INTRODUCTION OF STONE MASTIC ASPHALTS (SMA) IN ONTARIO

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INTRODUCTION

In the search for a premium asphalt pavement with greater durability, improved rutting and skid resistance, and reduced traffic noise, paving experts in Ontario have reviewed and evaluated stone mastic asphalt (SMA). These heavy duty paving mixes are characterized by a high content of crushed, quality stone and asphalt cement in mastic form. Known primarily as "Splittmastixasphalt," revealing its German origin (Splitt = crushed stone chips), SMA paving mixes were developed in Europe in the early 1970's to address and cope with the effects of the then rapidly increasing traffic in Europe.

In general, European highways stand up better to heavy traffic than North American roads and the approach to mix design may have something to do with it (1,2). The Japanese have started to use SMA paving mixes, as well, with good success (3). An assessment of its potential use in Ontario became justified. The need to know for sound business practice by contractors and user agencies alike led researchers to the following key questions which launched the Ontario SMA project:

Q-1. How does SMA work?—basic concept and key features.
Q-2. Is the technology matured and proven?—status of technology.
Q-3. How and to whom should the technology be transferred?—implementing technology ("know-how"), ownership and approach.
Q-4. Is the required level of detail and precision possible in North America?—expertise and workmanship.
Q-5. Are increased material and processing costs warranted?—economics of premium pavements or life cycle costs.

The Ontario SMA project was designed to address the above questions and to set the stage for fast-tracking implementation of SMA to the desired extent. This paper describes the observations and results of the initial phases of the project. Included is information gathered from visits to Europe and Japan, and also from two preliminary field trials with SMA.

In late 1990, McAsphalt Industries took the initiative to design and construct the first full-scale SMA field trial in North America. Subsequent work is being carried out jointly with the Ministry of Transportation of Ontario (MTO). The paper will discuss the basic concept and the approach

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to technology transfer aspects for SMA, based primarily on European findings. A description of design, construction and evaluation of the field trials will follow.

CONCEPT AND KEY FEATURES

Stone mastic asphalt (SMA) is a hot-mix with a relatively large proportion of stones and an extra large amount of mastic-stabilized asphalt cement. It must be emphasized here that mixes with high stone content are not considered SMA unless bonded with mastic asphalt. Furthermore, the reader is cautioned not to confuse mastic asphalt with "Gussasphalt" or "Asphaltmastix".

The basic idea or concept behind having a gap gradation of 100 percent crushed quality aggregates is to increase the pavement's stability through intimate contact and inter-action of the stones. The stone to stone contact is demonstrated in Fig. 1 showing close contact for an SMA gradation in the surface course and less stone-to-stone interaction for a densely graded paving mix. This first part of the SMA mix design concept is easily understood, accepted and also produced e.g. open-graded and drainage mixes.

The mix design jitters begin with the attempt to tailor the asphalt

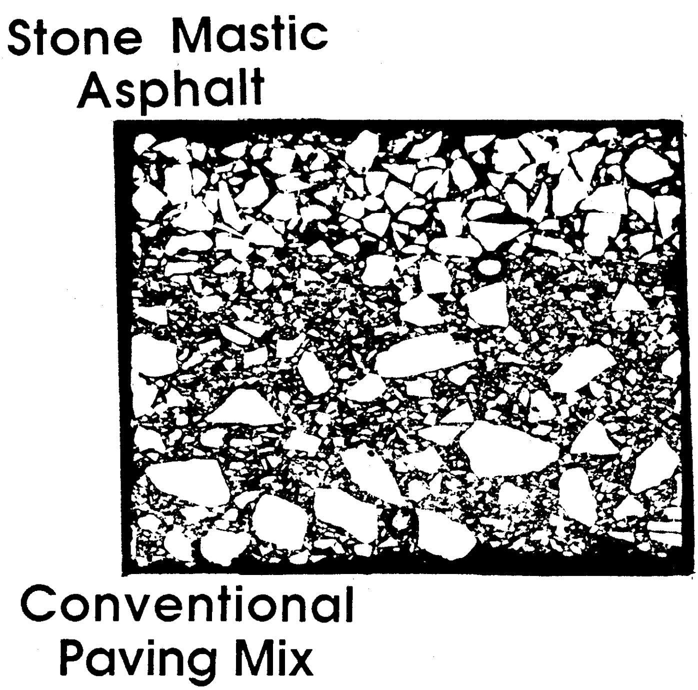

Figure 1. Pavement Section With a Stone Mastic Asphalt (SMA) Surface Course Overlaid on a Conventional Paving Mix.

cement mortar which glues the SMA stone matrix together. The crux of the matter appears to be the skill to incorporate and "stabilize" a lavish amount of asphalt cement in the mix using the asphalt mastic approach. The extra large amounts of asphalt cement binder are required primarily, to provide increased durability and resistance to aging and cracking to a mix which is, by choice of aggregates and gradation, already quite resistant to rutting.

