Asphalt Mixes Produced with Asphalt Shingle Sand

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ABSTRACT

The use of RAS particles obtained from grinding/shredding of asphalt shingles is currently limited to between 3 and 5 percent. The addition of the sand only portion of RAS can reach more than 10 percent or even 15 percent while providing rheological characteristics different enough from those of conventional HMA.

The technique is to sieve the shredded RAS particles to separate the fibres/bitumen clusters from the sand component. Only the shingle sand is recycled to the mix to facilitate obtaining a completely homogeneous mixture. The formulation of HMA containing a high RAS sand content is based on characterizing the mechanical properties of the HMA. HMA modified with high RAS sand content have a total bitumen content of about 8 percent.

This paper discusses the characterization of the mechanical properties of HMA modified with RAS sand and the advantages of this technique. It was determined that rutting, thermal cracking and asphalt module were close to values normally obtained for the same formulation without recycling. On the other hand, there is a significant difference in fatigue resistance which is increased compared to conventional HMA.

RÉSUMÉ

La limite actuelle de recyclage de bardeau incorporé sous de particules issues d'un broyage/déchiquetage est de 3.0 à 5.0 %. L'incorporation de la partie sable du bardeau d'asphalte seulement permet des teneurs en recyclage supérieures à 10 %, voire 15 % tout en offrant des caractéristiques rhéologiques assez différentes de celles des enrobés classiques.

La technique consiste à cribler les particules de bardeau déchiquetées pour séparer les agglomérations fibres/bitume de la composante sable. Seul le sable de bardeau est recyclé dans l'enrobé pour favoriser l'obtention d'un mélange complètement homogène. La formulation des enrobés incorporant un forte teneur en sable de bardeau est basée sur une caractérisation des propriétés mécaniques des enrobés. Les formules d'enrobés modifiés au sable de bardeau ont des teneurs totales en bitume de l'ordre de 8 %.

Cet article présente comment la caractérisation des propriétés mécaniques de formulation d'enrobés ainsi modifiés a permis de démontrer les avantages de cette technique. Il a été déterminé que l'orniérage, la fissuration thermique et le module de l'enrobé étaient proche des valeurs normalement obtenue pour la même formulation sans recyclage. Là où il y a une différence significative, c'est la résistance à la fatigue qui est augmenté par rapport aux enrobés classiques.

1.0 INTRODUCTION

Flexible pavements have several layers: sub-base, base, binder course, and surface course. Those pavement layers commonly comprise granular materials in the lower layers and asphalt-bound materials in the upper layers. Asphalt-bound materials are a mixture of various aggregate fractions, i.e., aggregate, sand and filler, and an asphalt binder.

The binder may be a "new" binder consisting of neat or modified asphalt obtained from the petroleum industry. The new binder may contain various additives, such as polymers or elastomers that modify its viscoelastic properties. For reasons of economy and to meet environmental requirements, the binder used in asphalt mixes may also consist of a mixture of binders obtained from recycled materials – an "old binder" and a "new binder" as described above, hereinafter called a "virgin binder".

It is in fact common practice to use, in the production of asphalt paving materials, recycled asphalt materials originating from degraded asphalt pavement. Those reclaimed materials are then crushed and screened to obtain a homogeneous gradation. The recycled asphalt materials thus produced are called Reclaimed Asphalt Pavement; commonly known as RAP.

Using RAP in asphalt mixes is a standard practice in most European countries [1] and in North America, where its use has been incorporated in the Superpave™ volumetric mix design system [2]. The RAP commonly available has an average composition similar to that of asphalt mixes produced and applied as paving materials, i.e., an average asphalt content by weight of 4 to 6 percent relative to total weight of RAP, with the rest of the composition being a mineral mix of coarse aggregate, sand and filler.

The asphalt binder contained in RAP has undergone an aging process during production and placement, and then progressively in place, due to oxidation and chemical evolution. Aging of asphalt binder is the result of volatile elements being lost, causing hardening of the binder. The hardening of the binder may be measured by simply comparing the RAP binder's rheological properties to those of the original binder. Thus, the binder of RAP originating from pavement located in a geographical area where the common binder is PG 58-28 grade may have hardened to a PG 70-16, or even harder binders.

More recently, Reclaimed Asphalt Shingles (RAS) have been used as recycled asphalt materials [3]. Reclaimed asphalt shingle originates either from batches of defective asphalt shingles rejected during manufacturing or from asphalt shingles removed from old roofs during roofing repairs. For example, it is estimated that between 150,000 and 200,000 tonnes of old asphalt roofing shingles are landfilled in Quebec at a cost of $25 to $30 per tonne every year. Once debris (e.g., wood, nails, etc.) has been removed, the shingles are finely shredded and screened into RAS to facilitate their incorporation into asphalt mixes.

The RAS generally contain 20 to 30 percent by weight of asphalt, 25 to 30 percent of fine mineral filler, 30 to 35 percent of mineral aggregates, and 5 to 10 percent of glass or cellulose fibres. Recycling shingles in asphalt mixes closely resembles RAP recycling. Thus, the aggregate in asphalt shingles makes it possible to use less aggregate when developing the final asphalt mix and the shingles' asphalt also makes it possible to use less virgin binder when manufacturing the final asphalt mix. Accordingly, the greater the shingle content, the less virgin binder required.

However, the RAS asphalt binder is different from the asphalt binder contained in RAP; it is generally much harder than asphalt binder used in road applications. Given that the asphalt binder in RAS is hard, the asphalt mix containing RAS and less virgin/soft binder may become more brittle. In addition, the density of shingles is relatively low which makes it difficult to obtain good density for an asphalt mixture. As a result, the addition of RAS in asphalt mixes is generally limited to 5 percent and the binder consideration from the shingle limited to 40 percent in Quebec. Incidentally, if the rate of recycling of RAS is 5.0 percent, the asphalt binder content of shingles is 25 percent, and 40 percent of that binder is available as mixing binder for the asphalt mixture, the rate of virgin binder for the asphalt mixture may be reduced by 0.5 percent. Beyond that, it is recognized that the asphalt mix may become lean in binder and more brittle.

