Making the Grade – How Do Municipal Marshall Mixes Fare Under Superpave Specifications?

Stephen N. Goodman, M.Eng., P.Eng.
Senior Pavement Engineer
City of Ottawa
Right of Way Management Division
Infrastructure Services Branch
Transportation, Utilities and Public Works

Paper prepared for presentation at the

Superpave Implementation and Experience in Canada Session

2003 Annual Conference of the Transportation Association of Canada, St. John's Newfoundland

Abstract

Over the past few years, the Ontario Ministry of Transportation (MTO) has gradually increased their usage of Superpave asphalt mixes in provincial paving contracts. It is anticipated that a complete transition to Superpave will occur at the provincial level within the next few years through the efforts of the multi-stakeholder Ontario Superpave Implementation Committee.

In early 2002, a study was conducted by the MTO to investigate how traditional Marshall mixes used by the province fared under the Superpave specifications. Results of that investigation indicated that the mixes tested generally fell within Superpave specifications, but that some adjustments would be required. However, the asphalt mixes tested under the MTO study (HL-1, HL-4, DFC and HDBC) are generally not used by municipalities in large quantities. In the City of Ottawa, the primary mixes used for residential streets and arterials are HL-3 and HL-8. Mixes such as HL-1, SMA and HDBC are used, but in smaller quantities for heavier trafficked routes, bridge decks and the Transitway.

In order to assess municipal mixes under Superpave criteria, the City of Ottawa retained numerous asphalt mix samples during normal quality assurance operations during the 2002 paving season. These mixes were compacted to 100-gyrations in the gyratory compactor to observe the gyration level at which the 4% air void criterion (N_{des}) was met. Significant adjustments to mixes currently used in the City of Ottawa will be required to meet Superpave specifications including (but not limited to) a reduction in the amount of natural sand, a slight reduction in asphalt cement content and gradation adjustment to fall below the restricted zone. Both internally and through the Ontario Superpave Implementation Committee, the City of Ottawa will continue to work toward implementation of Superpave and provide other municipalities with technical expertise during the transition.

Acknowledgements
The author would like to acknowledge the effort of Mr. Guy Lavallee, CET of the City of Ottawa Materials Test Laboratory who prepared the gyratory specimens and compiled the volumetric data for this investigation.

INTRODUCTION

Over the past few years, the Ontario Ministry of Transportation (MTO) has gradually increased its usage of Superpave designed asphalt mixes for provincial paving contracts. By 2005 or 2006, it is expected that a complete transition from Marshall mix design to Superpave will occur at the provincial level. Assisting in this transition is the Ontario Superpave Implementation Committee, or OSIC, consisting of representatives from government and industry stakeholders.

While adoption of Superpave at the provincial level is all but assured, it is likely that Ontario municipalities will require additional assistance, experience and equipment to move away from the current Ontario Provincial Standard (OPS) Specifications [1], which only include Marshall mixes. In early 2002, the Municipal Engineers Association (MEA) approached the City of Ottawa to represent its member's interests on the OSIC and provide technical expertise to Ontario municipalities during this transition. The City of Ottawa is particularly well suited for this task and readily accepted this offer - having been equipped with a full performance graded asphalt binder characterization laboratory and gyratory compactor since 1995 [2].

While Superpave may be considered a positive step toward improved mix design, it is important to consider that much knowledge has been gained with asphalt mixes designed with the Marshall method over the past decades. Therefore, Superpave should not automatically discard mixes that have performed well in the past. In an effort to evaluate its traditional mixes against Superpave criterion, the MTO conducted a study of aggregate gradations and mix volumetric properties for HL-1, HL-4, Dense Friction Coarse (DFC) and Heavy Duty Binder Coarse (HDBC) mixes [3]. Results of this investigation indicated that the standard MTO mixes tested generally fell within Superpave specifications, but that adjustments would be required.

While the results of the MTO investigation were very valuable, the mixes tested are not typically used by municipalities in large quantities. In the City of Ottawa, the primary mixes used for local roads and even most arterial routes are HL-3 (surface coarse) and HL-8 (base coarse). Mixes such as HL-1 and HDBC are used in small quantities - primarily for bridge decks and the Transitway, while Stone Mastic Asphalt (SMA) is used for very high traffic applications only. Thus, in order to assess municipal mixes under Superpave criteria, the City of Ottawa retained numerous asphalt samples during quality assurance operations during the 2002 paving season.

Overview of Marshall Mixes Tested

A total of thirteen different mixes were sampled for the investigation – two SMA mixes, one HL-1, five HL-3 mixes, one HL-4, three HL-8 mixes and one HDBC. A summary of the mixes, as well as the respective job mix formula (JMF) properties is shown in Table 1. Table 2 includes the actual volumetric properties as determined through quality assurance testing. As shown, many of the mixes displayed lower recompacted air voids than reported in the JMF, which would tend to suggest a potential for premature rutting in the field. At this time, the City of Ottawa imposes end result specifications (ERS) on asphalt content and gradation, as well as compaction, but not recompacted air voids. Although rutting is not considered a problem in Ottawa, it is evident from these results that an ERS for recompacted voids is prudent to ensure good field performance.

