DEVELOPMENT OF STONE MASTIC ASPHALT MIXES FOR ONTARIO USE

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ABSTRACT

Stone mastic (or matrix) asphalt (SMA) use in Europe (split mastic in Germany) and Japan, based on excellent frictional properties, plastic deformation resistance, fatigue endurance and durability, formed the basis for 1990 and 1991 technology transfer demonstration trials. The thrust of this SMA work has been to incorporate international experience using local aggregates, fillers, engineered asphalt cements and fibres. SMA is a gap-graded, dense, hot-mix asphalt with a large proportion of coarse aggregate (passing 2 mm limited to about 20 percent, all crushed material) and a rich asphalt cement/filler mastic. The coarse aggregate forms a high stability structural matrix and the engineered asphalt cement, fine aggregate, filler and stabilization additive (typically fibre) form a mastic binding the structural matrix together. Plant and placement trials of two preliminary SMA designs incorporating fly ash filler and fibre indicated no transportation, placement or compaction problems, but care must be taken to ensure proper mixing of any fibre added. From this demonstration work, SMA-modified Marshall mix design procedures have been developed and four highway trial sections have been completed in 1991. Quality assurance testing indicated no significant problems in meeting SMA mix design requirements once production parameters were established. Monitoring and characterization of these SMA pavements are in progress with, for instance, very favourable rutting resistance and surface texture performance shown.

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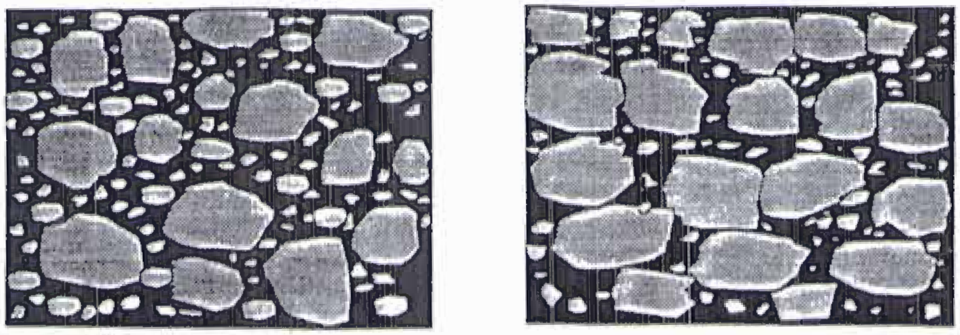
INTRODUCTION

With the growing use of stone mastic asphalt (SMA) in Europe and Japan, and the obvious technology transfer applicability to Canada in terms of both climate and pavement performance requirements, an SMA research and development team approach was used to quickly complete demonstration SMA trial sections in December 1990, the first in North America. This initial satisfactory SMA demonstration work was then extended to SMA highway trial sections in June and October 1991 assisted by the Ontario Ministry of Transportation (MTO). The use of SMA in Europe and Japan is based on demonstrated excellent frictional properties, plastic deformation (rutting) resistance, fatigue endurance and durability. The thrust of the team's SMA work has been to incorporate international SMA design and construction experience using locally available aggregates, fillers, engineered asphalt cements and fibres in conventional hot-mix plants.

STONE MASTIC ASPHALT (SMA)

What is stone mastic asphalt (SMA) and why is it getting so much attention from North American pavement experts [1-5]? SMA (termed split mastic in Germany where it has been developed and used for about twenty years) is a gap-graded, dense (about 3 percent air voids mix design), hot-mix asphalt with a large proportion of coarse aggregate (passing 2 mm limited to about 20 percent, all aggregate 100 percent crushed) and a rich asphalt cement/filler mastic (about 10 percent minus 75 μm) [6,7]. The coarse aggregate, through point-to-point contact as shown schematically in Figure 1, forms a high stability skeleton (structural matrix) with good internal friction and aggregate interlock to resist load-induced shear. A typical SMA grading band, compared to conventional hot-mix asphalt (HMA) is given in Figure 2 with further details on typical SMA aggregates and filler compositions.

The asphalt cement (typically polymer-modified), fine aggregate, filler and stabilization additive (if necessary, typically about 0.3 percent



HOT-MIX ASPHALT (HMA) STONE MASTIC ASPHALT (SMA)

FIGURE 1. COMPARISON OF 'FLOATING' COARSE AGGREGATE IN HMA WITH STONE-TO-STONE 'SKELETON' IN SMA.

(The point-to-point contact achieved in the SMA provides internal friction to resist load-induced shear. Adapted from Report on the 1990 European Asphalt Study Tour (EAST) [7].)

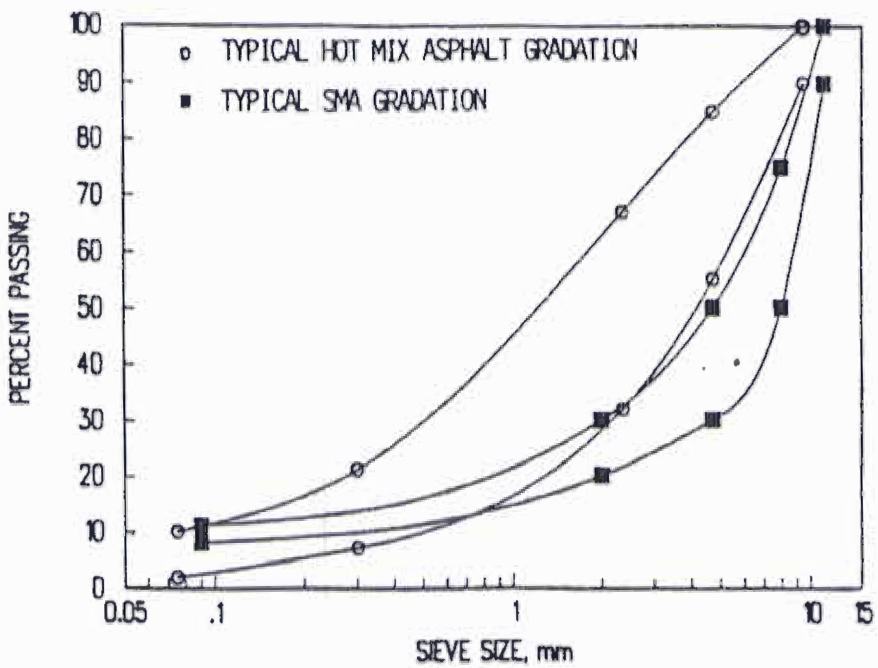


FIGURE 2. COMPARISON OF TYPICAL DENSE GRADED HOT-MIX ASPHALT (HMA) AND STONE MASTIC ASPHALT (SMA) GRADING BANDS.

