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Comparative Low-Temperature Thermal Cracking Investigations on Different Reinforcing Interface Systems

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ABSTRACT: This paper is dealing with the results of laboratory tests on bituminous overlays with reinforcing interface systems on cement concrete slabs. The purpose of this study was to investigate the differences in system behaviour between various reinforcing interface systems for the prevention of reflective cracking in pavement structures at low temperatures. The reinforced bituminous overlays were subjected to loads resulting from subsequent shrinkage and expansion of the cement concrete slabs due to cyclic temperature variations. The tests allowed to study: i) the effect of combining reinforcing systems with nonwoven fabrics; ii) the difference in system behaviour between very stiff (high modulus) and more flexible reinforcing interface systems.

KEY WORDS: Reflective cracking, Laboratory testing, SAMI, Asphalt reinforcing interface systems, Cement concrete slabs, Asphalt overlays.

1. INTRODUCTION

The type of damage considered in this paper is reflective cracking in an asphalt overlay on a cement concrete base, resulting from thermal variations. Due to the cyclic opening and closing of the joints, the asphalt covering the discontinuities suffers high stresses and cracks will be initiated at low temperatures, when the tensile stresses in the asphalt layer are maximum and the bituminous materials behave most brittle. In time, these cracks will propagate to the surface, reflecting the pattern of joints or cracks which was initially present in the base layer.

Interface systems are capable of preventing or retarding reflective crack initiation and growth. Their use in rehabilitation of cracked pavements should thus be considered and evaluated in terms of the enhanced durability of the pavement.

The performance of an interface system for prevention of reflective cracking is based on one or a combination of the following mechanisms:

- Interfacial shear at a flexible and ductile interlayer, which leads to a redistribution and relief of the tensile stresses in the top layer (e.g. SAMI).
- Partial de-bonding between the top and base layer, which has a similar effect as interfacial shear.
- Reinforcement of the top layer with a stiff and strong material, which reduces the stresses and strains in the asphalt.

Besides these mechanisms of stress reduction, it is also important to note that an interface system reduces water infiltration, which is also highly beneficial for the durability.

Nowadays, a wide variety of interface products is available, based on the combination of the above mechanisms. Knowing the material properties of all the components at a given temperature, the behaviour can be analyzed (e.g. making finite element simulations) and the system can be optimized. However, experimental verification of the behaviour of the system is also an imperative step. Finite element modelling has indeed its limitations, following from the assumptions and simplifications that need to be made and the lack of correct quantitative data on some material or geometrical properties.

For this purpose, BRRC developed an experimental set-up that simulates the reflective cracking phenomenon due to thermal movements. The test samples are representative structures consisting of a discontinuous concrete base (2 slabs separated by a joint), covered with an asphalt concrete overlay. In the past, many tests have been performed with different types of interface systems (Francken, 1993 and Vanelstraete, 1996). These tests allowed for comparative studies of the efficiency in preventing crack initiation and propagation.

This paper focuses on the behaviour of so-called combination products: impregnated nonwoven fabrics combined with reinforcing grids. The behaviour of these products is compared to the behaviour of grids without nonwoven fabrics.

2. EXPERIMENTAL SET_UP

The test set-up is contained in a thermostatic chamber which is held at a constant temperature of typically -5 °C down to -15 °C, depending on the application (see figure 1).