The "stabilization" of the asphalt mortar and, in particular, the prevention of binder run-off during construction, are achieved by:

1. Increase in fines and filler
2. Addition of organic or mineral fiber
3. Polymer-modification, or
4. combinations of the above.

The preferred fillers is coarse graded and must act as filler and not asphalt cement extender. The amount of filler is very much dependent on the type and particle size distribution of the fine aggregates. Furthermore, the asphalt cement content is sensitive to the combined aggregate fines and filler content.

Regarding the use of fiber and polymers, European experts have different opinions and preferences triggered in part by the advent of polymer-modified asphalts. Although fiber can accommodate extra asphalt cement in the mix, questions regarding the overall effectiveness must still be addressed by research, e.g. how much asphalt is absorbed by the fiber and rendered ineffective, dried up or unavailable as active binder? Polymers, on the other hand, enhance the asphalt viscosity and thereby increase the asphalt mortar film thickness of the hot mix. Polymer-modified asphalts are the latest development in SMA technology. The key features of SMA pavements, based on current understanding and status of SMA technology, are summarized in the following:

* High Stability, Rutting and Deformation Resistance
  caused by: quality stone, stone-stone interlock
* Good Skid Resistance
  caused by: quality stone, SMA surface texture
* Reduced Water Spray
  caused by: SMA surface texture and drainage
* Reduced Traffic Noise
  caused by: SMA surface texture, high binder content
* Increased Durability
  caused by: quality aggregate, high binder content
* Improved Low Temperature Performance
  caused by: high binder content, modified binder
* Improved Aging Properties
  caused by: high binder content

In summary, SMA technology has the potential to deliver premium pavements. The price for the superior quality and performance is:

A. Higher Material Costs
  -quality aggregates
  -additives
B. Higher Production Cost
  -lower production output (increased complexity)
  -rigid temperature and mix composition control

In principle, the success of SMA depends very much on the relatively large proportion of both quality stones and asphalt cement, and a high level of dedicated workmanship.

APPROACH TO TECHNOLOGY

Because of the European experience and established performance records, SMA can be considered proven technology (4). The scope of this technology includes most aspects of material selection, mix design, mix production, quality control and testing; as well as construction procedure. Given the status of this technology, and not withstanding minor differences in equipment or practices, the acquisition of expertise would be best achieved by direct technology transfer.

Furthermore, there are several sound reasons why a contractor could assume the key role in this technology transfer, and eventually also assume the custodianship and responsibility for any further development, update, and ownership. The main arguments for this approach are summarized here:

1. *Detail and Precision*
   The key to success with SMA lies in "detail" and "precision" of the mix design, and the proportioning of materials for mix production, mix temperature, etc. These variables are essentially all under the control of the contractor. SMA mixes are not as tolerant as regular hot mixes, and small deviations can result in failure.
2. *Material Selection*
   Performance of SMA mixes are more sensitive to quality and consistency of materials, which most often are supplied by the contractor.
3. *Production Output*
   At times, production output may have to be compromised for quality: e.g. increasing the mixing cycle and slowing the paver.
4. *Track Record of European Contractors*
   European contractors have a good track record in developing and exploiting this new technology and the performance of the finished SMA pavement has been proven successful.

To initiate the technology transfer, close liaison was set up between the Ministry of Transportation of Ontario, McAsphalt Industries, Westhill, Ontario and the German contractor, Wilh. Schuetz KG. The activities to-date include information exchange visits; assistance with material selection, SMA mix design, and mix production; and construction of field trials. So far, this approach has worked well.

The current plan is to schedule a major field application in a high trafficked area near Toronto, based on experiences with several smaller trial installations. This learning curve is needed to give SMA technology a proper chance to demonstrate in North America its claimed superior performance. The design and construction of three field trials at:

(a) Miller Avenue (Markham)
(b) Highway #7N (Toronto)
(c) Highway #404 (Toronto)

are described in the following sections.

MIX DESIGN

The mix designs for the first two field trial sections were carried out in the laboratories of McAsphalt Industries. The results of the mix designs are summarized and discussed in this section.

(a) *Miller Avenue*

Both the SMA surface (13-mm) and the SMA base (19-mm) mixes were designed using the Marshall method. The aggregates used were all 100 percent crushed and locally available (traprock stones, limestone screenings).

The traprock stone was added into the base mix (19-mm) to improve the gradation of the job mix formula of the base course design. The design gradations for both the surface course and base course mixes were based on the gradation bands used in Germany. Table 1 shows the job mix formulae for each mix and the respective gradation specification and the aggregate proportions used to obtain the desired gradation.

