Pavement Quality – The Forgotten Subject

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ABSTRACT

These days there is a lot of discussion about climate change and its impact on pavement infrastructure, including construction and performance. Green technologies, including alternative materials and recycling, and sustainable transportation also get a lot of attention. These subjects are important and the authors of this paper have written numerous papers on this. However, there is one subject that has somewhat became forgotten. This is pavement quality.

It is expected that since production and paving technology is getting better, and there are advanced and innovative materials, the issue of pavement quality has been solved and does not need attention. However, the reality is just the opposite. There are alarming voices in a number of provinces and among municipalities that pavement quality has drastically decreased. It is common to hear that in the past, pavements lasted 20 years, and recently you are lucky if you get half of this, and there are examples of dramatic premature failures. Some of this may be due to excessive traffic loading or extreme climate, but this are rare cases. More frequently, the problem is that the quality is ignored and taken for granted.

Pavement quality starts with pre-engineering, proper geotechnical investigation, analysis, design, appropriate specifications and quality construction. Reducing the geotechnical investigation to the bare minimum, or sometimes not doing it at all, is the first step to compromising quality. There is the same concern with pavement design, squeezing it to the minimum and assuming overly optimistic parameters. There are also numerous examples of implementing an inappropriate rehabilitation treatment. This is particularly a problem on alternative finance and procurement projects where there is less independent checking and testing. Substandard materials, inadequate design thickness and poor construction practice combine to increase risk of premature failure. Too often, Quality Assurance field and laboratory testing is reduced to the minimum or not required at all. This is particularly the case on projects where performance specifications are followed. On these projects, the contractors control themselves and QA testing is considered an unnecessary expense. But is it? Pavements that last half as long or less of what they should are very costly for tax payers.

This paper includes examples of pavements where poor investigation, design and construction practice or the use of substandard materials were reflected in compromised performance. It also includes recommendations of how to address the problems based on the authors' extensive experience in pavement and materials engineering.

1.0 INTRODUCTION

In the recent past the industry has placed significant focus on climate change and its impact on pavement performance, and pavement construction. In addition to the impact of climate change, the industry has also undertaken significant research into incorporating recycled materials into roads, in an effort to redirect these materials away from landfills. The primary goal of all these research efforts are to make the industry more sustainable. The afore mentioned topics are of critical importance, and the authors of this paper have participated in a number of these research efforts, and published papers on the findings. However, with the focus of the industry being primarily on climate change and recycling, other aspects that are required for achieving quality pavements that meet the required design life, have fallen by the way side.

Due to advancements in production methods and paving technology, with increased automation, it is assumed by many that the issue of pavement quality has been solved, and no longer requires attention to be paid to this aspect by the industry. The reality, however, has been quite different, with a number of owners, provincial and municipal, raising the alarm about poorly performing pavements. In the past where pavements often reached or exceeded their anticipated design lives, typically 20 years, road owners are now noting that major pavement rehabilitation is being required within 10 years of the original construction. Furthermore, owners are also identifying that higher frequency and volume of maintenance is being required to maintain the road in an acceptable condition, and the frequency of premature pavement failures has increase significantly.

Although the reduced design life may partially be be due to the increased traffic loading, as compared to the past, or increased frequency of extreme weather patterns; however, these cases are relatively rare. It has been noted that in a significant number of cases, the poor pavement performance and shorter design life, is due to an insufficient emphasis on pavement quality in terms of the following:

- Sufficient and accurate geotechnical investigations;
- Pavement structural design analysis with accurate traffic data;
- Accurate selection of pavement rehabilitation strategy;
- Comprehensive and technically accurate pavement materials and construction specifications;
- Construction supervision and enforcement of the project specifications; and
- Timely and appropriate application of pavement maintenance, including preventive maintenance treatments.

Although the industry is paying significant attention to pavement sustainability, the focus has been almost entirely on the aspects of recycling and climate change. Ensuring that pavements achieve there anticipated design, with limited intervention during this period, will have a dramatic impact on enhancing pavement sustainability, from an environmental, social and economic perspective.

2.0 PAVEMENT SUSTAINABILITY

Effectively designed and constructed sustainable pavements should aim to:

- Minimize the use of non-renewable natural resources;
- Reduce energy and fuel consumption during construction and operation;
- Minimize greenhouse gas emission;
- Limit pollution;
- Improve health, safety, and risk prevention;
- Ensure a high level of user comfort and safety, and

- Provide long term value for money.