There is a need to upgrade old asphalt shingles to produce an asphalt mix composition that avoids all or some of the disadvantages mentioned. In particular, it is desirable to provide an asphalt mix containing a substantial quantity of asphalt shingles, without modifying the mechanical and rheological properties of the asphalt mix, i.e., by ensuring that it is not brittle despite its high content of asphalt shingles.

Accordingly, the object of this paper is the evaluation of asphalt mixes produced with only shingle sand extracted from RAS. The shingle sand is obtained by screening out the fibre/bitumen flakes from the shredded asphalt shingles. The composition of the shingle sand obtained in this manner is 15 to 20 percent of asphalt binder, 80 to 85 percent of mineral aggregate with a top size aggregate less than 2.5 mm, and only traces of glass or cellulose fibres.

2.0 ASPHALT MIXES MODIFIED WITH ASPHALT SHINGLE SAND

The asphalt mix produced with RAS offers the advantage of reclaiming industrial waste. The commonly used RAS particles resulting from crushing/shredding asphalt shingles have a maximum size in the order of 12.5 mm. The asphalt mix produced according to the method proposed in this paper contains only the sand/filler fraction of asphalt shingles, i.e., it is free of particles larger than 2.5 mm and contains only trace amounts of glass or cellulose fibres.

To obtain shingle sand, the crude shingle particles undergo additional processing to separate the fibre/asphalt agglomerations from the shingle sand. Then, as opposed to the current shingle recycling practice, only the shingle sand is recycled in the asphalt mix to obtain a fully homogenous asphalt mix with density comparable to conventional asphalt mixes.

Even at recycling proportions up to 15 percent, the use of shingle sand makes it possible to obtain a homogenous and dense asphalt mix composition with mechanical performance similar to that of conventional asphalt mixes. Whereas the incorporation of complete RAS, with fibre/asphalt agglomerations, adversely affects both the homogeneity and mix density of the final asphalt mix. This is why the common recycling rate of “complete RAS” is often limited to a maximum of 5 percent.

In addition, the specific gravity of asphalt sand may be evaluated to about the same as that of RAP around 2.5 while the specific gravity of complete RAS is approximately 1.8. The content of fibre/asphalt particles is in the order of 20 percent by weight of the asphalt shingles and fibre/asphalt flakes have a specific gravity of less than 1. Without the fibre/asphalt flakes from the RAS and only incorporating shingle sand in asphalt mixes, it is possible to obtain asphalt mixes of adequate density and good mechanical performance.

For example, the asphalt mix produced according to the method proposed in this paper contains: 5 percent virgin asphalt binder, 15 percent shingle sand and 80 percent mineral aggregates. The asphalt from shingle sand makes it possible to replace a certain amount of virgin asphalt in the asphalt mix formula. However, the extent to which virgin asphalt may be replaced by asphalt from shingle sand appears to reach a certain plateau as the amount of shingle sand increases. Thus, by increasing the shingle sand content, it appears that the mortar portion of the asphalt mix is transformed into a mineral sand/shingle sand mix (coated with hard asphalt), which in turn is coated with the virgin binder of the mix.

3.0 TESTING PROGRAM

3.1 Overview

The testing program to evaluate asphalt mixes produced with asphalt shingle sand was set-up to determine three significant mechanical characteristics of asphalt mixes: resistance to thermal cracking, resistance to fatigue, and resistance to rutting. Table 1 summarizes the test conditions for each of the tests.

Table 1. Summary of test conditions for the thermal cracking, fatigue and rut tests.

Test	Standard/ Method	Specimen Sizes		Test Conditions
		Diameter (mm)	Length (mm)	
Thermal Cracking	Thermal Stress Restrained Specimen Test AASHTO TP 10-93 [4]	60	250	- Zero force preconditioning for 4 hours at 5°C - Temperature variation rate during the restrained thermal stress: 10°C/hour - No mechanical stress is applied
Fatigue	DGCB NF EN 12697-2 [5]	80	120	- Cyclic sinusoidal stress - Alternating tension/compression (average $\varepsilon = 0$) - Method: imposed deformation of 50 µdef amplitude - Warm-up period (hr): 6 - Test Temp (°C): 10 - Frequencies (Hz): 10
Rutting	NF EN 12697-22 [6]	Length x Width x Depth 500x180x50		- Tire pressure: P = 600 +/- 30 kPa - Applied rolling load: F= 5000 N+/- 50N - Relative rolling frequency: 1Hz /- 0.1 Hz - Test temperature: specimens are conditioned at 58°C or depending of the bitumen performance grade - Rutting depth measured at 1000, 3000 and 10,000

Note: DGCB is Département de Génie Civil et de Bâtiment.

3.2 Resistance to Thermal Cracking

The Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength (TSRST), AASHTO TP10-93, provides information on the temperature at which internal stress in the asphalt mix is too great and causes the latter to crack.

The test consists of preventing axial deformation of an asphalt mix specimen (i.e., maintaining constant height) while the ambient temperature decreases progressively. The cooling causes the specimen to contract, but the fixed restraint prevents it from deforming. Tensile stresses develop within the specimen and cause cracking due to restrained thermal stress. The cracking temperature and corresponding stress are determined. Asphalt mixes are conditioned at 5°C for 4 hours then the chamber's temperature is decreased gradually by 10°C per hour.

The tests were performed using a Servo-Hydraulic Universal Testing Machine (MTS 810) equipped with a temperature chamber. The chamber may be cooled down to -40°C. During the test, the temperature is measured directly at the specimen's surface and control of the chamber's cooling rate is determined by the temperature measured at the surface of the specimen. The average value of the measurements taken by the three temperature probes used is considered to be the specimen's surface temperature.

