THE USE OF PREVALENT MINERAL FRACTION FIBRES IN DRAINING BITUMINOUS MIXTURES SUBJECT TO THERMAL STRESS

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ABSTRACT

Results are provided of an experimentation carried out on particular draining bituminous mixtures, with the addition of stabilizing micro-fibres with prevalent mineral fraction, preventively subject to thermal stress and then to the indirect traction test..

In the manufacture of draining bituminous mixtures, as known, it is necessary to stabilize the binder in a suitable way in order to increase the mechanical features and in order to avoid bitumen dripping from the aggregates, so by now the use of fibres of different nature and composition is widespread.

The contribution that particular fibres give to the draining mixture has been studied in the paper, comparing the resistance values under thermal stress, in other words before and after freeze thaw cycles.

Actually, since the draining mixtures materials have a high porosity, they turn out to be particularly sensitive to the process known as cryoclastic process or frost wedging, which can cause crushing due to the variations of the water volume present in the voids, considering that the water volume increases of up to 10% because of the freeze.

Moreover, for the different mixtures manufactured the coefficient of permeability K has been determined studying its deviation in relation to the presence of fibres.

The experimental results confirm that in an open mixture the fibres made up of the used prevalent mineral fraction, acting as a support to the binder, improve the mechanical features of the binder and increase its ductility, improving also the capability of the mixture to resist the disintegrating action which derives from thermal stress.

1. INTRODUCTION

The main function of a paving is to guarantee users a high level of comfort and safety, in all climatic and environmental situations, especially when bad meteorological conditions make the traffic difficult to flow.

For this reason draining bituminous mixtures have been studied; they have the advantage of removing water from the road plane by filtering and decrease the phenomenon of aquaplaning but they have many structural limits essentially due to their high percentage porosity values.

The high percentage of air voids reduces the points of contact between the aggregates, causing the increase in tensions that concentrated in singular points, can induce cracking and breaking phenomena of the film of the bitumen that wraps the aggregate inside the mixture, because of the overcoming of the adhesion forces that bind the aggregates to the bitumen.

Moreover, the considerable presence of voids inside the mixture can induce oxidation phenomena in the binder.

For this reason besides (polymerized) modified bitumens, fibres are usually added [MONTEPARA & SANTAGATA, 1993; SANTAGATA, 1993] that, binding themselves mechanically to the bitumen, avoid the detachment from the aggregates controlling the diffusion and propagation of micro cracking,.

In the following experimental research the contribution that prevalent mineral fraction fibres give to the physical-mechanical characteristics of the mixture has been analyzed. Moreover the reaction that the draining mixture prepared in this way and imbibed with water has provided after several freeze thaw cycles has been studied.

2. PRELIMINARY STUDY

A draining pavement that is made to eliminate by filtering rainwater can be subjected, in particularly cold climates, to disintegration phenomena due to the repeated variations that the volume of the water present in the voids undergoes because of the succession of freeze thaw.

The experimental program therefore aims at the study of the influence that particular conditions, such as saturation and freeze thaw cycles, have on the performances that prevalent mineral fraction fibres provide to the mechanical properties of the draining bituminous mixtures with [SANTAGATA & TORALDO, 2002; AGOSTINACCHIO & OLITA, 2002].

Moreover the contribution that the use of these fibres gives to the draining capability of a bituminous mixture will be studied by measuring the variation of its permeability compared to the same mixture without fibres.

Several samples able to make a comparison between the mechanical and deformative reaction of simple draining bituminous mixtures with others with identical composition added with fibres have been manufactured.

Special attention has been paid on the mix design of the bituminous mixture [SANTAGATA, 1996; WITZAC & AL., 2002] that has to satisfy the requirements provided by the technical rules of the main standards followed at the Italian national level.

3. TRADITIONAL DRAINING BITUMINOUS MIXTURE

3.1 Materials

3.1.1 Aggregates

The mixture of the traditional bituminous mixture has been manufactured with aggregates of different granulometry opportunely selected.

For thin fractions (D < 4 mm) calcareous sand has been used, while the used thick aggregates are made of crushed grit (4 < D < 8 mm) and crushed stone (8 < D < 16 mm).

Moreover pozzolanic cement has been used as a filler.

The material (pozzolanic cement, calcareous sand, crushed grit, crushed stone, modified bitumen) has been provided by Ferrostrade SRL di Noci (BA - Italy), the fibres by Iterchimica di Bergamo (Italy).

The characteristics of the used aggregates are the following:

POZZOLANIC CEMENT (filler)
Sample weight: 454,00 gr.
Apparent volumic mass of granules: 3,00 g/cm^3
Sifting residue at 0,075 sieve = 98,00%

CALCAREOUS SAND (0/4)
Sample weight: 1021,2 gr.
Apparent volumic mass of granules = 2,69 g/cm^3
Sifting residue at 0,075 sieve = 9,50%
Equivalent in sand *E.S.* = 74%

CRUSHED GRIT (4/8)
Sample weight: 2005,8 g
Apparent volumic mass of granules: 2,70 g/cm^3
Sifting residue at 0,075 sieve: 0,04%
Micro-Deval wear and tear coefficient M_{DU} : 11,5%
Los Angeles coefficient *LA:* 19%

CRUSHED STONE (8/16)
Sample weight: 2093,8 g
Apparent volumic mass of granules = 2,68 g/cm^3
Sifting residue at 0,075 sieve = 0,05%
Micro-Deval wear and tear coefficient M_{DU} = 14,5%
Crushed element percentage = 100%
Accelerated smoothing coefficient *CLA* = 0,51
Los Angeles coefficient *LA* = 16,5%

3.1.2 Bitumen

An eliflex Hard 70/100 bitumen modified by SBS polymers in the percentage of 5.5%, which is included in the reference interval of "Società Autostrade"'s standards, has been used as a binder in the composition of the mixture.

The mixing and compacting temperatures are those provided by the rules related to the "determination of stability and flowing of bituminous mixtures and stony aggregates by means of Marshall Apparatus" [UNI EN 12697-34]; the manifacturing modalities are those used for draining mixtures.

The characteristics of the bitumen are the following:

- Penetration at 25°C [dmm] = 52
- Softening point P.A. [°C] = 85
- Viscosity 160°C [paxs] = 0,4 - 0,8
- Ductility at 25°C [cm] ≥100
- Elastic recovery at 25°C % ≥90

3.1.3 Bituminous mixture

For the preparation of the mixture, the granulometric composition has to be included in the granulometric size distribution "A" of the technical rules of the highway company "Società Autostrade" for draining carpets.