Table 1: Summary of Marshall Mixes Tested and Job Mix Formula Parameters

Mix No.	Superpave Class	Marshall Mix Type	No. of Samples	PG Asphalt	Job Mix Formula (JMF) Marshall Properties							
					%AC (Mass of Agg)	%AC (Total Mix)	% Voids	% VMA	Stability (N)	Flow	% Natural Sand	%RAP
1	9.5mm	SMA 9.5	5	70-34	6.8	6.4	2.0	17.3	13209	16.3	0	0
2	12.5mm	SMA 12.5	2*	70-34	6.0	5.7	3.5	17.8	n/a	n/a	0	0
3		HL-1	6	64-34	5.0	4.8	3.8	15.0	15042	9.3	35.3	0
4		HL-3	3	58-34	5.0	4.8	4.2	15.4	10515	9	36.7	0
5			2	58-28	5.0	4.8	3.7	15.0	12208	9	28.7	15
6			1	58-34	5.0	4.8	3.7	15.2	13667	15.2	35.3	0
7			2	58-28	5.0	4.8	4.4	15.3	14250	8.9	32	30
8			1	58-34	5.0	4.8	3.6	15.0	10900	10	32	0
9		HL-4	1	58-34	5.0	4.8	3.8	15.6	11250	9.5	37	0
10	19mm	HL-8	4	58-34	5.0	4.8	3.9	15.3	10250	9	36.7	0
11			1	58-34	5.0	4.8	3.6	14.6	10900	9.4	34	0
12			3	58-34	5.0	4.8	3.7	14.7	9725	8.2	30.5	0
13		HDBC	1	64-34	4.9	4.7	3.9	14.8	17750	11	0	0

Table 2: Actual Marshall Mix Volumetric Properties from Quality Assurance Testing

Mix No.	Superpave Class	Mix Type	No. of Samples	PG Asphalt		Average Actual (As Tested) Marshall Properties					Comments
						%AC (Total Mix)	% Voids	% VMA	Stability (N)	Flow	
1	9.5mm	SMA 9.5	5	70-34		6.3	1.1	16.2	13048	20.2	Low voids
2	12.5mm	SMA 12.5	2*	70-34		5.7	9.7	24.8	n/a	n/a	High voids
3		HL-1	6	64-34		4.7	2.4	14.6	n/a	n/a	Low voids
4		HL-3	3	58-34		4.9	1.6	13.7	n/a	n/a	Low voids
5			2	58-28		5.0	2.0	13.9	16522	12.9	Low voids
6			1	58-34		4.8	5.7	16.4	16669	10.5	High voids
7			2	58-28		4.7	5.5	15.3	20789	9.7	High voids
8			1	58-34		4.6	1.2	13.0	18775	10.3	Very low voids
9		HL-4	1	58-34		5.1	2.1	12.9	14434	8.2	Low voids
10	19mm	HL-8	4	58-34		5.0	0.9	14.5	17865	15.7	Very low voids
11			1	58-34		4.7	2.8	11.1	18570	8.8	Low voids
12			3	58-34		5.2	2.4	14.3	11024	10.0	Low voids
13		HDBC	1	64-34		4.7	3.1	14.8	19239	10.7	Low voids

Testing Program

The testing program was straightforward. The mix design information in terms of asphalt content, gradation, etc. was known from quality assurance testing completed during the 2002 paving season. Samples of each mix were simply reheated to the specified recompaction temperature and compacted in the gyratory compactor to 100 gyrations. The selection of a single gyration level, however, requires some explanation as follows.

While Superpave mixes are designed to 4% air voids at an anticipated 20-year traffic level (as represented by a design number of gyrations, N_{des}), standard Marshall mixes are not truly designed for specific traffic volumes. While it is generally true that HL-1 mixes resist rutting more so than HL-3 mixes, the tolerances within the OPS specifications are such that an HL-3 mix could be designed for either a 50, 75 or even 100 gyration N_{des}. As such, there was no way to determine what gyration level to use for each mix in the investigation. However, because the gyratory compactor provides the maximum specific gravity of the mix at each gyration, the volumetric properties of the mix may be back-calculated at any gyration on the compaction curve. Indeed, the original Superpave mix design system [4] involved compacting the mix to N_{max} and then back-calculating the N_{des} mix volumetric properties.

Based on more recent research [5], it was observed that in some cases, the back-calculation process might induce errors. From that research, the current Superpave system [6] compacts mix specimens to N_{des} for volumetric evaluation, and additional samples are compacted to N_{max} to ensure that the mix will not experience plastic flow at high traffic volumes. While the new procedure is more intuitive, the design gyration level must be known. As an exercise, two specimens of 12.5mm SMA were compacted to 75 and 100 gyrations, respectively. As shown in Figure 1, the two compaction curves are virtually identical, indicating that the back-calculation of volumetric properties would not induce significant errors. Therefore, all 13 mixes were compacted to 100 gyrations to observe whether or not the mixes compacted to 4% air voids at gyration levels at or near the 50, 75 or 100 gyration N_{des} traffic levels.