The Marshall method of design was used to obtain the physical test data. The compactive effort to achieve the proper air voids was the equivalent mechanical blow count with the 75 blow hand hammer. The mixes were designed to have an asphalt cement content that would give a value of 3.0 percent air voids. Although the European experience has shown that the use of 50 blow Marshall is adequate with design air voids of 3 percent, it was felt that the traffic conditions would cause over-densification of the mix. Consequently, the blow count was raised to 75. The Marshall properties for the 13-mm and 19-mm mixes shown in Table 1 are typical numbers for SMA mixes. The Marshall Stability and Flow Index values do not really reflect the true nature of the stone skeleton, which provides the stone on stone contact and prevents pavement deformation. The mixing and compaction temperature for these designs were 150 C and 145 C, respectively. A conventional 85/100 penetration asphalt cement was used.

Mix Type		Surface Course 13-mm	Base Course 19-mm
GRADATION Sieve		**Percent Passing**	**Percent Passing**
Size (mm)	**No. (Inches)**		
26.50	(1)		100.0
19.00	(3/4)		97.1
16.00	-	100.0	91.2
13.20	(1/2)	99.7	83.8
9.50	(3/8)	84.1	66.7
4.75	# 4	36.4	35.6
2.36	# 8	25.7	25.7
1.18	# 16	18.9	18.9
0.60	# 30	15.0	14.9
0.30	# 50	12.0	11.9
0.15	#100	9.8	9.7
0.075	#200	7.8	7.7
MIX PROPORTIONS (Percent)			
Limestone (Coarse Aggregate)			40.0
Traprock (Coarse Aggregate)		65.0	25.0
Limestone Screenings		30.0	30.0
Fly Ash Filler		5.0	5.0
Glass Fibre		0.3	0.3
Asphalt Cement (85-100 PEN)		6.5	5.5
MARSHALL PROPERTIES			
Bulk Relative Density (kg/m^3)		2.445	2.424
Maximum Relative Density (kg/m^3)		2.530	2.491
Percent Air Voids		3.36	2.69
Percent VMA		19.0	15.6
Marshall Stability (Newtons @ 60°C)		9720	13678
Flow Index (0.25-mm)		25 +	25 +

Table 1. Gradations, Mix Proportions and Marshall Data for Miller Avenue.

(b) *Highway #7N*

For the Highway #7N site overlay, only a surface mix was required. The aggregate used was 100 percent crushed Dolomite sandstone from Ottawa. The Dolomite aggregate was chosen because it exhibits higher stability and greater resistance to polishing than the cheaper limestone. Therefore, this SMA paving mix is expected to give improved performance, especially with regard to rutting and skid resistance.

Table 2 shows the SMA job mix formula and the respective gradation specification and aggregate (fiber) proportions. The briquettes were compacted with 37 blows mechanical (~50 blows manual to 50 blow hand) on

Mix Type		Surface Course 13-mm
GRADATION Sieve		**Percent Passing**
Size (mm)	**No. (Inches)**	
16.00	-	100.0
13.20	(1/2)	98.5
9.50	(3/8)	76.3
4.75	# 4	31.7
2.36	# 8	24.5
1.18	# 16	21.4
0.60	# 30	19.3
0.30	# 50	15.3
0.15	#100	13.0
0.075	#200	10.8
MIX PROPORTIONS (Percent)		
Dolomite Sandstone (Coarse Aggregate)		70.0
Dolomite Screenings		22.0
Ground Dolomite Filler		8.0
Glass Fibre		0.3
Asphalt Cement (60-70 PEN, Styrelf)		5.3
MARSHALL PROPERTIES		
Bulk Relative Density (kg/m^3)		2.372
Maximum Relative Density (kg/m^3)		2.471
Percent Air Voids		4.0
Percent VMA		15.8
Marshall Stability (Newtons @ 60°C)		8600
Flow Index (0.25-mm)		25 +

Table 2. Gradations, Mix Proportions and Marshall Data for Highway #7N.

each side at 135°C. The mechanical compactor used in the design process has a rotating base and a bevelled foot.

(c) *Highway #404*

Two acceleration ramps on Highway #404 were selected as test sites for trial SMA mixes with and without cellulose fiber, (total about 800 tons). Traprock was chosen as the sole coarse aggregate because the available Dolomite from Ottawa contained weak material, which seemed to break under the sheet roller even without vibration. Three trial sections were constructed with mix formulation containing:

i) Styrelf modified asphalt cement plus cellulose fiber.
ii) Styrelf modified asphalt cement without fiber.
iii) Vestoplast modified asphalt cement without fiber.

