JOINT TRANSPORTATION RESEARCH PROGRAM

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Mechanical Properties of Durable Pavement Marking Materials and Adhesion on Asphalt Surfaces

Introduction

The goal of this project was to evaluate the properties and performance of both temporary and permanent pavement marking materials that are currently used for asphalt and concrete pavements in the Midwestern United States. Research objectives were to (1) design and optimize new testing and analysis methods to characterize the mechanical and adhesive properties of pavement marking materials; and (2) evaluate the structure and properties of commercially available pavement marking materials and assess their durability on pavement surfaces maintained at different temperatures and ages. Commercially available temporary pavement marking (TPM) tapes and thermoplastic materials used as permanent pavement markings (PPM) were the pavement marking materials selected for investigation in this project.

Methods

To address the first research objective, the Tape Drape Test was first developed to measure the elasticity of TPM tapes in a non-destructive way that required minimal instrumentation. Next, a modular peel fixture was constructed to measure the force required to peel TPM tapes from immovable substrates and validated through a series of peel tests on consumer tapes and model surfaces. Finally, the peeling and tearing behavior of TPM tapes was investigated using a new metric for tape removability called the Tear Resistance Ratio.

To address the second research objective, the viscoelastic properties and critical transition temperatures of TPM tapes were measured by performing dynamic mechanical analysis of the tape's top layer and adhesive layer and by peel testing using the modular peel fixture in conjunction with smooth model pavement surfaces maintained at temperatures ranging from -20 to 40°C (-4 to 104°F). The adhesive performance of TPM tapes was then determined for tapes applied to asphalt core surfaces that were subsequently aged from 1 day to 5 months at -25, 25, and 32°C (-13, 77, and 90°F). For thermoplastic PPM, laboratory tests were first performed to measure the thermal degradation, fracture toughness, and flexural behavior of the thermoplastic materials. Then shear adhesion tests were conducted to determine how the adhesion of the different thermoplastic materials was influenced by characteristics of the asphalt surface (including surface temperature, surface roughness, sealant treatment) and aging duration and temperature.

Findings

The Tape Drape Test yielded quantitatively similar modulus values for most commercial TPM tapes in comparison to conventional testing techniques and also resulted in more realistic modulus values for tapes with raised surface patterns. For the variety of commercial tapes that were tested with the modular peel fixture, higher peel strengths were observed for tapes with reinforced backing layers and tapes adhered to smooth surfaces. For the relatively slow testing rates investigated in the project, all commercial TPM tapes had Tear Resistance Ratios greater than 1, indicating that tapes were more likely to peel rather than tear during removal.

For TPM tapes, the critical transition temperatures were used to define an effective operational temperature range for each tape. Measurement of peel strength from model smooth surfaces maintained at temperatures within the operational temperature range revealed that less force was required for tape removal as the surface temperature was increased from 0 to 40°C (32 to 104°F). For some tapes, reduced peel forces were measured at -20°C (-4°F) and brittle broken fracture was observed when the temperature was below the tape's critical transition temperatures. When tapes were applied to asphalt core surfaces, peel forces were approximately constant for most tapes for 3 months of aging at 25 and 32°C (77 and 90°F), while the peel force significantly decreased for all tapes within 1 week of aging at -25°C (-13°F). Ghost markings were observed for some tapes and were more likely at higher aging temperatures. The inherent mechanical properties of the TPM tapes appeared to influence their adhesive performance on asphalt surfaces, with relatively more flexible, low-moduli tapes exhibiting greater adhesion than less flexible, high-moduli tapes. However, the unknown chemical contributions of the tape's pressure sensitive adhesive layer to its overall adhesion to asphalt obfuscate the structure-property-performance relationships of these materials.

For thermoplastic PPM, the shear adhesion test proved to be a practical measure of debonding (failure) energy of thermoplastics materials applied to asphalt surfaces. Better adhesion was observed for PPM applied at increased asphalt surface temperatures. Native (un-cut) asphalt surfaces also resulted in improved adhesive performance than smooth (cut) surfaces. Initially, thermoplastic PPM applied to surfaces sealed with rapid penetrating emulsions (RPE) were more likely to fail at higher energies and in a cohesive manner compared to untreated asphalt surfaces. After 5 months of aging, PPM thermoplastics exhibited decreased debonding energies at all aging temperatures. At the coldest temperature (-25°C), the RPE treatment resulted in very low debonding energies and adhesive failure whereas thermoplastics applied to untreated surfaces displayed larger debonding energies and primarily cohesive failure. The inherent mechanical properties of the PPM thermoplastics also influenced their adhesive performance on asphalt surfaces, with the more ductile thermoplastic exhibiting greater adhesion to both smooth and rough asphalt surfaces than the more brittle thermoplastic.

Implementation

While future field testing is needed, over the course of this project no single product or pavement marking type demonstrated superior performance in all situations. Therefore, INDOT should continue to consider a wide variety of pavement marking products for inclusion on the list of approved construction materials. The four testing and analysis methods demonstrated in this project—the Tape Drape Test, the peel tests utilizing the modular peel fixture, the Tear Resistance Ratio, and the shear adhesion test—could be implemented by engineers tasked with evaluating the performance of new pavement marking products for the INDOT New Product Evaluation Committee as well as by manufacturers of TPM tapes and PPM thermoplastic materials.

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