Preventing Pavement Failure Caused by Hot-Mix Asphalt Temperature Differentials

Washington State's Systematic Approach

STEVE MUENCH AND KIM WILLOUGHBY

Muench is Assistant Professor, Civil and Environmental Engineering, University of Washington, Seattle. Willoughby is Research Manager, Washington State Department of Transportation, Olympia.

In recent years, large numbers of hot-mix asphalt (HMA) paving projects in Washington and other states in the United States and around the world have experienced what is generally called cyclic or end-of-load segregation, a cyclic occurrence of low-density areas in the mat. These low-density areas tend to fail prematurely through fatigue cracking, raveling, or both, which can be costly on high-volume Interstate routes.

The Problem

At first, aggregate segregation was considered the cause of premature failure of HMA pavements, but observations in Washington State and elsewhere suggested a second, and perhaps more prevalent, cause: construction-related temperature differentials that produce low-density areas (Figure 1). These areas are susceptible to isolated damage in an otherwise serviceable pavement.

Although patching provides temporary relief, the remedy is to resurface earlier than anticipated. Research and records in the Washington State Department of Transportation (DOT) pavement management system show that temperature differentials, depending on the severity, can reduce expected pavement life by 20 to 80 percent.

Solution

The Washington State DOT research began with an investigation of temperature differentials and culminated in the development of a rational specification.

FIGURE 1 Cyclic low-density spots just after construction.

Stage 1: Discovery (1995)

Cyclic segregation first received close attention on a large paving project on Interstate 5 north of Olympia in 1994. The visible problem served as the catalyst for formal research.

The investigation used handheld temperature measuring devices to determine the cause of prevalent cyclic segregation and discovered large temperature differentials in the mat after placement. Nuclear density checks showed that the cooler areas of the mix had lower densities than the rest of the mat.

Stage 2: Determination of Cause (1998)

An infrared camera was used to locate cool areas in the mat on four Washington State DOT projects (Figure 2). The cool areas then were sampled and tested for mix properties.

Construction-related HMA temperature differentials resulted in the placement of a significantly cooler portion of HMA mass into the mat. The cooler mass came from the surface layer or crust that typically develops during the transport of HMA from the mixing plant to the job site. Originally it was thought that the paver blended this crust sufficiently into the rest of the HMA, but many observations showed this did not happen. Instead, the cold HMA passed through the paver relatively intact and was placed in concentrated areas of the mat. These cold locations generally resisted adequate compaction, resulting in concentrations of higher air voids and open surface textures that were more susceptible to deterioration from traffic and the environment.

The cool areas did not show symptoms of aggregate segregation. Observations found that air voids increased by 1.6 to 7.8 percent in the cool areas compared with the mat as a whole.

Stage 3: Contributing Construction Factors (1999)

An infrared camera was used to view 35 Washington State DOT projects, and detailed data were collected to identify patterns in the occurrence of temperature differentials and construction operations. Temperature differentials of up to 68°F were observed with a resultant increase of up to 4.5 percent in air voids.

Remixing the HMA before placement reduced or eliminated temperature differentials, but some material transfer vehicles (MTVs) did a better job of remixing than others (Figure 3). Good compaction practices and higher HMA mix temperatures—which allowed additional compaction time—were found to reduce the density differences attributed to temperature differentials.

Stage 4: Identification Procedure (2000)

The temperature differentials easily identified with

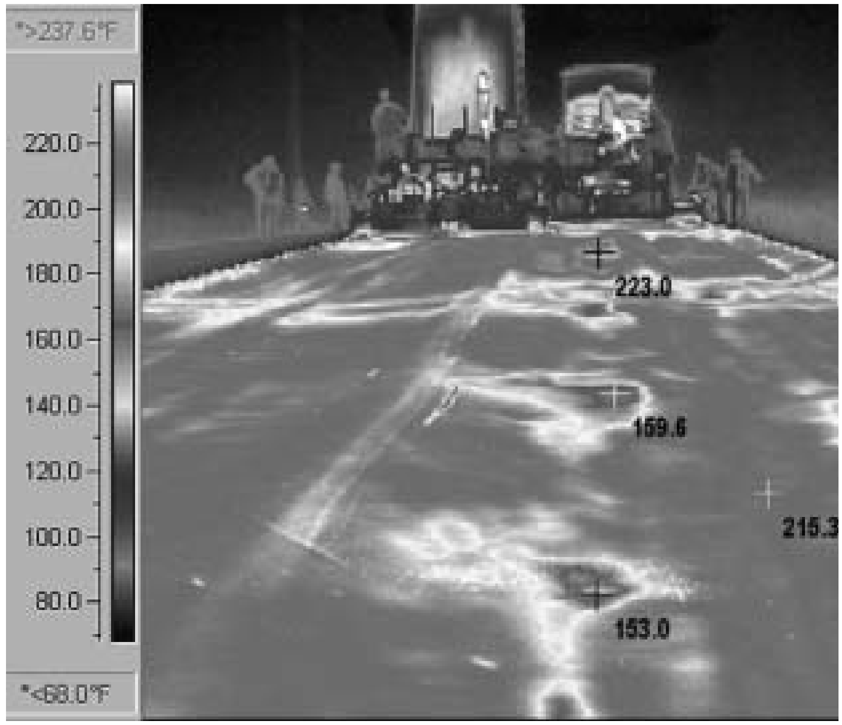

FIGURE 2 Infrared image showing classic temperature differentials. The cold spots are an average 60°F cooler than the mat as a whole. These spots are likely to fail before the rest of the mat.

an infrared camera do not always signify low-density areas. Therefore a method was developed to identify temperature differentials with handheld devices such as an infrared camera or temperature gun and then immediately investigate the potential low-density areas. The method was tested on 17 projects and found to work well. A threshold value was developed—when the temperature differential was 25°F or more, troublesome low densities were likely, with increases in air voids of greater than 4 percent occurring 82 percent of the time. Below the 25°F threshold, low densities were not likely.