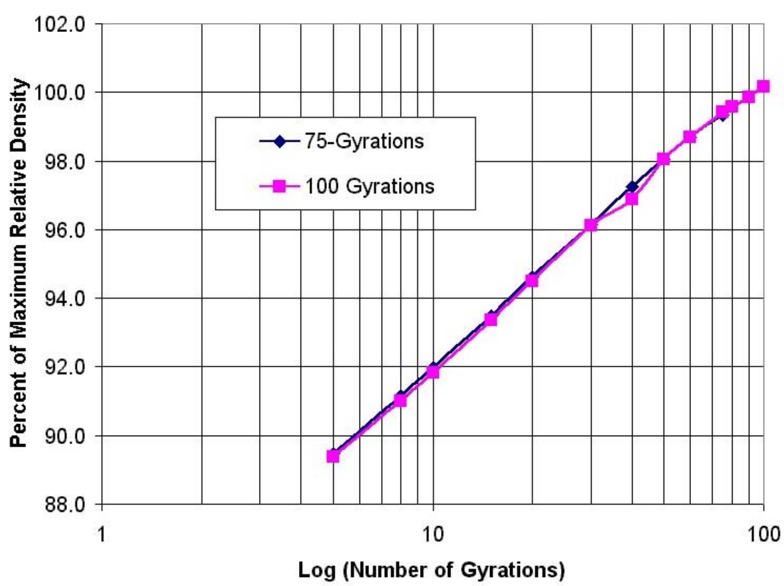


Figure 1: Compaction Curves of 12.5mm SMA at 75 and 100 Gyrations

DISCUSSION OF RESULTS

Gradation Comparison

The gradation ranges for each of the mix types tested are compared to their respective Superpave 0.45 power charts and control points as shown in Figure 2. The restricted zone has been plotted for reference, although recent NCHRP research has indicated that it is redundant if all other volumetric properties are satisfied [7].

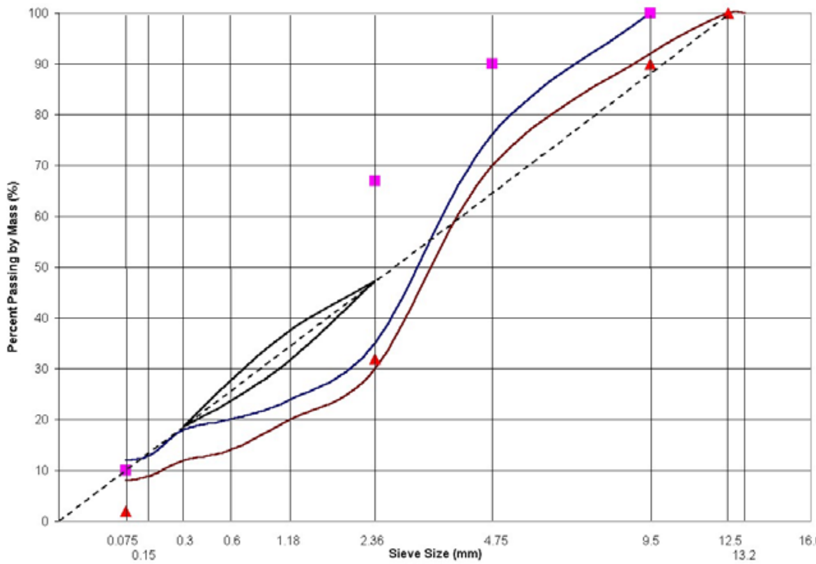
The traditional OPS surface mixes used by municipalities (HL-1 and HL-3) match well with the 12.5mm Superpave control points indicating that minimal (or no) gradation changes will be required to meet the Superpave specification. HL-1 and HL-3 have the same gradation tolerances in OPS, however, HL-1 specifies a higher quality trap rock coarse aggregate for enhanced rut resistance, skid resistance and durability. As shown in Figure 2c, the lower limit of the HL-1/HL-3 gradation closely matches the lower limit of the restricted zone. Thus, all of the HL-1 and HL-3 mixes tested had gradations above the restricted zone. The Superpave control points will allow for coarser mixes in this gradation class compared with HL-1 and HL-3.

The OPS base mixes (HL-8 and HDBC) match very closely to the Superpave 19mm control points as illustrated in Figure 2f. HL-8 and HDBC have the same gradation tolerances in OPS, however, the HDBC requires 100% crushed aggregate for enhanced rut resistance. The HDBC mix and all HL-8 mixes tested had gradations that passed above the restricted zone.

