3.02 Summary

THE USE OF FIBERS IN BITUMINOUS CONCRETE AS A SOLUTION TO DECREASE RUTTING

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The phenomenon of rutting in asphalt pavement is well known in Belgium.
It is directly related to the visco-elastic behaviour of the binder, but abrasive wear by vehicles and post-compaction of the foundation might also be considered.
Some solutions have been proposed to decrease these effects : the choice of gravels, sand or filler, or the use of bitumen modified with plastomers and elastomers. This presentation wants to consider the use of fibers as a solution for this problem.
After a theorical approach that will give some informations about the characteristics to be adopted for the fibers, it will be verified that the use of steel and synthetic fibers, mixed with the hydrocarbon concrete, do not disturb the homogeneity of the asphalt : this verification will be realized by means of a MARSHALL test.
The measurement of the creep by means of a test developed in the laboratory will show different behaviours for the fibers.
After a discussion about the shape and the treatment of the fibers, the results of a simulation traffic test will be presented, taking into account different types of fibers (steel, PES, PAN, ...), variable lengths, shapes, sections or percentages of incorporation so that it will be possible to definite the best solution for the best effects.
Other technological considerations, related to the laying down of such a material, will also be taken into account and some in-site realizations will be presented.

3.02 Résumé

L'EMPLOI DE FIBRES DANS LES REVETEMENTS HYDROCARBONES POUR LUTTER CONTRE L'ORNIERAGE

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Le problème de l'ornièrage est un phénomène bien connu en Belgique.
Il est directement lié au comportement visco-élastique du liant, bien que des phénomènes d'usure dus au passage des véhicules ainsi que la post-compaction des couches de fondations puissent aussi être prises en compte.
Quelques solutions ont été proposées pour combattre ces effets : le choix des graviers, du sable ou du filler ou l'adoption d'un bitume modifié avec des plastomères ou des élastomères. Cette présentation traitera de l'utilisation des fibres en tant que solution à ce problème.
Après une approche théorique qui a pour but d'informer sur les caractéristiques dimensionnelles des fibres, il sera présenté les résultats d'un test qui a permis de vérifier la possibilité d'incorporer les fibres dans le revêtement hydrocarboné sans perturber l'homogénéité du mélange : il s'agit du test MARSHALL.
La mesure du fluage au moyen d'un essai développé au laboratoire permettre ensuite de mettre en évidence des comportements différents suivant le type de fibre.
Après une discussion sur la forme et le traitement de surface à donner aux fibres, les résultats de l'essai au simulateur de trafic seront présentés, en prenant en compte les variables suivantes : type de fibres (acier, synthétiques), la forme, la longueur, la section ou le pourcentage.
Il sera ainsi possible de dégager la solution optimale.
Enfin, à l'aide de l'exemple d'applications réalisées in situ, différents facteurs d'ordre technologique pourront être pris en compte et intervenir dans la définition de la solution finale.

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1. The problem of deep cracking

The deep cracking is a permanent deformation parallel to the axis of the road; its length is equal to 4 times its width. This deformation can be more than 10 mm deep.
This deep cracking reduces the users safety when the crack is 15 to 17 mm deep and the road must be repaired or removed when it is 25 mm deep.
The causes are in relation with external factors - traffic and climatic effects - and internal factors - binder consistency, percentage of aggregates and binder, percentage of voids.

2. Experimental approach

A great number of fibers have been selected.
The parameters were :
- their constitutive material;
- their physical characteristics;
- their shape and length.

The results given hereafter present the principal types of fibers that were considered.
Glass fibers were rejected because of surface problems.
Polypropylen and polyethylen fibers were also rejected because of temperature resistance problem.

2.1. Marshall test

The aim of this test is to determine the mechanical characteristics (Stability and Marshall Flow) of the bituminous concrete after a hot compaction in normalized conditions.

The characteristics of the materials used for the making of the bituminous concrete type I were :
- aggregates 10/20 : 8 %
  (type sandstone) 7/10 : 29,4 %
  2/7 : 17 %
  0/2 : 37 %
- filler : 8,6 %
- bitumen 50/60 : 6 %

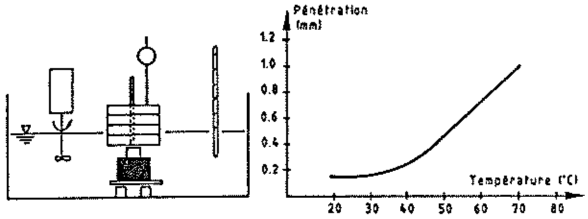
All the aggregates and sands have been washed, sieved and dried.
The results are given hereafter.