These mix formulae including their Marshall data are summarized in Table 3. The gradation and the filler content were kept the same for all three paving mixes. Only the amounts of asphalt cement were changed. The addition of 0.3 percent fiber increased the required binder content by 0.5 percent. Mix designs for the three SMA types were also produced independently by the German contractor, Wilh. Schuetz KG, who has been designing and constructing SMA paving mixes for over ten years in Germany. The data, which is shown in brackets "()" in Table 3, is amazingly close to the design by McAsphalt Industries. The McAsphalt briquettes

Mix Type		SMA Styrelf & Fibre		SMA Styrelf		SMA Vestoplast	
GRADATION Sieve		Percent Passing		Percent Passing		Percent Passing	
Size (mm)	No. (Inches)						
19.00	(3/4)		*(100.0)		(100.0)		(100.0)
16.00	-	100.0	-	100.0	-	100.0	-
13.20	(1/2)	99.9	(98.7)	99.9	(98.7)	99.9	(98.7)
9.50	3/8)	76.9	(79.3)	76.9	(79.3)	76.9	(79.3)
4.75	# 4	33.0	(34.8)	33.0	(34.8)	33.0	(34.8)
2.36	# 8	25.0	(27.1)	25.0	(27.1)	25.0	(27.1)
1.18	# 16	19.6	(22.1)	19.6	(22.1)	19.6	(22.1)
0.60	# 30	15.8	(18.5)	15.8	(18.5)	15.8	(18.5)
0.30	# 50	13.4	(15.8)	13.4	(15.8)	13.4	(15.8)
0.15	#100	11.9	(14.0)	11.9	(14.0)	11.9	(14.0)
0.075	#200	10.7	(11.6)	10.7	(11.6)	10.7	(11.6)
MIX PROPORTIONS (wt. %)							
Traprock (Coarse)		70	(68)	70	(68)	70	(68)
Dufferin Sand		20	(20)	20	(20)	20	(20)
Limestone Filler		10	(12)	10	(12)	10	(12)
Cellulose Fibre		0.3	(0.3)				
AC (85-100 PEN)						4.9	(4.9)
AC (60-70 PEN, Styrelf)		5.6	(5.7)	5.1	(5.2)		
Vestoplast % of AC						7.0	(7.0)
MARSHALL PROPERTIES							
BRD (kg/m^3)		2.574	(2.560)	2.582	(2.573)	2.597	(2.601)
MRD (kg/m^3)		2.653	(2.649)	2.668	(2.672)	2.678	(2.672)
Percent Air Voids		3.0	(3.4)	3.2	(3.7)	3.0	(2.7)
Percent VMA		15.8	(17.5)	15.1	(16.4)	14.4	(15.5)
Marshall Stab (Newtons @ 60°C)		8137	(7300)	7881	(7800)	7188	(7200)
Flow Index (0.25-mm)		24.9		23.1		15.5	

*() are independent results from Wilh. Schuetz (Germany)

Table 3. Gradations, Mix Proportions and Marshall Data for Field Samples from Highway #404.

were compacted at 135 C, 37 blows mechanical, which is about equivalent to 50 blows each side manual.

PLANT MIXING

The mixes were produced in a Barber-Greene 10-ton batch plant. The coarse and fine aggregates were fed from separate cold feed bins to the dryer, hot elevator, and screen deck into the hot storage bins, and then introduced into the pugmill. The filler material was packaged in 220 kg poly-melt bags. The filler was delivered on skids, moved to the RAP belt, placed manually on the belt, delivered to the weigh hopper, and then loaded into the pugmill. The fiber material was packaged in 10-kg poly-melt bags. These bags were placed as close as possible to the pugmill. As the dry mix cycle started, the fiber bag was shoved into the pugmill and mixed into other aggregates. The dry mix time was initially set at 15 seconds with a wet mix cycle of 45 seconds.

At the first trial, some problems were experienced during the production run. The filler bags tended to slip on the RAP belt and slow the mixing process down. In order to eliminate this slippage problem, a small amount of natural sand was placed behind each bag. The fiber bags were very awkward to handle, and the full dry mix cycle was not available for mixing the fiber into the SMA. Evidence of uncoated balls of fiber was present in some of the batches of mix.

For the second field trial, the dry mix cycle was doubled to approximately 30 seconds. Furthermore, the fiber bags were halved and its contents fluffed to facilitate the mixing in the pugmill. Some improvement in the dispersion and mixing of the fine glass fiber was achieved.

CONSTRUCTION

(a) *Miller Avenue*

The first SMA field trial was in the middle of December 1990 on Miller Avenue (Markham) approximately 1/2-km from the asphalt plant. The existing pavement was badly rutted and milled out. The area to receive the 13-mm SMA mix was milled out to a depth of 40 mm, while the section to receive the 19-mm SMA was milled to a depth of 50 mm. The exposed surface was swept with a power broom, but due to the cold weather conditions, a tack coat was not applied to the milled surface or the joints.