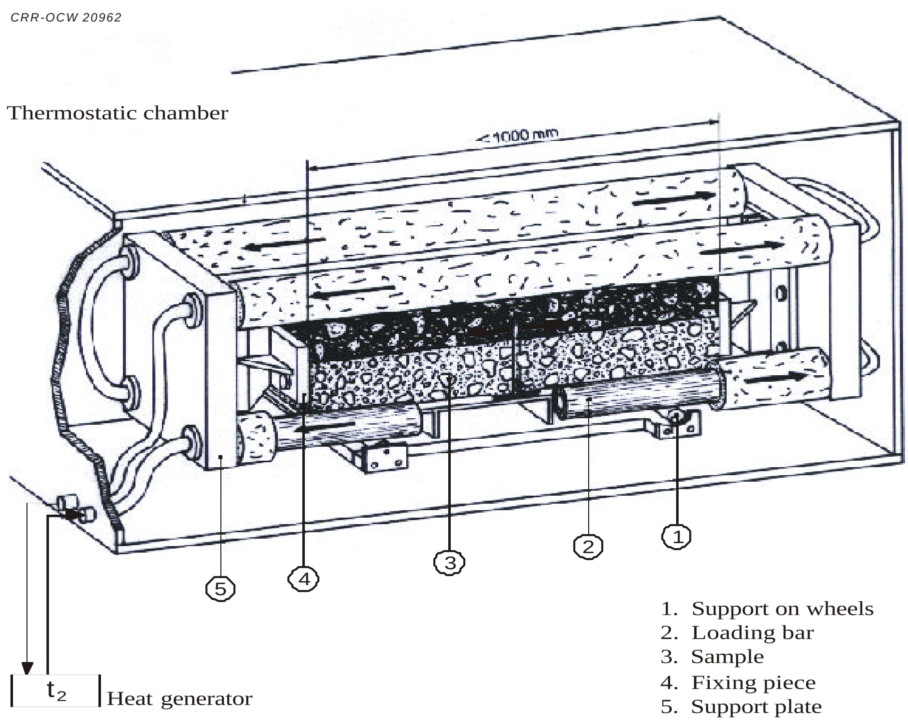


Figure 1: Experimental set-up

The sample is uniformly supported by a bed of steel balls, so that the horizontal movement of the sample is free, while bending due to the dead weight is avoided. Both ends of the cement concrete base layer are fixed in a frame of horizontal aluminium bars, through which a thermostatic liquid is circulating. In this way, the bars can be cooled or heated, simulating expansion or shrinkage of the concrete base layer.

A test starts by heating the bars, resulting in the widening of the discontinuity in the concrete base. When the width of the discontinuity has increased by 1mm, the bars are cooled until the discontinuity has regained its initial width (± 4 mm). The deformations resulting from these variations are sufficiently slow to be comparable to the typical rate of thermal deformations. The cycle of opening and closing is repeated until the specimen fails or until a stable state is attained.

At regular time intervals, the following data are measured and stored (see figure 2):

- The force applied to the cement concrete base in order to open and close the discontinuity (FORCE);
- The variation of the width of the discontinuity in the concrete base (crack opening displacement COD);
- The relative displacement in the asphalt layer 2 cm above the discontinuity (overlay displacement OVL);
- The displacement of the concrete base at the utmost left side (LEFT);
- The displacement of the asphalt at the utmost right (RIGHT).

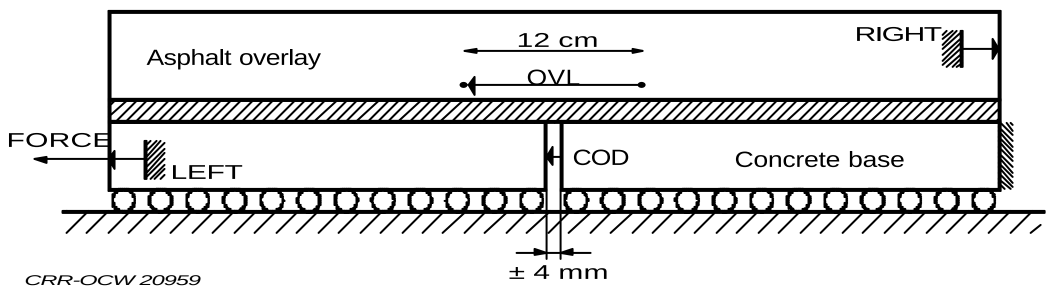


Figure 2: Test sample

Video images and pictures taken at maximum opening of the joint show the development and growth of thermal cracks.

3. TEST SAMPLES

The test samples discussed in this paper had a length of 60 cm and a width of 15 cm. The base layer was made of 2 concrete blocks, separated by a discontinuity of 4 mm. The top layer was an asphalt concrete wearing course of 6.5 cm thickness.

