UNDERSTANDING WORKABILITY BEHAVIOUR OF MULTI-LAYER PLASTIC MODIFIED ASPHALT CONCRETE WITH TEMPERATURE

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ABSTRACT: Post-industrial multi-layer plastic packaging (MPP) products face numerous challenges to their successful recycling or reuse. However, the presence of valuable polymers in MPP makes it a promising candidate for utilizing this recycled material stream in flexible pavements. This presents a feasible route towards greater sustainability and enhanced performance while alleviating the burden upon industrial waste streams. This study evaluates moderate to high-concentration MPP-modified asphalt mixtures produced from a small-scale plant trial. MPP-modified mixes exhibit different workability characteristics that change with temperature compared with conventional HMA. Understanding the workability of MPP-modified mixes plays a key role in the successful implementation of this technology. This aspect is typically overlooked at the laboratory scale as the mixes are produced under ideal conditions. The results of the study indicate that although high-concentration MPP-modified mixes can meet the general design requirements, mix workability can govern the maximum practical dosage for scaling up the technology. Based on the results, workability and compaction testing should be supplemented with asphalt mix performance testing, including cracking resistance, rutting resistance and stripping susceptibility tests, to further characterize the longer-term behaviour of MPP-modified asphalt mixes.

1. INTRODUCTION

1.1 Background

Continual improvements to pavement materials are necessary to minimize pavement distress and extend pavement structural service lifespans in a sustainable and economically viable manner, particularly to mitigate ongoing impacts on transportation infrastructure from increasing traffic loading and demand, as well as the effects of global climate change. As of 2017, it was estimated that there were over 1.13 million two-lane equivalent kilometres of public roadways in Canada, approximately 40% of which are paved with a bound surface material, and approximately 48% of all paved roads are estimated to be in poor or very poor condition (Transport Canada, 2023; CIRC, 2019). As Canada's roadways are among its largest infrastructure assets, the increased use of recycled or waste streams from other industries in both flexible and rigid pavements offers a feasible route toward improved sustainability and performance.

Since the 1950s, the use of synthetic plastic materials derived from polymers has become commonplace in a variety of industrial and consumer applications. In the 1980s, the first true polymer-modified asphalt (PMA) materials came into commercial production, and due to their increasing usage, the USA's Strategic Highway Research Program (SHRP) began developing the first North American standards and specifications for PMAs by the end of that decade (Zhu, Birgisson & Kringos, 2014). However, post-industrial plastics continue to face numerous challenges in their successful recycling or reuse, which helps divert them from diminishing landfill capacity and prevents their accumulation in the environment. This study examines the use of moderate- to high-concentration recycled multi-layer plastic packaging (MPP) material in asphalt concrete mixes to sustainably divert materials that would otherwise be destined for disposal after a single use.

1.2 Objectives

Diverting MPP waste streams from landfills presents several challenges; incorporating MPP into asphalt mixes not only provides a sustainable and economical pathway for this waste stream but also has the potential to improve pavement performance, thereby reducing the need for potentially costly maintenance and rehabilitation. Previous studies by Qabur, Baaj and El-Hakim (2022) have demonstrated the ability to successfully incorporate MPP modifiers into asphalt using the "wet method". However, this study presents the findings of a small-scale plant trial of moderate- to high-concentration post-industrial recycled plastic materials using the "dry method" of modification. This study seeks to establish and improve practical production methods and to further characterize hot mix asphalt (HMA) blends incorporating MPP materials, through the following objectives:

- To produce MPP-modified HMA mixes with moderate to high MPP percentage weight contents (1% and 2% by mix weight) in a conventional plant setting.
- To test and examine the plant-produced mixes to determine the influences and effects of MPP modification upon asphalt concrete workability and constructability.

2. METHODOLOGY

2.1 Production Trial

As part of this study, a plant-scale asphalt production trial was carried out in November 2023, examining a series of four asphalt concrete mixes: a Control HMA using a conventional Hot Laid 3 (HL3) surface course production mix design incorporating solely natural aggregate materials, and three experimental mixes using the same HL3 design scaled to include 1% or 2% MPP pellets blended into the mixture on a weight basis. The Control Mix was produced using a locally sourced PG 52-34 asphalt cement at 5.0% asphalt content (AC%) by weight of the mixture, which was incrementally scaled down for the test blends containing MPP to accommodate the anticipated partial melting of its polymer components at the target mixing temperature (148°C). These proportions are presented in Table 1. A variant of the 2% MPP test mix was produced using Evotherm M1 Warm Mix Asphalt (WMA) additive as a compaction aid, blended into the asphalt cement at a typical proportion of 0.3% by weight of the binder fraction.

Table 1: List of plant-produced asphalt concrete trial blends.