The granulometry and the study of the composition of the mixture, experimentally determined, are the following:

- Cement (filler) : 454,00 (g)
- Sand: 1021,20 (g)
- Grit: 2005,80 (g)
- Fine crushed aggregate: 2093,80 (g)

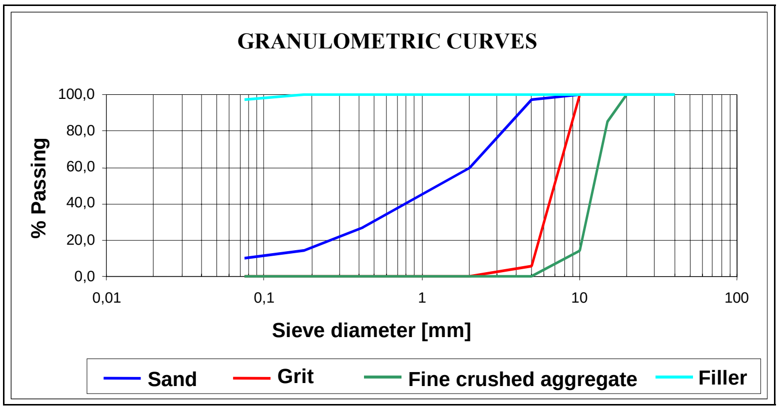

Figure 1 - Granulometric curves

Table 1 Mixture composition

Diameter	Curve A	Curve B	True
40	100	100	100,0

Diameter	Curve A	Curve B	True
30	100	100	100,0
25	100	100	100,0
20	100	100	100,0
15	80	100	88,8
10	15	35	32,6
5	5	20	11,6
2	0	12	8,7
0,40	0	10	6,7
0,18	0	8	5,9
0,075	0	6	5,5

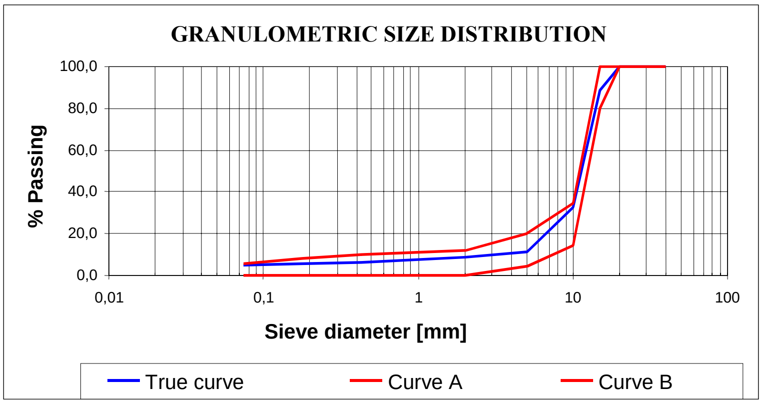

Figure 2 Granulometric size distribution

3.2 The experimentation

3.2.1 Physical Characteristics

Since the mixture presents a percentage of voids greater than 10 – 12%, the determination of the apparent volumic mass cannot be carried out by using liquid paraffin, because the voids would be filled, causing a consequent error in the calculation of the volume weight of the sample and so of the percentage of voids [CNR, 1973].

The determination of the apparent volumic mass of the draining mixture is made by using the geometric method, as defined by the ASTM D3549 rule [ASTM D3549, 1984] and by important authors [MONTEPARA & VIRGILI, 1996].

The determination of the volumic mass, and so of the porosity, has been carried out on 16 samples numbered from 1 to 16.

In order to determine the porosity, consider that:

$\gamma = 1.96$ g/cm^3 is the mean apparent volumic mass of the mixture;
$b_c = 5.5\%$ the percentage of bitumen;
$\gamma_b = 1.03$ g/cm^3 the specific weight of the binder;

γ_a = 2.70 g/cm^3 the apparent volumic mass of the granules, calculated as a function of granulometric composition of the mixture; the porosity of the mixture can be determined as the arithmetic average of the porosity of the sixteen tests, in accordance with the ASTM D3203 rule [ASTM D 3203, 1989].

Table 2 Apparent volumic mass - porosity

Sample n°	Mean diameter [cm]	Mean height [cm]	Total weight [g]	Total volume [cm^3]	Apparent volumic mass [g/cm^3]	Porosity [%]
1	10,05	6,53	1008,9	517,61	1,95	21,5
2	10,05	6,66	1028,7	528,52	1,95	22.0
3	10,10	6,38	1006,0	510,76	1,97	21.0
4	10,10	6,50	1040,9	520,77	2,00	19,5
5	9,98	6,40	971,7	500,14	1,94	22.0
6	10,05	6,05	957,1	479,93	1,99	20.0
7	10,11	6,16	975,0	494,95	1,97	21.0
8	10,13	6,11	966,6	492,15	1,96	21,0
9	10,15	5,90	954,2	477,39	2,00	19.5
10	10,13	6,55	1024,6	527,38	1,94	22.0
11	10,10	6,63	1030,4	530,78	1,94	22,0
12	10,14	6,23	979,2	502,45	1,95	21.5
13	10,10	6,28	977,6	502,74	1,94	22.0
14	10,11	6,50	1017,8	522,06	1,95	21,5
15	10,13	6,46	1015,3	520,33	1,95	21,5
16	10,08	6,18	977,4	492,29	1,99	20,0
					Mean 1,96	**Mean 21,0**

Moreover, in order to evaluate the resistance of the mixture to disintegration, the Cantabro Test has been carried out on 4 samples numbered from 1 bis to 4 bis [CENTRO DE ESTUDIOS DE CARRETERAS].

Such a test simulates the action of repeated traffic that causes the breaking of the bituminous mixtures acting on the characteristics of cohesion and adhesion inside the mixture.

The test has been carried out on 4 samples has given the following results:

Table 3 Cantabro test

Sample n.	Initial weight [g]	Final weight [g]	Loss of weight [%]
1 bis	1008,9	845,5	16,2
2 bis	1028,7	832,2	15.8

Sample n.	**Initial weight [g]**	**Final weight [g]**	**Loss of weight [%]**
3 bis	1006,0	851,4	15,4
4 bis	1040,9	875,6	15,9
Mean			**15.8**

3.2.2 Permeability – Experimental results

The permeability is a fundamental requirement for a draining bituminous mixture in order to assure its functioning.

This property, that is the attitude of allowing a liquid to pass through its pores, depends on the permeability coefficient K, which is determined by the Darcy Law.

Then the value of K is multiplied by a correction coefficient η that takes into account the variation of water viscosity as the temperature varies.

In order to verify the draining capabilities of a bituminous mixture manufactured in the Laboratory of Material Tests of the Department of Highways and Transportations of the Polytechnic of Bari a permeameter that allows us to carry out permeability tests on prepared samples applying the Darcy Theory has been manufactured [PISCIOTTA, 2005].

