Laboratory Validation of Surface-Initiated Transverse Cracking of Asphalt Pavement

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Abstract: Field pavement transverse cracking typically can be grouped into two categories, namely thermal cracking that initiates at the surface of the pavement and propagates downward, and reflective cracking that initiates at the pavement layer above the existing pavement cracks or joints and propagates upward. Recently, another transverse cracking phenomenon was noticed in some field investigations but was less studied. Cracks were observed from both the surface and the bottom of field cores, but they cannot be visually observed from the middle layer. In addition, the surface and the bottom cracks lined up well, showing the tendency of meeting each other. This study aimed to evaluate the causes of such transverse cracking phenomena by laboratory tests. Hamburg equipment was used as the evaluation equipment. Some samples were prepared with a saw cut notch 0.33 inches in depth and 0.25 inches in width, and some samples were prepared without the notch at the bottom. The results showed that such a crack type could have happened when samples are aged, the base below the sample is soft, and a notch exists in the bottom layer. A potential mechanism is when the wheel load moves on one side of the existing transverse cracking (the near side), as the specimen on this side tends to bend downward under the wheel load, especially when the support is relatively soft. If without constraint, the other side of the specimen (the far side) should consequently be tilted upward. However, the bonding with the base layer and the self-weight of the specimen restrict the upward movement of the far-side specimen. Therefore, the tensile stress at the surface of the specimen directly on top of the bottom crack is created. At the same time, the bottom crack has the potential of being squeezed and pushed together.

Keywords: surface-initiated transverse cracking; laboratory evaluation; aging; soft base; existing joint

1. Introduction

In general, transverse cracking can be categorized into climate-related thermal cracking and load or thermal-related reflective cracking. The sudden dramatic drop of pavement temperature or repeated daily temperature fluctuation could result in transverse cracking initiating from the surface of the pavement and propagating downward [1]. Reflective cracking is caused by the stress concentration at the bottom of asphalt overlay due to the movement of a crack or joint underneath the overlay layer, which will lead to crack propagation upward in asphalt overlays [2]. The movement of the crack or joint in the underneath layer could be caused by temperature or moisture fluctuation, traffic loading, or a combination of the above factors. In addition to temperature or traffic load, material properties such as the degree of aging could also contribute to the initiation of transverse cracking [3].

Based on field cores, many researchers have pointed out that not all asphalt overlays constructed on top of cracked hot mix asphalt (HMA) pavements or Portland cement concrete (PCC) pavements
will develop reflective cracks starting from the overlay bottom near the cracks of the already existing surface. Sometimes, cracks were observed at both the top and bottom surface of the layer but not in the middle portion. It is possible that transverse cracking initiates from the overlay surface and propagates downward to match the existing transverse cracking in this case. Such cracking type has been widely reported by other researchers [4–8].

However, it is still not clear how this type of crack was initiated and what are the associated key factors. Some studies [5,6] assumed that such crack types may correlate with the pavement structure and material properties, without providing any validation. It is the objective of this paper to provide a laboratory investigation about such crack types, evaluate the causes that would lead to the production of such cracks, and identify the roles of specific factors, such as layer thickness, existing crack or notch, aging, and the binder performance grade. By evaluation, this study identifies the factors that cause surface-initiated transverse cracking and will provide a possible mechanism to explain the initiation of such crack type.

2. Methodology

The Hamburg wheel-tracking device (HWTD) is used in this study to evaluate the cracking potential of the material or structure under various conditions. The HWTD was firstly developed in Germany and is now extensively used by many US state Departments of Transportation (DOTs) and industries to evaluate the rutting and moisture damage potential of asphalt mixture. It applies repeated loading on asphalt mixture specimens submerged in water at relatively high temperature (typically at 50 °C) and uses rut depth and a stripping inflection point at a specific loading cycle to describe the rutting and moisture resistance of the mixture. As specified in AASHTO T324 [9], Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA), the standard load on the wheel is around 705 N (158 lb). The wheel rolls on the specimen at 52 ± 2 passes per minute, with the position varying sinusoidally over time. The wheel-tracking device shall shut off when 20,000 passes have occurred or when the test has achieved the maximum rut depth (i.e., 0.5 inches). Research studies [10,11] indicate that the rut depth from the HWTD can correlate well with field rutting and moisture damage performance; thus, it has become popular equipment at both research institutes and industry laboratories.