(Coarse aggregate (plus 2 mm) about 70 to 80 percent, fine aggregate (2 mm to 90 μm) about 12 to 17 percent and filler (minus 90 μm) about 8 to 13 percent for SMA. SMA coarse aggregate top size typically between 11 and 16 mm. Adapted from Report on the 1990 European Asphalt Study Tour (EAST) [7].)

mineral, glass or cellulosic fibre to prevent asphalt cement runoff) form a mastic binding the structural matrix together. The polymer modified asphalt cement content is typically 1.0 to 1.5 percent greater than for a conventional HMA incorporating the same aggregates. This rich, durable mastic has a far higher filler (finer than 90 μm) to asphalt cement content ratio than the limit of 1.2 recommended by the Federal Highway Administration (FHWA) for conventional dense graded HMA [8]. The SMA's high stability skeleton must contain all the mastic binder while maintaining the point-to-point contacts (Figure 1) essential for shear deformation (rutting) resistance. SMA is usually designed to have an air voids content of 3 percent. Too much mastic will push the coarse aggregate particles apart with a drastic reduction in pavement shear deformation resistance, while too little mastic will result in high air voids with reduced pavement durability due to accelerated aging and moisture damage [6,7]. Obviously, there is little latitude during SMA production in the mix design, aggregate gradation, polymer modified asphalt cement content or fibre content.

The SMA typical mix design (50 blow Marshall method often used [9-11]) air voids content of 3 percent provides an in-place air voids content of less than 6 percent. Static steel-wheel compaction is generally used primarily to orient the coarse aggregate particles at the pavement surface and there is little additional roller densification or deformation. To avoid coarse aggregate fracture, vibratory rolling is not used in Europe, and to avoid possible mastic surface flushing, pneumatic rolling is not used. Vibratory rolling was used on part of the last SMA trial, and has been used on several trial sections in the United States. Since there is little compaction densification of SMA, the mastic must be rich in asphalt cement (binder) to achieve the low in-place voids essential to durability.

After placement and compaction, SMA has a coarse (open) surface texture characterized by good coarse aggregate macro-texture (large, rough depressions) that provides excellent frictional properties ('skid' resistance) over time. However, with the rich mastic involved, there may be a period of traffic action required to wear the binder film off the coarse aggregate in order to develop microtexture. If this is of concern, European experience indicates an asphalt cement pre-coated sand or hot sand application can be used to provide enhanced frictional properties until microtexture is developed.

By modifying the gradation to essentially a single-size coarse aggregate, a free-draining (porous) asphalt mix (porous asphalt, PA) can also be developed for open friction course applications. Porous asphalt (PA) mix designs have been developed by the team and it is anticipated that some PA trial sections will be completed in 1992.

A comparison of SMA and PA properties and features with those of conventional HMA is given in Table 1, which is based on Nordic experience. In summary, SMA has excellent wear and frictional properties, plastic deformation (rutting) resistance, fatigue endurance, resistance to low temperature cracking and durability, all critical attributes for surface course asphalt paving and high traffic density routes.

SUMMARY OF EUROPEAN AND JAPANESE EXPERIENCE WITH SMA

A review of practical experience with SMA in Denmark, Finland, Germany, Netherlands, Norway, Sweden and Japan [6,7,9,10, Wilh. Schütz and Taisei] indicated the following typical features and practices:

Reasons for Use

1. high stability (resistance to rutting) combined with good durability (20 to 40 percent longer life than conventional mixes)
2. good resistance to studded tire wear
3. good frictional properties ('skid' resistance)
4. thin surface course use allows relatively low costs
5. good placement and compaction characteristics

TABLE 1. RANKING OF STONE MASTIC ASPHALT (SMA) AND POROUS ASPHALT (PA) COMPARED WITH HOT-MIX ASPHALT (HMA) (a)

PROPERTY OR FEATURE	RANKING COMPARED TO HMA (b)	
	SMA	PA
Shear Resistance	2	2
Abrasion Resistance	2	-½
Durability	2	-1½
Load Distribution	-½	-1½
Cracking Resistance	1½	-½
Skid Resistance	1	1½
Water Spray	0	3
Light Reflection	1	1½
Noise Reduction	0	3
Public Recognition	2	3

a. Adapted from ranking by Nordic asphalt technologists given in Report on the 1990 European Asphalt Study Tour (EAST) [7].

b. Ranking Scale:

0	Equal		
1	Better	-1	Worse
2	Much Better	-2	Much Worse.
3	Very Much Better		

Reasons for Not Using

1. costs
2. lack of knowledge with new mix type

Hot-Mix Technology

1. mix design air voids of 3 to 4 percent, typically 3 percent
2. Marshall method of mix design (50 blows each face at 135°C) sometimes used with design at 3 percent air voids
3. all aggregates 100 percent crushed with suitable frictional properties (high quality aggregates)
4. coarse aggregate content 70 percent
5. maximum coarse aggregate size of 5 to 20 mm, typically 11 to 16 mm
6. mortar
   a. asphalt cement content 6.5 to 8 percent
   b. filler content 8 to 13 percent
   c. fibre content 0.3 to 1.5 percent
   (mineral, glass or cellulosic fibre - fibre not used in some high polymer loaded mixes)
7. asphalt cement
   a. range of penetration grades - 65, 80, 200
   b. polymer modified 80 penetration grade seems typical

Production and Placement

1. increased dry mixing time to allow for fibre dispersion
2. easier to place and compact than conventional mixes, especially in thin lifts
3. less sensitive to laying failure
4. use static steel-wheel compaction (avoid vibratory and pneumatic compaction)

Mechanical Properties

1. good resistance to plastic deformation (rutting) from wheel tracking tests
2. stiffness modulus and fatigue resistance not determined

Trends

1. expected to take the place of dense graded asphaltic concrete
2. will be more economic in long term because of better durability, stability, fatigue resistance and workability.

