Effect of field condition parameters on the performance of geosynthetic-based interlayer systems used to control reflective cracking in hot-mix asphalt overlays

Baek, J., Al-Qadi, I. L.[*], & Buttlar, W. G.
Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Illinois, USA
Vespa, J.
Bureau of Materials and Physical Research, Illinois Department of Transportation, Illinois, USA
[*]Corresponding author: alqadi@illinois.edu

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ABSTRACT: This study evaluated the performance of geosynthetic interlayer systems to control reflective cracking in hot-mix asphalt (HMA) overlays and determined the main field conditions that affect their performance. Four interlayer systems, which are utilized in the state of Illinois, were chosen for this study: area-type non-woven fabric interlayer, strip-type non-woven fabric interlayer, strip-type self-adhesive fabric interlayer, and strip-type three-layered composite interlayer. Based on a visual crack survey, the condition of the HMA overlays was evaluated in terms of the extent and severity of reflective cracking. A performance benefit ratio (PBR) was determined to represent the relative performance of an interlayer system. Statistical analysis showed that the PBR of the composite interlayer system is a function of traffic volume, lowest temperature, and joint spacing; the PBR decreases as the traffic volume, temperature, and joint spacing increase. However, the performance of the Geosynthetic interlayer systems was insensitive to all the parameters.

1 INTRODUCTION

Hot-mix asphalt (HMA) overlays are commonly used to rehabilitate deteriorated pavements. Despite HMA's numerous applications and utmost effectiveness, reflective cracking still remains a critical problem that appears early in a pavement's service life and cannot be completely prevented. Typically, when jointed concrete pavements (JCPs) are resurfaced with HMA overlay, reflective cracking develops within two years after the overlay construction. In a JCP, considerable stresses intensify in the vicinity of a joint because excessive bending and shear movements are induced in that location. When HMA is not capable of enduring the applied stresses, reflective cracking eventually develops. Additional deteriorations progress in the sub-layers and the overlay due to moisture penetration through the reflective cracks. Hence, an efficient technique is needed to properly prevent and/or reduce reflective cracking.

Interlayer systems have effectively delayed the occurrence of reflective cracking and/or lessened its severity. An interlayer system consists of a relatively thin single layer or multiple layers and is installed at the bottom of or within the HMA overlay. Reflective cracking can be controlled with two distinct mechanisms: strength reinforcement and strain absorption. Geogrid, fiberglass grids, and metallic grids are typically used for reinforcement. These materials are relatively stiffer than the surrounding HMA to compensate for the HMA's lack of strength and to reduce deflection of the HMA overlay. On the contrary, interlayer systems made of softer materials are designed as an isolation layer to dissipate strain energy occurring in the HMA overlay. Non-woven geosynthetics, stress absorbing membrane interlayer (SAMI), and interlayer stress absorbing composite (ISAC) are good examples in this category. Despite successful applications of various interlayer systems in many circumstances, little effectiveness or negative performance was also reported in several projects (Predoehl 1989, Buttlar et al. 1999, and Al-Qadi et al. 2008). Inappropriate installation of interlayer systems and existing pavement conditions were regarded as the primary causes of the many futile cases. However, other potential factors related to the interlayer systems' performance were not addressed.

Therefore, the objective of this study is to determine key parameters that affect the ability of interlayer systems to control reflective cracking in HMA overlays. To accomplish this research objective, pavement distress surveys were conducted to investigate the status of HMA overlays regarding reflective cracking. Based on the field observations, the performance of four geosynthetic interlayer systems was evaluated with a reflective cracking index. Then, a statistical analysis was utilized to examine the effect of the HMA overlay design parameters on the performance of the interlayer systems.