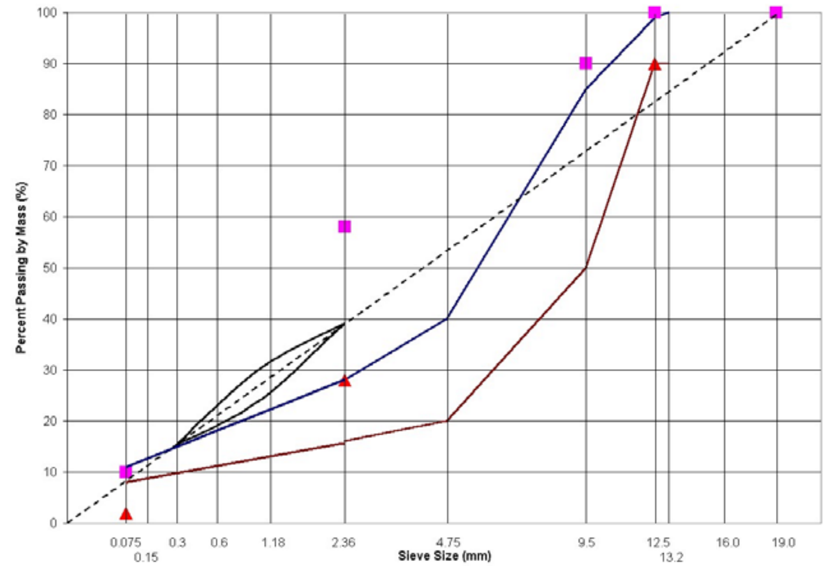
The 9.5mm City of Ottawa SMA is a premium surface mix that is used for high traffic volumes only. As shown in Figure 2a, it has very tight gradation tolerances but does tend to fall within the Superpave 9.5mm control points and falls below the restricted zone. The 12.5mm SMA was adopted by the City for the 2003 paving season and is almost identical to the 12.5mm AASHTO SMA [8]. This particular mix included 5% manufactured shingle modifier (MSM). As shown in Figure 2b, the 12.5mm SMA gradation is greatly deviant from the Superpave 12.5mm control points and falls exclusively below the restricted zone.

The final mix tested was HL-4. HL-4 is used regularly by the MTO, as it is flexible enough to serve as both a surface coarse and base coarse mix. It is not used routinely in the City of Ottawa, although the former City of Nepean did use HL-4 as base coarse asphalt on some projects prior to amalgamation. HL-4 is an interesting mix because it can be designed either as a 12.5mm mix or a 19mm Superpave mix as suggested by Figures 2d and 2e respectively. The HL-4 mix tested for this investigation was classified as a 12.5mm mix as its gradation consisted of 93.9% passing the 12.5mm sieve. Under Superpave, the nominal maximum aggregate size of a mix is defined as one sieve larger than the first sieve to retain more than 10% aggregate by mass, which in this case was the 9.5mm sieve. The gradation also passed above the restricted zone.

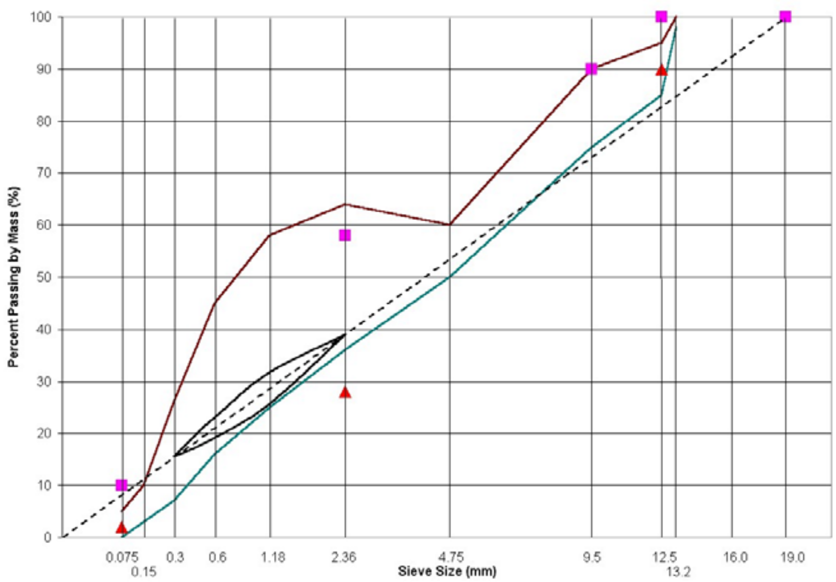
The MTO has developed a specification for a 16mm Superpave gradation to better characterize HL-4, although Superpave does not have a 16mm classification. Although the reason for this is somewhat understandable, it is important to remember that the Marshall and Superpave mix design systems are fundamentally different. Moulding existing Marshall mixes to fit Superpave criteria will therefore not necessarily provide better performing pavements.