This type of information on SMA and the practical advice of Taisei and Wilh. Schütz were particularly helpful to the team's ability to quickly complete SMA Marshall mix designs and place SMA trial sections.

INITIAL SMA TRIAL SECTIONS

SMA trial sections incorporating two different nominal maximum coarse aggregate sizes - SMA 1 surface course (13 mm) and SMA 2 binder course (19 mm) - were placed in December 1990 on Miller Avenue, an industrial road in Markham (northeast of Toronto). The prime purpose of these first two trial sections was to determine the general applicability of the SMA technology for locally available materials, Marshall method of mix design, production in a conventional hot-mix batch plant and use of standard paving/compaction equipment. Except for minor logistical problems at the plant in handling the filler and fibre addition that were readily overcome, the only significant production problem was ensuring the proper dispersion of the fibre in the SMA mixes.

The aggregates used in the SMA 1 and SMA 2 mixes were 100 percent crushed, quality, locally available aggregates with the gradations given in Table 2 (CA 1, CA 2 and FA 1). SMA mix aggregate and filler compositions were selected to give gradations based on typical grading bands (preliminary specifications) used in Germany, as summarized in Table 2. Standard

TABLE 2. AGGREGATE GRADATIONS FOR STONE MASTIC ASPHALT (SMA) TRIAL SECTIONS.

SIEVE SIZE	AGGREGATE OR FILLER, PERCENT PASSING (a)								
	CA 1	CA 2	CA 3	CA 4	FA 1	FA 2	FA 3	FILLER 1	FILLER 2
26.5 mm	100								
19.0 mm	92.8								
16.0 mm	78.1	100	100	100					
13.2 mm	59.8	99.5	97.9	99.9					
9.5 mm	32.1	75.6	66.1	67.0	100	100	100		
4.75 mm	2.3	4.2	5.3	4.5	95.5	90.7	98.9		
2.36 mm	1.3	1.2	3.5	0.5	66.4	63.8	73.1		
1.18 mm	1.1	1.1	3.4	0.4	43.8	50.3	46.6		
600 μm	0.8	1.0	3.1	0.3	31.0	41.6	28.1	100	
300 μm	0.7	0.9	2.2	0.3	21.7	26.4	16.3	98.5	
150 μm	0.5	0.8	1.7	0.2	15.4	17.2	8.8	94.0	
75 μm	0.4	0.5	1.2	0.2	10.4	9.0	3.0	86.7	100

a. Description of Aggregates and Fillers (all aggregates 100 percent crushed):

CA 1	Limestone Coarse Aggregate
CA 2	Traprock Coarse Aggregate (1990)
CA 3	Dolomitic Sandstone Coarse Aggregate
CA 4	Traprock Coarse Aggregate (1991)
FA 1	Limestone Screenings Fine Aggregate
FA 2	Dolomitic Sandstone Screenings Fine Aggregate
FA 3	Limestone Manufactured Sand Fine Aggregate
FILLER 1	Fly Ash Filler
FILLER 2	Ground Dolomite Filler

Marshall mix design procedures [11] were followed using 75 blows per face, as compared to some European experience with 50 blows per face. At this early stage of SMA work there was some concern for potential traffic densification effects and a higher laboratory compaction effort was considered to be prudent. The SMA 1 and SMA 2 mixes were designed at an asphalt cement content giving about 3 percent air voids as indicated in Table 3. While the designs were done with 60/70 penetration polymer (Styrelf®) modified asphalt cement, the late season paving work required the use of still available conventional 85/100 penetration grade asphalt cement.

The production, placement and compaction of the SMA 1 and SMA 2 mixes are given in Photographs 1 to 3, noting that late season paving was involved with a placement temperature of about 140°C. Extension of the hot-mix batch plant dry mixing time was required to ensure fibre dispersion as uncoated fibre 'balls' were evident in some batches. This was the only significant problem and it is clear that fibre addition for SMA mixes requires special attention. Typical Marshall compliance and compaction test results for the SMA 1 and SMA 2 mixes are given in Table 4.

The general observations on the SMA 1 and SMA 2 trial sections are as follows:

1. SMA mixes have a rich appearance with the aggregate well coated with a thick film of asphalt cement;
2. SMA mixes have an open texture but are not segregated; and
3. uncompacted SMA mixes can be laid in thinner lifts than HMA and have greater resistance to roller densification.

RUTTING STUDY

In order to evaluate the SMA 1 and SMA 2 trial sections, a series of rutting tests were completed on slabs removed from the test sections. Samples were taken from the centre of the lanes for the SMA 1, SMA 2 and existing pavement (control) sections. The slabs were then tested by the Ontario Ministry of Transportation Bituminous Section (MTO) according to

TABLE 3. STONE MASTIC ASPHALT (SMA) MIX PROPORTIONS, GRADATIONS AND PROPERTIES.

A. SMA MIX PROPORTIONS, PERCENT (a)							
MATERIAL	DESCRIPTION (SEE TABLE 2)	SMA 1	SMA 2	SMA 3	SMA 4	SMA 5	SMA 6
CA 1	Limestone Coarse Aggregate		40.0				
CA 2	Traprock Coarse Aggregate	65.0	25.0				
CA 3	Dolomitic Sandstone Coarse Aggregate			70.0			
CA 4	Traprock Coarse Aggregate				70.0	70.0	70.0
FA 1	Limestone Screenings	30.0	30.0				
FA 2	Dolomitic Sandstone Screenings			22.0			
FA 3	Limestone Manufactured Sand				20.0	20.0	20.0
Filler 1	Fly Ash Filler	5.0	5.0				
Filler 2	Ground Dolomite Filler			8.0	10.0	10.0	10.0
Fibre 1	Proprietary Glass Fibre	0.3	0.3	0.3			
Fibre 2	Arbocel® Cellulose Fibre					0.3	
AC	85/100 Penetration Asphalt Cement	6.5	5.5				4.9
PMA	Polymer (Styrelf® 60/70) Modified Asphalt Cement			5.3	5.1	5.6	
VES	Vestoplast®						7.0 (b)

a. Fibre and asphalt cement as percent of total mix.

b. Vestoplast® added as percent of asphalt cement.

