New System for Preventing Reflective Cracking: Membrane Using Reinforcement Manufactured on Site (MURMOS)

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The first experiments on the totally new process discussed in this paper were conducted in France in 1988. Since then, almost 1 000 000 m^2 have been successfully laid. The technique involves in situ creation of a reinforced membrane composed of a layer of elastomer binder onto which continous threads are sprayed immediately after it is laid. The threads interweave to create the reinforcement. This paper describes the process, gives the mix designs used, and introduces the machine that was especially designed to manufacture and lay the reinforced membrane. The results of laboratory tests conducted by one of the laboratories of the French administration and the Belgian Road Transport Research Center are also presented and discussed. These tests show that this process is one of the most efficient processes for preventing reflective cracking. Some examples of its application are mentioned. Its principal advantages over processes using shop-manufactured materials (geotextiles or geogrids) are outlined.

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PROBLEM

Cracking of pavements is a problem that has plagued road-builders for many years. Two types of cracking are particularly worrying.

- Fatigue cracking. Fatigue cracks appear primarily in flexible or conventional pavements and are caused by repeated tensile stresses in the bituminous materials as a result of traffic. They start at the base of these materials and gradually rise to the road surface where they form disorderly network (alligator cracking). Fatigue cracks are a sign of advanced breakdown caused by inadequate design, or a symptom betraying the fact that the road has reached the end of its service life. Maintenance or reinforcement is therefore necessary.
- Reflective cracking. Reflective cracks affect semirigid pavements and originate as soon as the cement or pouzzolanic binders used begin to set. The speed at which they rise to the surface depends on the type and thickness of the materials that form the upper layers, the amplitude of temperature variations, mix designs, etc. Reflective cracks generally form regular patterns (transverse cracks every 5 to 8 m), and although they are not a sign of serious deterioration, they nonetheless call for curative treatment.

To these cracks must be added the joints between concrete slabs of rigid pavements, and the fine but numerous cracks that run in all directions across continuously reinforced concrete pavements.

Whatever their origin, these cracks are waterproofing disorders. Water may infiltrate into the ground and significantly shorten the lifetime of pavements on soils that are not naturally self-draining or that may be affected by frost heave. Furthermore, traffic on cracked semirigid pavements can aggravate cracking, which eventually produces an unsightly wearing course. On concrete pavements, improper treatment of the joints can lead to relative movement of slabs, and eventually to rupture.

The problem is so important that in France, in 1983, the Ministry of Transport launched a contest for innovative techniques designed to prevent reflective cracks. Such processes were classified priority No. 1 by the Department of Road Transport in 1988 (*1*).

These processes concern a wide market, that of all semirigid roads built to date (curative applications) or currently being built (preventive application), as well as concrete pavements, particularly on densely trafficked roads. In France, the potential market for this process is approximately 3 000 000 m^2 per year for new roads, and about 30 000 000 m^2 per year for existing pavements.

FRENCH EXPERIENCE IN TECHNIQUES FOR PREVENTING REFLECTIVE CRACKING

Current French know-how in techniques for preventing reflective cracking was inventoried recently (*2*).

Several processes slow down the rate at which existing cracks rise to the surface:

- Sealing before laying of chip seals or asphalt overlays. A binder, generally modified, is applied along the crack and to about 10 cm on either side, and is then gritted with sand before being covered with chip seal or asphalt overlay.

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- Stress-absorbing membrane interlayer (SAMI). A binder is applied to the entire cracked pavement, then chippings are spread, and finally an asphalt overlay is provided as a wearing course. The binder is generally modified with polymers or rubber powder (from tires).
- Geotextiles impregnated with bituminous binder. This process involves rolling a manufactured geotextile onto the cracked surface, to which it is made to adhere with ample quantities of binder, and then applying an asphalt overlay.
- Geogrids impregnated with bituminous binder. As in the previous case, the geogrid is made to adhere with ample quantities of binder and is surfaced with a wearing course.
- Double-layer overlay. Double-layer overlays contain a 1.5- to 2.0-cm-thick first course of 0/4-mm sand in a 9 to 10 percent bitumen mix (the bitumen may be modified), topped with a 4- to 6-cm-thick course of asphaltic concrete (possibly using a modified binder).