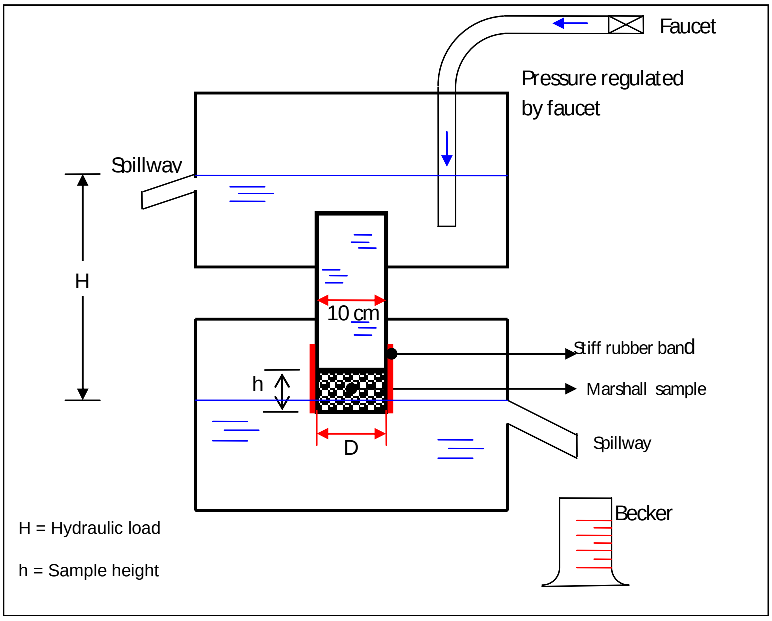

Figure 3 Permeameter diagram

The experimentation has been made on 4 samples of draining bituminous mixture, numbered with 5, 10, 11 and 12, for which the permeability has been determined multiplying the value of permeability coefficient K by the correction coefficient η which takes into account the variation of the water viscosity as a function of the temperature that at 16°C is equal to η = 1,2831.

The coefficient k has been obtained by the mean of 5 determinations for each sample.

Table 4 Coefficient of permeability K

Test settings:

- Test temperature T = 10.5 °C
- Water viscosity correction coefficient η = 1,2831
- Water specific weight = 1,003 g/cm3
- Test time: 30s

n°	**Size**			**Water quantity weight** [g]	**Water volume** [cm^3]	**Hydraulic load H** [cm]	**Coefficient of permeability K** [cm/s]		
	Diameter D [cm]	Height h [cm]	Section area A [cm^2]	Mean value P_m	V_m		k_m cm/s]	k_c corrected [cm/s]	K_{mc} mean corrected [cm/s]
5	9,98	6,40	78,15	4207,04	4194,46	23,00	0,50	0,64	0,68
10	10,13	6,55	80,52	4394,24	4381,10	23,00	0,52	0,66	
11	10,10	6,63	80,12	4910,26	4895,57	23,00	0,59	0,75	
12	10,14	6,23	80,71	4836,54	4822,07	23,00	0,54	0,69	

Being in general:

$$k = \frac{V \cdot h}{A \cdot t \cdot H} \eta \qquad \text{(Eq. 1)}$$

The value of the permeability coefficient K_{mc} = 0.68 cm/s so determined is included in the limits provided by the main road tenders according to which K ≥ 0.15 cm/s.

3.2.3 Indirect tension - Experimental results

In the experimental program the indirect tension test (Brazilian) is very important because it reproposes the conditions of fracture mechanic.

Through this test it is possible to compare the values of resistance to indirect tension as well as the deformations on the axial and orthogonal plane between simple draining samples and those manufactured with fibres.

Moreover it is possible to study the contribution that mineral fraction fibres give to the mechanical behaviour of aggregates, especially the values of resistance and deformation that are fundamental parameters in an open mixture, where the stresses are mostly concentrated in the points of contact between the aggregates [SANTAGATA, 1993].

Twelve samples have been subjected to breaking by using diametral compression loads; the test has been carried out at temperature T = 25°C with the modalities set by the standards on aggregate mixtures and hydrocarburic binders [CNR, 1991; CRISTENSEN, 2003].

The indirect tension resistance values have been subjected to statistical analysis as provided by the rules [CNR, 1991]; moreover the values of vertical and horizontal diametral deformation have been surveyed.

The survey of the sample temperature has been carried out by using a laser thermometer.

Table 5 Mean resistance to indirect tension

Sample n°	**Mean diameter [mm]**	**Mean height [mm]**	**Ultimate tensile strength [N]**	**Resistance to indirect tension [MPa]**	**Diameter deformation under breaking [mm]**					
					Under diametral compression			**Under indirect tension**		
					ΔDc [mm]	**Dv [mm]**	**ΔDc/D %**	**ΔDt [mm]**	**Do [mm]**	**ΔDt/D %**
5	99,75	64,00	4472	**0,45**	0,205	99,55	0,21	2,57	102,32	2,58
6	100,50	60,50	5778	**0,60**	0,420	100,08	0,42	3,27	103,77	3,25
7	101,13	61,63	4604	**0,47**	0,545	100,58	0,54	3,44	104,57	3,40
8	101,25	61,13	5870	**0,60**	0,506	100,74	0,50	1,99	103,24	1,97
9	101,50	59,00	5125	**0,54**	0,352	101,15	0,35	2,43	103,93	2,40
10	101,25	65,50	4673	**0,45**	0,313	100,94	0,31	2,91	104,16	2,88
11	101,00	66,25	3545	**0,34**	0,335	100,67	0,33	3,10	104,10	3,07
12	101,38	62,25	3913	**0,39**	0,446	100,93	0,44	2,22	103,60	2,19
13	101,00	62,75	3867	**0,39**	0,227	100,77	0,22	2,84	103,84	2,81
14	101,13	65,00	5998	**0,58**	0,205	100,92	0,20	2,06	103,19	2,04
15	101,25	64,63	4650	**0,45**	0,249	101,00	0,25	2,20	103,45	2,18
16	100,75	61,75	5156	**0,53**	0,397	100,35	0,39	3,38	104,13	3,36
MEAN RESISTANCE TO INDIRECT TENSION				**0,48**	**Temperature test T = 25°C**					

The mean value of indirect tension resistance is equal to: σ_{Tm} = 0,48 MPa, while for the diametral deformations the mean values are equal to: ΔDc/D = 0.35% and ΔDt/D = 2.68%.

4. DRAINING BITUMINOUS MIXTURE ADDED WITH FIBRES

Prevalent mineral fraction fibres compressed in granules have been added to the same mixture used to manufacture the draining mixture.

The samples so manufactured have been subjected to the same experimental program defined for the draining mixture.

It is known that the highest risk in an open mixture is the breaking of stony elements where the concentration of stresses is higher with consequent cracking and breaking of the film that wraps the granules [SANTAGATA, 1993].

The experiment therefore aims at verifying if the addition of fibres in the draining mixture is able to "stabilize" the mixture and create a kind of mechanical bond between aggregates and bitumen, improving its mechanical and deformative characteristics.

4.1 The fibres

The used fibre is produced by Iterfibra/C and appears as compressed granules; the physical and usage characteristics are reported in the following table.

Table 6 Iterfibra/C

ITERFIBRA - C/V COMPRESSED MICROFIBRE	
COMPOSITION	Natural fibres: 20% of weight Mineral fibres: 75% of weight Organic binders: 5% of weight
DOSAGE	0,30% ÷ 0,45% of aggregate weight
PHYSICAL PROPERTIES	Density: > 800 gr/l Humidity: max 5% R.S.a 550°: 70% (±5) Temperature resistance: from ≈. 230°C to ≈. 600°C

Special care has been dedicated to the preparation of the samples added with fibres; since in systems this kind of fibre is introduced directly into the mixer after the introduction of the aggregates from the sieves and before the bitumen, the same procedure has been followed in the laboratory during the preparation phase.

The fibres (0.35 % of the aggregate weight) have been preventively crushed and accurately mixed with the aggregates, then the bitumen has been added.