As a repeated loading device that simulates cyclic traffic loading in the field, it is hypothesized that HWTD can also be utilized for evaluating the cracking resistance of the pavement. However, considering the fundamental difference in failure mechanism between rutting and cracking, the HWTD needs to be modified and improved in the following four areas in order to make it potentially a cracking evaluation device as well. They include:

- Test conditions need to be changed to ensure that cracking instead of permanent deformation is the dominant failure mechanism. Typically, asphalt mixture reacts as viscoelastic–plastic material under standard HWTD loading condition, since the test is performed at a relative high temperature (i.e., 50 °C) and low loading rate (52 passes per minute). To obtain asphalt material that responds as more elastic–brittle solid, the test temperature should be decreased to room level (i.e., 20–25 °C) or even lower (close to zero degrees), or the wheel load speed needs to be increased to a higher value that can simulate a fast-moving vehicle.

- Long-term aging of the specimen should be included, since it is a critical factor that affects both fatigue cracking and low-temperature thermal cracking [3,12,13]. The aging of asphalt mixture increases the stiffness of the material, reduces its ductility, and could negatively affect its resistance to fatigue-induced cracking [14,15]. It is also found that aging decreases the low-temperature cracking resistance of asphalt concrete pavement and increases the crack frequency [16].

- The base (or support) stiffness of the test specimen should be adjustable to match with the field pavement condition. Such adjustment can be achieved by placing rubber with different stiffness under the specimen. Typically, the potential for fatigue cracking initiation increases with the decrease of the base modulus [17].
Based on these considerations, the equipment from the *James Cox & Sons, Inc.* company is selected, and some modifications were made to their standard Hamburg wheel-tracking device (HWTD) so that the cracking properties of the material can be evaluated. These changes include:

- An extra chiller was connected to the equipment to maintain test temperature at around 20 °C.
- Wider loading rate range: maximum 70 passes per minute, which is faster than the standard wheel load speed (52 ± 2).
- Capable of including rubber base to adjust the support conditions.

Figure 1 shows a picture of HWDT from *James Cox & Sons, Inc.* A linear variable differential transducer (LVDT) was used to measure the rut depth along the length of the wheel’s path over a range of 0 to 20 mm (0–0.8 inches).

![Figure 1. Hamburg wheel-tracking device.](image)

### 2.1. Scale Down of Sample Size

It should be noted that the specimen thickness used in the laboratory may not be equivalent to field pavement thickness directly. The reduced specimen size has been widely used to simulate field pavement conditions in the laboratory. A commonly used reduced-scale accelerated trafficking device is the one-third scale Model Mobile Load Simulator (MMLS3) [18]. Studies have shown that the application of MMLS3 loading creates stresses and strains in the pavement slab trafficked that are similar to those created in pavements subjected to field traffic if conditions of similitude are met [19].

Such scaled-down is based on dimensional analysis [20,21], which shows that if N is the scaling factor applied between the prototype and model, to get the same strains and stress in the model for inertial effect, it is necessary to scale down the length by 1:N and load magnitude by 1:N², while keeping a 1:1 scale for material properties and stress on the surface. For the MMLS3, these conditions entail scaling down of the pavement layer thickness and traffic velocity to one-third (N = 3) and applied load to one-ninth of those experienced in the field, respectively. The tire inflation pressure of MMLS3 is kept as a constant of 600 kPa.