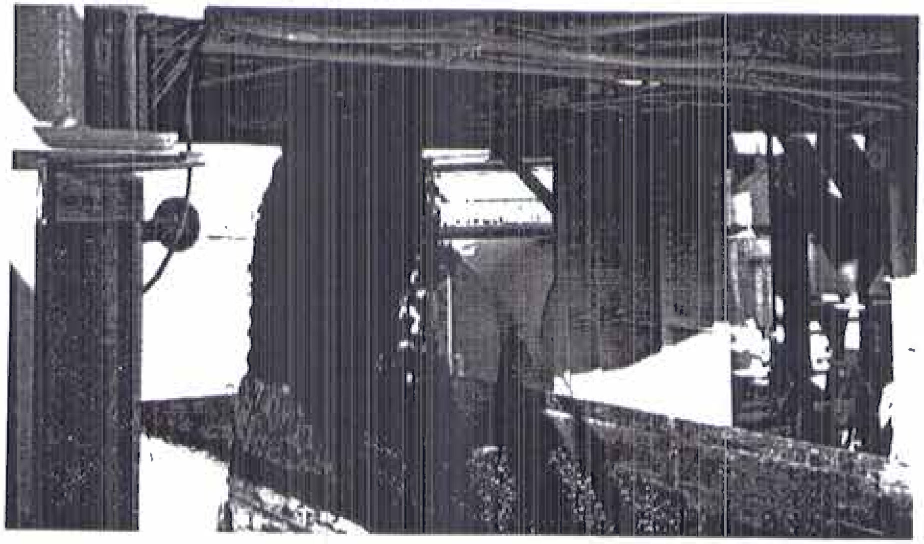
TABLE 3. (Continued)

B. SMA MIX GRADATIONS, PERCENT PASSING

SIEVE SIZE	PRELIMINARY SPECIFICATION		TRIAL SECTIONS					
	SURFACE SMA 13 mm	BINDER SMA 19 mm	SMA 1	SMA 2	SMA 3	SMA 4	SMA 5	SMA 6
26.5 mm		100		100				
19.0 mm		95-100		97.1				
16.0 mm		85-95	100	91.2	100	100	100	100
13.2 mm	100	80-90	99.7	83.8	98.5	99.9	99.9	99.9
9.5 mm	75-90	55-75	84.1	66.7	76.3	76.9	76.9	76.9
4.75 mm	29-49	30-50	36.4	35.6	31.7	33.0	33.0	33.0
2.36 mm	22-34	20-35	25.7	25.7	24.5	25.0	25.0	25.0
1.18 mm	16-28	15-30	18.9	18.9	21.4	19.6	19.6	19.6
600 µm	12-24	12-24	15.0	14.9	19.3	15.8	15.8	15.8
300 µm	10-22	10-22	12.0	11.9	15.3	13.4	13.4	13.4
150 µm	9-17	10-18	9.8	9.7	13.0	11.9	11.9	11.9
75 µm	7-12	8-13	7.8	7.7	10.8	10.7	10.7	10.7

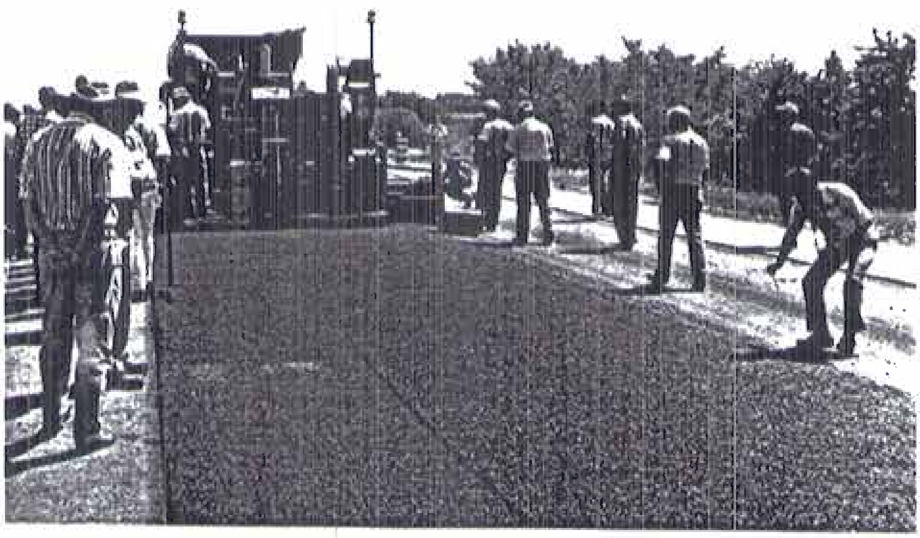
C. SMA MIX PROPERTIES

PROPERTY	SMA 1	SMA 2	SMA 3	SMA 4	SMA 5	SMA 6
Bulk Relative Density	2.445	2.424	2.372	2.582	2.574	2.597
Maximum Relative Density	2.530	2.491	2.471	2.668	2.653	2.678
Air Voids, percent	3.4	2.7	4.0	3.2	3.0	3.0
Voids Mineral Aggregate (VMA),percent	19.0	15.6	15.8	15.1	15.8	14.4
Stability, Newtons at 60°C	9700	13700	8600	7880	8140	7170
Flow, 0.25 mm	25+	25+	25+	23	25	16



PHOTOGRAPH 1. PRODUCTION OF FIRST ONTARIO STONE MASTIC ASPHALT (SMA 1) IN DECEMBER 1990.

(Conventional hot-mix batch plant with filler in poly-melt bags delivered by belt to weigh hopper/pugmill; fibre in poly-melt bags added to pugmill with increased dry mixing time.)



PHOTOGRAPH 2. PLACING OF STONE MASTIC ASPHALT (SMA 1) IN DECEMBER 1990.