Several years of experience in France have given the following results:

- Sealing of cracks is slow and laborious, the final appearance is not pleasing, and impermeability is only temporary. The wearing course near the cracks may soon start to deform.
- Thick SAMIs have been deemed to give not very satisfactory results on the jobsites where they have been applied. (Laboratory results are nevertheless good.)
- Impregnated goetextiles reinstate the impermeability of the pavement, but cracks nevertheless rise quickly through overlays. (These techniques have been little developed because of they are so slow to apply, being particularly difficult in bends. Folds and overlapping of strips do nothing to improve the efficiency of the system.)
- Geogrids have been judged to have given rather negative results;
- Double-layer overlays containing a binder-rich mortar covered with a thin asphalt overlay are currently the most efficient solution, but are relatively expensive.

There is therefore seen to be room for a process that combines the qualities of efficiency, moderate cost, and high speed of application.

DESCRIPTION OF PROCEDURE

Principle

The principle (see Figures 1 and 2) consists of a composite system formed by simultaneously spraying a bituminous binder and continuous organic threads that interweave to create reinforcement, and then spreading chippings onto this membrane before applying the wearing course.

Formula

The binder is an elastomeric bituminous emulsion applied at a rate of 0.9 to 1.8 kg/m^2 (equivalent to a residual binder content of 0.6 to 1.2 kg/m^2).

The polyester threads are sprayed on at high velocity. The multistrand threads ranging in size from 140 to 500 decitex (1 decitex is the weight in grams of 10 000 m of thread) are generally spread to a density of 100 g/m^2, with variation between 40 and 120 g/m^2 possible.

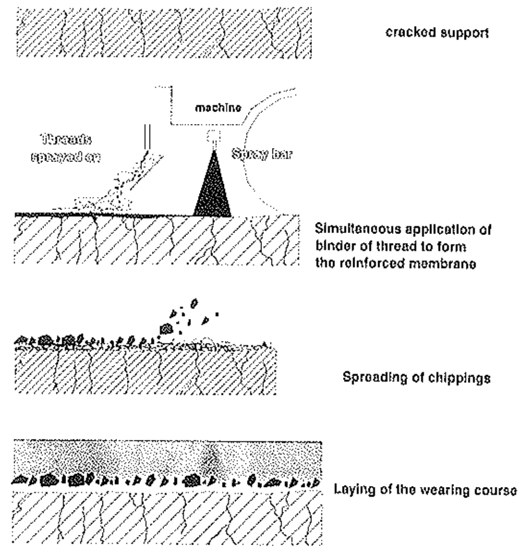


FIGURE 1 Steps in MURMOS application.

Chipping (6/10 or 10/14 mm) coverage is about 5 to 10 L/m^2.

There are several options for the wearing course: e.g., Glg-type chip seal (course chippings, binder interlay, and fine chippings) or conventional asphalt concrete, but the most frequent wearing course is fiber-based asphalt, which, because of its high binder content, further improves the performance of the membrane.

Filaflex Machine

This new MURMOS process required the development of a special machine. Once all the parameters for application of this concept had been defined with a sprayer-drawn prototype that sprayed threads under pressure in a 1-m-wide strip, two high-throughput machines were built. They were in fact slightly different, but the following equipment was common to them both:

- A roadgoing trailer with two steering axles that carries all the subunits required to make the membrane;
- A power source for the hyraulics units and the pump feeding the thread injectors;

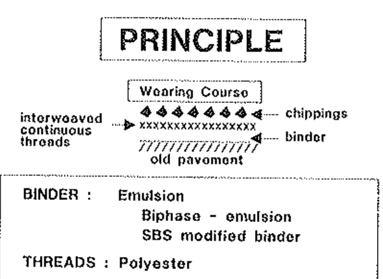


FIGURE 2 Schematic of MURMOS technique.