2 FIELD CRACK SURVEY

2.1 *Survey Sections*

Visual pavement distress surveys were conducted for 15 HMA overlay sections across Illinois. The state of Illinois is located in the eastern north-central part of the United States where the average low temperature in winter is -9°C in the north and -2°C in the south while the average summer temperature ranges from 27°C to 16°C (Illinois State Climatologist Data 2009). Illinois' oldest HMA overlay was built in 1988, i.e., its service life is 20 years as of 2008; while its youngest was constructed in 2000, i.e., its service life is 8 years as of 2008. The youngest HMA overlays were constructed on jointed concrete pavements (JCPs) in eleven sections and on existing HMA overlaid JCPs in four sections. No major rehabilitation has been performed after the last overlay construction; only routine maintenance has been performed. The typical overlay thickness used for Illinois off interstates is 5.7 cm, which includes 3.8-cm-thick wearing surface and 1.9-cm-thick leveling binder. The average HMA overlay thickness surveyed in this study is 6.0 cm with standard deviation of 0.9 cm. Most sections are two-lane highways or city roads. According to IDOT (2008), the annual traffic volume used for a design lane of these sections varies from 21,000 to 308,000 80-kN equivalent single axle loads (ESALs). Joint spacing of these sections is 10 m except for one section that is 17 m and two sections that are 33 m.

2.2 *Interlayer Systems Evaluated*

Four types of geosynthetic-based interlayer systems were evaluated in this study: area-type System A (designated as AA); strip-type System A (SA); strip-type System B (SB); and strip-type System D (SD). According to IDOT overlay specification (Schutzbach 1995), System A consists of non-woven reinforcing fabrics and is attached to a pavement using a tack coat. System B consists of woven or non-woven reinforcing fabrics to which a waterproofing membrane is attached and can be easily installed to a pavement via a self-adhesive bitumen material. System D has a sandwich-like structure where a rubberized asphalt core layer is surrounded by two geotextiles having opposite functions (Dempsey 2002). A top layer made of a very stiff and high-strength woven geotextile compensates for the HMA overlay's lack of strength while a bottom layer is comprised of a low stiffness non-woven geotextile and easily deformed to adhere strictly to an underlying layer. The middle asphalt layer not only dissipates strain energy but also binds the two layers. This system, developed in the 1990s, is referred to an interlayer stress-absorbing composite (ISAC). Strip-type interlayer systems are placed over small regions at discontinues while area-type interlayer systems cover entire lanes. System A can be used as both strip- and area-type; the other interlayer systems should be used as strip-type. Strip-type interlayer systems are applicable to all bases, but the area-type interlayer systems can be installed only for flexible bases.

2.3 *Crack Survey*

Previous research has recorded crack extension and severity for several years after overlay construction (Al-Qadi et al. 2009). Based on the Federal Highway Administration Distress Manual (Miller and Bellinger 2003) and Illinois crack survey guidelines (Al-Qadi et. al 2009), the cracks were classified into four levels of high, medium, low, and starting depending on crack width and the existence of adjacent cracks. To combine the extent and severity of cracks, previous research proposed the following two performance indices that depend on how easy it is to identify reflective cracking (Baek et al. 2008): weighted reflective cracking appearance ratio (R_{RCAW}) and weighted transverse cracking appearance ratio (R_{TCAW}). The R_{RCAW} is a weighted number of transverse reflective cracks per a joint if the reflective cracking can be differentiated from other transverse cracks. Crack severity is considered by means of a linear weighted factor: 0.75, 1.50, 2.25, and 3.00 for the starting-, low-, medium-, and high-severity-level cracks, respectively. The R_{RCAW} ranges from 0.0 (no reflective cracking) to 3.0 (high-severity-level reflective cracks at all joints). The R_{TCAW} is defined as the total number of transverse cracks per unit length, which represents the overall condition of HMA overlays regarding all transverse cracks. The R_{TCAW} remains zero when no cracking is observed, and it does not have an upper limit because an unlimited number of transverse cracks can exist. In this study, the R_{RCAW} was computed only for sections where joint locations were specified, while the R_{TCAW} was used for the other sections.