A sustainability comparison of pavement alternatives is typically considered from three main aspects: economical; environmental, and social.

This typical approach to pavement sustainability misses one major aspect; technical quality. In environmental and cost benefits analysis, the focus is often on the reduction of initial capital cost, initial gas emission and/or use of resources. Long term costs and environmental impacts of future maintenance and repairs are frequently ignored. Also ignored are the adverse impacts of poor pavement performance on user comfort and safety, which is a critical factor in pavement sustainability. The insufficient focus on technical quality may lead to the selection of or approval of 'green' technologies that are focused only on short term benefits that compromise long-term pavement performance.

3.0 PAVEMENT INVESTIGATION AND DESIGNS

The pavement rehabilitation or new construction design process begins with carrying out a field investigation and laboratory testing, in order to establish the existing site conditions. The field investigation at a site typically may include the following:

- Geotechnical borehole investigation;
- Falling Weight Deflectometer (FWD) load/deflection testing;
- Ground Penetrating Radar (GPR) survey;
- Visual distress inspection; and
- Drainage inspection.

In order to develop a comprehensive and technically sound pavement design, it is critical that a thorough field investigation be carried out to establish the existing conditions at the site. However, the recent trends that have been observed is that the field investigations, and in particular the geotechnical investigations are being limited to the absolute minimum. The number of boreholes being advanced and the amount of laboratory testing being carried out on the samples obtained during the borehole investigation are limited. This in turn results in inadequate information being available for the pavement structural design analysis, which makes it necessary for designers to make assumptions about the key values for pavement design parameters. Inadequate field investigations also results in localized weak areas not being identified during the design phase and therefore not being appropriately addressed during the construction. Finally, if an insufficient field investigation is carried out for carrying out a pavement rehabilitation design, this in turn may result in the selection of the incorrect rehabilitation strategy being selected for the pavement section in question.

Examples of inadequate field investigation for their intended purpose that has been observed by the authors includes:

- Utilizing a pocket penetrometer to evaluate the consistency/level of densification of in place soils rather than undertaking Standard Penetration Tests (SPTs);
- Minimal to no observations of the groundwater conditions in the boreholes and almost avoiding using piezometers;
- No observations of the pavement surface of subsurface drainage conditions;
- Avoiding using non-destructive testing including FWD load/deflection testing for pavement sections with known inadequacies in terms of their structural capacity; and
- Carrying out minimal to no grain size distribution analyses on subgrade soils to exactly evaluate soil type and the frost susceptibility of the material for relatively long road section with variable subgrade soils.

With respect to pavement design, the Authors would like to express their concern with the current common trend of reducing the thickness of the pavement structures, particularly granular layers, without proper consideration of the impact it may have on performance, mainly on frost heaving and drainage capacities. Two of the recent winters (2013/2014 and 2014/2015) in Ontario were very cold with severe frost heaving and associated cracking observed on number of roads and streets. Figures 1 and 2 show the effect of pavement frost heaving on a street and rural road, respectively. The damaged pavements required costly repairs and have negative impact of riding comfort.

Some agencies and pavement designers believe that reducing the thickness of granular layers in the pavement structures is sustainable by reducing the amount of depleting aggregates. Some designers also believe that by using pavement reinforcement systems such as geogrids or by stabilizing the soils, the thickness of granular layers can be significantly reduced. However, in the Canadian cold and wet climate, the main functions of the granular layers is providing good subsurface drainage and frost protection. Unjustified reduction in the thickness of the granular layers may result in pavement heaving in winter and deformation and cracking during the spring thaw period. Poor performance will increase the life cycle cost of the pavement and will have a negative impact on pavement sustainability.

Figure 1. Frost heaving deformation at an intersection in a vicinity of a manhole.

Figure 2. Severe cracking on a rural pavement due to frost heaving.