- A built-in binder spray bar (extendable from 1.25 to 3.70 m) for application of a uniform membrane at a constant rate, onto which the threads are sprayed immediately before spreading of chippings and laying of the wearing course;
- A 6 000-L emulsion tank (on one machine only);
- Two independent thread-spraying units, each including
  —A 900-kg reel of thread on a 1.5-m-long, telescopic arm that can be extended overboard to obtain a total width of application of 3.70 m (with both reels);
  —A tensioning system that unwinds the 900 threads from the drum; and
  —A thread spray bar (seven injectors on one machine, nine on the other) placed immediately behind the binder nozzles and connected to the pump by flexible hoses. As for the binder spray bar, the thread spray bar can be extended laterally to vary the width of application anywhere between 1.25 and 3.70 m.

The layout of the Filaflex machine is shown in Figure 3.

LABORATORY ASSESSMENT

Different structures were tested on a variety of devices to identify the most suitable systems.

Tests Conducted at the Regional Laboratory of Ponts et Chaussées in Autun, France

Principle Behind the Test

The tests (*3*) involved examining the speed at which a crack rises through a composite pavement including (a) a system intended to delay the reflection of cracks and (b) a wearing course (*4*,*5*).

Each test sample was representative of the system and was submitted to the following two simultaneous loads at a constant temperature (5°C):

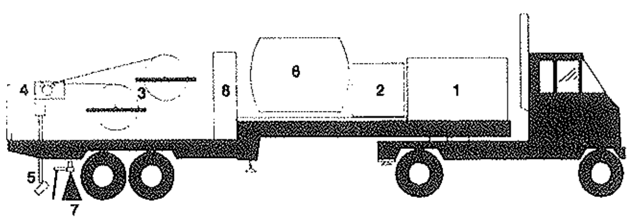
- Slow, sustained, longitudinal tensile stress to simulate thermal contraction; and
- Cyclic vertical bending at 1 Hz to simulate traffic.

The progress of the crack was monitored by means of a series of electrical conductors.

The test apparatus is shown in Figure 4. The test made it possible to assess various characteristics linked to the efficiency of the system studied (reflection of crack, speed of development, and time for full cracking of the system).

TABLE 1 RESULTS OF LABORATORY TESTING OF MURMOS SAMPLES OF VARIOUS COMPOSITION

Test	Binder	Binder content (kg/m^2)	Thread content (g/m^2)	Crack starting time (minutes)	Rupture time (minutes)
1	Biphase elastomer bituminous emulsion	1.2	50	110	450
2	"	1.2	100	160	570
3	"	1.6	50	200	520
4	"	1.6	100	260	630
5	SBS bitumen	1.0	80	270	540



1. Engine driving hydraulics unit.

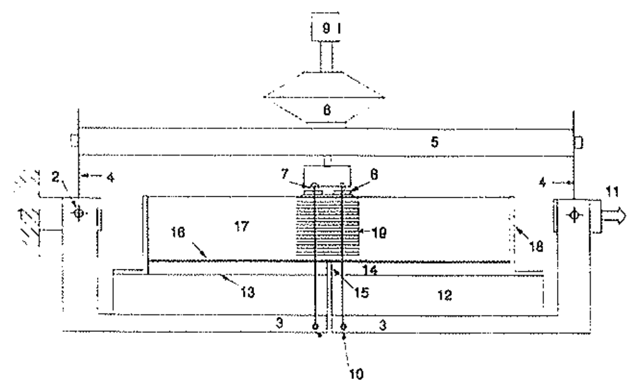
THREAD UNIT
2. Pump unit generating continuous flow of compressed air.
3. Two 900 kg reels, each wound with 900 threads and mounted on 4 bearings; they are gradually braked as the quantity of thread on the reel diminishes; this system is controlled by an ultrasound detector.
4. Tensioning-roller system for unwinding the threads: 2 smooth stainless-steel rollers, and 1 hydraulically-controlled rubber roller whose rotation speed is linked to the forward speed of the unit.
5. The thread is sprayed onto the road by a series of 18 polished stainless-steel nozzles with a tubular extension and deflector plate. The nozzle system can be moved laterally.