3 PERFORMANCE OF THE INTERLAYER SYSTEMS

3.1 *Performance Benefit Ratio (PBR)*

The performance of interlayer systems was evaluated using the two performance indices. Figure 1 shows the R_{RCAW} variations over the age of the HMA overlay with and without strip-type System D in a surveyed section. The R_{RCAW} increases with respect to overlay age in the treated and untreated sections, but the R_{RCAW} rate of increase, i.e., deterioration rate is different. In the untreated section, the R_{RCAW} jumps to 1.40 at the first evaluation year (three-year-old), then gradually increases, and finally converges to 1.77 at the end of the evaluation period (six-year-old). In the treated section, the R_{RCAW} increases gradually at the beginning of the evaluation period and starts to increase sharply at the fifth year. Hence, the performance benefit of the SD in this section decreases as the overlay ages.

Based on the area under the R_{RCAW} – overlay age, the performance benefit of the interlayer systems is determined to account for the nonlinearity of the curve. Relatively smaller area under the curve of the treated section indicates better performance. The performance benefit ratio (PBR) is defined as the ratio of area under the curve of the untreated section (A_{un}) to that of the treated section (A_{tr}). For the other interlayer system, however, the R_{RCAW} and overlay age have a linear relationship so that the PBR was alternatively defined as the ratio of the slope of the R_{RCAW} – overlay age curve of the untreated section to that of the treated slope (Baek et al. 2008).

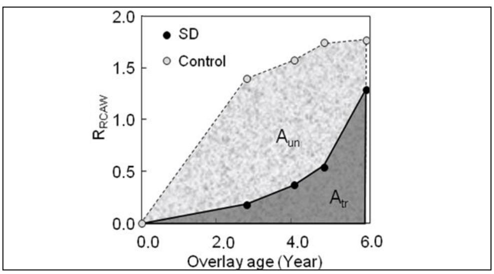

Figure 1. R_{RCAW} versus overlay age for an untreated and treated section.

3.2 *Performance of the Interlayer Systems*

A representative PBR was determined at each evaluation period for all the interlayer systems. For the AA, SA, and SB, the representative PBR was regarded as the average PBR over the evaluation period because the PBRs were not sensitive to overlay age. The representative PBR of the SD was determined as long-term performance corresponding to ten-year-old HMA overlay because the PBR of the SD is a function of overlay age. For each interlayer system, the PBRs vary in different ranges: 0.92 to 1.65 for the AA; 0.51 to 1.08 for the SA; 0.97 to 1.10 for the SB; and 1.68 to 1.95 for the SD (Fig: 2). Based on the average PBR of each interlayer type, the performance benefit of the SD (average PBR of 1.82) and AA (average PBR of 1.21) is effective; the SB is marginal (average PBR of 1.03); and the SA is ineffective (average PBR of 0.74). Under the assumption that the PBR follows normal distribution, the probability of failure to control reflective cracking effectively ten years after the overlay construction, P_f (PBR < 1.0), can be obtained using the average and standard deviation of the PBR. The P_f becomes 20.6%, 86.2%, 36.8%, and 0.0% for the AA, SA, SB, and SD, respectively. The performance of the SD is effective for 15.7 and 21.5 years with a 95% and 50% confidence level, respectively. Hence, the SD can be regarded as the most reliable method unconditionally to control reflective cracking for the HMA overlay service life of ten years. On the other hand, since the P_f of the SA is significantly high, the performance of the SA can be regarded as ineffective. For the AA and SB, the P_f is not significantly higher than that of the SA, but they have still higher chances of being ineffective. The performance of the interlayer systems varies with location, meaning that these interlayer systems are only able to control reflective cracking conditionally when they are used in suitable conditions. Hence, for each interlayer system, the specific conditions in which a beneficial performance can be achieved need to be identified.