4.2 The experimentation

4.2.1 Physical characteristics

In order to determine the apparent volumic mass of the mixture added with fibres, the geometrical method as defined by the ASTM D3549 rule has been used as well as for normal draining mixtures [ASTM D3549, 1984].

The determination of the volumic mass and of porosity has been carried out on 16 samples.

Table 7 Apparent volumic mass - porosity

Sample n°	Mean diameter [cm]	Mean height [cm]	Total weight [g]	Total volume [cm^3]	Apparent volumic mass [g/cm^3]	Porosity [%]
1	10,28	6,15	987,5	509,95	1,94	22,0
2	10,28	6,20	1023,1	514,10	1,99	20,0
3	10,29	6,19	986,9	514,31	1,92	23,0

Sample n°	Mean diameter [cm]	Mean height [cm]	Total weight [g]	Total volume [cm^3]	Apparent volumic mass [g/cm^3]	Porosity [%]
4	10,20	6,35	1007,0	518,88	1,94	22,0
5	10,29	5,93	981,2	492,49	1,99	20,0
6	10,28	6,05	1000,9	501,66	2,00	20,0
7	10,20	6,26	1008,3	511,73	1,97	21,0
8	10,20	6,54	1023,7	534,20	1,92	23,0
9	10,26	6,20	998,1	512,85	1,95	22,0
10	10,26	6,16	1012,1	509,75	1,99	20,0
11	10,28	6,35	1016,7	526,54	1,93	22,5
12	10,28	6,16	1008,2	510,99	1,97	20,5
13	10,24	6,15	1006,6	506,24	1,99	20,0
14	10,20	6,53	1022,8	533,18	1,92	23,0
15	10,31	6,28	1028,9	524,12	1,96	21,0
16	10,30	5,79	965,0	482,23	2,00	19,5
					Mean 1,96	**Mean 21,0**

Being unchanged: γ = 1.96 g/cm3, b_c = 5.5 %, γ_b = 1.03 g/cm3, γ_a = 2.70 g/cm^3

The test carried out on 4 samples has given the following results:

Table 8 Cantabro test

Sample n°	Initial weight [g]	Final weight [g]	Loss of weight [%]
1	987,5	883,7	10,5
2	1023,1	919,8	10,1
3	986,9	878,3	11,0
4	1007,0	892,8	11,3
Mean			**10,7**

Table 9 Coefficient of permeability K

The experiment has been carried out on 4 samples of draining bituminous mixture added with fibres numbered with 8, 9, 11 and 12 following the same previous modalities.

Test settings:

- Test temperature T = 10.5 °C
- Water viscosity correction coefficient η = 1,2831
- Water specific weight = 1,003 g/cm3

- Test time: 30s

n°	**Size**			**Water quantity weight** [g]	**Water volume** [cm^3]	**Hydraulic load** **H** [cm]	**Coefficient of permeability K** [cm/s]		
	Diameter D [cm]	Height h [cm]	Section area A [cm^2]	Mean value P_m	V_m		k_m cm/s]	k_c corrected [cm/s]	K_{mc} mean corrected [cm/s]
8	10,20	6,54	81,71	4890,80	4876,17	23,00	23,00	0,57	0,62
9	10,26	6,20	82,72	4214,06	4201,46	23,00	23,00	0,46	
11	10,28	6,35	82,92	4588,34	4574,62	23,00	23,00	0,51	
12	10,28	6,16	82,92	3883,80	3872,18	23,00	23,00	0,42	

The value of the permeability coefficient $K_{mc} = 0.62$ cm/s so determined is included in the limits provided by the main road tenders, according to which $K \geq 0.15$ cm/s.

4.2.2 Indirect tension - Experimental results

With the same modalities seen in the previous paragraph 3.2.3., twelve samples of mixtures added with fibres numbered from 5 ÷ 16 have been subjected to the indirect tension test [CNR, 1991; CRISTENSEN, 2003].

The results of the experiment are the following:

Table 10 Indirect tension test

Sample n°	**Mean diameter [mm]**	**Mean height [mm]**	**Ultimate tensile strength [N]**	**Resistance to indirect tension [MPa]**	**Diameter deformation under breaking [mm]**					
					Under diametral compression			**Under indirect tension**		
					ΔDc [mm]	**Dv [mm]**	**ΔDc/D %**	**ΔDt [mm]**	**Do [mm]**	**ΔDt/D %**
5	102,75	61,50	7688	**0,77**	0,920	101,83	0,90	3,03	105,78	2,95
6	102,75	62,00	7711	**0,77**	0,646	102,10	0,63	2,96	105,71	2,88
7	102,88	61,88	6998	**0,70**	0,530	102,35	0,52	2,86	105,74	2,78
8	102,00	63,50	5916	**0,58**	0,722	101,28	0,71	3,05	105,05	2,99
9	102,88	59,25	6514	**0,68**	0,504	102,37	0,49	2,82	105,70	2,74
10	102,75	60,50	7435	**0,76**	0,598	102,15	0,58	2,42	105,17	2,35
11	102,00	62,63	6883	**0,69**	0,766	101,23	0,75	2,69	104,69	2,64
12	102,00	65,38	7366	**0,70**	0,540	101,46	0,53	2,33	104,33	2,29
13	102,63	62,00	8586	**0,86**	0,718	101,91	0,70	2,90	105,52	2,82
14	102,63	61,63	5133	**0,52**	0,648	101,98	0,63	2,96	105,58	2,88
15	102,75	63,50	8885	**0,87**	0,526	102,22	0,51	2,92	105,67	2,84
16	102,75	61,63	6310	**0,63**	0,670	102,08	0,65	3,49	106,24	3,40

Sample n°	Mean diameter [mm]	Mean height [mm]	Ultimate tensile strength [N]	Resistance to indirect tension [MPa]	Diameter deformation under breaking [mm]					
					Under diametral compression			Under indirect tension		
					ΔDc [mm]	Dv [mm]	ΔDc/D %	ΔDt [mm]	Do [mm]	ΔDt/D %
MEAN RESISTANCE TO INDIRECT TENSION				**0,71**	**Test temperature T = 25°C**					

The values of indirect tension resistance have been subjected to a statistical analysis as as required the rule [PISCIOTTA, 2005]; moreover the values of vertical and horizontal diametral deformation have been surveyed.

The mean value of indirect tension resistance is equal to: σ_{Tm} = 0,71 MPa, while for diametral deformations the mean values are equal to: ΔDc/D = 0.63% and ΔDt/D = 2.80% respectively.

A comparison of results of the indirect tension test for the traditional mixture and the mixture added with fibres is shown in the following diagrams, where both the values of deformation under diametral compression and indirect tension have been expressed in percentage.