The scale-down factor N is not a fixed number and typically is determined by users [20]. In this study, the same scale-down factor as MMLS3 is applied to HWTD (N = 3) to take into account the mold geometry (thickness) size of the existing HWTD test without disturbing the rubber mold and specimen diameter (5.9 in). Assuming the scale factor as 3 means that when the authors evaluated overlay from 1 to 2.4 inches thickness, the full-scale overlay thickness was 3 to 7.2 inches. The HWTD wheel is tracked across the sample using a 445 N load onto a pneumatic linear hose pressurized to 0.69 MPa.
2.2. Materials

Two mix designs using the same aggregate source and similar gradation were included. The only difference is the performance grade (PG) of binders, two types of binders (PG58-28 and PG64-2) are considered. Table 1 summarizes the information about mix design.

| Design Parameter | Mix Design #1 | Mix Design #2 |
|------------------|---------------|---------------|
| Asphalt PG       | 58–28         | 64–22         |
| NMAS, in         | 0.38          | 0.38          |
| Asphalt content, % | 5.9          | 5.8           |
| Gyration number  | 75            | 75            |
| % voids @ Nmax   | 4.0           | 4.0           |
| Gnb              | 2.449         | 2.462         |
| Gmm              | 2.551         | 2.527         |
| Aggregate Gsb    | 2.78          | 2.74          |
| Design ESALs, million | 0.3 to <3 | 0.3 to <3 |

Note: NMAS indicates nominal maximum aggregate size; ESAL indicates equivalent single axle load.

2.3. Specimen Preparation

The asphalt mix was prepared in the laboratory using the batch mixture proportion in accordance with the job mix formula, with a mixing temperature of 160 °C. Then, the mixtures were conditioning at a high temperature of 135 °C for a duration of 4 h in accordance with AASHTO R30. Then, the mixture was heated up to 150 °C for gyratory compaction purposes. After gyratory compaction, specimens were extruded before 2–3 h’ cooling. After removing the specimen from the mold with further cooling, the test specimens were cut by saw into desired shapes to fit the molds of HWTD.

2.4. Design of Test Condition

Table 2 presents a summary of all the tested specimens and test conditions. The conditions through which surface-initiated transverse cracking is observed are also pointed out. All the experiments were carried out by using the James Cox & Sons HWDT equipment. There are in total of 12 specimens tested. The reasons to include these conditions are:

- **Layer thickness**: Layer thickness has been proved to affect top–down longitudinal cracking significantly [22]. As seen elsewhere [22], pavement thickness could be a critical factor that correlates to surface-initiated transverse cracking. Therefore, it is expected that the initiation of cracks can be observed at different wheel load repetitions by using varied specimen thicknesses. Therefore, HWT samples with different thicknesses are used, consisting of 1 inch, 1.5 inches, and 2.4 inches.
- **Aging condition**: Specimens with different degrees of aging (5-day aging, 10-day aging, and 15-day aging) are applied. Five-day aging at 85 °C is considered to be equivalent to long-term aging in the field pavement in accordance with AASHTO R30 [23]. Ten-day and 15-day agings are used to obtain asphalt mixture with even higher stiffness (more brittleness), which is critical for surface-initiated cracks, as suggested elsewhere [22].
- **With or without existing notch**: Some specimens have joints in the bottom layer, and this is simulated using a notch or saw cut (0.33 inch depth and 0.25 inch width). Both specimens with and without existing notches are used to evaluate the effects of existing notches on the property of surface-initiated transverse cracking.
- **Weak base or strong base**: For pavement under traffic load, the modulus of the base can greatly affect the stress magnitude at the pavement surface. Von Mises stress is the maximum octahedral shear stress; it takes into account the multiaxial stress state, including the shear when potential failure location is near the pavement surface [24]. It was found that the higher the base modulus, the
smaller the Von Mises stress value at the pavement surface. In contrast, the lower the base modulus, the higher the Von Mises stress value at the pavement surface [8]. The effect of base stiffness on pavement response has also been confirmed by other researchers as well [17,25]. Specifically, the sensitivity analysis of flexible pavement performance prediction to Mechanistic-Empirical Pavement Design Guide (MEPDG) design inputs shows that the top-down longitudinal cracking is very sensitive to base resilient modulus [25], a greater amount of longitudinal cracking is predicted if the lower base modulus is used. It is also pointed out that pavement with a lower base modulus is more prone to initiate top–down fatigue cracking [17]. Therefore, with a flexible base, it is expected that surface-initiated reflective cracking (SIRC) is easier to be simulated in the laboratory. SIRC refers to such cracks that initiate at the surface of the pavement layer in the transverse direction and propagate downward to match the existing transverse cracking, and there is no cracking in the intralayer. In this paper, rubber with an approximate stiffness range of 400–700 MN/m was placed under test specimen to simulate a weak base, as shown in Figure 2a, and the HWTD steel frame was used as a strong base instead of a rubber pad, as shown in Figure 2b.