Test Blend	MPP Content	AC Content
Control Mix	-	5.0%
1% MPP	1.0%	4.9%
2% MPP	2.0%	4.8%
2% MPP + WMA	2.0%	4.8%

The processed MPP materials were pelletized to facilitate their incorporation as additives in this study (Figure 1). MPP pellets are composed of 85% to 90% polyethylene (PE), with the remainder being a mixture of polyethylene terephthalate (PET), nylon (NY) and metalized polyester (METPET) with an approximate composite density of 0.95 g/cm^3. The primary component, PE, has a melting temperature in the range of 120 to 135°C. A hand sample of the 4% MPP-modified test mix from an earlier plant production trial is shown in Figure 2, which displays characteristic interconnections in the mixed asphalt resulting from the inclusion of partially melted recycled MPP material.



Figure 1: A sample of processed MPP pellets.



Figure 2: View of a hand sample of mixed 4% MPP HL3 HMA. (Image by A. Qabur)

2.2 Laboratory Testing Program

Samples of each HMA Control and experimental mix were retrieved from the plant site and were then stored separately for subsequent laboratory testing. Initially, asphalt Maximum Relative Density (MRD, or G_{mm}) tests were conducted in accordance with MTO Test Method LS-264 and AASHTO T 209.

A Pine Instrument Co. Superpave Gyratory Compactor apparatus was then used in conjunction with the compatible Dongré Workability Test (DWT) procedure to test the workability of each asphalt concrete mix. The DWT procedure employs a series of constant loading rates on a 4810 g sample of loose, uncompacted asphalt material in a standard 150 mm-diameter metal cylindrical mould. The DWT procedure involves the Superpave compactor pushing vertically, without any gyrating action, at constant loading rates of 4.00 mm/s until 25 kPa normal stress is reached, then 1.50 mm/s from 25 to 40 kPa normal stress, and finally 0.05 mm/s until the test terminates at 700 kPa normal stress. The slope of applied stress versus percentage strain is then calculated between the points at which normal stresses of 550 kPa and 650 kPa are achieved,

to obtain the DWT workability index per Equation 1 below (Williams, Braham & Casillas, 2023). This value is typically higher for materials that are easier to manipulate and lower for those that are more difficult to manipulate. DWT index threshold values of 150 kPa and 170 kPa are typically recommended as nominal limits for estimating mix temperatures during field compaction.

$$[1]\ W = \frac{\sigma_{650} - \sigma_{550}}{\varepsilon_{650} - \varepsilon_{550}}$$

where:

W = DWT workability index (kPa);
σ_{650} = normal stress at the point nearest to 650 kPa;
σ_{550} = normal stress at the point nearest to 550 kPa;
ε_{650} = volumetric strain (%) at the point nearest to 650 kPa normal stress; and
ε_{550} = volumetric strain (%) at the point nearest to 550 kPa normal stress.

DWT procedures were carried out on each of the four asphalt concrete mixes at the mix design compaction temperature of 138°C, as well as at lowered temperatures of 123°C and 108°C, to examine the effects of temperature drops upon the workability of each mix. Following completion of each DWT procedure, each specimen was compacted using Superpave gyratory cycles at a standard 600 kPa applied stress until a final specimen height of 115 mm or 250 gyrations, whichever was reached first.

3. RESULTS AND ANALYSIS

DWT testing indicated that the conventional Control Mix exhibited higher workability index values at all test temperatures relative to the 1% MPP test mix, which in turn met or exceeded the corresponding workability values of the 2% MPP test mixes with and without the Evotherm M1 WMA additive. At the 108°C test temperature, both of the 2% MPP test mixes' workability values fell below the 150 kPa level recommended for the final roller compaction temperature. This indicates that high levels of MPP inclusion, along with the partial replacement of some of the PG 52-34 AC content, leads to the vulnerability of these mixes' compactibility properties to temperature drops that normally occur between production at the asphalt plant and placement and compaction at the work site. The DWT test results are summarized in Table 2 and Figure 3 below.

Table 2: Numerical summary of DWT test results for the test mixes.