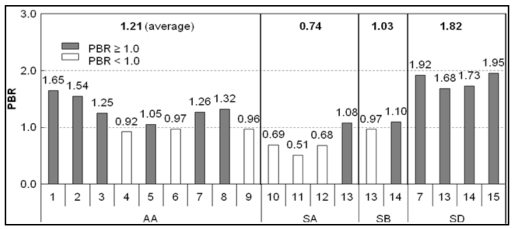

Figure 2. Performance benefit ratio of the interlayer systems.

4 EFFECT OF OVERLAY DESIGN VARIABLES ON THE PERFORMANCE

The evaluated HMA overlays were constructed with different pavement designs and have been exposed to various traffic and environmental conditions. Statistical analysis was conducted to examine the possibility that overlay design variables affect the performance of interlayer systems. The potential variables evaluated include overlay thickness, existing pavement type, traffic volume, temperature, and joint spacing. Wherein, the existing pavement type represents the use of a previous HMA overlay. Since only numeric data should be given for the statistical analysis, 0 and 1 were specified to indicate "no previous HMA overlay exists" and "previous HMA overlay exists," respectively. Also, the traffic volume and the temperature were given as annual ESALs on a design lane and the lowest monthly temperature in a year. The SB was excluded in this statistical analysis because only two data were available.

Based on the coefficient of correlation (CC), the degree of linearity and relationship between the PBR and potential variables were evaluated. The CC ranges from -1.0 to 1.0 and becomes positive if one variable increases as the other variable increases. The greater the absolute value of the CC, the stronger the correlation becomes. The magnitude as well as the sign of the CC is different for each interlayer system as well as each variable (Table 1). The results showed that, overall, traffic volume and joint spacing always adversely influence the PBR of all the interlayer systems. So, regardless of interlayer system type, a lower PBR is expected when a HMA overlay is constructed on a high volume road with longer joint span concrete pavement. The other variables have different roles in the PBR for each interlayer system. Overlay thickness positively influences the PBR of the SA and AA but negatively influences that of the long-term SD. When a previous HMA overlay exists, both of the SD sections have better performance, but the SA section shows worse performance. For temperature, the SB and SD have the same trend where the PBR increases as the lowest temperature during winter increases. The AA has an opposite trend which is not stronger than the others.

Table 1. Coefficient of correlation between overlay design parameters and the PBR of the interlayer system

Overlay design parameter	AA	SA	SD
Overlay thickness	0.67	**0.98**	-0.69
Existing pavement type	0.15	**-0.93**	**0.98**
Traffic volume	-0.51	-0.68	-0.12
Temperature	-0.49	0.66	0.64
Joint spacing	-0.57	N/A	-0.55

5 SUMMARY AND CONCLUSIONS

In this study, four types of interlayer systems were evaluated for their ability to control reflective cracking in HMA overlays. The evaluated interlayer systems were non-woven polypropylene reinforcing fabrics (System A); woven or non-woven reinforcing fabrics with a self-adhesive bitumen waterproofing membrane (System B); and a sandwich-like structure having a rubberized asphalt core layer and two surrounded geotextiles (System D). Depending on the application region, the System A is used as an area type (AA) and a strip type (SA) and the System B and System D are always used as strip types (SB and SD, respectively). The performance benefit of each interlayer system was evaluated using the proposed performance benefit ratio (PBR) which is the area ratio of the performance indices versus the overlay age curve for untreated and treated overlay. Then, the effect of several variables related to HMA overlay design on the performance of the interlayer systems was examined. This study resulted in several conclusions about interlayer systems:

- The most significant variable to affect performance is different for each interlayer system.
- The performance of the AA, SA, and SB is not sensitive to overlay age.
- The performance of the SD is highly dependent on overlay age; its short-term performance is significantly higher than that of the other interlayer systems; its long-term performance is still marginally effective.
- The SA achieves a better performance when the new HMA overlay is thicker and was constructed over existing HMA pavements.
- The SD has enhanced long-term performance when a previous HMA overlay existed.

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