The laydown of the SMA mixes was completed using a conventional asphalt spreader. Only minor changes were necessary. Because of the type of mix being laid, the lift thickness of the loose mix could be reduced. Under the roller action, the mix did not compact as much as conventional hot mix. With regard to rolling, the only type of roller recommended and used was either a static 10–12 ton roller, or a vibratory roller used only in the static mode. The reason for only static rolling is to prevent the coarse aggregate in the mix from being fractured. A rubber-tired roller is not used for the same reason, as it tends to pump the mastic portion to the surface.

The 13-mm material was laid first. There were no uncoated fiber balls in the first two loads, but the third load contained a ball of fiber. The dry mixing cycle was increased to 25 seconds to try to eliminate this problem. The mix temperatures were quite consistent; the following typical values being observed:

Location	*Temperture °C*
In Hopper	150
Spreader Augers	140
After First Roller Pass	125

The 19-mm SMA mix was placed right after the end of the 13-mm section. The first two loads of mix contained uncoated fiber balls even though the dry mixing cycle had been increased by an extra 10 seconds. The mix temperatures obtained on the 19-mm material were the same as the first section.

(b) *Highway #7N*

The second SMA field trial was constructed on June 25, 1991, on the eastbound lane of Hwy. 7N between the Dufferin and Bathurst Streets. The road surface was badly cracked and was being repaired with a 40-mm overlay. The SMA mix was placed on the driving lane and shoulder alongside two lanes of densely-graded friction course. Aside from some initial problems with the mixing of the fiber, the paving and compaction were done in a conventional manner.

(c) *Highway #404*

The third SMA field trial was constructed on October 28, 1991, after a 100-ton trial mix was successfully placed a few days earlier. The test site is located on the two southbound acceleration lanes at the new Highway #404 intersection, near the Buttonville airport. Highway #404 has an average daily traffic load of 260,000 vehicles and this new intersection near the airport is expected to see much traffic.

FIELD TEST DATA

(a) *Miller Avenue*

Samples were taken of both mixes and analyzed in the laboratory. In general, the air void values obtained were much lower than the design values. Table 4 gives the test data on both the 13-mm and 19-mm mixes. Although the air void results were quite low, the test sections did not exhibit any signs of premature distress. Two months after the test sections were placed, slabs were removed from each section and tested in the labo-

Mix Type / Sample No.		Surface Course 13-mm Field	Surface Course 13-mm Slab	Surface Course 19-mm Field	Surface Course 19-mm Slab
GRADATION Sieve		**Percent Passing**		**Percent Passing**	
Size (mm)	**No. (Inches)**				
26.50	(1)				
19.00	(3/4)			100.0	100.0
16.00	-	100.0	100.0	92.0	89.6
13.20	(1/2)	99.5	98.6	79.8	83.2
9.50	(3/8)	76.8	75.1	59.7	63.9
4.75	# 4	32.0	37.6	31.1	36.9
2.36	# 8	24.2	28.4	21.8	28.8
1.18	# 16	20.2	23.3	16.5	22.8
0.60	# 30	14.9	19.0	13.2	16.5
0.30	# 50	12.2	14.2	11.2	13.3
0.15	#100	9.7	10.4	9.6	13.1
0.075	#200	7.7	7.9	8.1	8.5
MARSHALL PROPERTIES					
Asphalt Cement (85-100 PEN)		6.11	5.92	5.15	5.24
Bulk Relative Density (kg/m^3)		2.545	2.551	2.437	2.460
Maximum Relative Density (kg/m^3)		2.595	2.569	2.472	2.502
Percent Air Voids		1.92	0.70	1.42	1.68
Percent VMA		15.9	14.3	12.5	13.1
Marshall Stability (Newtons @ 60°C)		7103	6450	8839	9221
Flow Index (0.25-mm)		22.0	35 +	36.5	34.0
Compaction, Percent			93.0		93.0

Table 4. Marshall Data for Field Samples from Miller Avenue.

ratory for their physical properties. The data labelled "Slab" in Table 4 are the test results on these samples. The samples were removed from the middle of the lane between the wheelpaths in order to obtain compaction results which would closely represent the compactive effort at the time of construction. The percent compaction results achieved were only 93.0 percent, which is below the values normally expected. considering the time of year that the trial sections were placed, the compactive effort achieved is within the expected range.

The two pavement "slabs" were also used to determine the SMA rutting resistance using the Ministry of *Transportation (MTO) wheel tracking* machine. The MTO rutting test is done at a controlled temperature of 60 C using a rubber tired wheel rim along the test "slab" for 4,000 cycles. The following rutting depths were obtained:

Surface Coarse (13-mm) SMA	5.1-mm
Base Coarse (19-mm) SMA	6.7-mm
Control Asphalt Concrete	16.8-mm

The rutting resistance of the SMA mixes is better compared to the control asphalt concrete.