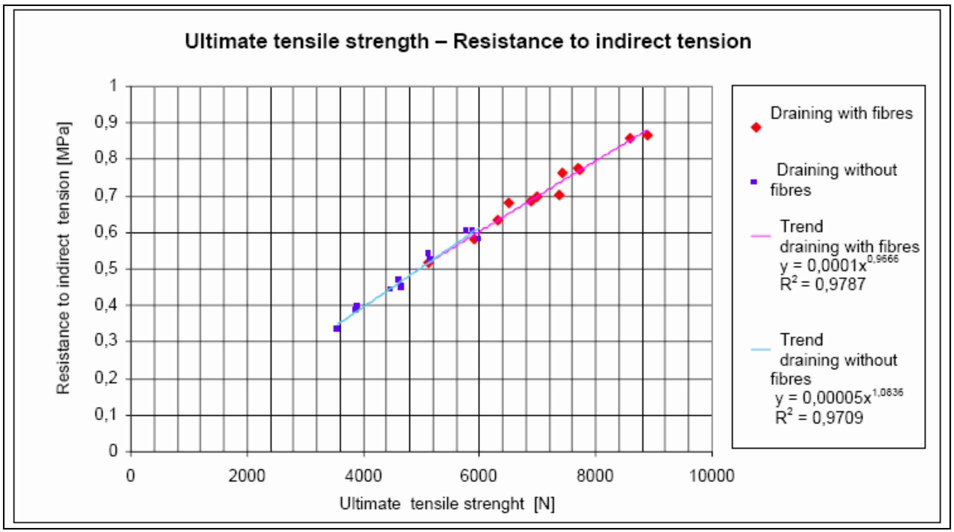

Figure 4 Ultimate tensile strength – Resistance to indirect tension

Draining trend without fibres:

$$y = 0{,}00005 \cdot x^{1{,}0836}, R^2 = 0{,}9709 \qquad \text{(Eq. 2)}$$

Draining trend with fibres:

$$y = 0{,}0001 \cdot x^{0{,}9666}, R^2 = 0{,}9787 \qquad \text{(Eq. 3)}$$

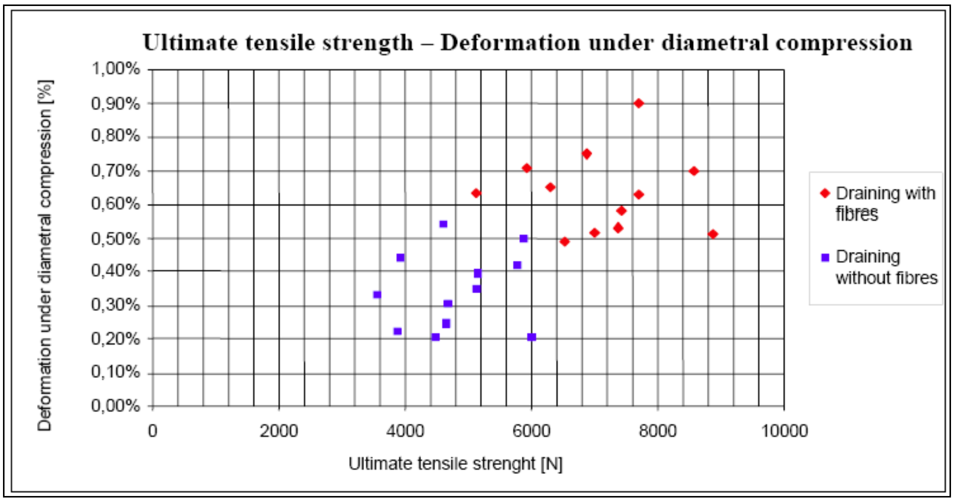

Figure 5 Ultimate tensile strength – Deformation under diametral compression

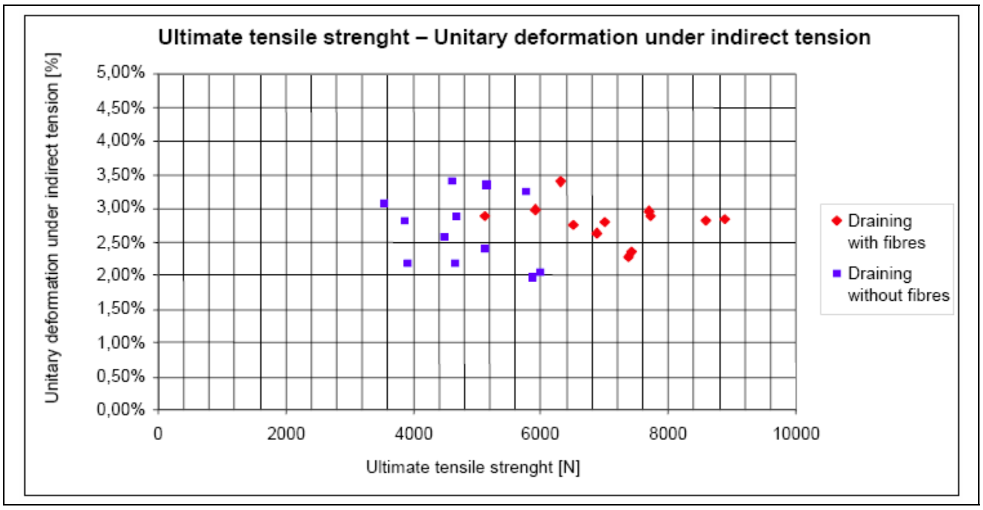

Figure 6 Ultimate tensile strength – Unitary deformation under indirect tension

5. DETERMINATION OF THE RESISTANCE OF MIXTURES UNDER THERMIC STRESS

The aim of this experiment is to understand the mechanical and deformative behaviour of a draining mixture, with and without fibres, when subjected to freeze thaw cycles.

On the one hand the high percentage of porosity of draining carpets is an advantage because it eliminates water from the surface, on the other it may be a limit because of the variations of the volume that the water present in the voids undergoes at low temperatures.

This increase of water volume, which can reach 10%, may cause the crushing and disintegration of the mixture with consequent deterioration of the paving.

Both the traditional draining mixture and those with fibres, prepared as seen in § 3.1.3. and § 4, have been subjected to freeze thaw cycles in accordance with the rules in order to study the sensitiveness of the mixture to frost wedging [UNI EN 1367-1, 2001].

The method proposed by the rule, extensively applied to bituminous mixtures, is based on the immersion of the samples in a thermic bath in order to completely fill the voids and subsequent exposure to the action of freeze.

The temperature varies in accordance with the modalities set by the rule, between +20°C and –17.5°C, for a total of 10 load cycles.

For all the samples, with and without fibres, the values of apparent volumic mass and porosity have been determined in order to check the composition of the mixture; these values have remained unchanged compared to the previous mixture.

5.1 Indirect tension - Experimental results

Twelve samples of draining mixture numbered from 1 to 12 and the twelve samples of draining mixture added with fibres numbered from 1÷12 have been subjected to the indirect tension test after 10 freeze thaw cycles [UNI EN 1367-1, 2001], by following the same modalities seen in paragraph 3.2.3. [CNR, 1991; CRISTENSEN, 2003].