Three extensometers are placed on the specimen to measure axial displacements. Those extensometers are positioned on three axial generators spaced 120° apart around the specimen. During the thermal stress restrained specimen test, the extensometers control the specimen's height. The specimens tested are cylindrical in shape. The specimen's diameter is 60 mm and its length is 250 mm.

Each extensometer touches the specimen's surface at two contact points by means of two metallic blades. Those blades move according to the axial deformations sustained by the specimen. The distance between both blades is 165 mm in the case of thermal stress restrained specimen tests. Deformation measurements are therefore performed only in the specimen's central part, between both contact blades, in order to eliminate edge effects.

3.3 Resistance to Fatigue

Material fatigue is a loss of rigidity that may lead to breaking as a result of the material's repeated deformation. That deformation is necessarily less than that resulting from the material's instantaneous breaking. Given that no testing method is established yet by the Ministère des Transports du Québec (MTQ), the tension-compression test developed in France by the Département de Génie Civil et de Bâtiment (DGCB) of the École Nationale de Travaux Publics de l'État (ENTPE) was used to evaluate fatigue resistance.

The test consists of submitting a cylindrical specimen to repeated tension-compression stresses (NF EN 12697-2). The purpose of the test is to predict the value of a specimen's service life on the basis of a number of stress cycles (300,000 cycles). The MTS 810 equipment was used to perform the fatigue testing.

The asphalt mix specimen has a cylindrical shape with a diameter of 75 mm and a length of 120 mm (Figure 1). It is tested along its axis and subjected to cyclic sinusoidal stress in terms of strength or displacement. The main advantage of this test is the homogenous condition of stress and deformation fields, so that the combination of stress and deformation (σ, ε) is almost identical in the measured area of the specimen.

The axial deformation measurement system is comprised of three extensometers. They are similar to those used for the TSRST. The distance between contact blades for this test is 50 mm. The deformation value is calculated directly on the basis of the contact blades' displacement. This value is equal to the displacement divided by the 50 mm distance between the blades.

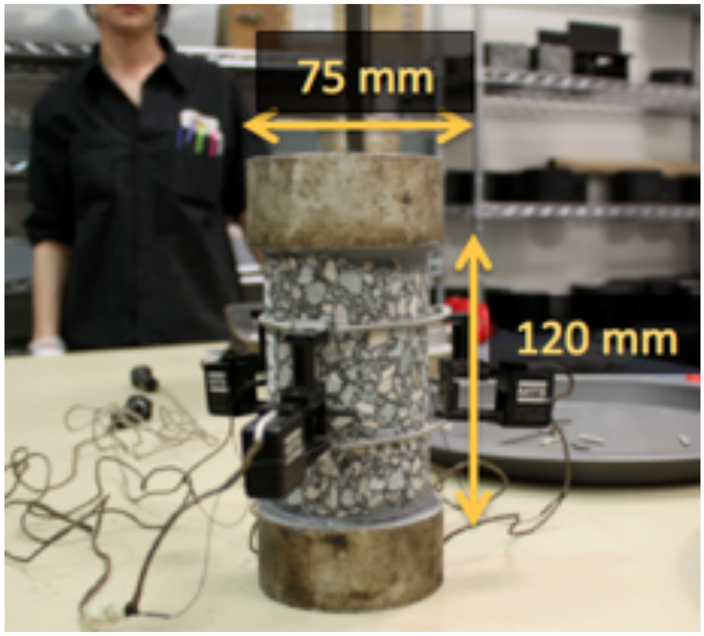

Figure 1. Cylindrical Asphalt Specimen for Fatigue Testing

The stiffness modulus is measured in terms of small deformations. The imposed deformation has a sinusoidal shape and a frequency of 10 Hz at a temperature of 10°C. Those stresses are imposed until a loss of stiffness modulus of 50 percent.

3.4 Resistance to Rutting

The rutting test is described in standard NF EN 12697-22, Standard Test Method for Bituminous Mixtures, Test Methods for Hot Mix Asphalt, Wheel Tracking. The rutting test indicates whether an asphalt mix is resistant to permanent deformations associated with repeated loading. The test's principle consists of measuring rut depth according to the number of cycles of a loaded wheel passing back and forth over an asphalt mix slab. Test conditions depend on the type of mix tested and the type of virgin binder.

4.0 ASPHALT MIXES TESTED

4.1 Materials

Table 2 provides information on the materials used to produce the asphalt mixes evaluated. Table 3 present some mix characteristics and test performed on each mix.

Table 2. Asphalt Mix Materials

Material	Description
Virgin asphalt	Grade PG 58-28 or 52-34 asphalt
Virgin aggregates	Sintra Granby quarry, 0-2.5 mm, 0-5 mm and 5-10 mm aggregate fractions
Shingle sand	Screened RAS to eliminate glass or cellulose fibres