(b) *Highway #7N*

Hot mix samples were taken from the augers and analyzed in the laboratory. Typical results are listed in Table 5. Additional test specimens gave very similar results. The average compaction based on 17 core samples was 96 percent.

The MTO rutting test (Ref. 5) was performed on two SMA test slabs taken from the trial section at Highway #7N and compared with two test slabs of an adjoining lane, which was overlaid with a DFC (Dense Friction Course) paving mix at the time of the SMA trial construction. The rut depth of the SMA pavement after 4,000 passes at 60 C on the wheel track-

Mix Type		Surface Course		
Sample No.		No. 2	No. 4	No. 6
GRADATION Sieve		Percent Passing		
Size (mm)	No. (Inches)			
16.00	-		100.0	100.0
13.20	(1/2)	100.0	99.0	99.7
9.50	(3/8)	71.4	72.6	69.9
4.75	# 4	29.2	28.6	27.6
2.36	# 8	23.9	23.0	22.1
1.18	# 16	21.0	20.5	19.5
0.60	# 30	19.1	18.9	17.9
0.30	# 50	15.3	15.7	14.4
0.15	#100	12.5	12.8	11.3
0.075	#200	9.3	9.3	8.3
MARSHALL PROPERTIES				
Asphalt Cement (60-70 PEN, Styrelf)		5.10	5.17	5.03
Bulk Relative Density (kg/m^3)		2.404	2.368	2.731
Maximum Relative Density (kg/m^3)		2.506	2.501	2.503
Percent Air Voids		4.07	5.31	5.27
Marshall Stability (Newtons @ 60°C)		11098	9021	10335
Flow Index (0.25-mm)		29.9	27.0	26.5

Table 5. Marshall Data for Field Samples from Highway #7N.

ing machine was only 2.6-mm. The DFC mix, which is a heavy-duty surface mix used for heavy trafficked areas in Ontario, gave a rut depth (average of two samples) of 5.0-mm. These initial test results for SMA field samples are very encouraging.

Since the Highway #7N test site is equipped with a WIM (Weight-In-Motion) scale and also instrumented for temperature and moisture measurements, this location is opportune for a comprehensive evaluation of the SMA pavement.

(c) *Highway #404*

Two SMA hot mix samples were taken during construction from each of the trial mixes. The hot mix test report data are summarized in Table 6. The values of the air voids are higher than called for by design. Cores taken from the test section show that the 3M traprock used for the construction of the trial section contains a greater than average proportion of flat and elongated stones. The stones can be seen to form 'air pockets' in

Mix Type		SMA Styrelf		SMA Vestoplast		SMA Styrelf & Fibre	
Sample No.		A_1	A_2	B_1	B_2	C_1	C_2
GRADATION Sieve		Percent Passing		Percent Passing		Percent Passing	
Size (mm)	No. (Inches)						
16.00	-	100.0	100.0	100.0	100.0		
13.20	(1/2)	99.5	99.4	99.4	100.0	100.0	100.0
9.50	(3/8)	67.2	76.0	76.1	76.9	79.9	77.9
4.75	# 4	39.9	27.7	24.7	28.0	26.1	25.8
2.36	# 8	24.7	22.0	17.7	22.0	17.6	19.1
1.18	# 16	19.6	17.9	15.5	17.2	14.8	16.3
0.60	# 30	16.2	15.4	14.3	14.5	13.4	14.3
0.30	# 50	14.0	14.1	13.5	12.5	12.6	13.2
0.15	#100	12.5	12.9	12.4	11.4	11.7	12.1
0.075	#200	9.9	10.4	9.8	9.1	9.6	9.7
MARSHALL PROPERTIES							
Asphalt Cement (%)		4.9	4.7	5.0	4.9	5.35	5.25
Bulk Relative Density (kg/m³)		2.589	2.537	2.495	2.518	2.488	2.503
Maximum Relative Density (kg/m³)		2.688	2.701	2.688	2.678	2.686	2.670
Percent Air Voids		3.7	6.0	7.1	6.0	7.4	6.2
Marshall Stability (Newtons @ 60°C)		8663	8354	4634	7262	7424	7077
Flow Index (0.25-mm)		17.5	12.3	10.7	11.4	14.3	12.1

Table 6. Marshall Data for Field Samples from Highway #404.

the compacted pavement. The occurrence of these 'air pockets' was increased at lower compaction temperatures.

The field compaction for the three trial sections, based on 28 cores was;

A	SMA Styrelf	95.0 Percent
B	SMA Vestoplast	97.2 Percent
C	SMA Styrelf & Fiber	97.3 Percent

The lower average compaction (95.0 percent) of the SMA-Styrelf trial section, which was constructed first, may be attributed to the lower plant mixing and compaction temperature (100 C-130C). Initially, the plant did not produce the mix hot enough and some unmelted filler bags were found in the truck boxes. During the remaining two test sections the plant mixing and compaction temperatures were higher which could help to explain the improved compaction results. The ambient temperatures during placement of all three trial sections was generally 8°C to 11°C.