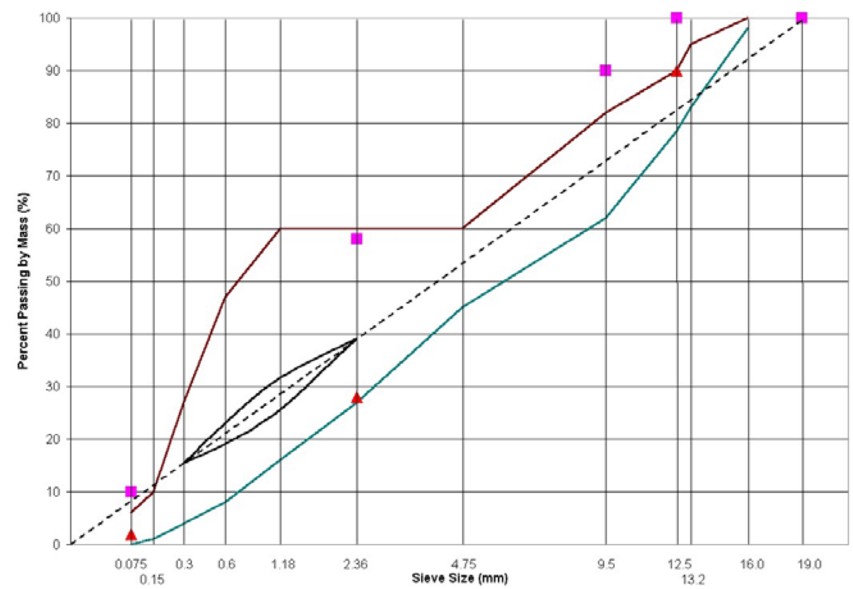
a) 9.5mm SMA vs. Superpave 9.5mm



b) 12.5mm SMA vs. Superpave 12.5mm

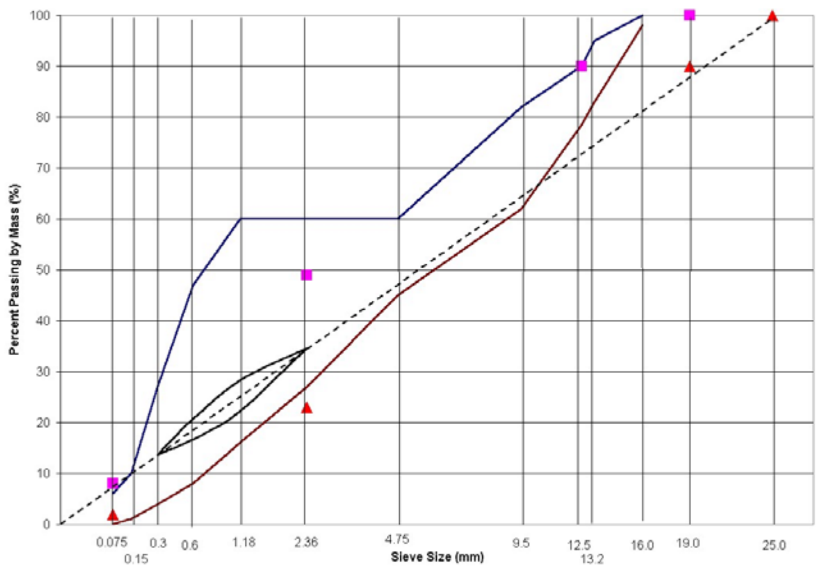


c) HL-1 and HL-3 vs. Superpave 12.5mm

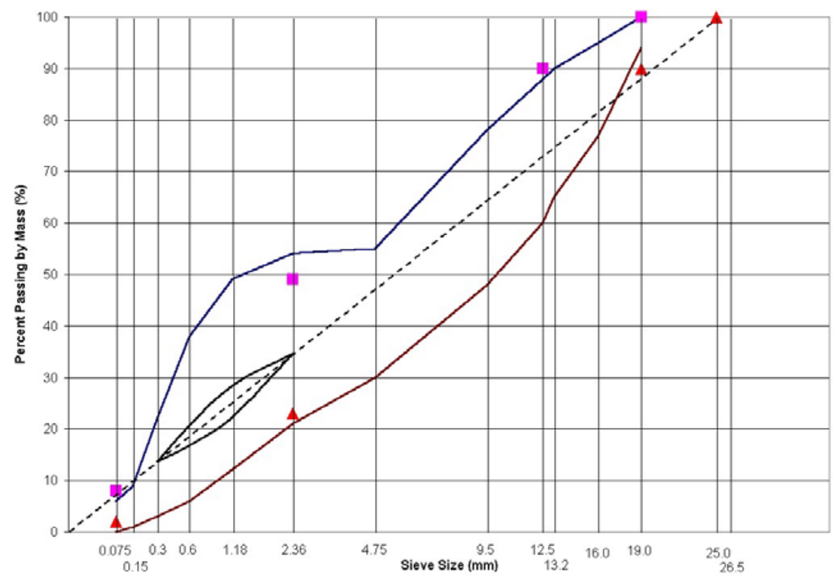


d) HL-4 vs. Superpave 12.5mm

Figure 2: Comparison of Standard OPSS Marshall Mix Gradation vs. Superpave Gradation



e) HL-4 vs. Superpave 19mm



f) HL-8 and HDBC vs. Superpave 19mm

Figure 2 Cont.: Comparison of Standard OPSS Marshall Mix Gradation vs. Superpave Gradation

Figure 2 <u>Notes</u>:

i) Superpave control points are shown as solid squares (upper limits) and solid triangles (lower limits);
ii) Solid lines indicate upper and lower gradation limits for the respective Marshall mixes;
iii) The maximum density line is indicated by a dotted line;
iv) The Superpave Restricted Zone (now defunct) is shown for reference purposes only by the enclosed solid lines between the 2.36 and 0.3mm sieves.