BINDER UNIT
6. 6,000 litre binder tank.
7. Built-in spray bar. Can be extended outboard.

8. Crane for loading reels of thread.

Dimensions: L = 16 m (trailer and tractor unit) W = 2.5 m H = 4 m

FIGURE 3 Description of Filaflex II machine.



1. Frame of the apparatus
2. Hinge axis of L-shaped plates
3. L-shaped plates
4. Flexible blades
5. Hydraulic cylinder thrust bar
6. Hydraulic cylinder (adjustable stroke)
7. Rollers
8. Bearing plates
9. Adjustment of hydraulic cylinder stroke
10. Load transmission lines.
11. Recirculating-ball thread tensioning jack
12. Base plates bolted to L-shaped plates (thickness varies with that of samples).
13. Glue (sample glued to base plates)
14. 1.5 cm thick layer of precracked asphaltic concrete to simulate the old cracked pavement.
15. Crack inducer (cardboard)
16. Interface system (geotextile, membrane, sealant) (in some cases)
17. Sample
18. Glued foil to prohibit vertical movement of the ends of the test sample whilst allowing horizontal movement.
19. Crack-detection system (electric wires).

FIGURE 4 Contraction and bending test apparatus of the regional laboratory at Autun.

Results

Five MURMOS systems were studied. The differences between them concerned

- Binder content (per square meter),
- Type of binder, and
- Thread content (per square meter).

The compositions of the system are presented in Table 1, along with the experimental results.

In all cases, the wearing course was 4-cm-thick fiber-based asphalt with the following characteristics:

- Continuous grading curve: 0 to 10 mm.
- Binder content: 7.2 percent of 60/70 pen
- Fiber content: 1.5 percent.

This table, as well as information on other existing solutions assessed with the same test procedure, indicates that the best performance was obtained with the system containing 1.6 kg/m² of biphase elastomeric bituminous emulsion and 100 g/m² of thread (Figure 5).

Tests Conducted by the Belgian Road Transport Research Center

The Belgian Road Transport Research Center has developed a tensile and compressive test device that simulates the movement of a cracked concrete support as a result of thermal stresses. This apparatus was described at the RILEM Congress in Liège in March 1989 (*6*). It complements a mathematical model based on the finite difference method, which uses the mechanical properties of the materials (fatigue and modulus of elasticity) as its principle input.

Principle of the Test

The test simulates thermal stresses by means of the apparatus shown in Figure 6.

The outstanding feature of this test device is that it simulates crack opening and closing at a speed close to that observed

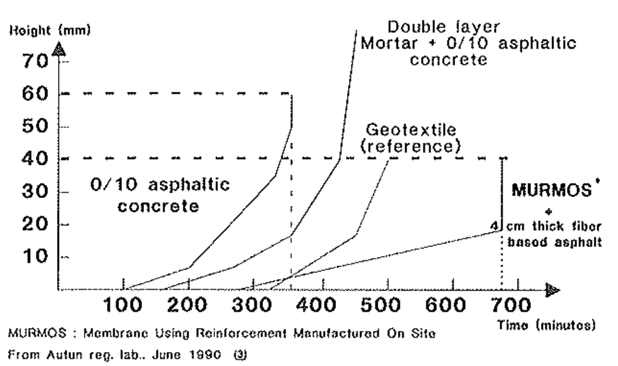


FIGURE 5 Results of contraction and bending tests on various systems for preventing reflective cracking.