Vibratory compaction was used for some of the SMA with Vestoplast. There was some coarse aggregate breakage, but probably not significant. All trial sections will be monitored and compared with conventional heavy duty surface mixes, which were constructed at the same time.

CONCLUSIONS

From the experience gained with the design and construction of the first three SMA field trials it is concluded:

1. That SMA paving mixes can be produced and placed employing local materials and equipment.
2. That much attention has to be given to details and precision in proportioning mix components and controlling mix and laying temperatures.
3. That interaction with the European experts is helpful.
4. That initial results are very encouraging and warrant the continuation of the project.

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Much credit for the successful introduction of SMA paving in Ontario is due to Mr. John Carrick, President of McAsphalt Industries for his entrepreneurship and courage in initiating the first field trial in North America. Gratefully acknowledged is also the assistance and advise from Ottmar Schuetz (Germany), Mr. Sherocman (U.S.A.) and John Emery (JEGEL), who supplied laboratory services, in addition to his capable staff.

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DISCUSSIONS

MR. GALE C. PAGE: You indicated that we have to use quality aggregates. Primarily the reason being the crushing resistance that is required because of the stone-to-stone contact. The test we normally use here in the U.S. is the LA abrasion. I understand the Germans have used some sort of impact hammer to measure crushing resistance. What test did you use and what is your opinion of the test you used?

DR. GERHARD KENNEPOHL: We used our traditional LA abrasion test which is more or less accepted by the Europeans. They did not do any additional testing. Their complaints were not so much on that aspect but on particles that you could pick out which were actually too soft. Also the particles were not cubical, they were elongated. These were the main complaints.

MR. PAGE: Did the Europeans run the impact hammer test?

DR. KENNEPOHL: They did not run any of these tests. They accepted our data. I know they do use them, but for these samples they did not run them. We were pretty well stuck with these sources. As I said, we sought initially from our data the dolomite was alright except we had some material that would crush on compaction.

MR. PAGE: Do you have any opinion regarding the LA as a measurement of crushing resistance?

DR. KENNEPOHL: I think that compares very well with the European test.

MR. WILLIAM EAST: I was interested in your comments on the noise reduction. Were any studies run by Ontario regarding the reduction compared to a normal gap-graded? We found that any open-graded type mix will produce a substantial noise reduction. I wonder if you could address that.

DR. KENNEPOHL: We are intending to do that. We do not yet have data. However, I agree with you that the open-graded mixes, which we often use in Ontario, do give noise reduction. I do not think there is any reason why these SMA mixes with that texture will not do what is expected. As I said, the construction paper is basically talking about putting it down and what we expect from it. We do not have much field data. We did some skid resistance.

PROFESSOR KENNETH ANDERSON: Just to follow up a bit more on the technology transfer; in suggesting the contractor be the vehicle for doing that. Did you have a local contractor who then became involved with the European experience?

DR. KENNEPOHL: That is correct. McAsphalt Industry of Toronto and William Schütz from Frankfort, Germany.

PROFESSOR ANDERSON: Then it was the local contractor, McAsphalt, who was actually placing the material but had the technology assistance from the Germans.

DR. KENNEPOHL: Yes. We had them do the mix designs, which is how I think it needs to be done, and compare notes. Obviously I was there all the time also because I want to learn too. The contractors should be the custodians handling that.

MR. JAMES A. SCHEROCMAN: You mentioned at the beginning of your presentation to not compact the SMA mix using a vibratory roller. Last fall, however, on Route 404 Interchange project, we did compact the mix, in part, with a vibratory roller. I have not seen the compaction test results on the degree of density obtained or the amount of aggregate that was crushed, if any, by the use of the roller in the vibratory mode. Do you know if there were any differences in the densities from the use of the vibratory roller?

DR. KENNEPOHL: I guess that between you, John Emery and myself we were not quite in agreement on how much crushing we had. However, I was invited to attend in Michigan and it seemed there fairly obvious.

MR. SCHEROCMAN: We have started to use vibratory rollers to compact some of the SMA mixes now in the U.S. and I am concerned about the effect of this type of compactive effort on the ability to obtain the desired level of density. I just did not know what the results were from your test sections because I have not seen any of the density data. I am not aware of any problems that occurred because of the use of the vibratory roller.

DR. KENNEPOHL: As I said that probably needs to be additionally verified. I go somewhat by what our European friends tell us. They would not vibrate although there may a certain amount possible.

MR. SCHEROCMAN: I think that we will find out at the Symposium that they do things a lot differently in Europe then we do. They have better quality and more consistent materials then we do. It is interesting to try to transfer that technology to North America.

