrence of localized damage as a result of DTC. The objective of this study is to analyze damage occurring mechanism of asphalt concrete under severely cold temperatures.

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EXPERIMENTAL PROGRAMS

Acoustic emission (AE) response analysis was performed to evaluate the role of low temperature on asphalt concrete damages. A microscopic investigation of asphalt concrete sample was designed to visualize the damage associated with low temperatures. Since a limited number of references (Valkering and Jongenell, 1991, Danish Road Institute, 1993) were found, designs of the two experimental procedures were solely developed by the Center for Surface Transportation Technology, NRC Canada.

Two aggregates, granite and limestone, and one asphalt cement, penetration grade of 85/100, were used to make Marshall specimens for the microscopic analysis. Special mix using coarse aggregate, mineral filler and the asphalt cement, was developed to make microscopic examination. This mix was designed for clearer observation of cracks in the specimen which contained limited number of coarse aggregate in filler (passing # 200 sieve). Table 1 shows proportion of this special mix.

Table 1. Proportion of materials (%) by weight

Asphalt Cement	Coarse Agg.	Mineral Filler
12	40	48

For Marshall specimens in acoustic emission test, limestone were used to make Hot dense asphalt mixes referred to as HL4 by Ontario Ministry of Transportation (MTO) specification. An environmentalchamber was used for conditioning sample and detecting acoustic emission. Microscopic analysis was carried out at -30°C in a cold room.

Acoustic Emission

This method involved a non-destructive technique to detect generation of micro-cracks by analysis of acoustic emission data collected from the surface of an asphalt sample exposed to low temperatures. Acoustic emission is the term used to describe transient elastic waves resulting from local internal micro-displacements in the material caused by applied stress. The waves generated by rapid release of energy in the material are then detected by means of sensitive piezoelectric transducers mounted on the surface of the sample. The signal, reflecting events, are then characterized by determination of such features as the amplitude, duration and rise time of individual events.

Recorded events (emission)are related to free contraction of the sample since only the effect of DTC was under consideration. A hole was drilled in a Marshall specimen and a temperature prove was inserted in the hole to measure temperature inside sample. Air temperature of the chamber inside was also measured and recorded during recording the acoustic emission. Other specimen was freely placed inside the same chamber without applying any external load after wiring installation (Fig. 1). Since the objective is only to prove the occurrence of defects in the asphalt matrix as a result of thermal stresses during free thermal shrinkage of mixture, no quantitative interpretation of the AE data was made.

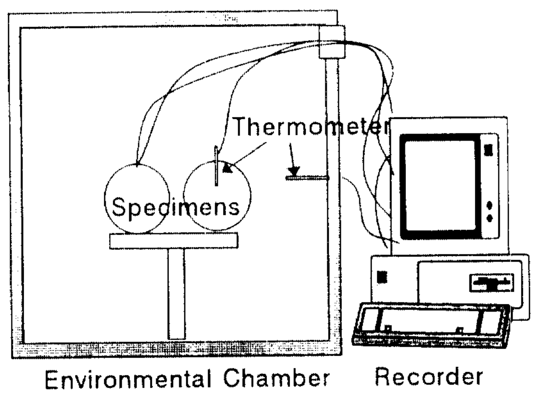

Fig. 1. Illustration of Acoustic Emission Test

Microscopic Investigation

Microscopic analysis provided an excellent opportunity to study for performance evaluation of a number of physical properties of engineering materials. This technique was widely acceptable for many materials such as portland cement concrete. However, for asphalt concrete, the technique proved to be difficult due to low viscosity of binder at room temperature. Saw-cutting of asphalt concrete usually results in asphalt flow which may smears the sample surface and, therefore, obscures some of the features under investigation. Therefore, in this study, the investigation was thoroughly performed in a cold room at -30°C. Smearing of the sample surface feature was significantly reduced during sawing and polishing at this temperature.

Specimens were conditioned at -30°C for over 48 hours without applying any external load. The specimen was cut by a masonry saw at -30°C using an antifreeze fluid. Polishing was carried out at the same temperature because the surface of the sample must be extremely fine to permit observation at high magnification levels (12 to 50 times). To eliminate traces of saw blade, polishing with grinding powder was started using No. 80 grit size (coarse) and continued in order of increasing fineness up to the required higher quality provided by the No. 1000 grit size. Observations were made using a stereo microcope inside the cold room because cracks might be close up or heal if the sample is moved to room temperature.

RESULTS AND ANALYSIS

Acoustic emissions were recorded following the sudden release of energy associated with cracking when specimens were exposed to low conditioning temperature. In the absence of any other source of stresses, this cracking can only be a result of thermal incompatibility on components. Micro-cracks which is absent in unconditioned specimens were observed by the microscope on the surface of saw-cut and polished surface from 12 times or higher magnification levels. Details are explained in the following subsections.

Acoustic Emission

The temperature of the surface and inside a specimen and acoustic emission response from the surface of other specimen in the same chamber were recorded as shown in Fig. 2. The temperature of the chamber was lowered while recording emission from the main sample.