The experimental results are the following:

Table 11 Indirect tension test

DRAINING BITUMINOUS MIXTURE WITH FIBRES										
n°	**Mean diameter [mm]**	**Mean height [mm]**	**Ultimate tensile strength [N]**	**Resistance to indirect tension [MPa]**	**Diameter deformation under breaking [mm]**					
					Under diametral compression			**Under indirect tension**		
					ΔDc [mm]	**Dv [mm]**	**ΔDc/D %**	**ΔDt [mm]**	**Do [mm]**	**ΔDt/D %**
1	101,00	64,50	3550	**0,35**	0,170	100,83	0,168	2,73	103,73	2,705
2	100,50	62,00	4250	**0,43**	0,106	100,39	0,105	2,23	102,73	2,216
3	100,25	63,00	3800	**0,38**	0,158	100,09	0,158	1,83	102,08	1,822
4	100,00	65,13	3800	**0,37**	0,206	99,79	0,206	2,11	102,11	2,113
5	101,38	62,50	4100	**0,41**	0,218	101,16	0,215	1,39	102,77	1,372
6	100,50	65,25	2800	**0,27**	0,250	100,25	0,249	2,15	102,65	2,139
7	101,00	63,75	4200	**0,42**	0,280	100,72	0,277	2,50	103,50	2,474

DRAINING BITUMINOUS MIXTURE WITH FIBRES										
n°	**Mean diameter [mm]**	**Mean height [mm]**	**Ultimate tensile strength [N]**	**Resistance to indirect tension [MPa]**	**Diameter deformation under breaking [mm]**					
					Under diametral compression			**Under indirect tension**		
					ΔDc [mm]	**Dv [mm]**	**ΔDc/D %**	**ΔDt [mm]**	**Do [mm]**	**ΔDt/D %**
8	100,50	63,50	3400	**0,34**	0,107	100,39	0,106	1,20	101,70	1,190
9	100,00	65,00	3650	**0,36**	0,166	99,83	0,166	1,80	101,80	1,800
10	100,00	64,25	3702	**0,37**	0,294	99,71	0,294	2,71	102,71	2,708
11	100,88	62,75	3540	**0,36**	0,194	100,68	0,192	1,98	102,86	1,963
12	101,63	62,00	4870	**0,49**	0,242	101,38	0,240	1,99	103,62	1,963
MEAN RESISTANCE TO INDIRECT TENSION				**0,38**	**Temperature test T = 25°C**					

The indirect tension resistance values have been analysed, as required by the rule [PISCIOTTA, 2005]; some of the tested samples has not satisfied the statistical rquirements. Moreover the vertical and horizontal diametral deformative values have been surveyed.

The mean value of indirect tension resistance assumed in accordance with the survey is equal to: σ_{Tm} = 0,38 MPa, while for the diametral deformation the mean values are equal to: ΔDc/D = 0.19% and ΔDt/D = 2.05% respectively.

Table 12 Indirect tension test

DRAINING BITUMINOUS MIXTURE WITH FIBRES										
n°	**Mean diameter [mm]**	**Mean height [mm]**	**Ultimate tensile strength [N]**	**Resistance to indirect tension [MPa]**	**Diameter deformation under breaking [mm]**					
					Under diametral compression			**Under indirect tension**		
					ΔDc [mm]	**Dv [mm]**	**ΔDc/D %**	**ΔDt [mm]**	**Do [mm]**	**ΔDt/D %**
1	101,88	62,75	4150	**0,41**	0,269	101,61	0,26	2,60	104,48	2,55
2	101,50	61,50	5650	**0,58**	0,135	101,37	0,13	1,80	103,30	1,77
3	101,88	64,38	6195	**0,60**	0,412	101,46	0,40	2,44	104,31	2,39
4	101,75	59,75	6552	**0,69**	0,222	101,53	0,22	2,79	104,54	2,74
5	102,25	61,75	6232	**0,63**	0,427	101,82	0,42	2,93	105,18	2,87
6	101,88	60,88	5846	**0,60**	0,283	101,59	0,28	2,33	104,20	2,29
7	102,00	59,75	4760	**0,50**	0,143	101,86	0,14	2,17	104,17	2,13
8	101,88	60,00	4950	**0,52**	0,376	101,50	0,37	2,12	103,99	2,08
9	102,00	60,25	5386	**0,56**	0,372	101,63	0,36	3,12	105,12	3,06
10	102,25	58,50	5700	**0,61**	0,346	101,90	0,34	2,24	104,49	2,19

DRAINING BITUMINOUS MIXTURE WITH FIBRES										
n°	Mean diameter [mm]	Mean height [mm]	Ultimate tensile strength [N]	Resistance to indirect tension [MPa]	Diameter deformation under breaking [mm]					
					Under diametral compression			Under indirect tension		
					ΔDc [mm]	Dv [mm]	ΔDc/D %	ΔDt [mm]	Do [mm]	ΔDt/D %
11	101,88	58,63	6615	**0,71**	0,909	100,97	0,89	5,36	107,23	5,26
12	102,00	61,50	6238	**0,63**	0,377	101,62	0,37	1,99	103,99	1,95
MEAN RESISTANCE TO INDIRECT TENSION				**0,59**	**Temperature test T = 25°C**					

The mean values of indirect tension resistance assumed have been subjected to the survey, as provided by the rule [PISCIOTTA, 2005].

The value of indirect tension resistance is equal to: σ_{Tm} = 0,59 Mpa, while for the diametral deformation the mean values are equal to: $\Delta Dc/D = 0.35\%$ and $\Delta Dt/D = 2.61\%$ respectively.

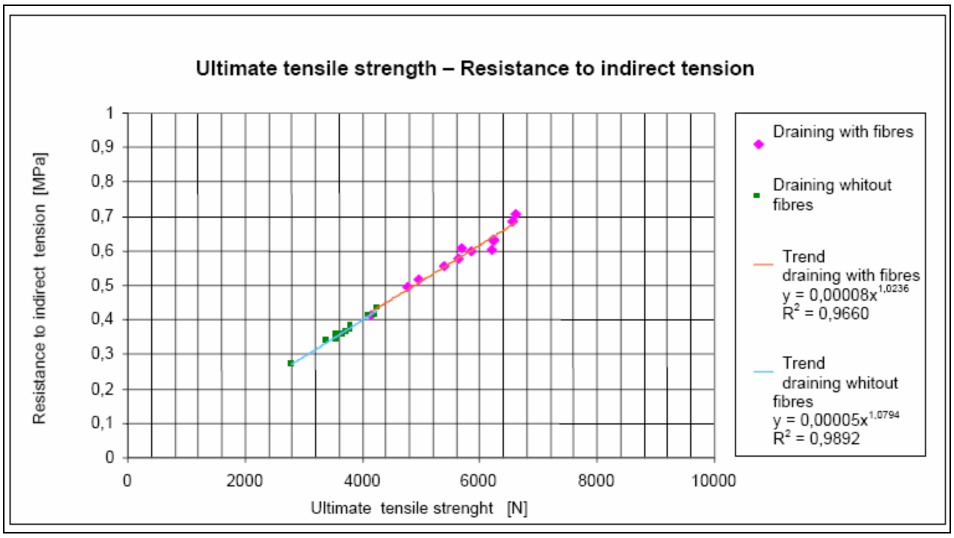

Figure 7 Ultimate tensile strength – Resistance to indirect tension

Draining trend without fibres:

$$y = 0,00005 \cdot x^{1,0794}, R^2 = 0,9892 \tag{Eq. 4}$$

Draining trend with fibres:

$$y = 0,00008 \cdot x^{1,0236}, R^2 = 0,9660 \tag{Eq. 5}$$

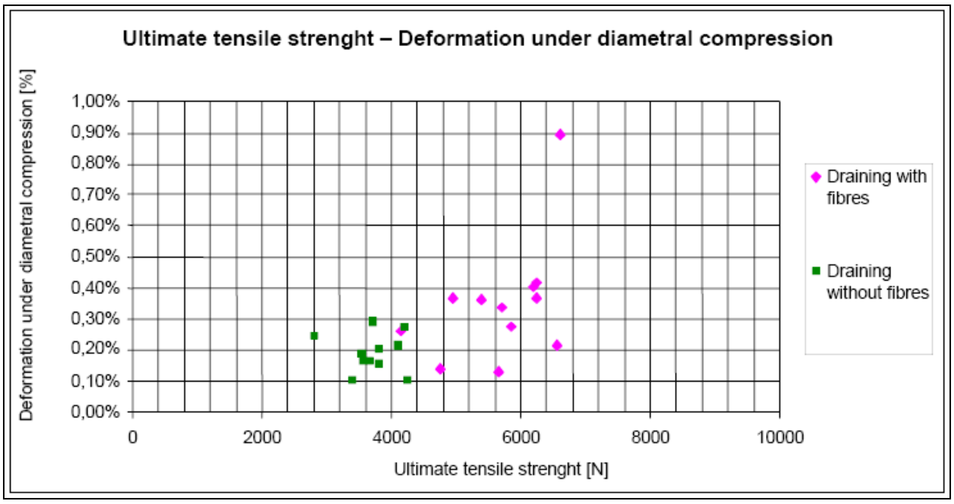

Figure 8 Ultimate tensile strength – Deformation under diametral compression

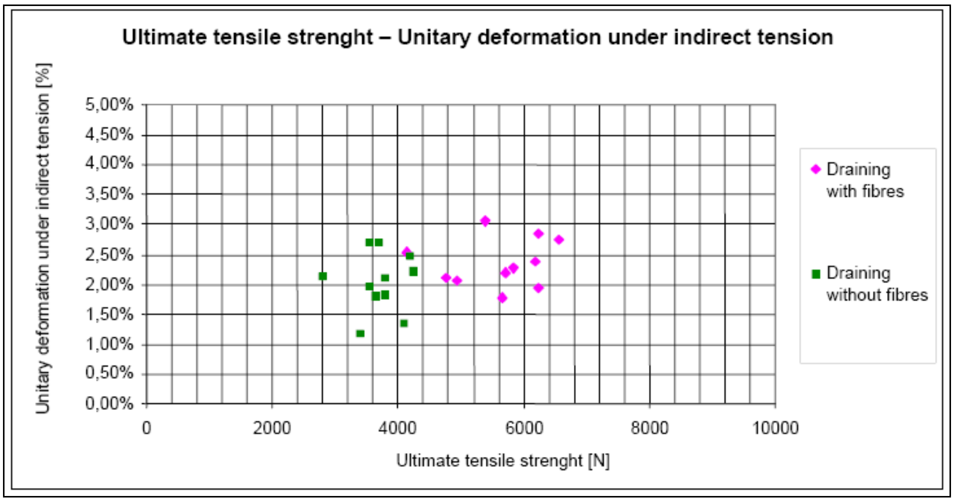

Figure 9 Ultimate tensile strength – Unitary deformation under indirect tension

6. ANALYSIS OF THE RESULTS

The analysis of the experimental results highlights the contribution that the used fibres provide to the performances of the draining mixture with, improving the mechanical, deformative characteristics and especially the ductility; moreover the contribution of the fibres leaves the values of porosity and permeability almost unchanged.

The general increase in the performances, which is especially evident after the freeze thaw cycles, becomes important especially if considering that a draining bituminous mixture is structurally planned with a high concentration of stresses located in few points because of the high percentage of voids due to the granulometric discontinuity of the mixtures.

By analyzing the results of the indirect tension test, it is evident that for the traditional mixture, after the thermic stresses, there is a decrease in the resistance value from σ_{Tm} = 0.48 MPa to σ_{Tm} = 0.38MPa with a mean loss percentage equal to 23.8%.

In the mixture prepared with fibres there is a decrease of the indirect tension resistance value from σ_{Tm} = 0.71 MPa to σ_{Tm} = 0.59 MPa, with a mean loss percentage of resistance equal to 17.72%, therefore more limited if compared to the previous case.

The presence of fibres, therefore, increases the resistance values of the materials; in fact the fibres have a greater capability of making the bitumen dense in the points of contact of the aggregates than the traditional filler; this effect is evident after subjecting the mixture to the freeze thaw cycles

The breaking loads, moreover, for the mixtures prepared with fibres are always higher according to a trend with respect to indirect tension resistance values like the power type that is expressed by: $y = \alpha \cdot x^{\beta}$ (equations 2,3, 4 and 5) where α and β are functions of the type of mixture and of "elasticity" of the bitumen depending on being the test carried out at 25°C or after the thermic stresses.

The mean diametral deformation percentage values ΔDc/D and ΔDt/D, for the samples without fibres, tested at 25°C and after freeze thaw cycles, are reported in the following table, where on the positive part of the x axis there are compression values and on the negative part the tension values which are equal to:

Table 13 Mean diametral deformation – Draining without fibres

BITUMINOUS MIXTURE	ΔDC/D [%]	ΔDT/D [%]
DRAINING WITHOUT FIBRES **TEST AT 25°C**	0.35	2.68
DRAINING WITHOUT FIBRES **TEST AFTER FREEZE THAW CYCLES**	0.19	2.05

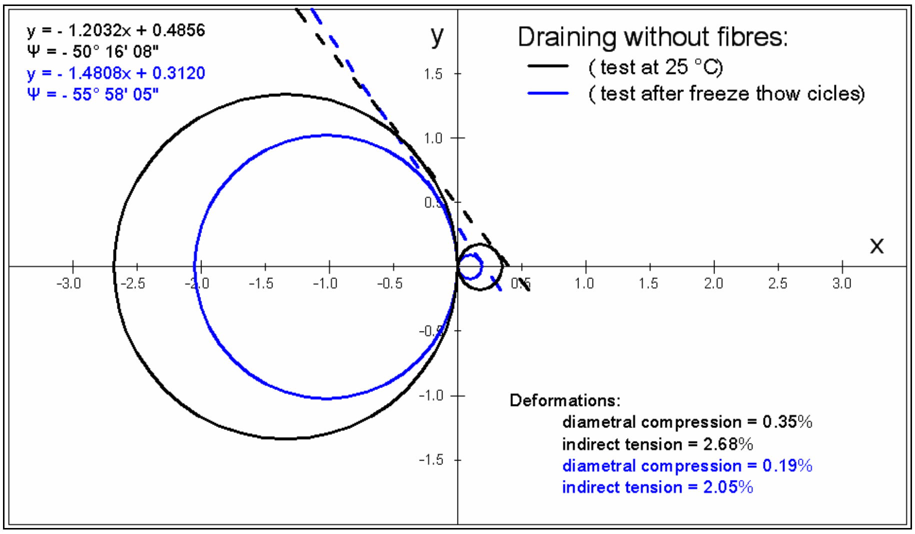

Figure 10 Breaking envelope curves of the mixture without fibres

Moreover the breaking envelope curves of the mixture without fibres, regarding the experiment carried out at 25°C and after freeze thaw cycles, have been found; these curves represent the domain of the equilibrium of the material.