- **Binder performance grade (PG):** Asphalt binder PG is used since it fully characterizes asphalt binders for different environmental and climatic conditions and is an important indicator for asphalt stiffness [26]. The binder PGs consisted in this study are PG 58-28 and PG 64-22.

**Table 2.** Design of test condition.

| Binder PG | Sample # | Layer Thickness, in. | Aging Condition | With or Without Existing Joint | Strong or Weak Base | Observed Crack |
|-----------|----------|----------------------|-----------------|-------------------------------|--------------------|----------------|
| 64-22     | 1        | 1.0                  | 10-day          | With                          | Weak Base         | Yes            |
| 64-22     | 2        | 1.0                  | 10-day          | With                          | Weak Base         | Yes            |
| 64-22     | 3        | 1.5                  | 10-day          | With                          | Weak Base         | Yes            |
| 64-22     | 4        | 1.0                  | 10-day          | Without                       | Weak Base         | No             |
| 64-22     | 5        | 1.0                  | 5-day           | With                          | Weak Base         | No             |
| 64-22     | 6        | 1.0                  | 5-day           | With                          | Weak Base         | No             |
| 64-22     | 7        | 2.4                  | 10-day          | With                          | Strong Base       | No             |
| 64-22     | 8        | 2.4                  | 10-day          | With                          | Strong Base       | No             |
| 64-22     | 9        | 2.4                  | 10-day          | With                          | Strong Base       | No             |
| 58-28     | 10       | 1.0                  | 10-day          | With                          | Weak Base         | No             |
| 58-28     | 11       | 1.5                  | 10-day          | With                          | Weak Base         | No             |
| 58-28     | 12       | 1.0                  | 15-day          | With                          | Weak Base         | No             |

**Figure 2.** Cross-sectional detail of Hamburg wheel-tracking device (HWTD) cut from the center with mold and specimen assembly. (a) Specimen with a strong base placed directly on top of an HWTD steel frame (b) specimen with a weak base placed on top of the rubber.

### 2.5. Test Results and Analysis

Testing results are shown in accordance with the specimen sequence as shown in Table 1. The specimens (#1 to #3) with observed surface-initiated transverse cracking are firstly introduced and analyzed, followed by specimens (#4 to #12) without observed surface-initiated transverse cracking.
3. Testing with Observed SIRC

Specimen #1 is 1 inch in thickness, 10-day aged, with an existing notch at the specimen bottom, and with a rubber base placed below the sample to simulate a soft base in the field. The notch is approximately 0.33 inches in depth and 0.25 inches in width. The placement of rubber and specimen #1 in the HWTD mold is shown in Figure 3.

![Figure 3](image1.png)

**Figure 3.** (a) Rubber placed at the bottom of the mold, and (b) specimen placed on top of the rubber.

In this test, 40,000 passes are applied daily with a testing period of 12–13 h. The load is applied in a bidirectional manner. At the end of each 10,000 passes, specimens are taken out to check if there is any crack initiated at either the surface or the bottom of the specimen.

As can be seen in Figure 4, it is found that after 40,000 wheel passes, a minor crack appeared at the specimen surface. The crack is perpendicular to the wheel loading direction and therefore can be considered as a transverse crack. In addition, the crack location matches well with the existing crack or notch at specimen bottom, indicating that the existing crack or notch may be a critical reason for the initiation of such a crack type. It is also noticed that there is a recordable rut depth.