Table 3. Asphalt Mixes Produced and Test Performed

Asphalt Mix No.	Name of the Asphalt Mix	Shingle Sand	Virgin Asphalt	Asphalt from Shingle Sand	Total Asphalt	Mineral Aggregates	TSRST	Fatigue Test	Rutting Test
1	3%SS-5.45VA 58-28	3 %	5.45 %	0.60 %	6.05 %	93.95 %	X		
2	3%SS-5.08VA 58-28	3 %	5.08 %	0.60 %	5.68 %	94.32 %	X		
3	3%SS-5.21VA 58-28	3 %	5.21 %	0.60 %	5.81 %	94.19 %	X		
4	0%SS-5.45VA 58-28	0 %	5.45 %	0.00 %	5.45 %	94.55 %	X	X	X
5	15%SS-5.45VA 58-28	15 %	5.45 %	3.00 %	8.45 %	91.55 %	X		
6	15%SS-3.24VA 58-28	15 %	5.24 %	3.00 %	8.24 %	91.76 %	X		
7	15%SS-5.08VA 58-28	15 %	5.08 %	3.00 %	8.08 %	91.92 %	X		
8	15%SS-5.08VA 52-34	15 %	5.08 %	3.00 %	8.08 %	91.92 %	X		
9	15%SS-4.96VA 52-34	15 %	4.96 %	3.00 %	7.96 %	92.04 %	X		
10	15%SS-5.21VA 58-28	15 %	5.21 %	3.00 %	8.21 %	91.79 %		X	X
11	4%SS-5.00VA 58-28	4 %	5.00 %	0.80 %	5.80 %	94.20 %		X	
12	0%SS-5.45VA 52-34	0 %	5.45 %	0.00 %	5.45 %	94.55 %			X
13	0%SS-5.08VA 52-34	0 %	5.08 %	0.00 %	5.08 %	94.92 %			X
14	15%SS-5.45VA 52-34	15 %	5.45 %	3.00 %	8.45 %	91.55 %			X

Note: TSRST is the Thermal Stress Restrained Specimen Test.

4.2 Reference Asphalt Mix

The asphalt mix without shingle sand (reference asphalt mix) was produced by using the 5-10, 0-5, and 0-2.5 mm aggregate fractions in respective proportions of 47, 38 and 15 percent with an asphalt content of 5.45 percent. For all mixes with shingle sand, all or a portion of the 0-2.5 mm aggregate fraction was replaced by shingle sand. The other aggregate fractions remained in the same proportions.

4.3 Resistance to Thermal Cracking Test

The TSRST was performed on asphalt mix Nos. 1 to 9 described in Table 3, which includes the reference mix No. 4. The specimens' desired target compaction was 95 percent. The average compaction obtained was 96.2 percent. This compaction was measured by hydrostatic weighing.

For asphalt mixes with 3 percent shingle sand, PG 58-28 virgin binder was added at three different rates: 5.45, 5.21 and 5.08 percent, respectively for mix Nos. 1, 2 and 3. For these three mixes, the proportion of binder from the shingle considered available to blend with the virgin binder for the asphalt mixtures represented 0, 40 and 60 percent, respectively. Aggregates from the shingle sand were removed directly from the 0-2.5 mm aggregate fraction of the reference asphalt mix.

For asphalt mixes with 15 percent shingle sand, PG 58-28 virgin asphalt was added at three different rates: 5.45, 5.21 and 5.08 percent, respectively for mix Nos. 5, 6 and 7. For these three mixes, the proportion of binder from the shingle considered available to blend with the virgin binder represented 0, 8 and 12 percent, respectively. This low rate of replacement asphalt was chosen because of the high shingle sand content of 15 percent. Aggregate from the shingle sand added to the mix was removed directly from the 0-2.5 mm aggregate fraction of the reference asphalt mix design.

It was observed that asphalt mixes with 15 percent of shingle sand were always more compacted than the reference asphalt mix despite all the precautions taken. The void contents of asphalt mixes with 15 percent shingle sand were only 1 to 2 percent.

Lastly, another asphalt mix was produced, with 15 percent shingle sand but with PG 52-34 virgin binder. The specimens were produced in the same way as those with 15 percent of shingle sand and PG 58-28 virgin binder. Two contents of virgin binder were produced, 5.08 and 4.96 percent, so that the virgin binder was replaced by 12 and 16 percent, respectively of the asphalt available in the shingle sand (mix Nos. 8 and 9, respectively).

4.4 Resistance to Fatigue Test

Fatigue resistance tests were performed on asphalt mix Nos. 4, 10 and 11 as shown in Table 3. The specimens were produced from a large asphalt block of 75 kg. The specimens prepared for fatigue tests had high compaction of around 98 percent on average. During production of the blocks, it was observed that compaction was very quick and easy.

4.5 Resistance to Rutting Test

Rutting resistance tests were performed on asphalt mix Nos. 4, 12, 13, 10 and 14 as shown in Table 3. The asphalt mixes containing 15 percent shingle sand, already TSRST and fatigue tested, were then tested for rutting. For all mixes containing shingle sand, a portion of the 0-2.5 mm aggregate fraction was replaced by shingle sand. The other aggregate fractions remained in the same proportions.

Asphalt mix Nos. 4, 12 and 13 without shingle sand were produced using 5-10, 0-5, and 0-2.5 mm aggregate fractions in respective proportions of 47, 38 and 15 percent, with asphalt content of 5.45 percent for asphalt mix Nos. 4 and 12 and 5.08 percent for mix No. 13. Asphalt mix No. 10 with 15 percent of shingle sand was formulated with 5.21 percent of virgin asphalt. When 15 percent of shingle sand and 5.21 percent of virgin asphalt was incorporated, the total asphalt content of this asphalt mix was 8.21 percent. Asphalt mix No. 14 with 15 percent shingle sand was formulated with 5.45 percent of PG 52-34 virgin asphalt.

5.0 TEST RESULTS

5.1 Resistance to Thermal Cracking

The test results provided in Table 4 for the reference asphalt mix without shingle sand and with 5.45 percent PG 58-28 asphalt indicate that the temperature at maximum stress is -30.4°C on average. This result is expected for an asphalt mix produced with 58-28 performance grade asphalt.

Figure 2 provides a graphic representation of the TSRST results performed on mixes produced with 3 percent shingle sand and different percentages by weight of virgin asphalt (5.45, 5.21, and 5.08 percent) in comparison with the asphalt mix reference, mix No. 4.