(Conventional paver and static steel-wheel compaction. Ambient temperature about 4°C. No problems were experienced in placing and compacting the SMA 1 and SMA 2 (Table 3) mixes.)

TABLE 4. TYPICAL STONE MASTIC ASPHALT (SMA) MARSHALL COMPLIANCE AND COMPACTION TEST RESULTS FOR TRIAL SECTIONS.
(See Table 3 for Design Proportions, Gradations and Properties.)

A. SMA MIX GRADATIONS AND ASPHALT CEMENT CONTENTS

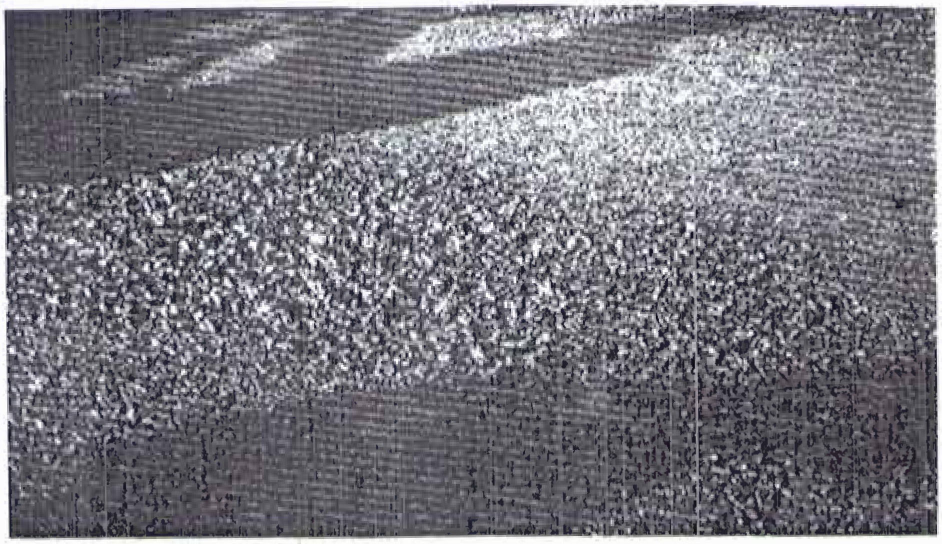
SIEVE SIZE (PERCENT PASSING)	TRIAL SECTIONS					
	SMA 1 (AC)	SMA 2 (AC)	SMA 3 (PMA/Fibre)	SMA 4 (PMA)	SMA 5 (PMA/Fibre)	SMA 6 (AC/VES)
19.0 mm		100				
16.0 mm	100	92.0	100	100		100
13.2 mm	99.5	79.8	99.6	99.4	100	99.7
9.5 mm	76.8	59.7	71.3	71.6	78.9	76.5
4.75 mm	32.0	31.1	28.5	33.8	26.0	26.4
2.36 mm	24.2	21.8	23.0	23.4	18.4	19.8
1.18 mm	20.2	16.5	20.3	18.8	15.6	16.2
600 µm	14.9	13.2	18.6	15.8	13.8	14.4
300 µm	12.2	11.2	15.1	14.0	12.9	13.0
150 µm	9.7	9.6	12.2	12.7	11.9	11.9
75 µm	7.7	8.1	9.0	10.2	9.7	9.4
ASPHALT CEMENT CONTENT (Percent of Total Mix)	6.1	5.2	5.1	4.8	5.3	5.0

a. For SMA 3, the gradation, asphalt cement content and properties are the average of 3 tests, and the compaction the average of 17 tests.

B. SMA MIX PROPERTIES AND COMPACTION

PROPERTY	SMA 1	SMA 2	SMA 3	SMA 4	SMA 5	SMA 6
Bulk Relative Density	2.545	2.437	2.381	2.563	2.496	2.507
Maximum Relative Density	2.595	2.472	2.503	2.695	2.678	2.683
Air Voids, percent	1.9	1.4	4.9	4.9	6.8	6.6
VMA, percent	15.9	12.5	15.3	15.5	18.1	17.5
Stability, Newtons at 60°C	7100	8840	10150	8510	7250	5950
Flow, 0.25 mm	22	36	28	15	13	11
COMPACTION (Percent of Compliance)	93.0	93.0	96.0	95.0	97.3	97.2

b. For SMA 4, SMA 5 and SMA 6 the gradation, asphalt cement content and properties are the average of 2 tests, and the compaction the average of 4, 14 and 10 tests, respectively.



PHOTOGRAPH 3. GENERAL APPEARANCE OF SMA 1 MIX AFTER PLACEMENT AND IN AREA WITH ONE PASS OF STEEL-WHEEL ROLLER.

(The coarse (open) surface texture of the stone mastic asphalt (SMA) is evident after compaction. SMA is very stable with low compaction densification or deformation.)

their test procedure "Using a Wheel Tracking Machine for Evaluation of Asphalt Rutting" [12].

The laboratory rutting test is done at a controlled temperature of 60°C using a rubber tired wheel run along the specimen for 4000 cycles (8000 passes). The final rut profile is measured and the average rut depth in millimetres is determined. The temperature is maintained throughout the two hour test by the use of a temperature controlled water bath and infra-red lamps. The specimens are measured across the rut in three places at various stages of the rutting cycles and the average rut depth obtained. The rut depth with number of passes for SMA 1, SMA 2 and control tests are given in Figure 3. The MTO has tentatively set a maximum allowable rut depth of 3.5 mm as the standard for rut resistant mixes. The test data on the three slabs tested indicate the following values:

SMA 1	5.1 mm
SMA 2	6.7 mm
Control	16.8 mm.

Based on the test data presented in Figure 3, it would appear that there was an initial seating of the SMA 1 and SMA 2 specimens prior to the true rutting occurring under the wheel loading. Looking at the plots for both SMA 1 (surface mix) and SMA 2 (binder mix) there appears to have been a seating depth of approximately 3 mm. If this initial seating is accounted for, the SMA 1 and SMA 2 stone mastic mixes meet the MTO criteria. The seating depth translates into a change in compaction from 93 percent (which was achieved in December, Table 4) and 97 percent which would be more typical under normal paving conditions.