Aggregate Consensus Properties

As outlined in [6], Superpave aggregate consensus properties include coarse aggregate angularity, fine aggregate angularity, flat and elongated particles and clay content (sand equivalent). The vast majority of coarse aggregates in the City of Ottawa are produced from quarried stone, with a small amount produced from crushed pit run cobbles and boulders. With quarried stone, 100% of the faces are crushed, while the crushed pit run material usually has 95% of the particles with 2 or more crushed faces. In this regard, the City of Ottawa is fortunate since many municipalities in southern Ontario do not have access to such high quality aggregates. However, for most municipal roads, a Superpave mix would be designed to either 50 or 75 gyrations to meet the design traffic volumes. For a 50-gyration mix, only 75% of the coarse aggregate must have one crushed face, while a 75-gyration mix requires 85% with one crushed face and 80% with two or more crushed faces. This should not be an insurmountable problem.

Fine aggregate angularity (FAA) requirements for municipal roads should also not present a major difficulty. For a 50-gyration mix, there are no requirements for FAA, while 75-gyration mixes require an FAA of 40. Only when a 100-gyration mix design is required does the FAA potentially become problematic. The City of Ottawa has already tested its various aggregate suppliers and found an average FAA of 42.5 for local natural sands, which may be qualitatively characterized as "rounded." Therefore, the local natural sands may be used for both 50 and 75 gyration mixes. Manufactured fines would likely be required for 100-gyration mixes, although mixes such as SMA and HDBC already require 100% crushed coarse and fine aggregates.

Finally, the requirements for flat and elongated particles and clay content are not seen as a concern in Ottawa and may be minimized by good crushing and processing techniques.

Gyratory Compactor Results

Each of the samples were reheated to the specified recompaction temperature and compacted in the gyratory compactor to 100 gyrations. Prior to the investigation, the external angle of the gyratory compactor was calibrated to 1.25 degrees. There is currently some debate as to whether or not the angle should be calibrated internally [9], however, the internal angle validation device was not available for this investigation.

The results of the gyratory compaction effort are summarized in Table 3. As shown, all of the mixes compacted to the design 4% air voids at very low gyrations with the exception of the HL-3 mix with 30% recycled asphalt pavement (RAP). These results were nothing short of stunning. Even the SMA and HDBC mixes were compacted to 4% air voids between 18 and 28 gyrations, despite being "premium" mixes to reduce rutting. It was immediately surmised that the City's gyratory compactor was somehow faulty. To investigate this further, samples from four of the mixes were taken to a local consultant for gyratory compaction. The comparative results are displayed in Table 4. Fortunately, it was confirmed that the City's gyratory compactor was functioning properly, although it was also clear that significant changes to the current mixes used in the City of Ottawa would be required to meet even the lowest Superpave N_{des} of 50 gyrations.

Table 3: Volumetric Properties at 100 Gyrations

Mix No.	Superpave Class	Marshall Mix Type	PG Asphalt	Superpave Volumetric Properties at 100 Gyrations			Average Gyrations to 4% Voids
				% Voids	% VMA	Dust to Binder	
1	9.5mm	SMA 9.5	70-34	1.0	15.9	1.3	18
2	12.5mm	SMA 12.5	70-34	0.0	15.9	1.2	29
3		HL-1	64-34	1.9	13.9	0.6	32
4		HL-3	58-34	1.0	13.1	0.9	20
5			58-28	0.4	12.6	0.9	16
6			58-34	1.3	12.8	1.5	21
7			**58-28**	**3.9**	**14.1**	**1.1**	**88**
8			58-34	2.1	13.8	0.7	32
9		HL-4	58-34	1.0	13.1	0.9	19
10	19mm	HL-8	58-34	0.0	12.0	0.9	10
11			58-34	2.2	13.4	0.4	38
12			58-34	1.5	12.6	0.5	25
13		HDBC	64-34	1.2	12.5	0.6	28

Table 4: Comparison of City and Consultant Gyratory Compactors

Mix Type	Mix Properties at 100 Gyrations	City	Consultant
9.5mm SMA	Bulk specific gravity	2.397	2.403
	%Air Voids	1.16	0.90
	%VMA	15.8	15.6
	%VFA	92.4	94.2
	No. of Gyrations to 96% Gmm	**17**	**14**
HL-1	Bulk specific gravity	2.423	2.426
	%Air Voids	2.6	2.5
	%VMA	14.2	14.1
	%VFA	81.7	82.3
	No. of Gyrations to 96% Gmm	**40**	**46**
HL-3	Bulk specific gravity	2.463	2.469
	%Air Voids	1.045	0.8
	%VMA	13.1	12.8
	%VFA	92.4	93.8
	No. of Gyrations to 96% Gmm	**18**	**22**
HL-8	Bulk specific gravity	2.490	2.490
	%Air Voids	-0.04	-0.04
	%VMA	12.1	12.1
	%VFA	99.7	99.7
	No. of Gyrations to 96% Gmm	**7**	**12**

Upon further consideration, a number of explanations for the "collapse" of the asphalt mixes in the gyratory compactor may be put forth as follows:

1. High Percentage of Natural Sands

As shown in Table 1, the HL-1, HL-3, HL-4 and HL-8 mixes contain between 29 and 37% natural sand. Although the sand meets the FAA requirements, it is not likely resisting the compactive effort of the gyratory. An HL-1 modified mix tested in [10] was limited to 10% natural sand and met the Superpave mix design criteria for an N_{des} of 100 gyrations.