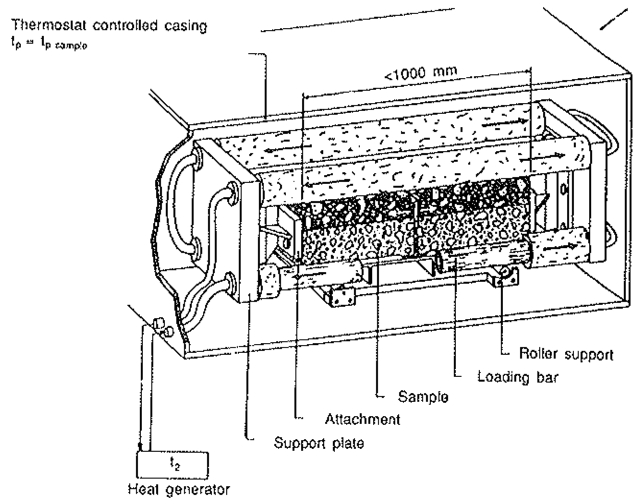


FIGURE 6 Apparatus for simulating thermal cracking.

in situ as a result of daily temperature variation, i.e., several 10ths of a millimeter per hour.

With this apparatus, deformation is induced by the expansion or contraction of the frame to which the sample is attached. Such slow and perfectly controllable deformation is obtained by periodically changing the temperature of a liquid circulating in the bars of the frame. The sample is kept at a constant −5°C or −10°C throughout the test. The roadbase lies on a bed of steel balls that allow free and practically frictionless movement. The apparatus is fitted with sensors for measuring the stresses applied, the opening of the crack, and the displacement of the pavement relative to the cracked support. Visual observation of the phenomenon is facilitated by a video system: filming is controlled by the data acquisition and verification system.

The system to be tested is glued to the road base, a block of precracked concrete. It is then covered with a wearing course. The test samples measure 60 cm in length, and 7 cm in width, and the concrete is 7 cm thick. The speed at which cracks open and close is 15 μm/min, i.e., 1 mm/hr.

The test is computer-controlled, with continuous measurement of (a) the opening of the crack in the support and in the asphalt overlay, (b) the displacement of the wearing course relative to the support, and (c) the applied stress. The progress of the crack is video recorded.

The maximum strain (tensile stress) applied at the edges of the crack inducer is about 25 percent (i.e., 1 mm of opening during a 2-hr cycle for a starting gap of 4 mm).

Figures 7 and 8 show the resulting variation of crack opening and the evolution of the measured forces with time. The results were summarized by Vecoven (*6*): "In general, the interface systems with the highest tensile strengths crack rapidly whereas those comprising emulsions of low-viscosity bitumen can withstand high relative displacement between the overlay and the cracked support without cracking or separation of the various layers of the structure (*5*)."

Results

Given the results of the MURMOS tests performed at the Regional Laboratory in Autun, only systems containing 100

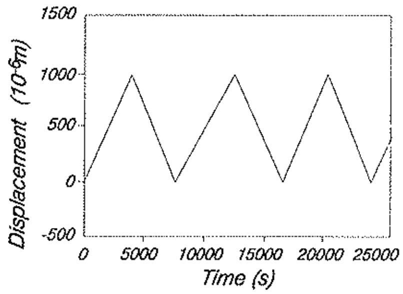


FIGURE 7 Thermal cracking test: variation of crack opening with time.

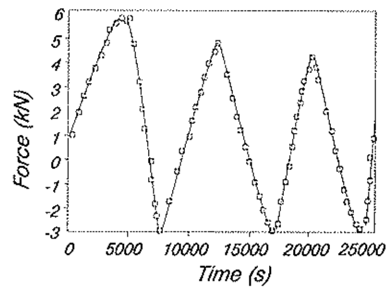


FIGURE 8 Thermal cracking test: variation of force with time.

g/m² of thread and 1.6 kg/m² of emulsion were tested. Table 2 presents descriptions of the structures and the results obtained.