Test Blend	DWT Average at 138°C (kPa)	DWT Average at 123°C (kPa)	DWT Average at 108°C (kPa)	Est. Breakdown Roller Temp. (DWT=170 kPa)	Est. Final Roller Temp. (DWT=150 kPa)
Control Mix	369.5	320.5	297.3	<80°C	<80°C
1% MPP	283.3	253.1	195.0	97.9°C	91.1°C
2% MPP	193.2	185.1	141.9	120.5°C	108.4°C
2% MPP + WMA	216.4	192.6	138.8	117.8°C	110.0°C

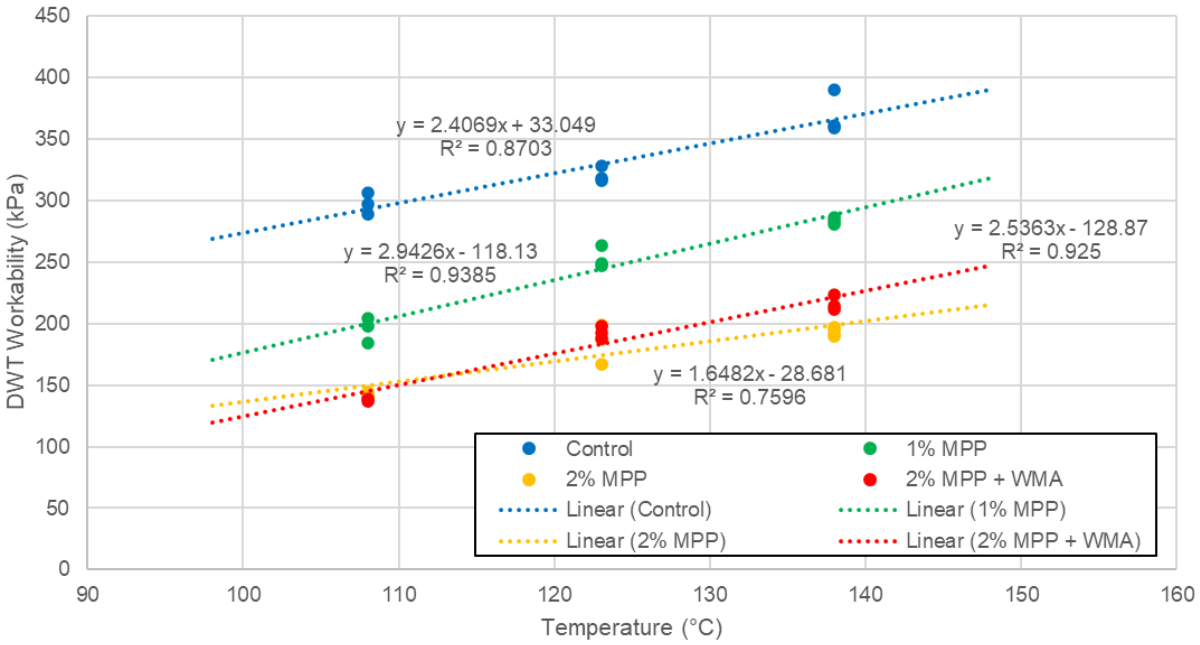


Figure 3: Summary of DWT results for the test mixes.

Although it was anticipated that the inclusion of MPP material in asphalt concrete mixes would lead to lower DWT workability values, given the addition of polymers which primarily melt and solidify in the range of 120°C to 135°C, it is unclear why the addition of the Evotherm M1 WMA additive led to minimal, if any differences between the two 2% MPP test blends. It is possible that the WMA additive lost effectiveness in the period between mixing at the plant (in late 2023) and DWT testing (in early 2024). Additionally, the plant where the trial occurred recorded a mixing temperature of 173°C for the 2% MPP test blend incorporating the WMA additive, which is well above the mixing temperature of 148°C originally prescribed in the Control Mix's Job Mix Formula (JMF), and also above the typical mixing temperature range for WMA, which generally lies in a range from 100°C to 150°C. The elevated mixing temperature may have led to the degradation of the WMA additive, preventing it from achieving its intended impact as a mix compaction aid.

It is therefore recommended that future mix workability testing should be carried out on trial mixes incorporating both MPP material and WMA additives for further examination, and that any such trial mixes should be blended at temperature levels which are appropriate to WMA materials.

4. CONCLUSIONS

This research utilized the Dongré Workability Test (DWT) procedures to assess the impact of MPP on the workability of asphalt concrete mixes. The samples were obtained from a small-scale plant trial of moderate to high-concentration MPP-modified asphalt blends. The samples were subjected to the DWT procedure followed by Superpave gyratory compaction cycles. Based on the findings presented, the following conclusions can be drawn:

- The inclusion of MPP materials in asphalt concrete blends at moderate to high concentrations negatively affected test-mix workability. It increased the minimum temperatures required for proper compaction in field settings.
- The addition of Evotherm M1 WMA additive did not significantly affect the workability properties of the asphalt mix at the 2% MPP content level. Still, its impact as an intended compaction aid may have been diminished or nullified by excessive mixing temperatures and/or time between mixing and compaction.

- It is possible to maintain adequate workability properties at the 1% MPP content level across a range of feasible mix temperatures, including the mid-90s Celsius and above. Further testing and optimization efforts should focus on MPP inclusion levels up to and including 1% by mix weight proportion.

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