4.0 CONSTRUCTION AND MATERIALS SPECIFICATIONS

4.1 Asphalt Cement Specification

Poor asphalt pavement performance has been observed in numerous municipalities in Ontario over the last few years. It included mainly premature cracking and raveling. Some of the observed issues were described in a technical paper presented at CTAA in 2015 [1]. In Southeastern Ontario, the standard asphalt cement grade is PG 58-28, which is often bumped to PG 64-28 for heavier, slow-moving traffic, and even to PG 70-28 for very heavy, slow-moving or static traffic. The observed pavement problems were mainly with the pavements where the asphalt mixes incorporated PG 64-28 or 70-28 grades. Pavements that were considered to be properly designed and had good Quality Control/Quality Assurance (QC/QA) results exhibited extensive cracking after 2 to 3 years and sometimes after less that a year. Figures 3 to 5 show typical cracking of those pavements. The most visible is the medium severity midlane cracking. Low severity random cracking was also observed. Careful pavement inspection also revealed extensive pavement microcracking. There were concerns that the problems were mainly due to the irresponsible use of Recycled Engine Oil Bottom (REOB) and Reclaimed Asphalt Pavement (RAP), lean mixes and some mix production issues. Customized asphalt paving specifications were developed for some of these municipalities. They also included special provisions for asphalt cement.

Figure 3. Midlane cracking of a 6 months old pavement on Bleams Road in Region of Waterloo.

Figure 4. Premature pavement cracking on Region of Niagara Regional Road 25 Doan's Ridge Road.

Figure 5. Check cracking on Moser Young Road in Region of Waterloo.

As a result of the poor performance observed in the field, customized specifications in five large municipalities in Ontario, Regions of Waterloo, Niagara, Durham, Peel and York, were developed and implemented in 2015. The Regions introduced customized specifications or special provisions for asphalt cement to update the requirements of Ontario Provincial Standard Specification (OPSS), OPSS.MUNI 1101 Material Specification for Performance Graded Asphalt Cement, 2013 [2]. The changes included restriction on some of the asphalt cement modifiers, particularly REOB, and the addition of advanced laboratory testing. These additional tests were:

- LS-227 (Ash) test “Method of Test for Determination of Ash Content [3];
- LS-299 (DENT) test “Method of Test for the Determination of Asphalt Cement’s Resistance to Ductile Failure Using Double edge Notched Tension Test [4];
- LS-308 (Extended BBR) test “Method of Test for Determination of Performance Grade of Physically Aged Asphalt Cement Using Extended Bending Beam Rheometer (BBR) Method” [5]; and
- AASHTO T 350-14 “Multiple Stress Creep Recovery (MSCR) test [6].

The limits for the new tests were mainly based on the Ministry of Transportation, Ontario (MTO) experience and experience in other provinces. With the exception of one of these municipalities, there are no acceptable, borderline and rejectable limits but only one pass/fail limit.

Generally, the customized specifications included limitations on asphalt cement modification as follows:

- The asphalt cement shall not be air blown or catalytically oxidized in any manner;
- The asphalt cement shall not contain a number of additives including waste engine oils, re-refined engine oils, cracked residues, tall oils;
- If modifiers or additives other than styrene-butadiene (SB, SBS, SBR) or epoxy type are used for modification on neat asphalt, pre-approval from the Contract Administrator is required; and
- The asphalt cement shall not contain more than 0.3% of polyphosphoric acid (PPA) and it shall only be used as a catalyst for the purpose of modification with epoxy polymers.
- After the initial discussions with asphalt cement suppliers and paving contractors, the customized specifications and/or special provisions were introduced before the 2015 paving season.

A new asphalt cement Ontario Provincial Standard Specification, OPSS.MUNI 1101 [9] was published in November 2016. It addresses the observed concerns about asphalt cement and includes the advanced testing including Ash Test, Extended BBR Test, DENT Test and MSCR Test. About 80 percent of municipalities in Ontario have decided almost immediately to implement the new specification without or with minor modifications in 2017 or 2018.

4.2 Reclaimed Asphalt Pavement in New Asphalt Mixes

RAP has been used in asphalt mixes in Canada for a long time. Typically up to 15 or even 20 percent RAP may be allowed in the surface course mixes and up to 40 percent in the binder course mixes [8-10]. Some agencies allow up to 50 percent RAP in binder course mixes. The addition of small percentage of RAP, up to 15 or maximum 20 percent, may not require changing of the asphalt cement grade in the mix design, however if more RAP is added the asphalt cement should be changed [8]. If between 20 and 40 percent is added, a one PG softer grade should be used. However, if more than 40 percent of RAP is added the asphalt cement should be two grades softer or special grades should be used. However, in practice these rules are almost never followed and asphalt paving specifications do not clarify how the mix design should be changed for high content RAP.