From Table 3, it was observed that the HL-1 mix better resisted gyratory compactive effort than the HL-3 mixes with the exception of Mix No. 7. This was likely due to the greater high temperature PG binder grade (64 for HL-1 vs. 58 for HL-3) as the gradations and percentage of natural sand was virtually identical between the two mix types.

2. Too Much Asphalt Cement

As outlined by [10] and others, the Superpave gyratory compactor has been shown to produce a higher density in hot-mix asphalts compared to 75-blow Marshall compaction and therefore results in a lower optimum asphalt content for the same gradation. A reduction in asphalt cement content would greatly improve the resistance to compactive effort, at the potential expense of durability. The key to improving mix resistance to compactive effort then should be directed at the aggregate gradation.

The rapid densification observed with the SMA mixes is likely due to the high asphalt cement content as compared to dense graded mixes – although the high temperature PG binder grade of 70 should have offset this to some degree. Since SMA has been successfully used in high traffic areas to prevent rutting and since the Superpave mix design system was developed to produce dense graded asphalt mixes, it is surmised that the current Superpave system is not well suited for designing SMA mixes. This sentiment has been echoed by [10].

3. Gradations Above the Restricted Zone

The poor performance of the HDBC mix in the gyratory compactor was quite surprising as it is produced with 100% manufactured (i.e. crushed) particles and has a relatively low asphalt cement content of 4.9% by mass of aggregate. However, the gradation curve for the HDBC was above the restricted zone and had 49% fine aggregate. As shown in Figure 2f, the current OPSS gradation range for HDBC is such that HDBC mixes can be designed below the restricted zone and would therefore better resist the gyratory compactive effort. The HL-1 modified mix tested in [10] was designed below (and slightly through) the restricted zone and met the Superpave mix design criteria for an N_{des} of 100 gyrations.

Both of the SMA mixes were 100% crushed material and fell below the restricted zone. Therefore it was surprising to observe how readily these mixes compacted in the gyratory compactor. The City of Ottawa has used its 9.5mm SMA for over 10 years and has been greatly satisfied with its rutting resistance. As already discussed, it appears that the Superpave system is not well suited for designing SMA mixes.

4. Contractor Design of "Compactable" Mixes To Maximize Pay Factors

In the City of Ottawa, it is the responsibility of the contractor to develop asphalt mix designs. Mixes are reviewed and approved by the City of Ottawa against the OPS specifications and subjected to end result specifications (ERS) for asphalt cement content, gradation and in-place compaction. The maximum ERS pay factor for AC and gradation is 100% of the bid price, while the contractor may achieve up to 3% bonus for in-place compaction. At this time, the City does not impose an ERS pay factor for recompacted Marshall voids. Based on the recompacted void data shown in Table 2, it appears that the contractors are designing mixes that are more easily compacted in the field in order to maximize the compaction bonus.

Mix No. 7 – What's So Special?

Of the 13 mixes tested, only Mix No. 7 resisted the gyratory compactive effort to Superpave design levels. Two samples of Mix No. 7 were tested. Sample 1 achieved the 4% air void criterion at 100 gyrations, while Sample 2 required only 75 gyrations. The volumetric properties of Samples 1 and 2 for both 75 and 100 gyrations are displayed in Table 5.

With the exception of the $N_{initial}$ criterion, Sample 1 may be considered a Superpave 100-gyration mix, while Sample 2 may be considered a 75-gyration mix. The fact that they are actually the same job mix formula is interesting, although the samples were taken at different locations. Thus, it may be said that Mix No. 7 qualifies as a Superpave 75-gyration mix.

The underlying reason for this mix meeting the Superpave criteria when the other mixes did not is not clear. The only fundamental difference between Mix No. 7 and the other HL-3 mixes is that it contained 30% RAP. The percentage of natural sand was similar to the other HL-3 mixes, as was the gradation and asphalt cement content. However, the actual PG grade of the asphalt mixture was not tested since an abson recovery is required to extract the blended asphalt cement from RAP paving mixtures for PG verification. The abson recovery test requires 2 days and is not routinely conducted by the City of Ottawa. For mixes containing more than 15% RAP, the City requires that the contractor use a softer PG grade to mix with the stiffer asphalt cement contained in the RAP. In this case, the contractor used a PG 52-34 with the RAP mix to achieve a final PG grading of 58-28. It is possible that the final PG binder grade was stiffer than anticipated.

Table 5: Superpave Volumetric Properties of Mix No. 7 (HL-3 with 30% RAP)

	Sample 1 at 100 Gyrations	Sample 1 Back-Calculated to 75 Gyrations	Sample 2 at 100 Gyrations	Sample 2 Back-Calculated to 75 Gyrations
Bulk specific gravity	2.428	2.417	2.422	2.414
%Air Voids	4.1	4.9	3.60	3.9
%VMA	14	14.4	14.2	14.5
%VFA	70.7	71.5	74.6	74.5
Dust to Binder Ratio	1.1	1.1	1.0	1.0
No. of Gyrations to 96% Gmm	100	75	75	75

WHAT DO THE RESULTS MEAN?