The TSRST tests demonstrated that for asphalt mix Nos. 1 to 3 tested with 3 percent shingle sand, the results are all similar to those of the reference asphalt mix without shingle sand (mix No. 4). Thus, with 3 percent shingle sand incorporated in the mixture while removing some virgin asphalt, asphalt mix Nos. 1 to 3 fractured at -30°C, the same temperature as the reference asphalt mix.

Table 4. Test results for the Thermal Stress Restrained Specimen Test (TSRST) performed on various mixes.

Asphalt Mix No.	Virgin Asphalt (%)	Virgin Asphalt PG	Shingle Sand (%)	Total Asphalt (%)	Temperature at Maximum Stress (°C)	Maximum Stress (MPa)	Compaction (%)
1	5.45	58-28	3	6.05	-31.0	4.1	97.6
2	5.08	58-28	3	5.68	-30.2	3.8	96.8
3	5.21	58-28	3	5.81	-29.6	3.7	97.3
4	5.45	58-28	0	5.45	-30.4	3.3	96.2
5	5.45	58-28	15	8.45	-28.2	3.5	99.2
6	5.21	58-28	15	8.21	-29.1	3.7	98.9
7	5.08	58-28	15	8.08	-25.5	3.2	98.6
8	5.08	52-34	15	8.08	-32.1	4.0	99.1
9	4.96	52-34	15	7.96	-31.2	4.2	99.1

Note: PG is Performance Grade.

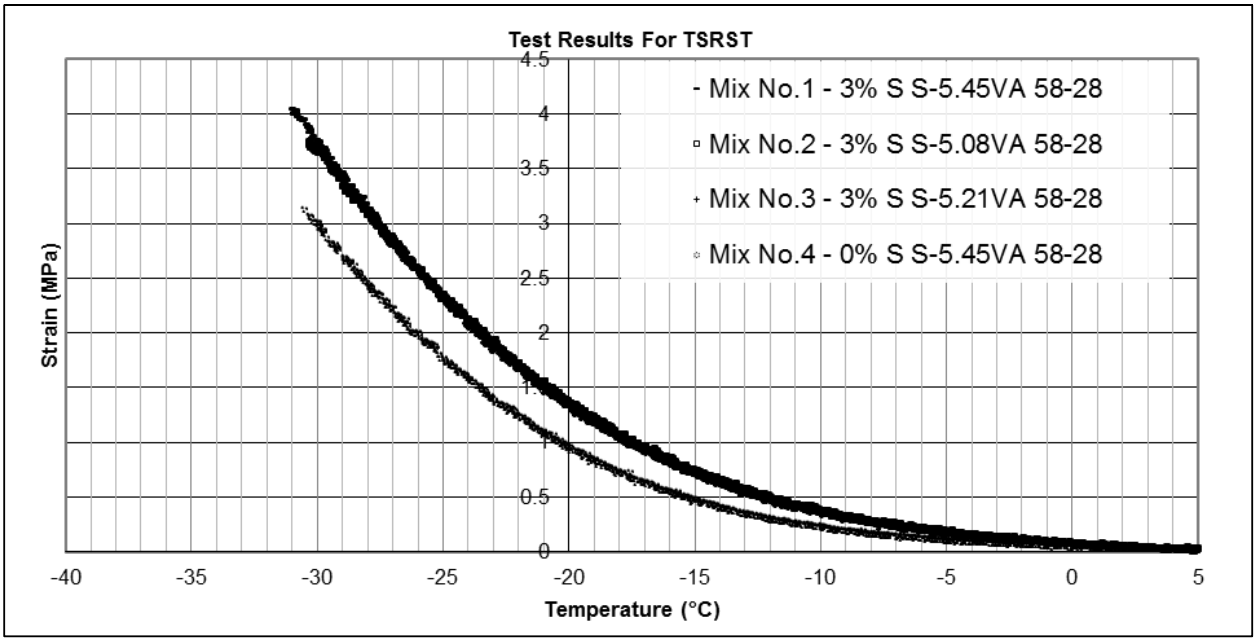

Figure 2. Thermal Stress Restrained Specimen Test (TSRST) graphic representation for mix with 3% shingle sand and 58-28 binder

Figure 3 provides a graphic representation the TSRST results performed on the reference asphalt mix in comparison with the asphalt mixes produced with 15 percent shingle sand and different percentages by weight of virgin asphalt (5.45, 5.24, and 5.08 percent).