Stage 5: Specification (2002–2006)

Standard random quality assurance sampling could not identify the low densities resulting from temperature differentials because the areas were small in size and the causes were recurrent. Washington State DOT therefore developed a three-step specification to counter the detrimental effect of temperature differentials:

- Locate temperature differentials with a handheld infrared camera or temperature gun.
- If the temperature differential between a particular location and the surrounding mat is 25°F or greater, perform nuclear density testing at the cool spot.
- If the densities are verified as unacceptably low, with a minimum of four locations per density lot, a

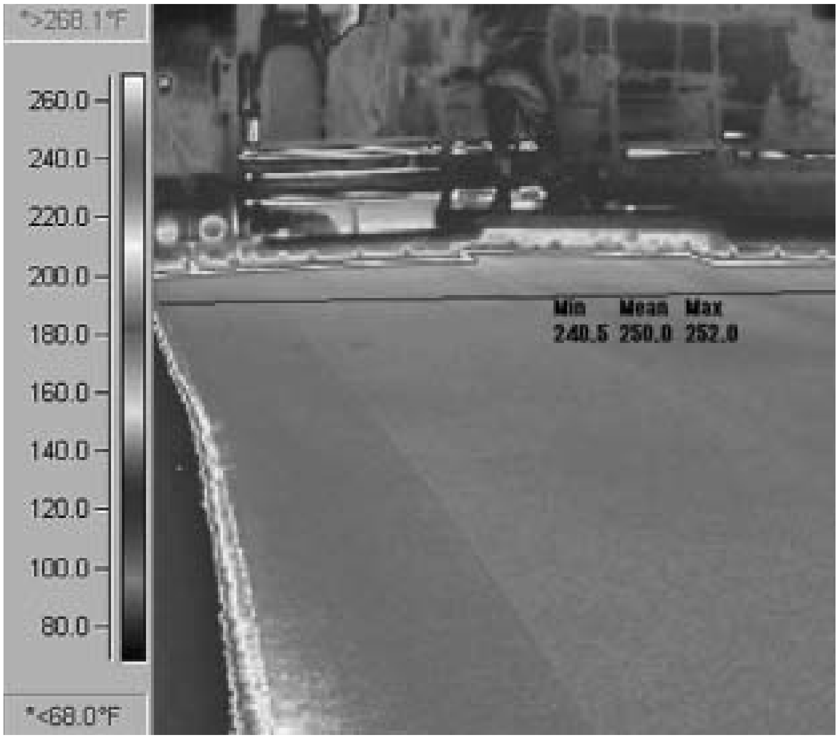

FIGURE 3 Infrared image showing a mat with uniform temperature as a result of remixing in a material transfer vehicle before the paver.

penalty of 15 percent of the HMA unit price for the affected lot of material is assessed on the contractor.

Temperature differentials always have been present in HMA pavement construction to some degree. Washington State DOT personnel and the research team have had 30 years of experience with cyclic open-textured HMA. Some early occurrences may have been misidentified as aggregate segregation, which is another problem. Improvements made in the past 20 years—with better construction quality, the elimination of more pressing problems, and tighter HMA and aggregate specifications—have highlighted the detrimental effects of temperature differentials and the low-density areas that result.

Application

In Washington State, the specification detailed in Stage 5 is a standard in all 2006 paving contracts. A slightly modified version of the specification has been used in more than 60 select HMA paving projects since 2002.

Washington State DOT has seen an increase in the use of MTVs and a decrease in temperature and density differentials. Although using an MTV does not guarantee that temperature differentials will be eliminated, temperature differentials observed during construction have decreased significantly, as have the early failures that they cause.

Benefits

Since 1995 Washington State DOT research on cyclic segregation in HMA pavements has identified the following:

- The cause of cyclic segregation, which results in low-density areas;
- The mechanism of the formation of low-density areas; and
- The contributing construction factors.

Washington State DOT also developed a systematic method of identification and a rational specification to eliminate the problem.

The cost savings of eliminating temperature differentials are difficult to estimate. Washington State DOT uses approximately 1.5 million tons of HMA for paving in each construction season at a current average cost of $60 per ton. If reducing temperature differentials could prevent a potential 20 percent loss of pavement life on half of the state's projects, the savings would amount to approximately $9 million per year.

Related Websites

- Complete project report: http://depts.washington.edu/trac/bulkdisk/pdf/476.1.pdf
- Summary of the investigation: www.wsdot.wa.gov/biz/mats/Pavement/Technotes/TemperatureDifferentialTechNote2001. pdf
- Summary of the specification: www.wsdot.wa.gov/biz/mats/Pavement/Technotes/CyclicDensitySpec2004.PDF
- Images from infrared camera investigations by other states—notably Maryland, Texas, Minnesota, Connecticut, and California: http://sptc.ce.washington.edu/InfraredImages/search. asp

For more information about this research article, please contact Kim Willoughby, WSDOT Research Manager, 310 Maple Park Avenue SE, P.O. Box 47372, Olympia, WA 98504-7372, telephone 360-705-7978, fax 360-705-6911, e-mail willouk@wsdot.wa.gov.

EDITOR'S NOTE: Appreciation is expressed to G. P. Jayaprakash, Transportation Research Board, for his effort in developing this article.

Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail gjayaprakash @nas.edu).