Numerous papers have been written on the impact of RAP on mix behaviour and pavement performance. Its sustainable benefits are obvious. Not surprisingly, some of rating systems prepared by road agencies offer credits for the addition of RAP. However, if an excessive amount of RAP is added to asphalt mixes it will likely significantly harden the asphalt cement in the mix. Also, not all asphalt cement in the RAP may blend with the virgin asphalt cement and part of the RAP may act as ‘black rock’. This will reduce the effective asphalt cement content and cause the mix to be brittle and prone to cracking. Figures 6 to 8 show a new binder course that incorporated very high RAP content and exhibited cracking, raveling and cracking very shortly after paving.

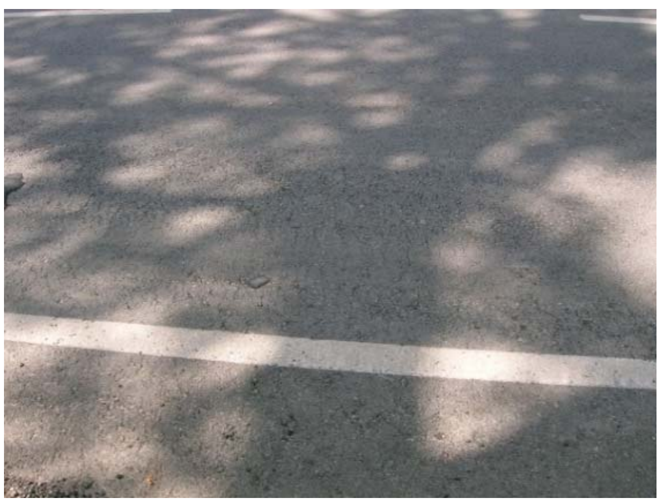

Figure 6. Microcracking and raveling of new binder course mix that incorporated very high content of RAP.

Figure 7. Raveling of new binder course mix that incorporated very high content of RAP.

Figure 8. Raveling and cracking of new binder course that incorporated very high content of RAP.

Due to the fact that some poor performance of Superpave asphalt mixes as observed in the past was related to poor durability, resulting in raveling and cracking, some of the recent customized specifications were focused on ensuring that enough asphalt cement is incorporated in the mix and the amount of RAP in the mix is controlled. Some of the customized specifications and/or special provisions updated OPSS.MUNI 1151 “Material Specification for Superpave and Stone Mastic Asphalt”, 2006 [11] and included the bidding asphalt cement content and minimum asphalt cement content in the mixes.

The special provision for asphalt pavement construction developed by some of the municipalities also updated OPSS.MUNI 310 “Construction Specification for Hot Mix Asphalt”, 2010 [12]. It included stricter asphalt mix production tolerances, particularly asphalt cement content, tightened compaction requirements and clear and tightened requirements for joint construction. After an initial period of difficulties with the implementation and discussions with the paving contractors, the special provisions were implemented.

4.3 Recycled Asphalt Shingles in New Asphalt Mixes

The use of Recycled Asphalt Shingles (RAS) or Manufactured Shingle Modifiers (MSM) is gaining popularity in Canada. There have been numerous technical papers written on the RAS application in HMA mixes and its sustainable benefits [10-17]. However, the safe percentage of RAS that can be added is still not clear and it is also not clear how the asphalt cement grade should be modified when RAS is added. The addition of up to 7.0 percent of RAS is considered by some agencies. Emery [15] considered the addition of up to 3.0 percent of MSM to asphalt mix without asphalt cement modification is safe and does not have negative impact on pavement performance. The Authors of this paper carried out research that showed that if 5.0 percent of RAS or more is added, the mix becomes stiff and has lower resistance to low temperature cracking unless the asphalt cement is softened [12]. The addition of hardened asphalt cement from RAP to the mix limits the amount of RAS that can be added to the mix. It is considered in Ontario that the addition of 1.0 percent of RAP has similar impact on asphalt cement hardening as 0.1 percent of RAS.

Figures 9 and 10 show a new binder course that incorporated 5.0 percent RAS and 15 percent RAP in the mix. The binder course developed extensive cracking shortly after paving and required extensive and costly repairs.

Figure 9. Cracking of new binder course that contained high percentage of RAS.

Figure 10. Repairs of new binder course that incorporated high amount of RAS.