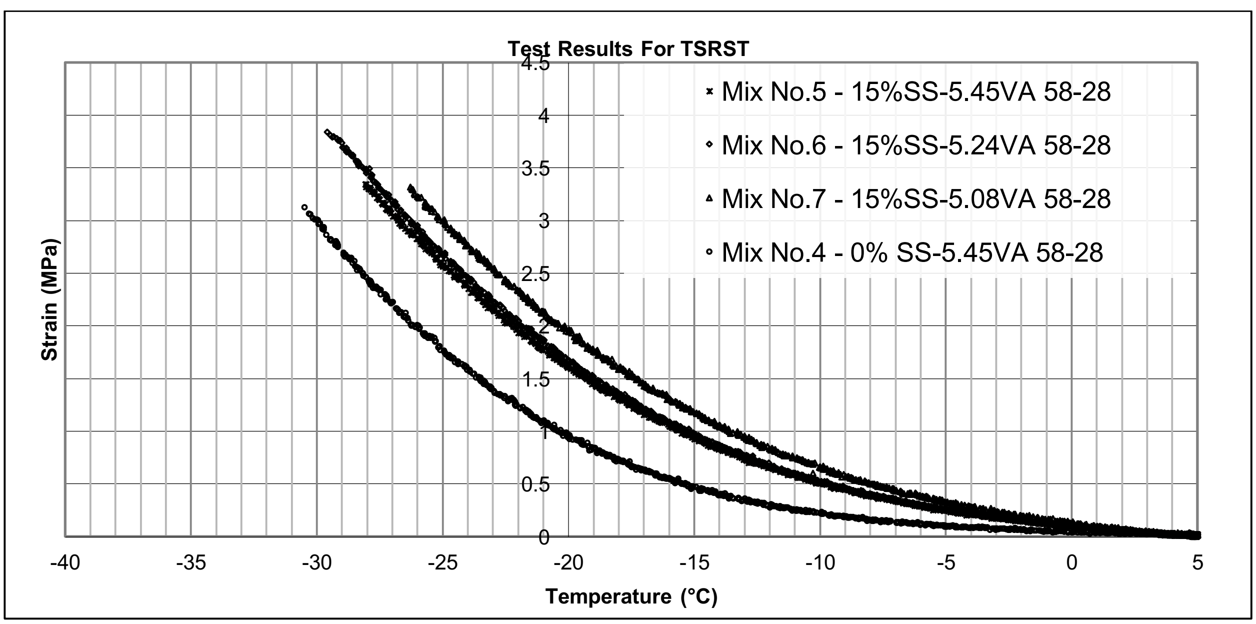

Figure 3. Thermal Stress Restrained Specimen Test (TSRST) graphic representation for mix with 15% shingle sand and PG 58-28 binder.

Figure 4 provides a graphic representation of the TSRST results performed on the reference asphalt mix in comparison with the asphalt mixes produced with 15 percent shingle sand and different percentages by weight of virgin asphalt PG 52-34 (5.45 and 5.08 percent).

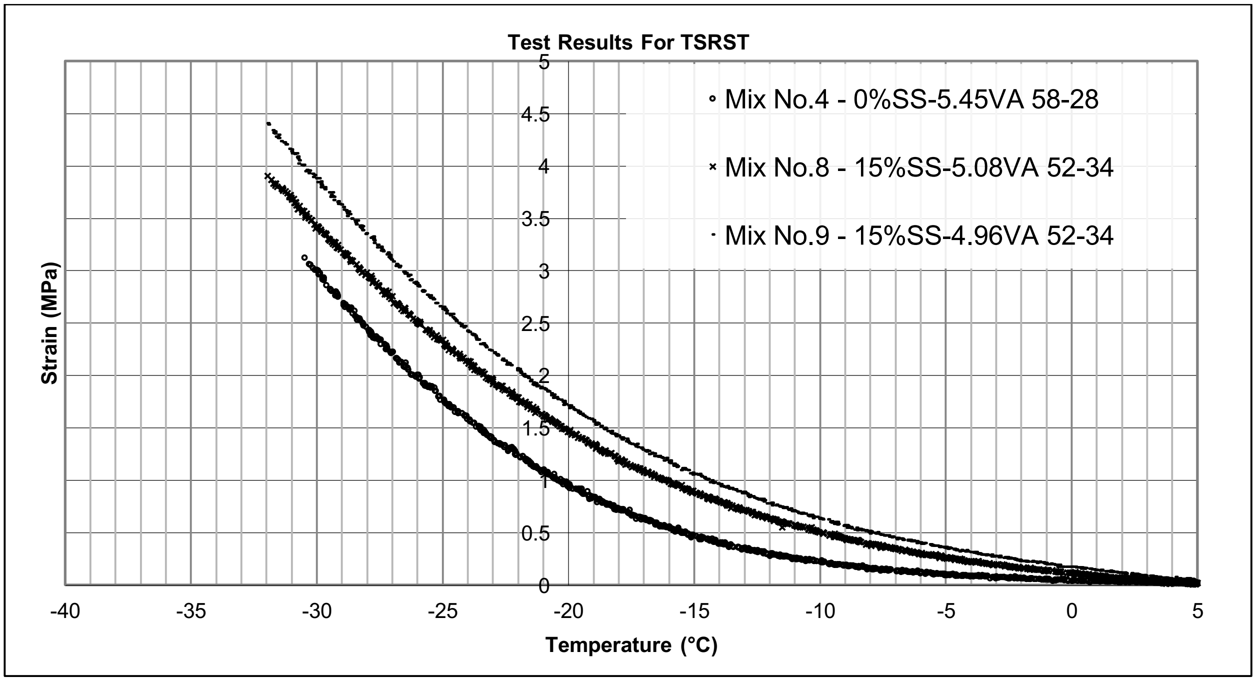

Figure 4. Thermal Stress Restrained Specimen Test (TSRST) graphic representation for mix with 15% shingle sand and PG 52-34 binder.

The TSRST results demonstrated that asphalt mix Nos. 5 to 7 with 15 percent shingle sand and 5.45 or 5.21 percent of 58-28 virgin asphalt behaved in the same way as the reference asphalt. This means that the cracking temperature was approximately -30°C. However, the asphalt mix with 5.08 percent of 58-28 virgin asphalt cracked at approximately -25°C.

As for the asphalt mixes with 15 percent shingle sand and 5.08 percent 52-34 virgin asphalt (asphalt mix Nos. 8 and 9, respectively), the TSRST results demonstrate that they are more resistant to low temperature cracking than the reference asphalt mix with PG 58-28 grade asphalt.

Accordingly, the resistance to thermal cracking indicates that asphalt mixes produced with 15 percent shingles may be developed to provide good resistance to low temperatures.

5.2 Resistance to Fatigue

Figure 5 represents the result of fatigue tests with 0 percent (reference mix), 4 or 15 percent shingle sand. The fatigue tests on asphalt mix No. 10 (15 percent shingle sand and 5.21 percent virgin asphalt PG 58-28) demonstrated behaviour entirely different from the reference asphalt mix without shingle sand. Asphalt mix No. 10 demonstrated a resistance to fatigue over 30 times greater for an imposed deformation of 200 µdef. Asphalt mix No. 10 was capable of undergoing 1,245,000 cycles before reaching 50 percent of the initial stiffness modulus, compared to 39,000 for the reference asphalt mix.