![Figure 4](image2.png)

**Figure 4.** Specimen #1 (1-inch thickness, 10 days aging, with a notch) with surface-initiated reflective crack, (a) specimen within mold, and (b) specimen after taken out from the mold.

The specimen was continuously tested for an additional 30,000 passes. As noted in Figure 5a, after a total of 70,000 passes, the original crack further propagates to the outside of the specimen, and at the same time, the crack initiates at the other side of the specimen (Figure 5b). Figure 5c implies
that the surface transverse crack matches well with the existing transverse crack or notch. It is also observed that the rut depth increases at the end of the test compared with that at 40,000 cycles.

Figure 5. Specimen #1 (1 inch thickness, 10 days aging, with a notch) with surface-initiated reflective cracking (SIRC), (a) specimen with propagated transverse crack; (b) transverse crack that initiates at the other side; (c) SIRC matches well with existing notch, and (d) specimen bottom.

4. Potential Mechanism

It is interesting to note that the specimen bottom is squeezed from outside toward the specimen middle in Figure 5d. By seeing Figure 5c,d together, it is reasonable to assume that when the wheel load moves to one side of the existing transverse cracking (the near side), the specimen on this side tends to bend downward under the wheel load, especially when the support is relatively soft. If without constraint, the other side of the specimen (the far side) should consequently be tilted upward. However, the bonding with the base layer and the self-weight of the specimen restrict the upward movement of the far-side specimen. Therefore, tensile stress at the surface of the specimen directly on top of the bottom crack or notch is created. At the same time, the bottom crack has the potential of being squeezed and pushed together. A schematic to explain the hypothesized causes of such a crack is shown in Figure 6.
A repetition specimen (#2 in Table 1) uses the same conditions (specimen thickness of 1.0 inch, 10-day aging, with an existing joint and with a weak base) is tested and the specimen after 80,000 passes is shown in Figure 7. Apparently, the transverse crack initiates from the surface and the specimen bottom tends to squeeze to the middle. Similar to the first specimen shown in Figure 5, the repetition specimen has the same crack direction (perpendicular to wheel load) and location (at the specimen surface) and matches well with the existing notch. The repetition test proves that the appearance of surface-initiated transverse cracking does not happen by accident in the laboratory test; it should appear as long as the specific conditions are satisfied (weak base, long-term aged material, proper layer thickness, with existing joint). Again, recordable rut depth is observed for this specimen.

Specimen #3 listed in Table 1 also showed surface-initiated reflective cracking. Specifically, the specimen is 1.5 inches in thickness, 10-day aged, with the existing notch at the specimen bottom and with a weak base placed below the sample. The testing result shows that it takes in total 180,000 passes before the surface transverse crack was observed. As seen in Figure 8, there is a transverse crack in the middle of the specimen under wheel load, and the specimen bottom severely squeezes to the middle. The test was continued for an additional 60,000 passes, but the crack was not further developed. A recordable rut depth is seen as well for this specimen.
Figure 8. Specimen #3 (1.5 inch thickness, 10 days aging, with a notch) with SIRC, (a) specimen top and (b) specimen bottom.

Considering that the only difference between specimen #3 and specimens #1 and #2 is layer thickness, it can be concluded that the layer thickness is a critical factor for SIRC. It is possible that with the increase of layer thickness, the traffic load-induced bend on the specimen end decreases as well. This has been confirmed by the finite element method (FEM) analysis in another study [8] that showed that the magnitude of the Von Mises stress at the pavement surface decreases with the increase of HMA layer thickness. More traffic repetitions are required to induce the same stress level for thicker pavement compared with the thinner pavement. In addition, unlike the specimens that are shown in Figures 5 and 7, the crack in Figure 8 is within the wheel load, while no crack is found on the two sides; the reason for such a crack location needs to be further evaluated.

