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Preliminary experience with improved asphalt cement specifications in the City of Kingston, Ontario, Canada

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HIGHLIGHTS

- Acceptance testing for HMA is best done on extracted and recovered asphalt cement.
- Both DENT and EBBR tests are highly sensitive to the quality and durability of the asphalt cement.
- Implementation of DENT and EBBR for material acceptance provides improved grading.
- Phase angle is a property that deserves further investigation for specification grading.
- Recycling of REOB, RAP and RAS must be controlled in the interest of sustainability.

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ABSTRACT

The City of Kingston in Ontario, Canada, has implemented improved asphalt cement specifications, implemented double-edge-notched tension (DENT) and extended bending beam rheometer (EBBR) tests on paving contracts, and set reasonable acceptance criteria. Several contracts from 2009 and 2010 showed unanticipated, premature and excessive cracking, possibly due to contamination or overheating of the asphalt mix, or other issues unforeseen during the pavement design process. However, more recent contracts investigated for this study are expected to perform well, highlighting the importance of testing the asphalt cement recovered from the loose mix and of using appropriate specification tests and acceptance criteria.

1. Introduction

The quality of Canada's road infrastructure is deteriorating. Currently, approximately 38% of our roads rate as being in fair, poor or very poor condition (Canadian Infrastructure Report Card 2016 [1]). Across Canada, $48 billion-worth of municipal roads are in poor or very poor state and $73 billion-worth in fair state only. Maintaining the networks at their current state would take a reinvestment rate of 2–3%/year. With the actual replacement rate estimated at 1.1%/year, the condition of roads is bound to worsen over time. The Office of the Auditor General of Ontario reports a 50–60% decline in the lifespan for Ontario roads over the last 25 years, largely due to poor practices and materials [2].

Many smaller cities and towns are not spending the recommended 2–3%/year to keep their networks in good condition. Municipal staff often lack detailed expertise on asphalt; relying instead on the contractors to do a good job and understand all the important issues. Asphalt grade requirements are determined

Abbreviations: AASHTO, American association of state transportation and highway officials; CTOD, critical crack tip opening displacement; DENT, double-edge-notched tension; EBBR, extended bending beam rheometer; HMA, hot-mix asphalt; MTO, Ministry of Transportation of Ontario; PAV, pressure aging vessel; REOB, recycled engine oil bottoms; RAP, reclaimed asphalt pavement; RAS, reclaimed asphalt shingles; RTFO, rolling thin film oven; SB, styrene-butadiene type polymer modifier.

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indiscriminately and, more often than not, quality assurance testing is incomplete. Larger cities have additional resources but they are also responsible for roads spread over a greater surface area and more kilometres of pavement, so find themselves in only a slightly better position.

Doing more with less has become the mantra of all levels of government. While the approach is laudable, it should not come at the expense of spending money wisely for long-term good or leaving taxpayers on the hook to spend more money on roads now than in the past for less service. The City of Kingston in Eastern Ontario has recognized the problem and is acting to reverse the trend.

Kingston is home to approximately 125,000 citizens. Its roads are continually challenged due to factors such as the Canadian climate and aging infrastructure. As a result, the road network has deteriorated significantly in recent years. Exposure to low temperatures is a major reason: a lot of the distress appears in the form of transverse and longitudinal cracks, starting sometimes only a few years after construction. However, there appears to be little to no alligator-type wheel-path cracking, which suggests the thickness of the pavement and subgrade stability are adequate for the prevailing traffic levels, nor is there much evidence of distress from high temperatures aside from the occasional ruts at intersections and bus stops. Hence, the main cause of road failure is aging followed by low temperature-induced cracking and subsequent moisture damage.

The grade of low-temperature asphalt cement used in downtown Kingston is −28 °C in accordance with the LTPPBind® online selection algorithm [3]. The required grade changes to −34 °C towards the northern city limits. Recovered grades often show premature physical and chemical aging, two of the most important phenomena that promote cracking. However, it is unclear if this is due to a deficiency in the quality of the virgin asphalt cement, an over-abundance of reclaimed asphalt pavement (RAP) in the mix, reclaimed asphalt shingles (RAS) contamination, overheating the asphalt mixture during production, a combination of these factors or other unknown issues. Since 2010, recycled engine oil bottoms (REOB) has been banned from the asphalt supply. Starting in 2017, recycled asphalt is banned from all hot-mix asphalt resurfacing.