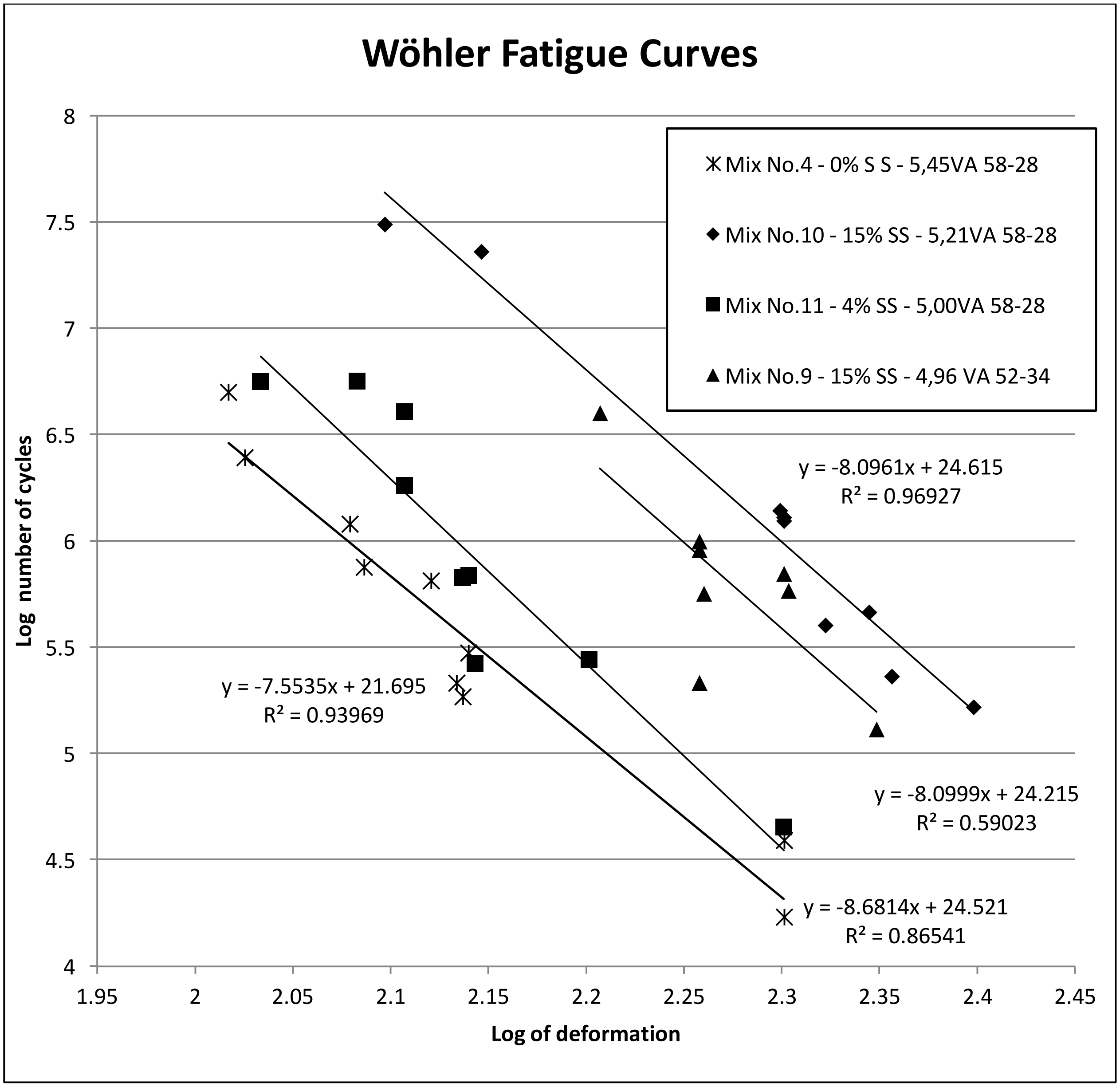

Figure 5. Wöhler fatigue curves for Asphalt Mix Nos. 4 (Reference Mix), 10 and 11

As shown in Figure 5, trend line equations shown as Equations 1 through 3 make it possible to approximate the deformation for a service life of 1 million cycles (ε6):

$$y = -7.55x + 21.7 \quad (1)$$

$$y = -8.10x + 24.6 \quad (2)$$

$$y = -8.68x + 24.5 \quad (3)$$

Equation 1 corresponds to the Wöhler fatigue curve of the asphalt mix without shingle sand (No. 4). The deformation at ε6 corresponds to 120 µdef. Equation 2 corresponds to the Wöhler fatigue curve of the asphalt mix with 15 percent shingle sand and 5.21 percent virgin binder (No. 10). The deformation at ε6 corresponds at 200 µdef. Asphalt mix No. 10 thus demonstrates both good resistance to restrained thermal stress and good fatigue behaviour. According to Equation 3, a deformation of 136 µdef is necessary for obtaining a service life of 1 million cycles for asphalt mix No. 11 with 4 percent shingle sand and 5 percent of PG 58-28 virgin binder, so its service life was slightly increased compared to mix No. 4.

A pavement structure design calculation was performed using the LCPC – Alizé pavement design method, which uses the specific mechanistic characteristic of the mixture including fatigue, modulus and acceptable deformation. That analysis made it possible to determine the thickness of layers with the different materials used (50 MPa soil support). As demonstrated in the Table 5, for daily traffic of 200 heavy trucks, the layer thickness decreases from 20 cm for asphalt mix No. 4 (without shingle sand) to 12 cm for asphalt mix No. 10 (with 15 percent shingle sand).

Table 5. Mechanistic pavement design calculation using fatigue resistance results.