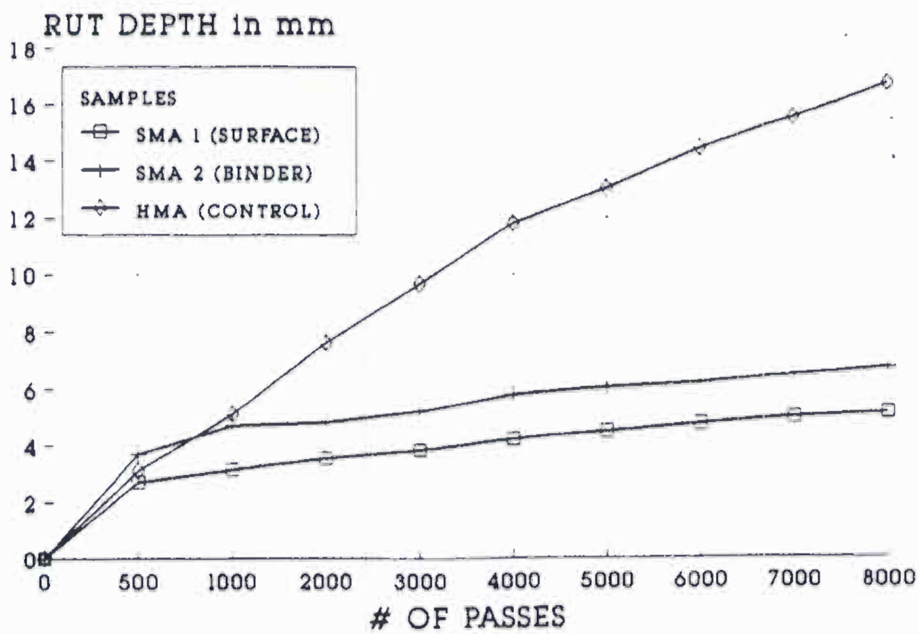


FIGURE 3. RUTTING TEST RESULTS FOR SMA 1 (SURFACE), SMA 2 (BINDER) AND HMA (HOT-MIX ASPHALT SURFACE) PAVEMENT SAMPLES.

(Rutting tests completed by Ontario Ministry of Transportation using their wheel tracking machine [12]. There appears to be an initial 'seating' deformation of about 3 mm at 500 passes for SMA 1 and SMA 2.)

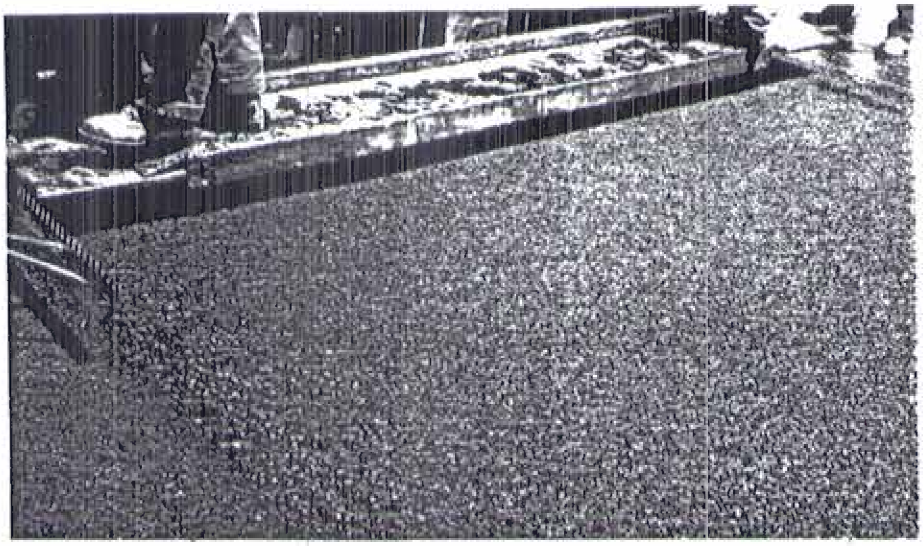
HIGHWAY 7 TRIAL SECTION

While the initial trial section indicated that SMA is somewhat more complicated to produce than HMA, the SMA 1 and SMA 2 trials were considered an overall success. The next step in the SMA technology trials was to refine the Marshall method of SMA mix design and complete a high volume heavy traffic highway trial section. With the assistance of the Ontario Ministry of Transportation, this SMA 3 trial section (shoulder and driving lanes) was completed in June 1991 on Highway 7 north of Toronto, along with adjacent dense friction course (DFC) on the passing lanes as a 'control'.

The SMA 3 mix was designed at 4 percent air voids based on a 50 blows per face Marshall mix design (about 3 percent air voids for 75 blows per face) as there was still a concern with potential overcompaction during rolling and heavy traffic densification. Details on the materials and mix design used for the SMA 3 trial are given in Tables 2 (CA 3 and FA 2) and 3.

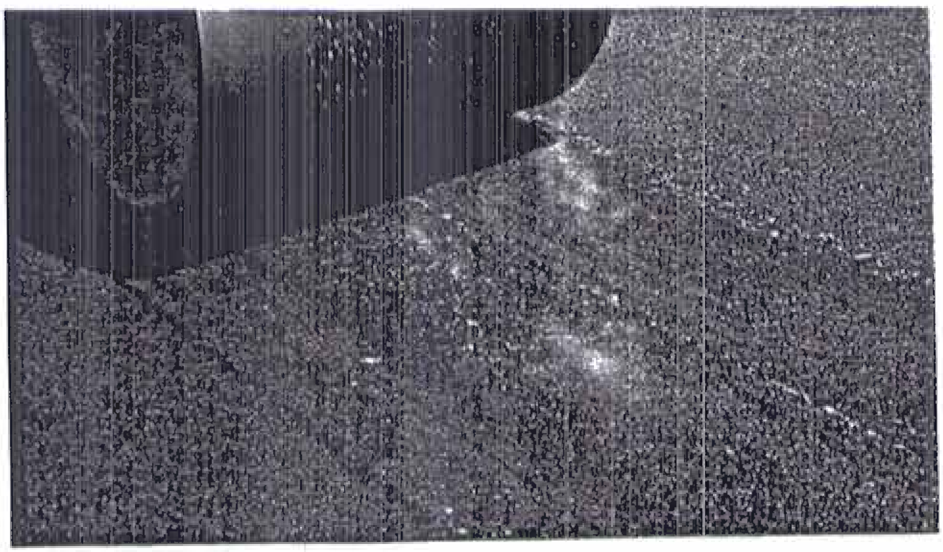
The placement, compaction and early appearance of the SMA 3 trial sections are shown in Photographs 4, 5 and 6 respectively. There was again some problem with glass fibre dispersion and current development work is focusing on other fibres (cellulosic, for instance), fibre dispersion and fibre use in hot-mix drum plants [10]. Typical Marshall compliance and compaction tests results for the SMA 3 mix given in Table 4 indicate no problem in meeting SMA mix design requirements once production parameters are established.