The two layers were separated by an interface system. Six different interface systems were used, all six containing a reinforcing fibre grid. In three of these systems, the grid was combined with a nonwoven fabric. These interface products were placed according to the following steps:

- A quantity of 1.0 kg/m² of elastomeric binder 85/130 was spread on top of the concrete base;
- The interface product was placed;
- A quantity of 0.8 kg/m² of elastomeric binder 85/130 was spread on top of the interface product.

The three other interface systems were plain grids, without nonwoven fabric. They were placed according to the procedure prescribed by the Belgian standard tender specifications (SB250,2001):

- An emulsion of 0.6 kg/m² was spread on top of the concrete base (without PmB);
- The interface product was placed;
- A quantity of 1.2 kg/m² of elastomeric binder 85/130 was spread on top of the interface product;
- A quantity of 10 kg/m² of stones 7/10 was spread.

Other variants in this comparative study were the stiffness of the grid, expressed by the strain at nominal strength, and the strength of the grid. The six different types of interface systems and their corresponding characteristics are shown in table 1.

Three samples were fabricated with the interface system of type 1. One sample was tested at -10 °C, like all the samples of the other types. The two other samples were tested at -15 °C, to see the effect of temperature on the test results. Consequently, eight tests were conducted: 6 tests at -10 °C (1 sample of each type) and 2 tests at -15 °C (2 samples of type 1).

Table 1: Overview of the different interface systems with their main characteristics (in the direction perpendicular to the joint)

Type	Sample numbers	Nonwoven	Fibres	Strain at nominal strength	Strength
1	138-1; 138-2 and 138-7	Yes	PVA	6 %	50 kN/m
2	138-3	Yes	Glass	3 %	50 kN/m
3	138-4	Yes	Glass	3 %	50 kN/m
4	138-5	No	Polyester	12 %	50 kN/m
5	138-6	No	Glass	3 to 4 %	35 kN/m
6	138-8	No	Basalt	3 %	50 kN/m

4. EXPERIMENTAL RESULTS

4.1. Overview of the experimental data

The main outcome of the thermal cracking test is the crack history of the asphalt overlay, summarized in table 2. The last column shows the result for a reference sample without any interface system. This clearly illustrates the fact that every tested interface system improved the resistance to reflective cracking. The last row shows whether the sample failed and after how many cycles it failed. In this test, total failure is defined as the state where a crack runs through the entire thickness of the asphalt layer, visible on both sides of the sample.

Table 2: Overview of the crack history

Sample	138-1	138-3	138-4	138-5	138-6	138-8	138-2	138-7	ref
Interface	Non woven+ grid	Non woven+ grid	Non woven+ grid	grid	grid	grid	Non woven+ grid	Non woven+ grid	No
Test Temperature	-10°C	-10°C	-10°C	-10°C	-10°C	-10°C	-15°C	-15°C	-10°C
First visible crack at cycle	-	-	-	-	12	7	1	1	1
Total failure In cycle:	No	No	No	No	Yes 44	No	Yes 1	Yes 12	Yes 1

Table 3 compares the maximum and minimum forces exerted to open and close the discontinuity. Table 4 compares the maximum and minimum displacements in the asphalt layer, OVL. These tables are discussed further on in this paper.