Commercial name	Type	%	Marshall stability (N)	Marshall flow (mm)	Ratio (N/mm)
Without fiber	-	-	8500	3	2833
DRAMIX ZC 30/.50	steel	1,5	10767	3,5	3076
HAREX SF 12-16	steel	1,5	11867	3	3956
DACRON D157-10mm	PES	0,3	10600	2,8	3786
DOLANIT 11 100/6	PAN	0,3	11400	2,9	3931
EXXON (G)	PP	0,3	13533	2,7	5012

2.2. Behaviour of the bituminous concrete at elevated temperature

A new test has been developed to determine the behaviour of a bituminous concrete, loaded with a constant weight, when the temperature regulary increases. Samples of Marshall type (diameter = 10 cm, height = 6,5 cm) are placed in a thermoset bath with glycerin. The increasing of temperature is 1°C by minute.

The load on the bituminous concrete samples is 5 kg/cm²; a deformator allows to follow the penetration and the behaviour of the sample as a function of the temperature (see the scheme and the curve hereafter).



The results can also be presented in a table where you can see the values of the penetration for 40, 60 and 80°C.

T (°C) / Sample	40	60	80
A8 without fiber	0.2	0.58	0.75
B8 DRAMIX ZC 30/.50	0.08	0.47	0.72
C8 DOLANIT 11 100/6	0.03	0.33	0.46
H8 HAREX SF 12-16	0.13	0.58	0.72
I5 DOLANIT 10 30/6	0.19	0.35	0.53
08 RP 17	0.05	0.3	0.5

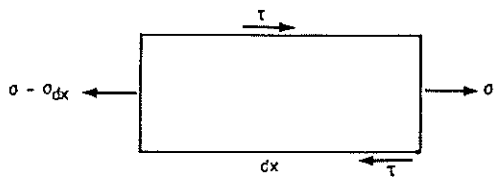
Conclusions

The test first shows the positive effect of the incorporation of fibers into the bituminous concrete - from 40°C, we observe an excellent behaviour of some plastic and steel fibers - and, secondly, that, when the temperature increases, the positive effect due to the incorporation of steel fibers becomes not significant and the one due to plastic fibers, such as DOLANIT and RP 17, remains important.

2.3. Study of the fiber shape

We have to study the behaviour of a steel or plastic fiber, into an unhomogeneous middel constituted by bitumen, sand and gravels.
However, for a simplified approach, we shall consider that the bituminous concrete is homogeneous. Consequently, the bituminous concrete with fibers will be a composite system where the bituminous concrete is the homogeneous phasis and the fibers the dispersed one.

We consider a part of fiber of dx length :



The forces acting on this element are in equilibrium when a variation of the normal force is compensated by an opposed shear force.

$$\pi r^2 \, d\sigma_f = 2 \pi r_r \, \tau \, dx$$

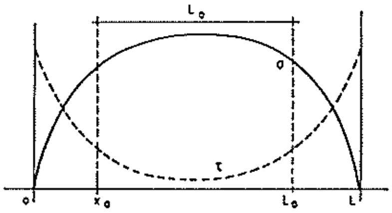
r_f = fiber radius
σ_f = normal stress
τ = shear stress at the interface

The shear force comes from the shearing γ of the matrix around the fiber and this effect is proportional to the displacement u, due to the presence of the fiber into the matrix.
We can write :

$$\tau = G_m \cdot \gamma = C \, G_m \frac{U}{r_f}$$

where C is a constant, G_m the shear modulus of the matrix.
The calculation of the derivated equation permits to calculate x_o.

$$x_o = r_f \sqrt{\frac{E_f}{2CG_m}}$$



Variation of the normal stress σ and the tangential stress τ along the fiber

Only the length l_o of the fiber is influenced by the matrix and is strained, that means that the deformation of the fiber increases progressively from the extremities and is equal to the one of the composite at a distance proportional to $r_f \sqrt{\frac{E}{G_m}}$

So it is like only a little quantity of fibers x_o/l had the same deformation than the composite and the rest was almost not deformed.