5.0 Pavement Construction Quality

Even though a designer may developed a suitable pavement design and specify a technical sound construction and material specification, the pavement construction is a critical step in ensuring the final pavement achieves the desired life, with minimal maintenance efforts required. Recent trends have indicated that some owners are relying primarily on the results of the Contractor's Quality Control (QC) testing, with minimal Quality Assurance (QA) testing, if any, to verify the QC testing results. This trend places too much reliance on the testing results produced by the Contractor, and although this may reduce costs during construction, it has been noted that quality is compromised due to the elimination of the findings from an independent laboratory. The advantageous impact of basing acceptance on QA testing has been observed by the Authors at numerous airports that have transitioned away from acceptance based solely on QC testing. However, it is important to note that the MTO has in recent years transitioned from acceptance based QC, as verified by QA, to acceptance based only on QA.

It is critical to ensure that specifications are enforced in order to achieve a quality pavement product. If rejectable material is produced by the Contractor, it is essential that the Contractor is required to provide a remedy for the rejectable product. The remedies for the rejectable materials may include removal and replacement, providing extended warranty, or acceptance of the rejectable material at a reduced price. It is also critical that when the test results indicate borderline values, that the Contractor is duly notified of the results and advised that the corrective actions need to be taken in order to improve the quality materials being produced. The authors have seen examples of pavement projects where the Contractor was not even advised of any borderline or rejectable results and therefore, although the many of the QA testing results were identified as being rejectable, the Contractor was not required to remedy any of the rejectable material. On the contrary, the Authors have also been involved in assignments where the Contractor was immediately informed of any borderline parameters and required to identify corrections that would be made. This timely communication of the borderline results, and implementation of corrective measures, resulted in quality improvement and a very minimal amount of rejectable material being produced.

In addition to the QA/QC testing, it is also critical that there are experienced and well trained inspectors on site full-time during asphalt and concrete paving. A number of the aspects of a poor quality product may not be evident from the testing results; however, there would be visual evident to an experienced inspector, e.g. overheating of asphalt cement; unstable asphalt mixtures; microcracking or bleeding in asphalt; honeycombing in concrete; and shrinkage cracking in concrete. If these deficiencies are not identified in the field by an experienced, qualified inspector, they will likely have a significant detrimental impact of pavement performance; however, the deficiencies may not become immediately evident during the typical one year warranty period following construction. Therefore, the cost for the repair of the defective product would have to be borne by the tax payers.

6.0 Examples of Focus on Quality

Numerous municipalities in Ontario, including the Regions of Waterloo, Niagara, Peel, York and Durham, made a decision to fight for the quality of their pavements. Their focus was on the entire life cycle of the pavement from design, specifications, construction and maintenance. Their customized asphalt specifications, and specification enforcement, impact on improved pavement quality were documented in TAC papers in 2015 and 2016.

Ontario Hot Mix Producers Association (OHMPA) formed a Task Force with the main objective of improving the quality of asphalt pavement. The Task Force produced seven bulletins addressing the quality of asphalt cement, amount of asphalt cement in mixes, and responsible use of RAP and RAS. The members of the Task Force included the industry, MTO, several municipalities, academia, and consultants.

The new Ontario Provincial Standard Specification, OPSS.MUNI 1101, dated November 2016, has addressed the main concerns related to the quality of asphalt cement. Furthermore, having an advanced standard specification that can be used by the majority of municipalities, allows for the Contractors to produce a uniform asphalt cement product that minimizes confusion with the type of asphalt cement that is required to be used, and minimizes the potential for errors in the asphalt cement that is included in any given mix.

The Authors of this papers work closely with numerous municipalities, including City of Hamilton, Region of Waterloo, and Region of Niagara, in ensuring that they achieve their goal of high quality and long lasting pavements. A good example of quality improvement that has been evidenced by the Authors is in the Region of Niagara (Region), for instance. The Region has a very tight construction and material specifications. The tolerance for asphalt cement content in the plant-produced mix, for instance, is borderline if the asphalt cement content varies by 0.2 to 0.3 percent of the job mix formula, and rejectable is the variation is greater than 0.3 percent. The Region transitioned to Superpave technology in 2015, and in this year 25 percent of the asphalt mix samples were noted to be rejectable due to asphalt cement content. In 2016 when the Region began strong enforcement of their updated specifications and worked closely with the contractors, the proportion of rejectable asphalt mix samples due to asphalt cement content was reduced to 15 percent. Table 1 provides a comparison of the proportion of acceptable, borderline and rejectable asphalt mix samples on asphalt cement content that represent the asphalt mix paved in the Region of Niagara in 2015 and 2016. The table clearly shows the improvement in quality that was observed in 2016, as compared to the asphalt mix placed in 2015.