As with most municipalities, the City of Ottawa is concerned with the cost and performance of its hot-mix asphalt pavements. Unfortunately, as Ontario municipalities struggle for funding to rehabilitate and maintain an ever-aging road network, the cost considerations of hot mix asphalt often outweigh potential performance gains during the selection process.

The results of this investigation clearly indicate that modifications to the traditional Marshall mix designs used in the City will be required to meet Superpave specifications. If such modifications can be made without significant additional cost, then the City (and other municipalities) will likely follow the provincial direction and adopt Superpave without much fanfare. Although some reduction in asphalt cement content may be feasible, the major step toward meeting the Superpave volumetric criteria must involve a combination of adjusted aggregate gradation and material quality. As all of the standard Marshall mixes tested had gradations that went above the restricted zone, the first step will be to evaluate mixes with gradations that fall below the restricted zone, but perhaps remain within the OPS tolerances. If this adjustment does not solve the problem, the issue of aggregate quality must then be addressed.

The coarse aggregates used in Ottawa are of premium quality and 100% quarried rock. Therefore, the key to success appears to surround the fine aggregate fraction and the limitation of natural sand in the mix. An increase in manufactured fine aggregate will likely result in some increased cost, although the extent of this increase remains to be seen.

In summary, the Superpave philosophy of designing to a specific air void content at a compactive effort representative of the expected traffic volume as opposed to a minimum asphalt cement content is much more performance oriented than the Marshall method and will likely produce better performing asphalt concrete mixes. The results of this investigation suggest that some adjustments will be required to meet the specifications. Both internally and through the Ontario Superpave Implementation Committee, the City of Ottawa will continue to work toward implementation of Superpave and provide other municipalities with technical expertise during the transition.

CONCLUSIONS

In order to evaluate the performance of standard municipal Marshall mixes used in the Province of Ontario, the City of Ottawa compacted multiple samples of 13 different asphalt mixes in the gyratory compactor. The following conclusions were drawn:

1. Aggregates used in the City of Ottawa meet the Superpave consensus properties of coarse aggregate angularity, fine aggregate angularity, flat and elongated particles and sand equivalent.
2. The gradation tolerances for standard Ontario mixes such as HL-1, HL-3, HL-4, HL-8 and Heavy Duty Binder Coarse (HDBC) generally match the control points of the respective Superpave gradation classes. HL-4 may be designed as either a 12.5mm or 19mm Superpave mix.
3. Twelve of the 13 mixes compacted in the gyratory compactor achieved the target density of 96% of maximum theoretical density (i.e. 4% air voids) at gyration levels much lower than even the lowest Superpave N_{des} of 50 gyrations.

4. All 13 mixes had gradations that went above the Superpave restricted zone and many mixes contained over 30% natural sand.
5. Mix No. 7 – an HL-3 with 30% recycled asphalt pavement (RAP) met the requirements of a 75-gyration Superpave mix, with the exception of the $N_{initial}$ criterion.
6. Significant adjustments to mixes currently used in the City of Ottawa will be required to meet Superpave specifications including (but not limited to) a reduction in the amount of natural sand, a slight reduction in asphalt cement content and gradation adjustment to fall below the restricted zone.

REFERENCES

[1] Ontario Provincial Standard Specifications. "Material Specification for Hot Mix, Hot Laid Asphaltic Concrete." OPSS 1150, May 1994. Ronen House, Toronto.

[2] Corbett, M.A. "Seven Years of Superpave in Ottawa, Canada." Proceedings of the 14th International Road Federation World Road Congresss, Paris, June 2001.

[3] "Ontario Aggregates and Superpave – An MTO Study." Asphaltopics. Summer 2002. Ontario Hot Mix Producers Association (OHMPA), Toronto.

[4] Superpave Mix Design. Superpave Series No. 2 (SP-2), First Edition. Asphalt Institute, Lexington, Kentucky. 1995.

[5] Mallick, R., Buchanan, S., Brown, E.R., and Huner, M. "An Evaluation of Superpave Gyratory Compaction of Hot Mix Asphalt." NCAT Report No. 98-5. National Center for Asphalt Technology, Auburn, Alabama. 1998.

[6] Superpave Mix Design. Superpave Series No. 2 (SP-2), Third Edition. Asphalt Institute, Lexington, Kentucky. 2001.

[7] Kandal, P.S. and Cooley Jr., L.A. "The Restricted Zone in the Superpave Aggregate Gradation Specification." NCHRP Report 460. National Cooperative Highway Research Program, Transportation Research Board. Washington, DC. 2001

[8] American Association of State Highway and Transportation Officials. "Standard Practice for Designing Stone Matrix Asphalt (SMA)." AASHTO Designation PP41-00. Washington, DC. 2000.

[9] Cooley, A. "Relationship Between Internal Angle and Density." Northeastern Superpave Centre News, Vol. 3, No. 3, Spring 2002.

[10] Burlie, R., Uzarowski, L. and Emery, J. "Evaluation of Superpave Volumetric Mix Design Technology for Urban Hot-Mix Asphalt." Proceedings of the 1998 Annual Conference of the Canadian Technical Asphalt Association, Volume 43.