Asphalt No.	Type of Mix	Initial Stiffness Modulus (MPa)	ε6 (µdef)	Slope of the Wöhler Curve	Necessary Thickness (cm)
4	0%SS + 5.45VA 58-28	8,800	119	-7.55	20
11	4%SS + 5.00VA 58-28	10,500	136	-8.35	16
10	15%SS + 5.21VA 58-28	8,200	199	-8.09	12

Note: ε6 is the deformation level that may be applied to achieve 1 million fatigue cycles.

5.3 Resistance to Rutting

The results for the resistance to rutting are summarized in Table 6 and in Figure 6. The results show that all the asphalt mixes produced with a high percentage of shingle sand meet the requirements of MTQ standard 4202 of less than 10 percent at 1000 cycles and less than 20 percent at 3000 cycles for a surface type mix ESG-10.

Table 6. Rut resistance test results for various mixes.

Virgin Asphalt (%)	Asphalt Performance Grade	SS	Rutting After 1,000 Cycles	Rutting After 3,000 Cycles	Rutting After 10,000 Cycles
5.45	58-28	0	4.8	6.9	10.6
5.21	58-28	15	9.7	12.4	15.3
5.08	52-34	15	8.0	11.1	13.3
5.45	52-34	0	6.3	9.3	13.9
5.08	52-34	0	4.3	7.4	13.7

Note: SS is the percentage of Shingle Sand in the mix.

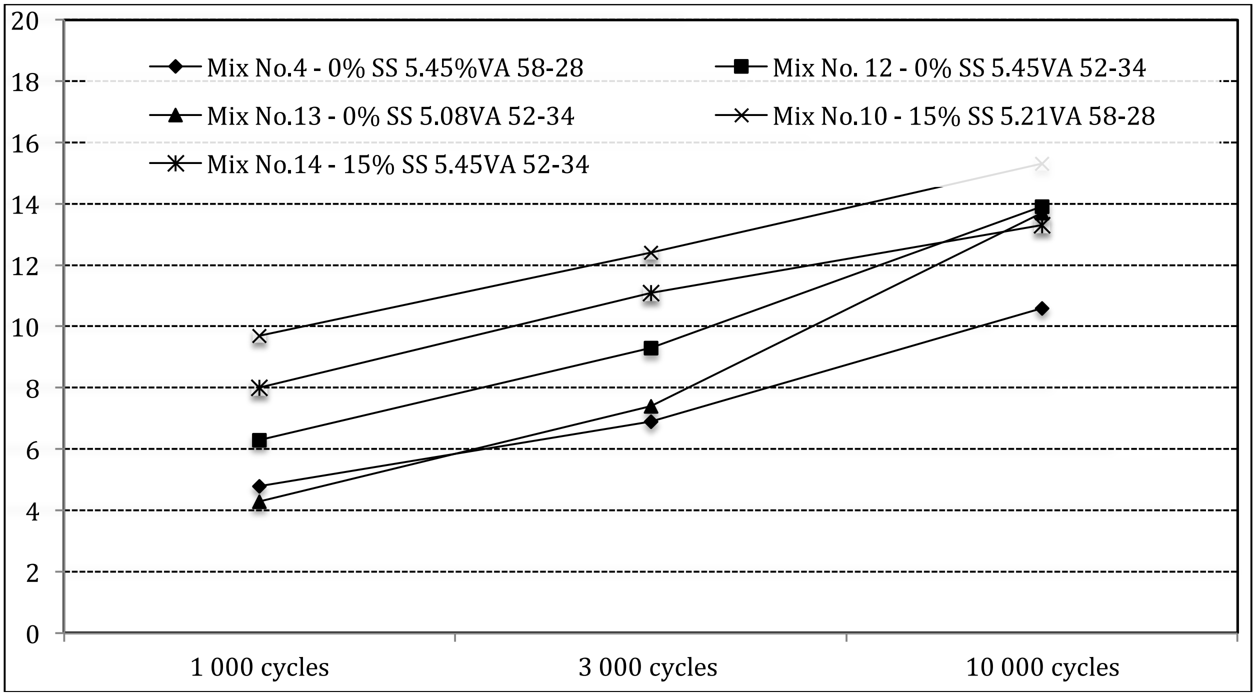

Figure 6. Graphic representations of the rut resistance test results for various mixes.

6.0 CONCLUSIONS

Asphalt mixes modified with RAS sand are new asphalt mixes that reduce the consumption of natural resources, notably the quantity of virgin binder and sand in asphalt mixes, while obtaining an asphalt mix demonstrating good mechanical properties (i.e., good resistance to fatigue or rutting, as well as resistance to low temperatures). Asphalt mixes produced with 15 percent shingle sand have asphalt content by weight (virgin binder + asphalt from shingle sand) in the order of 8 percent relative to the total weight of the asphalt mixes. This high asphalt content can be separated into a hard component (3 percent) originating from the shingle sand and a soft component (for example in the order of 5 percent) originating from the new binder.

The testing performed indicates that it is possible to produce asphalt mixes with a high content of shingle sand without affecting the mechanical criteria's of the final asphalt mix over time. An asphalt mix produced with 15 percent asphalt shingle sand may improve service life compared to a reference asphalt mix produced without shingle sand. The fatigue resistance values obtained in laboratory for an asphalt mix modified with asphalt shingle sand are significantly increased compared to the values obtained for conventional asphalt mix at an imposed sinusoidal deformation of 10 Hz frequency and a temperature of 10°C for an imposed deformation of 200 µdef up to a 50 percent loss of stiffness modulus.

The laboratory characterization of the mechanical properties of asphalt mixes containing 15 percent asphalt shingle sand has made it possible to determine that the rutting and thermal cracking of asphalt mixes approached the values normally obtained for the same mix design using only virgin materials. Moreover, this same asphalt mix makes it possible to produce thinner base courses than the reference asphalt mix (12 cm instead of 20 cm), for the same service life.

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