It appears that none of the MURMOS systems tested cracked after 20 cycles at −5°C. The same result was obtained with the test at −10°C.

At −5°C, the tested systems using geotextiles and geogrids indicated forces in concrete three or four times higher than that obtained with test sample RTE 3.1. At the time this paper was written, the results of testing at −10°C indicated that no system other than that described in Table 2 withstood cracking. This excellent performance was ascribed to a decoupling effect caused by the thread reinforcement in the membrane that considerably reduced the maximum stress induced in the asphalt overlay when the crack opened.

To sum up the results of the laboratory tests performed by the French Public Service in Autun and by the Belgian Road Transport Research Center, it appears that the composite overlay presented in this paper is the best of the crack-inhibiting courses known to date.

PRACTICAL EXPERIENCE

As of mid-1990, almost 1 million m² of MURMOS systems had been applied.

The first test sections were laid at the end of 1988 and early 1989. These sections enabled definition of the various application parameters, which led to the development of the Filaflex machine, and they also gave the opportunity for long-term testing of several types of composite systems under different conditions:

- Different types of support;
  - —Alligator-cracked flexible pavement,
  - —Cracked semirigid pavements,
  - —Cracked rigid pavements;
- Different circumstances;
  - —Densely trafficked roads T0, T1;
  - —Urban roads, e.g., rue St. Ferjus, Gallieni bridge; and
  - —Surfaces with special stresses—mountain bends, carparks, etc.

TABLE 2 TESTS PERFORMED AT THE BELGIAN ROAD TRANSPORT RESEARCH CENTER

Test Sample	R.T.E.1	R.T.E.2	R.T.E.3-1	R.T.E.3-2
System for preventing reflective cracking	M.U.R.M.O.S. with biphase elastomer-bitumen emulsion 1.6 kg/m²	M.U.R.M.O.S. with biphase elastomer-bitumen emulsion 1.6 kg/m²	M.U.R.M.O.S. with biphase elastomer-bitumen emulsion 1.6 kg/m² 6/10 chippings	M.U.R.M.O.S. with biphase elastomer-bitumen emulsion 1.6 kg/m²
Wearing course	Fiber based asphalt	Type 1 overlay (7 cm)	Type 1 overlay (7 cm)	Type 1 overlay (7 cm)
Test temperature (°C)	-5°C	-5°C	-5°C	-10°C
OBSERVATIONS				
Duration	20 cycles	26 cycles	20 cycles	20 cycles
Cracking	None	None	None	None
Maximum elongation of support	1.012 mm	1.021 mm	1.10 mm	1.014 mm
MEASUREMENTS (cycle)	1st cycle	1st cycle	1st cycle	1st cycle
- Max. force in concrete	2,745 N	4,595 N	1,501 N	3,346 N
- Max. elongation in overlay	0.180 mm	2.225 mm	0.051 mm	0.084 mm
- Max. stress in overlay	0.89 MPa	0.97 MPa	0.30 MPa	0.68 MPa
- Max. stress at interface system	0.125 MPa	0.210 MPa	0.069 MPa	0.159 MPa
MEASUREMENTS (cycle)	20th cycle	20th cycle	20th cycle	20th cycle
- Max. force in concrete	530 N	2,216 N	504 N	1,452 N
- Max. elongation in overlay	0.098 mm	0.179 mm	0.025 mm	0.039 mm
- Max. stress in overlay	0.17 MPa	0.47 MPa	0.10 MPa	0.30 MPa

These test sections have been followed up, and they confirm the good performance of the MURMOS system. Some details of actual applications are given in the following sections.

RN 86 in the Ardèche

A 20 000 m^2 stretch of national highway RN 86 in the center of France (Ardèche) was upgraded in 1988. The MURMOS innovative technique was selected as part of the contest organized by the regional administration.

The technique consisted of two processes:

- Preventing cracks rising to the surface of the old semirigid pavement. The solution proposed replaced the basic solution, which consisted of 12 cm of conventional asphalt concrete.
- Preventing cracks rising to the surface of the new pavement or the existing pavement reinforced with a cement-treated layer.