Consequently, the fibers must be relatively long to have any influence on the modulus; there is a critical length for the fiber. About the shape of the fiber, its influence will be important at the extremities of the fiber, where the shear stresses are maximum.

The shear modulus G_m can be written :

$$G_m = \frac{E}{2\ (1 + \text{Poisson's coefficient})}$$

where the Poisson's coefficient is equal to 0,3.

We can calculate $r_f \sqrt{E_f/G_m} = Z$ for a bituminous concrete type I at different temperatures.

Fibre type	R_f (mm)	E_f (N/mm²)	T (°C)	Bituminous concrete E (N/mm²)	G (N/mm²)	Z (mm)
Steel	0,25	206.000	- 20	30.000	11.538	1,056
Steel	0,25	206.000	0	22.000	8.462	1,233
Steel	0,25	206.000	+ 20	9.000	3.462	1,928
Steel	0,25	206.000	+ 40	900	346	6,100
Steel	0,25	206.000	+ 60	90	35	19,180
Acrylo-nitryl	0,009	18.000	- 20	30.000	11.538	0,011
Idem	0,009	18.000	0	22.000	8.462	0,013
Idem	0,009	18.000	+ 20	9.000	3.462	0,021
Idem	0,009	18.000	+ 40	900	346	0,065
Idem	0,009	18.000	+ 60	90	35	0,204

The conclusion is : to play an efficient role, the steel fibers must be relatively longer than the synthetic fibers.

2.3.1. Steel fibers

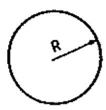
A test was realized to quantify the influence of the steel fibers shape on the adherence to bitumen. The pull-out resistance of the fibers from a 50/60 type bitumen has been measured. The immersion depth was 1 cm and the temperature 20°C.

Fibre type		Load (g)
Right fiber ϕ 500 µm		1020
		800
		1060
	Average	960
Fiber with hooks ϕ 500 µm		1470
		1640
		1480
	Average	1530
Gulf fiber ϕ 500 µm		2050
		2600
		2300
	Average	2317

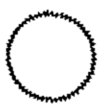
Fibers with waves or hooks exhibit a higher bitumen adherence. This is normal and due to the mechanical interlocking so that a higher cohesion may be expected from bituminous concrete where fibers with waves or hooks are incorporated.

2.3.2. Synthetic fibers

The question was then to determine how the fiber-bitumen adherence was influenced by the fiber cross section type. For the same quantity of incorporated fibers in weight, the next cross section types were analysed.

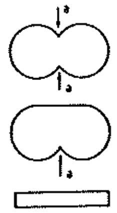


circular (I)



circular with rugosity (II)

2 circular sections with $r = R / \sqrt{2}$ (III)



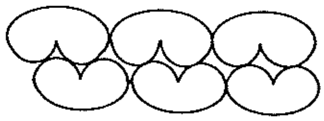
8 section (IV)

kidney section (V)

band (VI)

Bituminous concrete cohesion and fiber-bitumen adherence are in close relation : the higher the fiber external surface, the higher the adherence force (of course if the substrate surface energy is higher than the binder one).
At this point of view :
- the least is the circular section (I);
- the best is the band(VI) or the circular with rugosity (II). But it will be necessary to increase the quantity of bitumen to realize a good wetting. It is against the considerations of the chapter 2.2.2.;
- the solutions III, IV and V are the best :
  . solution III : it can produce a reduction of the tensile resistance and some problems of dispersion;
  . solution IV : added to a good surface development, there is a mechanical effect at the level of the "a" zones;
  . solution V : it seams to be better because the dispersion of the fibers will be easier

Indeed in order to produce an agglomeration with this type of fibers, we would have such a structure which is statistically not probable.



2.4. Influence of the surface treatment

2.4.1. Steel fiber

We considered three fibers types - steel, solder, galvanized steel - of 0.5 mm diameter. The samples were immerged into a 50/60 bitumen with an anchorage length of 3 cm. We determined the pull out force of the wire. The temperature was 20°C.

	Load (g)
Steel	3500
	3270 $\bar{x}$ = 3385
Soldier	2850
	3350 $\bar{x}$ = 3100
Galvanized steel	3150
	3500 $\bar{x}$ = 3325

The treatment of the fiber, which can be eventually interesting against corrosion, has no influence on the behaviour or the adhesion of the bitumen.