5. Testing without Observed SIRC

Other test conditions are also evaluated while no surface-initiated transverse cracking is found. Detailed testing of each specimen and analysis is listed as follows.

5.1. Without the Existing Notch

Specimen #4 in Table 1 is 1 inch in thickness, 10-day aged, without an existing notch at the specimen bottom, and with a weak base placed below the sample. The test result shows that after 100,000 passes, no crack is observed on either the specimen surface or bottom, as seen in Figure 9. Considering that the only difference between specimen #4 and specimens #1 and #2 (test ends with crack) is with or without the existing notch, it can be concluded that the existing joint is a critical precondition for such a cracking type.

Figure 9. Specimen #4 (1-inch thickness, 10 days aging, without a notch), (a) specimen top and (b) specimen bottom.
5.2. Aging Days

In addition, specimens #5 and #6 listed in Table 1 are evaluated. Specifically, they are both 1 inch in thickness, 5-day aged, with the existing notch at the specimen bottom, and a weak base is placed below both samples. The test result shows that after 100,000 passes, no crack was observed on either the specimen surface or bottom, as seen in Figure 10. Considering that the only difference between specimens #5 and #6 and specimens #1 and #2 (test ends with crack) is material aging (5-day and 10-day aging, respectively), it can be concluded that the aging (stiffness or brittleness) is a critical precondition for surface-initiated transverse cracking. It is within the expectation that the specimen in Figure 7 experienced more rut depth than that in Figure 8 due to less aging.

5.3. Base Stiffness

Specimens #7, #8, and #9 are also evaluated, which are 2.4 inches in thickness, 10-day aged, and with an existing notch at the specimen bottom. Since 2.4 inches is the maximum specimen thickness for the HWTD, no rubber layers are used in the test. In such a case, the base of the specimen is the metal model, which is very strong in terms of stiffness and can be considered as a strong base. The three specimens are different from each other in terms of the existing joint depth. The notch depth is 0.3
inches, 0.6 inches, and 1.2 inches for specimens #7, #8, and #9, respectively. This is designed to evaluate the effects of varying joint depths on SIRC. Specimens and the test setup are shown in Figure 11.

![Specimens #7, #8, and #9](image)

**Figure 11.** Specimens #7, #8, and #9 (2.4-inch thickness, 10 days aging, with a notch), (a) specimen with varied notch depth, and (b) specimen placed in molds.

No crack is observed after in total 1,500,000 passes, as seen in Figure 12. There is no material squeezing at the specimen bottom as well. The phenomenon that no crack was observed under such conditions could be attributed to the following reasons: (1) the ratio of specimen thickness to length (0.46) is too high to induce specimen bending, and (2) the strong base is used, which could reduce the stress level at the pavement surface and not allow specimen bending.

![Specimen #9](image)

**Figure 12.** Specimen #9 (2.4-inch thickness, 10 days aging, with a notch), (a) specimen top and (b) specimen bottom.

5.4. Binder PG

Specimens #10, #11, and #12 are also evaluated. Specifically, #10 and #11 are 1.0 inch in thickness and 10-day aged, with the existing notch at the specimen bottom. Specimen #12 is 1.0 inch in thickness and 15-day aged, with the existing notch at specimen bottom. No crack is observed at the loading cycle of 500,000. Considering that the only difference between specimens #10, #11, and #12 and specimens #1 and #2 (test ends with crack) is binder PG (PG 58-28 and PG 64-22), it can be concluded that the binder source is a critical precondition for surface-initiated transverse cracking.
6. Summary of Crack Initiation Cycles and Rut Depth

Table 3 summarizes the cycle at crack initiation, the rut depth at crack initiation, the cycles of the final test, and the final rut depth. As shown, the surface crack appears very fast in terms of specimens #1 and #2 with 1 inch in thickness, while it takes more passes to initiate cracks when the thicker layer is used (#3). It is also seen that cracks are always observed with different levels of rut depth.

