Comparison of Physical and Oxidative Aging Tendencies for Canadian and Northern European Asphalt Binders

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ABSTRACT

A total of 15 asphalt binders produced by Canadian and Northern European refineries were investigated for their Superpave™ performance characteristics as well as enhanced quality and durability indicators.

The grade changes due to additional oxidative aging at high temperatures in the Pressure Aging Vessel (PAV) were found to be correlated with the loss due to extended, isothermal conditioning at low temperatures in the Bending Beam Rheometer (BBR). However, the correlation was found to be dependent on the origin of the crude oil. Hence, it is useful to consider both reversible and irreversible extended aging protocols independently. Extended BBR (EBBR) grades are also correlated with the phase angle of the binder in the intermediate to low temperature range, which is a sensitive measure of durability, is correlated with pavement cracking performance, and can be measured with high precision in a short amount of time on a small amount of material.

The Fraass breaking point temperature as used in much of Northern Europe for the control of cold temperature cracking was found to show little correlation with limiting grade temperatures obtained by BBR, EBBR and Dynamic Shear Rheometer (DSR) protocols.

RÉSUMÉ

Au total, 15 liants à base de bitume produits dans des raffineries canadiennes et nord-européennes ont été examinés pour leurs caractéristiques de performance Superpave ™ ainsi que pour leurs indicateurs de qualité et de durabilité améliorés.

Les variations de teneur dues au vieillissement par oxydation supplémentaire à haute température dans le vaisseau de vieillissement sous pression (PAV) se sont avérées corrélées à la perte due au conditionnement isotherme prolongé à basse température dans le rhéomètre à flexion de poutre (BBR). Cependant, la corrélation a été trouvée dépendante de l'origine du pétrole brut. Par conséquent, il est utile d’examiner indépendamment les protocoles de vieillissement prolongé réversibles et irréversibles. Les nuances BBR prolongés (EBBR) sont également corrélées avec l'angle de phase du liant dans la plage de températures intermédiaire à basse, ce qui est une mesure sensible de la durabilité, est corrélé aux performances de fissuration de la chaussée et peut être mesuré avec une grande précision dans de cours laps de temps sur une petite quantité de matériel.

Il a été constaté que la température du point de rupture Fraass telle qu’elle était utilisée dans une grande partie de l’Europe du Nord pour contrôler la fissuration à froid montrait peu de corrélation avec les températures limites obtenues par les protocoles BBR, EBBR et rhéomètre à cisaillement dynamique (DSR).

1.0 INTRODUCTION

In northern climates it is often the cold weather that continues to be the main cause of premature pavement failures [1-5]. Ideally a pavement reaches the end of its design life due to a very slow progression of raveling, thermal and fatigue cracking, moisture damage, and rutting. If pavement thickness and material properties are carefully selected during the design process and controlled during production, and construction follows best practices, then there should be no reason for why the design life cannot be reached and why any one of the main distresses should cause an early failure. Preventative maintenance in the form of crack sealing, the application of rejuvenating seal coats, and the replacement of the surface asphalt can prolong the service life beyond the design.

However, premature raveling and excessive cold temperature cracking remain widespread in Canada, Northern Europe, and similar cold regions around the world, largely due to the fact that many asphalt binders are somewhat under-designed for the prevailing climates [1-5]. In winter the binder becomes too hard and is often unable to relax thermal shrinkage stresses through viscous mechanisms [6]. This leads to the formation of micro cracks at the mastic-coarse aggregate interface, which eventually coalesce to form bigger cracks that allow water to enter the pavement during spring thaw [7]. Once a critical amount of damage occurs, subsequent cold temperature spells can produce transverse cracks along the entire width of the pavement, with a resultant decrease in ride quality. Construction related problems can add longitudinal cracks, eventually producing block type patterns in old age.

Binder stiffness and binder relaxation ability have been recognized for a very long time as the two main properties that govern the onset and progression of cold temperature cracking [8-13]. Binders that are too stiff typically fail at lower strains and are therefore more prone to thermal shrinkage and fatigue distress. Binders that are unable to flow at cold temperatures when stressed prevent relaxation of considerable shrinkage stresses, allowing for the growth of micro cracks and thus accelerating pavement deterioration [14]. Thermal stresses are a fact of life in very cold climates, like those of Canada and Northern Europe, simply because binders would have to be too soft for practical use. In laboratory tests on restrained asphalt specimens, measured stress levels due to cold temperature exposure can easily reach as high as 2 to 4 MPa just prior to catastrophic failure [15]. A stress of such magnitude corresponds to about 200 to 400 tonnes of force along a typical two lane, two lift pavement. It is not hard to accept then that even at a small fraction of such stress, if present for a few months during winter, significant transverse cracking becomes inevitable.

One reason for why asphalt binders lose their ability to relax stresses is that they can suffer from thermoreversible aging processes. These reversible processes have been described in the asphalt literature for a very long time by names such as age hardening [16], steric hardening [17], physical hardening [18, 19], physical aging [20], reversible aging [21], and others. Binders that are cooled from high handling temperatures reach a point where flow slows down considerably. Cooling rate affects the ability to reach and maintain equilibrium, typically diminishing at higher rates and lower temperatures. So when binders are poured from high temperature for testing at a considerably lower temperature, after insufficient time to equilibrate, poorer quality materials that are high in waxes and other unstable constituents that would stiffen at low temperatures will be rewarded. In service, such poorer quality materials will continue to structure, harden, and gel for prolonged periods, eventually leading to cold temperature cracking distress [22].

A second reason for why asphalt binders lose their ability to relax thermal stresses is due to irreversible oxidation processes that occur over prolonged periods of exposure to high temperatures and/or solar radiation. This could happen during production and hot silo storage and is inevitable during long-term service [23]. The oxidation tendency of binders produced from different crude oils varies a great deal [24]. If the laboratory aging protocol used for specification grading is too permissive then, once again, poorer quality materials will be rewarded relative to superior ones. Making only minor changes to the laboratory aging protocol can have profound consequences for grade determination and long-term pavement cracking performance [23].

The objective of this paper is to provide users and producers alike with insights on how minor changes in sample conditioning and specification protocols can be implemented in a practical manner to provide much enhanced control over long-term cracking distress. More accurate and precise specifications will benefit both users and producers of asphalt cement as they help to lower risk and thus improve the sustainability of the asphalt industry.