DR. KENNEPOHL: It is obviously a sensitive point. Just like some of the other tolerances. We see that when you compact it does not give much. You have vibration of 80 percent on the screed and you perhaps have a tamping action. The difference that you see in a normal hot mix compaction is not there. In other words you get fairly good compactions the first run. We know clearly from the number of blows and the number of temperature ranges that you compact in the lab that you can destroy the rock fairly easily. It is a sensitive point and I am not claiming to be an expert.

PROFESSOR BOB M. GALLAWAY: We have placed a lot of light-weight aggregate in Texas. The susceptibility to crushing of a piece of aggregate of this type is such that you could crush it with your foot. This same material has been incorporated in mixes very much like what you are talking about. Same size range. The only difference being that it is not cushioned as well as the split mastic because it has less fines and less filler. No problem with crushing. Therefore I agree with Jim; in construction and under traffic it does not crush. Technical speaking it is very fragile. You are talking about restricting split mastic to rock that you cannot crush with a hammer. I think that is wrong. If it will perform friction-wise and durability with respect to freeze/thaw, I do not think you have any problem with it. I do not think crushing susceptibility is the problem.

DR. KENNEPOHL: I am afraid, Bob, I do not agree. I have worked with soft aggregate in Saudi Arabia I could crush with my hand and we had a lot of problems there. I think when we talk stone mastic and quality aggregate they are two major components, the stability of the rock as determined by the LA abrasion; also the shape factor. These are major factors in the quality of rock that you need for stone mastic asphalt. If you have soft material, I think you are not getting your money's worth. We have to really seriously think this through. We were told by our contractor the cost would be 25 to 30 percent more. I have heard much higher figures on the cost of SMA and I believe that unless you really use quality material you are wasting additives, effort and workmanship. I think the stability of the rock is definitely something one must consider.

PROF. GALLAWAY: This is contrary to about 30 years of service on Texas roads and probably in excess of 20,000 lane miles. By the way, these materials of which I speak have an L.A. abrasion loss of 20 to 25. The surface function is 0.5§ for the life of the surface.

DR. KENNEPOHL: I suppose it is time we catch up then.

MR. JOHN D'ANGELO: In your report you show that you perform a 75-blow Marshall design for SMA mixes instead of the 50-blow design typically used in Europe. I was wondering if you had done any studies comparing the results between 50 and 75-blow Marshall designs for SMA mixes.

DR. KENNEPOHL: Keith has been doing all the Marshall work in his lab and I should let him answer that.

MR. KEITH DAVIDSON: The first trial we did with 75-blow Marshall. We were concerned about the 50-blow because in Ontario we do not use 50-blow Marshall. The very first trial was done using 75. Based on the results we got we switched back. The original trial was done almost totally in-house through McAsphalt and their sister company, Millers. When we were talking with Gerhard we got involved with Ottmar. We got into the 50-blow side. We did some work in he lab and we were finding differences but we felt after that we could go with the 50-blow. We will probably continue that. As far as what I am personally concerned, the 50-blow seems to do what we want it to do. Based on the results we are getting in the field, it is more than adequate.

DR. KENNEPOHL: I think the danger is if we apply our standards to this new technology. I think the first part that we have to do is listen and accept. If we can find out that there are modifications that we can allow to make, like use in some instances softer materials, all the better.

DR. ERVIN DUKATZ: Just a quick comment. I was very happy to see that you tried a wide range of materials in your study. Somewhat in answer to Jim's comment that the European rocks are different than U.S. rocks or North American rocks, I felt that I could not sit here and not speak up. We at Vulcan Materials Co. have studied a number of the European rocks and I can assure you that basalts from Germany and Sweden and elsewhere are like the basalts that we have in the U.S. or Canada. Likewise, our granites are every bit as susceptible to the LA abrasion test as the European granites in producing high LA abrasion losses. I think when we talk about rock quality, we really need to talk about engineering properties much like they are trying to do in the SHRP work. We need to be comparing rocks on their measurable engineering properties like the compressive strength, or the tensile strength rather than saying that this rock is better because somebody went out and kicked it and they couldn't sink their boot into up to the shank.

DR. KENNEPOHL: I sort of agree with you. Thank you for your comments.

MR. JOS VAN DER HEIDE: We are studying about introducing the LA test in the European Standard now because it gives good results for the abrasion of the aggregate. We found that the test we normally use, an impact test or a static compression test, gives the same ranking for the common aggregates but the LA test may be more generally applicable. Concerning traffic noise, in one particular case it was found that stone mastic asphalt gives a noise reduction of about the same level as porous asphalt: about 3 decibel related to the normal dense asphaltic concrete. This was explained from the very smooth surface of the stone mastic asphalt.