Table 3. Summary of crack initiation cycles and rut depth.

| Binder PG | Sample # | Observed Crack | Cycle at Crack Initiation | Rut Depth at Crack Initiation, mm | Total Test Cycle | Final Rut Depth, mm |
|-----------|----------|----------------|--------------------------|----------------------------------|------------------|---------------------|
| 64-22     | 1        | Yes            | 40,000                   | 5.0                              | 70,000           | 7.0                 |
| 64-22     | 2        | Yes            | 40,000                   | 5.5                              | 80,000           | 7.0                 |
| 64-22     | 3        | Yes            | 180,000                  | 2.0                              | 240,000          | 3.0                 |
| 64-22     | 4        | No             | N/A                      | N/A                              | 100,000          | 2.0                 |
| 64-22     | 5        | No             | N/A                      | N/A                              | 100,000          | 10.0                |
| 64-22     | 6        | No             | N/A                      | N/A                              | 100,000          | 10.0                |
| 64-22     | 7        | No             | N/A                      | N/A                              | 1,500,000        | 6.0                 |
| 64-22     | 8        | No             | N/A                      | N/A                              | 1,500,000        | 6.0                 |
| 64-22     | 9        | No             | N/A                      | N/A                              | 1,500,000        | 6.0                 |
| 58-28     | 10       | No             | N/A                      | N/A                              | 500,000          | 11.0                |
| 58-28     | 11       | No             | N/A                      | N/A                              | 500,000          | 11.5                |
| 58-28     | 12       | No             | N/A                      | N/A                              | 500,000          | 9.8                 |

7. Conclusions

Surface-initiated transverse cracking has been continuously reported but has not been validated by laboratory tests. By using Hamburg equipment and gyratory compacted specimens, this paper evaluates the key factors that are correlated to surface-initiated transverse cracking. The conclusions of this paper are:

1. The specimen thickness, base stiffness, material stiffness (aging effect), existing notch, and binder source are critical factors for surface-initiated transverse cracking. Specifically, laboratory tests indicate that such a crack type is seen easier for the softer base, stiffer asphalt mixture, with the existing transverse notch.

2. In terms of pavement thickness, although some studies in the literature indicate that thicker pavement may crack easier due to shear failure, laboratory tests indicate that specimens with thinner thickness (1 inch) takes less wheel load passes before the crack was observed. Two reasons could be used to explain this difference: (a) a thin specimen cannot be directly equal to field thin HMA layers, the scale-down factor needs to be considered in laboratory tests, and (b) sufficient thickness is important to shift the critical distress position to the surface of the pavement and lead to surface-initiated cracking. However, there may exist a threshold value, and if the value above the threshold, the pavement with thinner thickness is more prone to develop SIRC and cracks may appear with fewer traffic repetitions that need a further demonstration.

3. Surface-initiated transverse cracking can be induced under traffic load. Although the thermal load gradient (cooling cycles) could accelerate the development of the surface-initiated transverse cracking, the laboratory evaluation proved that such a crack type can be caused by repeated traffic load at intermediate temperature.

4. The possible mechanism that induces the surface-initiated transverse cracking is that with the existence of a transverse joint at the pavement bottom, it is possible that when the traffic load tracks back and forth in the middle of the road, a bending is induced in an upward direction near the load area. Therefore, tensile stress is caused on the pavement surface and tears the pavement apart under repeated wheel loads. Compression is caused on the pavement bottom surface and
leads to the asphalt mixture squeezing together, which has been validated by the laboratory tests. Such bending may only occur when the base structure is relatively weak. If a strong base is applied, no bending is expected, and surface-initiated transverse cracking is not seen anymore. When the tensile stress is higher than the strength of the material, the crack initiates. The asphalt material with higher stiffness or brittleness may crack easier than soft material, since soft asphalt mixture can relax stress faster.

8. Recommendations

The following recommendations are given based on this study:

(1) It is recommended to further explore this mechanism in the lab by introducing a discontinuity in the rubber pads instead of a notch to simulate an existing crack in the HMA bottom layer.

(2) Use more replicates to see whether the phenomena are the same or not for other samples as well.

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