2.4.2. Synthetic fiber

To obtain a good substrate wettability (and so to wet the fiber with hot bitumen), it is necessary that the substrate surface energy is greater than the liquid one.

The surface energy of the bitumen is ± 25 mJ/m².
For the synthetic fibers, we have :

PP	:	± 32 mJ/m²
PA	:	± 41 mJ/m²
PAN	:	± 40 mJ/m²

So there is no problem with PA or PAN types and we shall have a good adhesion between these types of products and the hot bitumen.

2.5. Simulation of traffic test

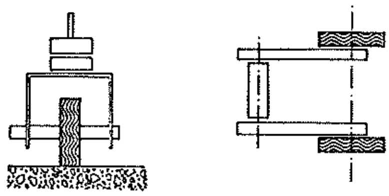
The most important test to be realized was the deep cracking test by simulation of traffic. Indeed it was essential to study directly the influence of the fiber on the apparition of deep cracking into a bituminous concrete.
The results of the tests described hereabove allowed to select a certain number of fibers : it was now necessary to point out some parameters like :
- the constitutive material of the fiber;
- the fiber shape;
- the fiber diameter;
- the fiber length;
- the percentage of fibers.

a. Principle of the test

The aim of the test is to estimate, for certain experimental conditions, the susceptibility to deep cracking of a compacted bituminous concrete and to evaluate the effect of the fibers on this phenomenon. The surface of the samples is loaded by means of two loaded wheels.

b. Description and characteristics of the test

A sample of 63 cm diameter and 5 cm thick is laied down in a fixed mould on the rotative part of a traffic simulation testing machine. Two wheels are rotating in a fixed vertical plane, around an horizontal axle.



These wheels are loaded with series of 20 kg weights.

Characteristics :
- maximum circumferencial speed : 1 m/s
- load applied on each wheel : 40 kgf
- type of wheel : VREDESTEIN 260 x 85 - 4 P/R
- air pressure of the wheels : 6 bars (this corresponds to a load of 35 to 40 kg/cm² on the bituminous concrete)
- temperature of the test : 40°C.

c. Tests procedure

A recorder allows to determine the number of rotations and the measurement of the deep cracking is realized on two perpendicular diameters (4 measurements) by means of a dial gauge.

d. Tests results

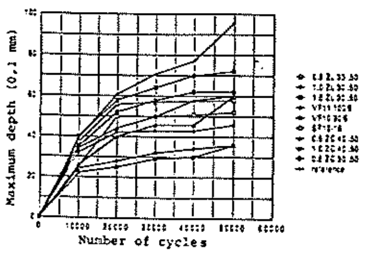
The general table presents hereafter the results for different types fiber and percentages.

Maximum depth of deep cracking (mm)					
Sample	Commercial mark	%	Type	Results	% voids
1	DRAMIX ZL 30/.50	0,5	A	5,8	6,9
2	idem	1	A	4,6	6,4
3	idem	1,5	A	7,2	7,5
4	Reference	-	-	9,6	5,2
5	HOECHST 11 100/6	0,3	AN	3,6	5,3
6	HAREX SF 12-16	1,5	A	5,2	5,3
7	HOECHST 10 30/6	0,3	AN	3,6	5,4
8	DRAMIX ZC 40/.50	0,5	A	6,0	6,5
9	idem	1	A	6,0	6,0
10	idem	1,5	A	6,2	5,3
11	DRAMIX ZC 30/.50	0,5	A	6,2	5,3
12	idem	1	A	4,6	4,5
13	idem	1,5	A	5,4	4,3
14	DACRON D 157-10 mm	0,3	PES	3,8	11,5
15	DRAMIX 30/.50 golf 1,2 mm	0,5	A	4,6	7,3
16	idem	1	A	7,2	10,6
17	idem	1,5	A	6,0	4,2
18	idem, golf 1 mm	0,5	A	4	4,5
19	idem	1	A	3,8	7,0
20	idem	1,5	A	4,8	6,4
21	bicouche 1 % DRAMIX + 0,3 % HOECHST			4,4	7,2
22	bicouche 0,5 % DRAMIX + 0,3 % HOECHST			3,8	8,5

A = steel AN = acrylo-nitryl PES = polyester

It is also possible to present the results in the form of graphics where the values of the deep cracking measurements are presented versus the number of cycles of loading.