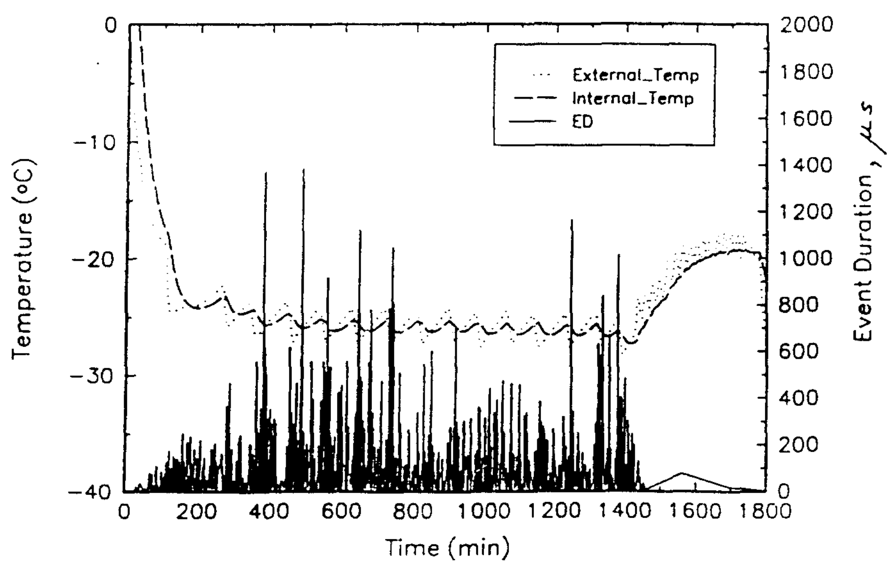

Fig. 2. Recorded acoustic emission.

Events recorded indicated noticeable internal activities in the form of energy release close to -15°C. These activity intensified at -25°C and duration of a number of events were very high, which might be interpreted as propagation of the initiated cracks. It is very interesting to notice that these activities cease to occur when temperature was raised to above -25°C. This pause of emission indicates that stress resulting from DTC were no longer high enough to cause further damage.

Microscopic Examination

Examination under the microscope of the surfaces of a number of saw-cut and polished specimens following exposure to -30°C revealed the nature of defects caused by DTC. Fig. 3 shows a typical hairline crack, from granite aggregate, perpendicular to aggregate surface at 25 times magnification. As expected from the analytical study (El Hussein 1993), the crack was initiated at the aggregate/matrix interface by the wider opening of the crack at right angle of the aggregate side.

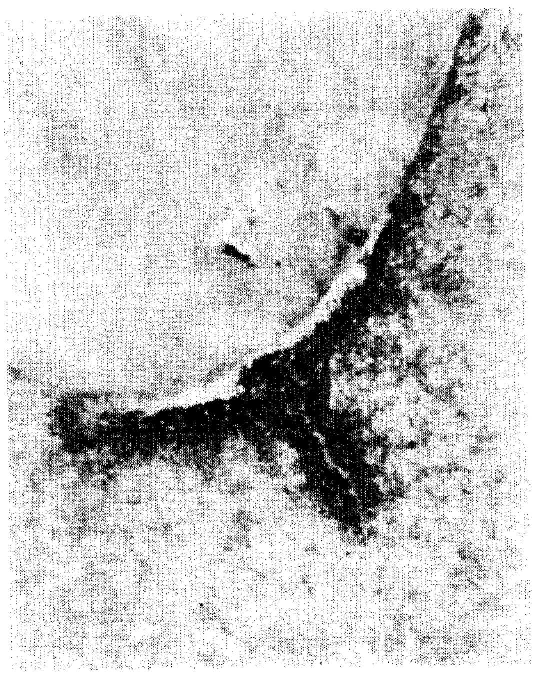

Fig. 3. Typical perpendicular microcrack (25x)

Fig. 4 shows cracks propagated at the interface around the aggregate particle. The detachment of the matrix from aggregate was usually accompanied by the perpendicular crack. Most of the cracks were observed from granite specimens. This may be an indication that the granite, which is the harder in nature, has more incompatibility with asphalt binder in thermal contraction coefficient.

Fig. 4. Typical detachment of interface (25x)

CONCLUSIONS

Following conclusions were drawn from the results of tests conducted in this study.

1. Thermal incompatibility was a serious source of stresses in asphalt concrete which was exposed to low temperatures.
2. Acoustic emission confirmed occurrence of localized damage as a result of cooling alone. Analysis of the emission data showed the temperature where such damage initiated and later propagated under further exposure to lower temperatures.
3. Hairline crack due to low temperature initiated at the interface and propagated

perpendicularly in the asphalt matrix or along the aggregate surface.

4. The two investigation technique showed how the damages in asphalt concrete initiated under low temperature and how they behaved under continuous exposure.
5. These damage mechanisms were considered to be the primary cause of major thermal cracking of asphalt pavement in cold region.

REFERENCES

El Hussein, H. M. and Halim, A. O. A. (1993) "Differential Thermal Contraction, A Mechanistic Approach to Adhesion in Asphalt Concrete," The Canadian Journal of Civil Engineering, Vol. 20, pp. 366-373

Danish Road Institute (1993), "Microscopic Analysis of Asphalt Concrete Mixtures," Information Guide of the Road Directorate of Denmark Ministry of Transport, Production SV/LIB, 1993

Kim, K. W. and El Hussein, H. M.(1994), "Effect of Differential Thermal Contraction on Fracture Properties of Asphalt Materials at Low Temperatures," Submitted to Journal of AAPT, Vol 64.

Valkering, C. P. and Jongenell, D. J. (1991), "Acoustic Emission for Evaluating the Relative Performance of Asphalt Mixes under Thermal Loading Conditions," Journal of AAPT, vol. 60, pp. 160-187