By implementing better asphalt cement specifications that pay equal attention to quality and durability, and that exclude a wide range of known problem additives, Kingston is reversing the deterioration of its road system. Local contractors have adapted well to implementing the specifications, and not raised contract bid prices noticeably. A significant number of user agencies are now following Kingston's example in the hope of bringing back more acceptable performance levels. We hope that, with due diligence, pavement infrastructure becomes more sustainable throughout these jurisdictions, and city taxpayers obtain better value for money.

2. Background

The new asphalt cement specification implemented in Kingston is based on the double-edge-notched tension (DENT) and extended bending beam rheometer (EBBR) tests. These specification tests and associated acceptance criteria were developed through a long-term collaborative effort involving the City of Kingston, the Ministry of Transportation of Ontario, Queen's University, other organizations, and numerous individuals ([4–13], others).

2.1. Double-edge-notched tension testing

Our research on the DENT test was inspired by Dow (1903 [14]), who published the first account of a ductility test well over 100 years ago. Dow [15] noticed that superior-performing asphalt cements flow well before failing. In contrast, inferior quality materials, including those that were oxidized (air blown), fail abruptly. Along with penetration and softening point, ductility has become one of the most widely used and successful specification tests for asphalt cement.

Later, others described the ability of asphalt cement to flow from a colloidal science perspective. Among others, the terms "sol" to describe asphalt cement that flows readily with only minimal elasticity, and "gel" for asphalt cement that flows little were promoted by a number of researchers. Since those early publications, it has been shown on many occasions that sol-type binders outperform gel-type binders in the ductility test, and in terms of their resistance to loss of fines, raveling, cracking and moisture damage in real-world pavements ([16–18], others). Because sol-type binders flow in spring and summer, they suffer less from irreversible longitudinal and transverse cracking. Small micro-cracks and failed interfaces heal once the weather warms, which can provide a significant advantage over gelled binders that don't flow as readily [19–22]. Doyle [23], Kandhal [17] and Van Gooswilligen [18] all chose to test ductility at temperatures below 25 °C to make the testing more severe, discriminating and repeatable.

We set out to adopt the DENT test as a standard for asphalt cement testing in an attempt to model ductility in a more fundamental and refined framework. The DENT test was created to control fatigue-type cracking distress [4,8]. It is based on a fundamental essential work of ductile failure (EWF) analysis by Cotterell and Reddel [24], following hypotheses by Broberg [25]. The DENT test is conducted at a relatively fast 50 mm/min and moderate temperature of 15 °C to speed up the analysis. These conditions were chosen to mimic significantly slower speeds at lower temperatures around the freeze–thaw regime, where significant cracking is believed to occur. Time-temperature superposition appears to be valid although the shift factors for failure properties are not the same as those from rheological measurements, especially regarding polymer-modified asphalt [8]. The test is conducted on three DENT specimens with varying notch depths, providing ligaments of 5, 10 and 15 mm. This design allows for an extrapolation of specific total work of failure data to zero ligament length providing an essential work of failure energy (w_e) from which we calculate an approximate critical crack tip opening displacement (CTOD). The CTOD is the amount by which a tiny fibre (fibril) of asphalt cement can be stretched under severe constraint in the ductile state until it fails. A higher CTOD allows the pavement to flex more under traffic and therefore provide better resistance to fatigue-cracking. Of course, an upper limit exists as for very tough binders the distress arises from adhesive failure, and cracks will still appear at and above that limit.

At first glance, the DENT test appears simple, however a more detailed study shows otherwise. The shape and size of the sample have a slight effect on both w_e and CTOD, and the standardized dimensions and test parameters are compromises based on what was considered feasible when the test was developed. The original EWF analysis was developed for very thin polymer specimens exhibiting plane-stress failure, but the asphalt cement specimen used for the test is thicker to facilitate handling. The DENT specimens also require deep-enough notches to limit plastic deformation far away from the ligament. This is not always the case, especially when testing very tough polymer-modified materials which may still want to pull out of the aluminum inserts. Hence, the DENT test is best considered a "somewhat improved" ductility test.

The DENT test also provides a measure of the plastic work of failure (βw_p), which reflects the asphalt cement's ability to dissipate energy away from the failure-process zone. The current specification only sets a lower limit on the CTOD but the essential and