The early, and one year, performance of the SMA 3 trial section on Highway 7 has been excellent as shown in Photographs 7, 8 and 9. There has been no significant tightening of the SMA 3 coarse (open) surface texture, which indicates good resistance to heavy traffic densification. Test cores and slabs (Photograph 10) were taken from the trial section for standard testing and MTO wheel tracking (rutting) tests [12]. The rut depth for the SMA 3 wheel tracking tests (average for two slabs, 60°C, 4000 cycles) was only 2.6 mm, as compared to [illegible].0 mm for the conventional DFC 'control', and lower than the MTO's tentative maximum allowable of



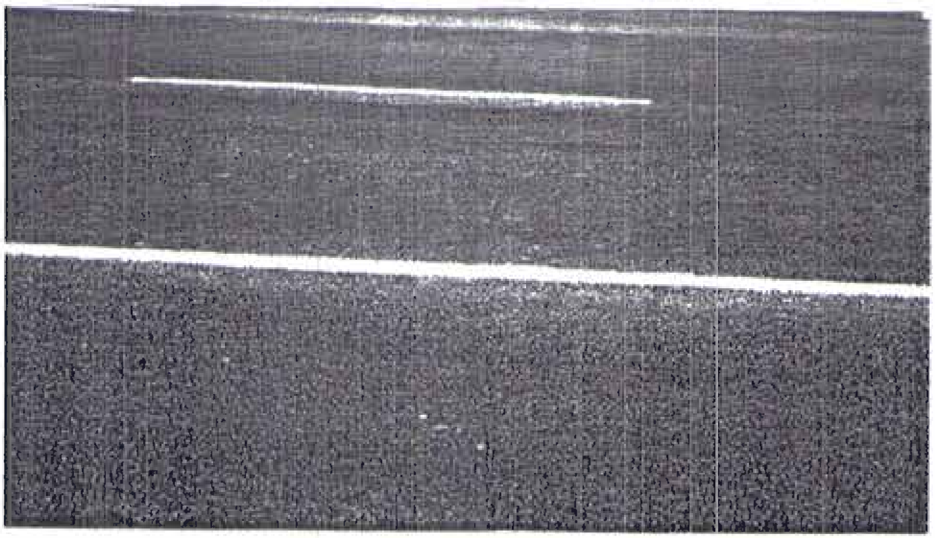
PHOTOGRAPH 4. PLACING OF STONE MASTIC ASPHALT (SMA 3) TEST SECTION ON HIGHWAY 7 IN JUNE 1991.

(Note the coarse (open) surface texture of SMA 3 on the right compared to the conventional dense friction course (DFC) in the lower left.)



PHOTOGRAPH 5. COMPACTION OF STONE MASTIC ASPHALT (SMA 3) TEST SECTION.

(There were no problems in producing (with extended dry mixing time), placing and compacting the SMA 3 mix. Static steel-wheel compaction is used to avoid potential fracture of coarse aggregate with vibratory compaction and surface flushing of mastic with pneumatic compaction. A soap solution should be used with rollers on SMA mixes containing polymer modified asphalt cement.)



PHOTOGRAPH 6. APPEARANCE OF STONE MASTIC ASPHALT (SMA 3) TEST SECTION AFTER ONE WEEK.

(Note the coarse (open) surface texture of the SMA 3 shoulder and driving lanes in the foreground compared to the conventional dense friction course (DFC) passing lane in the background.)

PHOTOGRAPH 7. APPEARANCE OF STONE MASTIC ASPHALT (SMA 3) TEST SECTION COMPARED TO DENSE FRICTION COURSE (DFC) AFTER FIVE WEEKS.

(The coarse (open) surface texture of the SMA 3 driving lane on the left has been maintained under heavy traffic. There has been some surface texture tightening of the DFC passing lane on the right.)

PHOTOGRAPH 8. CLOSE-UP OF STONE MASTIC ASPHALT (SMA 3) SURFACE TEXTURE AFTER FIVE WEEKS.

(The SMA 3 driving lane surface texture has been maintained with no evidence of deformation or mastic flushing.)

PHOTOGRAPH 9. APPEARANCE OF STONE MASTIC ASPHALT (SMA 3) TEST SECTION COMPARED TO DENSE FRICTION COURSE (DFC) AFTER ONE YEAR.

(The SMA 3 driving lane surface texture on the left is still as coarse (open) as when placed (Photograph 8) with no evidence of tightening or deformation.)

PHOTOGRAPH 10. TEST SLAB FROM STONE MASTIC ASPHALT (SMA 3) TEST SECTION.

(Note the stone-to-stone skeleton (Figure 1) in the SMA 3 surface course. The SMA 3 in this area was placed over the cracked existing asphalt concrete courses.)

3.5 mm as the standard for rut resistant mixes. This rutting resistance is considered to be excellent and provides comparative confirmation of this important desirable characteristic of SMA mixes.