These graphics are established in order to compare the results obtained with different types of fibers and different percentages in relation with a reference sample.



3. Conclusions

The results given by the theoretical and the experimental approachs permitted to define an interesting solution in order to avoid bituminous concrete deep cracking along the roads : the incorporation of short steel or synthetic fibers to the mixture.

For steel fibers

The optimum parameters for a Belgian type I bituminous concrete were :

Fiber length (L) : 1 or 2 times the maximum dimension of the aggregate.

Fiber percentage : 0,4 to 1,5 % in weight

Ratio fiber length/fiber diameter : 40 < L/D < 100

Fiber shape : generalized waves with specific anchorage

Surfacic treatment : against corrosion.

For synthetic fibers

The optimum parameters for a Belgian type I bituminous concrete were :

Fiber length : 0,5 to 1 times the maximum dimension of the aggregate

Fiber percentage : 0,1 to 0,7 % in weight

Fiber shape : kidney

Fiber raw material : must resist to temperatures greater than 190°C without any deterioration.

The advantages of these solutions are very clear :

1. increase of the road structure service life (minimum two times);
2. reduction of the repair costs;
3. no recycling problems;
4. possibility of reduction of the road structure thickness (because of increasing of the rigidity modulus);
5. almost no adaptation of the fabrication technics or laying down machineries.

Finally, the solution adopted by the LEGROS S.A., public works society in Anthisnes (Belgium), with the aim to avoid psychological problems due to the possible presence of corroded fibers at the overlay surface, was to use steel fibers in the underlays and synthetic fibers for the overlay.

This system is protected by an international patent.

Bibliography

[1] Centre de Recherches Routières.
Code de bonne pratique pour le dimensionnement des chaussées à revêtement hydrocarboné.
Recommandations CRR - R49/83.

[2] A.GOTTSCHALL et S. HOLLSTEINER.
Steel fibre reinforced asphalt.
3rd Eurobitume Symposium, La Haye, 1985.

[3] Fiber Pave, Hercules, incorporated.
Wilmington, Delaware and Norcross, Georgia (U.S.A.).

[4] Résistance à l'orniérage des chaussées à revêtement hydrocarboné.
La Technique Routière 1978.

[5] J. GORDILLO, R. TOMAS, F. GOMEZ.
Avantages de l'incorporation de fibres aux microenrobés à froid.
4ème Eurobitume Symposium 1989.

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VOLUME IA

SUMMARIES AND PAPERS
RESUMES ET RAPPORTS

SESSION 1
SESSION 2

Contents - Table des matieres

Curricula vitae

Report No	Report title	Page
Session 3	**Asphalt - Recent Developments and cost effectiveness** **Enrobés - Nouvelles applications et rapport coût/performance**	491
	Austria	
3.01	Mineral Fibre for the Modification of Asphalt Fibres minerales pour la modification d'asphalte G. Dohr, H. Piber	493
	Belgium	
3.02	The use of Fibers in Bituminous Concrete as a Solution to Decrease Rutting L'emploi de fibres dans les revêtements hydrocarbonés pour lutter contre l'orniérage J. M. Rigo, L. Courard	497
3.03	New Developments in Analytical Asphalt Mix Design Nouveaux développements de la formulation analytique des enrobés bitumineux L. Francken, A. Vanelstraete	502
	Bulgaria	
3.04	First Attempts in the Appliance of Splittmastix Asphalt in Bulgaria Expérimentations premières pour l´application du splittmastixasphalt en Bulgarie D. Grosshans, S. Nikolova, and I. Chivarov	508
	Czechoslovakia	
3.05	Possibilities of the Improvement of Asphalt Mixes by Modifying Bitumen Binders Amélioration des enrobés bitumineux par la modification des liants F. Luxemburk, V. Hanzik	510
3.06	Bituminous Mixes with Rubber Modified Binders Des liants modifiés de caoutchouc dans les melanges bitumnieux M. Sekera, I. Gschwendt	516
	Finland	
3.07	Effect of Binder Properties on Polymer Modified Asphalt Concrete Effet des propriétés du liant sur les betons asphaltiques en polymère modifié S. Schüller, L. Forstén	520