Table 1. Comparison of Asphalt Mix QA Testing of Asphalt Cement Content Results for the Region of Niagara

Mix Type	Year	Percent Acceptable	Percent Borderline	Percent Rejectable
SP 12.5	2015	67%	16%	17%
	2016	85%	5%	10%
SP 19.0	2015	49%	20%	31%
	2016	56%	25%	18%
All Mixes	2015	57%	18%	25%
	2016	69%	16%	15%

Figure 11 and 12 shows examples of excellent quality asphalt pavements that were paved in the Region in 2016.

Figure 11. Excellent current condition of asphalt pavement placed in the Region of Niagara in 2016.

Figure 12. Excellent current condition of asphalt pavement placed in the Region of Niagara in 2016.

7.0 Conclusion

Pavement quality starts with pre-engineering, proper geotechnical investigation, analysis, design, appropriate specifications and quality construction. It has been noted in recent years that due to advancement in technology and materials, the focus of technical quality of pavements has fallen by the wayside. The emphasis has been transitioned to the environmental aspects of pavements sustainability, and has moved away from the economical and social aspects of sustainability. It has been discussed in this paper that pavement quality has a critical impact of aspects of pavement sustainability. Also discussed in this paper are the various phases of the pavement life that impact the overall quality of the pavement product. Finally, the paper discussed examples of changes that have recently been made in the industry with the goal of improving pavement performance, and the beneficial impact that these changes have had.

8.0 References

[1] Ludomir Uzarowski, Gary MacDonald, John Rizzo, Gary Moore and Vimy Henderson, “Cold Winter and Early Asphalt Pavement Cracking Observed in Ontario”, Canadian Technical Asphalt Association (CTAA) Proceedings, 2015, Page 347-360.

[2] Ontario Provincial Standards, “Material Specification for Performance Graded Asphalt Cement”, Ontario Provincial Standards for Roads & Municipal Works, Volume 8, Division 11 – Bitumens, Index 1101, OPSS.MUNI 1101, November 2013.

[3] Ministry of Transportation, Ontario, “Method of Test for Determination of Ash Content”, Laboratory Testing Manual, Revision 29, Test Method LS-227, February 17, 2015.

[4] Ministry of Transportation, Ontario, “Method of Test for Determination of Asphalt Cement’s Resistance to Ductile Failure Using Double Edge Notched Tension Test (DENT)”, Laboratory Testing Manual, Revision 29, Test Method LS-299, February 17, 2015.

[5] Ministry of Transportation, Ontario, “Method of Test for Determination of Performance Grade of Physically Aged Asphalt Cement Using Extended Bending Beam Rheometer (BBR) Method”, Laboratory Testing Manual, Revision 26, Test Method LS-308, May 1, 2011.

[6] American Association of State Highway and Transportation Officials (AASHTO), “Standard Test Method for Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using Dynamic Shear Rheometer”, AASHTO Designation T 350-14, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 35th Edition, Washington, D.C., 2015.

[7] Ontario Provincial Standards, “Material Specification for Performance Graded Asphalt Cement”, Ontario Provincial Standards for Roads & Municipal Works, Volume 8, Division 11 – Bitumens, Index 1101, OPSS.MUNI 1101, November 2016.

[8] J. Keith Davidson, “Evaluation of Reclaimed Asphalt Pavement and Virgin PG Binder Blends”, Canadian Technical Asphalt Association (CTAA) Proceedings, 2009, Page 3-30.

[9] Art Johnston, Karim Mohammad, Joe Chyc-Cies, “Industry Challenges Associated with Utilizing Recycled Asphalt Shingles in Asphalt Mixtures – An Agency Perspective”, Canadian Technical Asphalt Association (CTAA) Proceedings, 2013, Page 429–441.

[10] John A. D’Angelo, Raj Dongre and Audrey Copeland, “Evaluation of the Extent of Asphalt Blending in RAP Mixes”, Canadian Technical Asphalt Association (CTAA) Proceedings, 2011, Page 289-308.

[11] Ontario Provincial Standards, “Material Specification for Superpave and Stone Mastic Asphalt Mixtures”, Ontario Provincial Standards for Roads & Municipal Works, Volume 8, Division 11 – Bitumens, Index 1151, OPSS.MUNI 1151, November 2006.

[12] Ontario Provincial Standards, “Construction Specification for Hot Mix Asphalt”, Ontario Provincial Standards for Roads & Municipal Works, Volume 1, Division 3 – Pavement (Flexible and Rigid), Index 310, OPSS 310, November 2012.