To date, i.e., almost 2 years later, no crack has reached the surface.

The wearing course is a 4-cm-thick fiber-based asphalt concrete.

A55 Highway

The A55 highway is a highly cracked thick flexible pavement. A 30 000-m^2 stretch was upgraded in August 1989. The T0+ traffic corresponds to 1,200 trucks per day in each direction.

The wearing course is a 2-cm-thick fiber-based asphalt concrete.

A6 Highway

A 100 000-m^2 stretch of highway was upgraded in May 1990. Traffic there is also more than 1,200 trucks per day in each direction.

The wearing course is a 4-cm-thick fiber-based porous asphalt.

In this case, the process was applied to three types of support:

- Continuous reinforced cement concrete,
- Californian cement slabs stabilized with connectors (in order to prevent relative vertical movement), and
- Thick cement concrete slabs.

The MURMOS system proposed for all three supports was

- 1.6 kg/m^2 of binary elastomer bituminous emulsion,
- 100 g/m^2 of threads,
- 6 litres/m^2 of 6/10 chippings, and
- 80 kg/m^2 of porous asphalt.
  - —Gradation: 0 to 14 mm,
  - —Binder: 6 percent of 60/70 pen., and
  - —Fibers: 1 percent.

ADVANTAGES OF MURMOS PROCESS COMPARED WITH PARALLEL PROCESSES

The MURMOS process has three types of advantage:

- Technical advantages,
- Advantages linked to application, and
- Economic advantages.

Technical Advantages

Although applied relatively recently (2 years ago), the MURMOS test strips laid in 1988 and at other job sites since then total more than 1 000 000 m^2. The efficiency of the process has been demonstrated because, to date, no cracks have risen to the surface on the sites monitored.

In addition, the experiments performed by the Autun laboratory, part of the Ponts et Chaussées technical network, specialized in the study of processes for preventing reflective cracking, as well as those performed at the Belgian Road Transport Research Center in Liège, have led to selection of the most efficient formulas that provide some of the best performances for processes known to date.

Advantages of MURMOS System Application

The advantages that the MURMOS system has over techniques using shop-manufactured materials are as follows:

- System parameters can be adjusted to meet needs;
- The system can be fully adapted to the longitudinal profile of the road (no folds in curves, no overlap problem); and
- High daily application rates (close to 30 000 m^2 per day) can be obtained.

Economic Advantages

In the MURMOS process, the form in which the raw materials are used (reel of threads instead of ready-manufactured geotextiles), together with the high daily application rate, permits entirely competitive costs. According to the laboratory test results, the application rate must nevertheless be near the following mean values: binder 1.6 kg/m^2 (1.4 to 1.8 kg/m^2), threads 100 g/m^2 (80 to 100 g/m^2).

CONCLUSIONS

First experimented with in 1988, a new system for preventing reflective cracking has been developed. MURMOS consists of manufacturing a reinforced membrane in situ by simultaneously spraying a layer of generally modified binder and continous threads that interweave to form the reinforcement. This composite system is then covered with a wearing course.

After nearly 3 years of experiments, the main conclusions are as follows:

- Laboratory tests indicate that the performance of the MURMOS system is among that of the best;
- With the specially designed machine, daily laying rates are high; they can reach 30 000 m^2 per day;
- In distinction to systems using shop-manufactured reinforcement, the MURMOS process presents no problem with respect to bends or road width (no folds in curves or problem of overlapping);
- Although relatively recent, the upgrading work performed with the MURMOS process up to mid-1990, amounting to almost 1 000 000 m^2 on a wide variety of roads (cracked flexible pavements, semirigid pavements, and concrete roads), demonstrates the excellent performance of the process in the field; and
- The MURMOS process is felt to be an economic solution for cracking problems on all types of road (flexible, semirigid, and rigid).

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