The equation of the generic envelope curve that represents the limit state of the mixture has the following expression:

$$y = -\gamma \cdot x + \delta \qquad \text{(Eq. 6)}$$

where γ and δ coefficients are functions of the type of mixture and conditions of the test.

These curves, comparable to lines, form with the abscissa axis an angle ψ, function of the same parameters.

Same thing for the samples added with fibres for which the mean percentage values of diametral deformation ΔDc/D and ΔDt/D, tested at 25°C and after freeze thaw cycles, written in the following table with the previous modalities are equal to:

Table 14 Mean diametral deformation – Draining with fibres

BITUMINOUS MIXTURE	ΔDC/D [%]	ΔDT/D [%]
DRAINING WITH FIBRES **TEST AT 25°C**	0.63	2.80
DRAINING WITH FIBRES **TEST AFTER FREEZE THAW CYCLES**	0.35	2.61

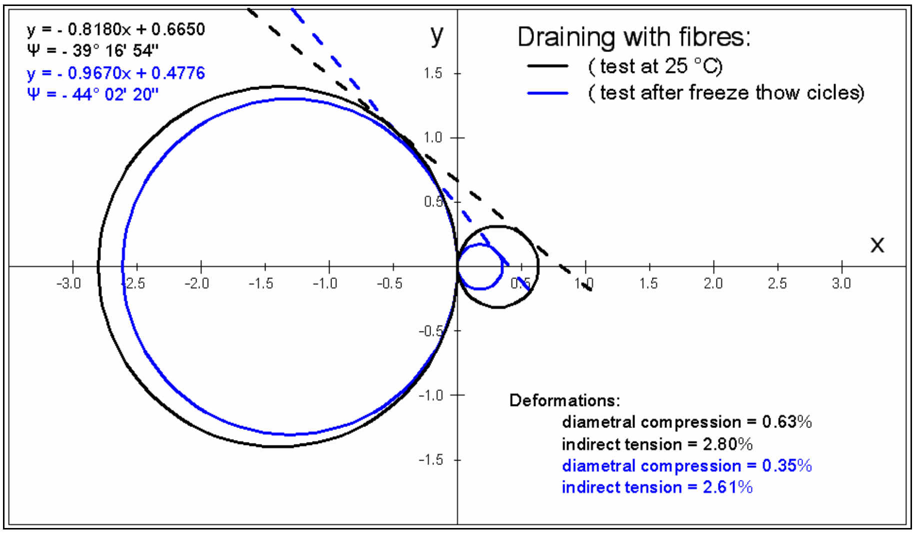

Figure 11 Breaking envelope curves of the mixture with fibres

The curves of breaking envelope for the mixture with and without fibres regarding the experiment carried out at 25°C and after freeze thaw cycles have been found; these curves represent the domain of the equilibrium of the material.

The equation of the generic envelope curve, which represents the limit state of the mixture, has this kind of expression:

$$y = -\gamma \cdot x + \delta \qquad \text{(Eq. 6)}$$

where the γ and δ coefficients are functions of the type of mixture and conditions of the test.

These curves, comparable to lines, form with the abscissa axis an angleψ, function of the same parameters.

Also for the simple draining samples the value of indirect tension resistance has never been lower than the limit σT = 0.25MPa, with a loss percentage that has never been higher than 25% of the initial values for all mixtures.

The analysis of the results show that the freeze thaw cycles causes in the sample a substantial decrease in diametral deformations with a decrease in ductility of the mixture due to the oxidation of the bitumen.

The experiment shows that the effect of the fibres affects noticeably the indirect tension deformations.

For all samples without fibres the freeze thaw cycles have induced a decrease in the values of $\Delta Dc/D$ from 0.35% to 0.19% with a percentage variation equal to 45.7%.

For the samples with fibres from a value of $\Delta Dc/D$ 0.63% to 0.35% with a decrease equal to 44.4%.

In relation to indirect tension deformative values, instead, the contribution of fibres has been more evident: for ΔDt/D from 2.68% to 2.05% after the freeze thaw cycles for the samples without fibres, with a decrease equal to 23.5%, while for samples with fibres, after the thermic stress, from 2.80% to 2.61% with a decrease equal to 6.78%.

The Cantabro test shows thta the aggregates with fibres are less subjected to disintegration, since their loss of weight percentage is equal to 10.7, versus the value of 15.8 found for traditional draining mixtures.

The complete synthesis of the experimentation is written in the following table:

Table 15 Results of the tests

BITUMINOUS MIXTURE	**Porosity [%]**	**K [cm/s]**	**Cantabro weight loss [%]**	**σ_{Tm} [Mpa]**	**Red. [%]**	**ΔDc/D [%]**	**Red. [%]**	**ΔDt/D [%]**	**Red. [%]**
Draining without fibres test at 25°C	21	0.68	15.8	0.48	**23.8**	0.35	**45.7**	2.68	**23.5**
Draining without fibres test after freeze thaw cycles	====		====	0.38		0.19		2.05	
Draining with fibres test at 25°C	21	0.62	10.7	0.71	**17.7**	0.63	**44.4**	2.80	**6.78**
Draining without fibres test after freeze thaw cycles	====		=====	0.59		0.35		2.61	

7. CONCLUSIONS

The analysis of the results shows that increase that the previous mineral fraction fibres used as additive provide to the performances of the traditional draining bituminous mixtures.

The physical explanation of this result is due to the greater capability to thicken the bitumen that fibres have compared to a traditional filler, avoiding dripping and limiting the dispersion inside the mixture.

The analysis of the Cantabro results in particular show that the effect of the fibres limits considerably the loss of weight of the samples because the aggregates are better wrapped by the binder and less subjected to wearing.

Also the indirect tension test, related to both indirect tension resistance values σ_{Tm}, and diametral deformations ΔDc/D and ΔDt/D, shows the contribution of the fibres which besides increasing the mechanical resistance values enlarge the ductility field of the material.

The contribution of the fibres appear clearer after subjecting the mixture to freeze thaw cycles.

The normal decline of indirect tension resistance values σ_{Tm} is more limited in mixtures added with fibres which break under sensitively greater loads.

A similar comparison can be made in relation to shortening and lengthening diametral deformations for which after the freeze thaw cycles the contribution of the fibres leads especially for the indirect tension deformations to a substantial stability of the deformation values maintaining the ductility of the mixture.

The fibres in fact form inside the matrix binder a sort of grating that acts as a support to the mixture exerting a control on the cracking.

Therefore, especially in cold climates and temperature range, the use of draining mixtures added with prevalent mineral fraction fibres appears a suitable solution to limit the phenomena of crushing due to the frost wedging to which high porosity material as draining mixtures are subjected.

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