HIGHWAY 404 RAMPS TRIAL SECTIONS

Three further SMA highway trial sections were completed on ramps to the 404 Highway (at Regional Highway 16 near Buttonville north of Toronto) in October 1991. Given the satisfactory compaction achieved with the SMA 3 trial section, apparent lack of traffic densification and current German SMA mix design experience (technical interaction with Wilh. Schütz KG Construction - Ottmar Schütz and James Scherocman), a 'standard' SMA Marshall mix design with 50 blows per face at 135°C and design air voids of 3 percent was adopted for these trial sections. Details on the materials and mix designs used for the SMA 4, SMA 5 and SMA 6 trial sections are given in Tables 2 and 3 and can be summarized as:

SMA 4 - polymer modified asphalt cement (Styrelf® 60/70);

SMA 5 - polymer modified asphalt cement and Arbocel® cellulosic fibre; and

SMA 6 - 7 percent Vestoplast® added as percent of asphalt cement (85/100).

The mix designs (Table 3) were confirmed by Wilh. Schütz with very close results.

The SMA 4, SMA 5 and SMA 6 trial sections were placed late in the 1991 paving season (October 28, ambient temperature 8 to 11°C) and there were initial problems with low SMA 4 mix temperatures related to both the relatively low mix temperature adopted (135°C) for Styrelf® 60/70 and significant mixing temperature decrease with filler addition 'cooling', that resulted in some incompletely melted filler poly-melt bags. These temperature problems were readily rectified and subsequent mixing, placement and compaction of the SMA mixes proceeded satisfactorily. While the 135°C may be satisfactory for Vestoplast® (SMA 6), it is clear that higher temperatures are necessary for polymer modified asphalt cements such as Styrelf® 60/70 (about 150°C for SMA 4 and SMA 5) in accordance with each supplier's recommendations.

Typical Marshall compliance and compaction test results for the mixes in Table 4 indicate somewhat high air voids, particularly for SMA 5 and SMA 6. Cores taken from these trial sections show that the traprock coarse aggregate used for the mixes contained more flat and elongated particles, than during the mix designs, which tend to 'bridge' (bulk) in the mix, particularly at lower compaction temperatures. Vibratory compaction was used for some of SMA 6, to gain placement experience, with no apparent improvement in compaction but some coarse aggregate breakage.

CURRENT SMA ACTIVITIES

All seven trial sections are being monitored along with conventional control mixes, with emphasis on SMA 3, SMA 4, SMA 5 and SMA 6 compared to DFC. This will involve both field testing (densification, transverse profile and frictional properties) and laboratory testing (wheel tracking and performance properties characterization). The team has installed a Nottingham Asphalt Tester (NAT, Figure 4) which permits the measurement of elastic stiffness (resilient modulus) using the repeated load indirect tension test, resistance to permanent resistance using the uniaxial creep and/or repeated load axial test and fatigue endurance using repeated tension loading [13-16]. This SMA characterization is considered critical to developing the deformation resistance, fatigue endurance and durability of SMA mixes, and such full asphalt concrete characterization is also the focus of current Strategic Highway Research Program Activities [15]. As the structural matrix of SMA mixes is critical to their performance, volumetric methods of optimizing the aggregates selection are also being investigated [17].

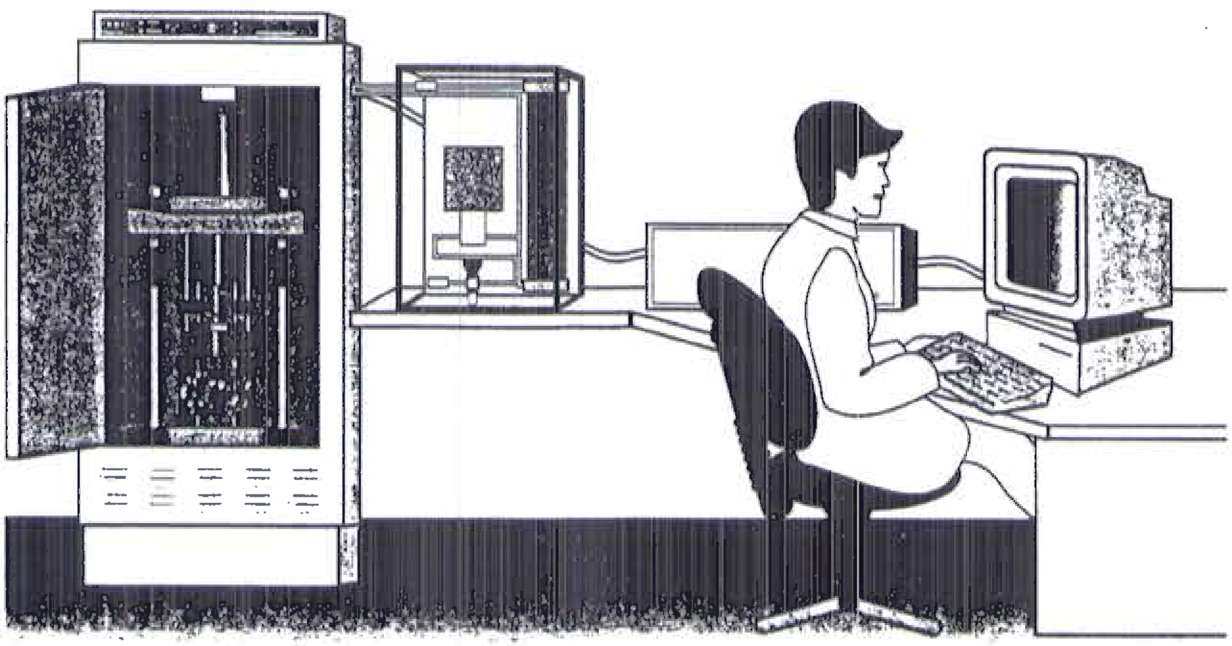


FIGURE 4. SCHEMATIC OF NOTTINGHAM ASPHALT TESTER.

(The Nottingham Asphalt Tester (NAT) is used to measure the mechanical properties of asphalt concrete such as elastic stiffness (resilient modulus) and resistance to permanent deformation [16].)

CONCLUSIONS

While the Ontario technology transfer of SMA is still in progress with a focus on SMA characterization, the trial section results to date must be considered a success [18]. This SMA work, in parallel with current United States SMA test sections, should quickly provide the technical and practical basis for regular SMA use in Ontario.

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