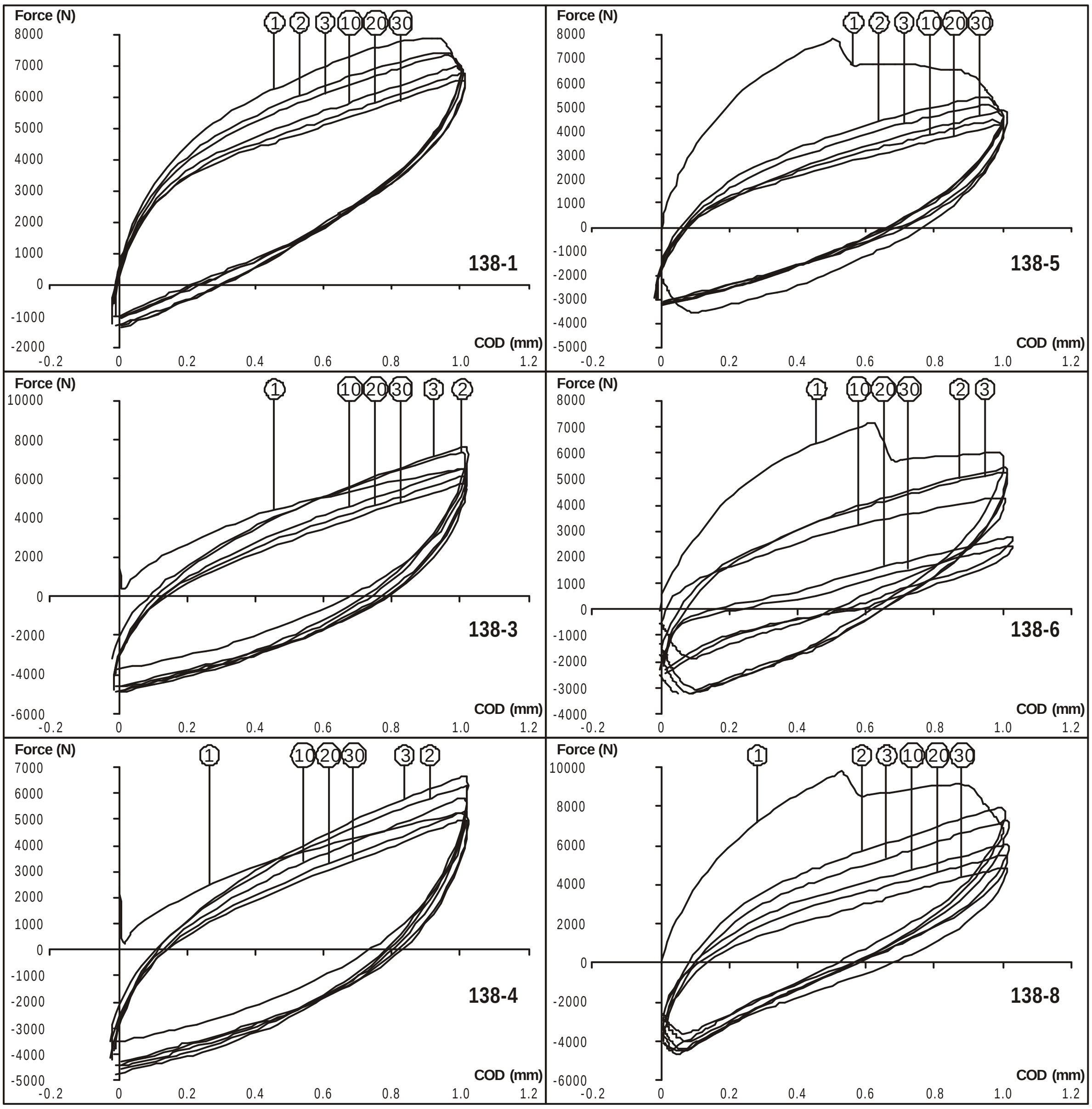
Table 3: Comparative table of maximum and minimum forces

Sample	138-1	138-2	138-3	138-4	138-5	138-6	138-7	138-8
Max. force (N) Cycle 1	7887	11530	6428	5136	7760	7884	13555	9721
Max. Force (N) Cycle 2	7425	-	7358	6435	5389	5918	6987	7557
Max. force(N) Cycle 3	7319	-	7577	6643	5089	5742	5867	7243
Max. force (N) Cycle 10	6965	-	6489	5738	4455	4602	4088	6050
Min. force(N) Cycle 1	-1261	-	-3739	-3535	-3136	-4057	-4951	-4683
Min. force (N) Cycle 2	-1321	-	-4610	-4439	-3208	-4011	-4148	-4620
Min. Force (N) Cycle 3	-1377	-	-4843	-4573	-3233	-3814	-3255	-4542
Min. force (N) Cycle 10	-1079	-	-4801	-4514	-3116	-2441	-624	-3980

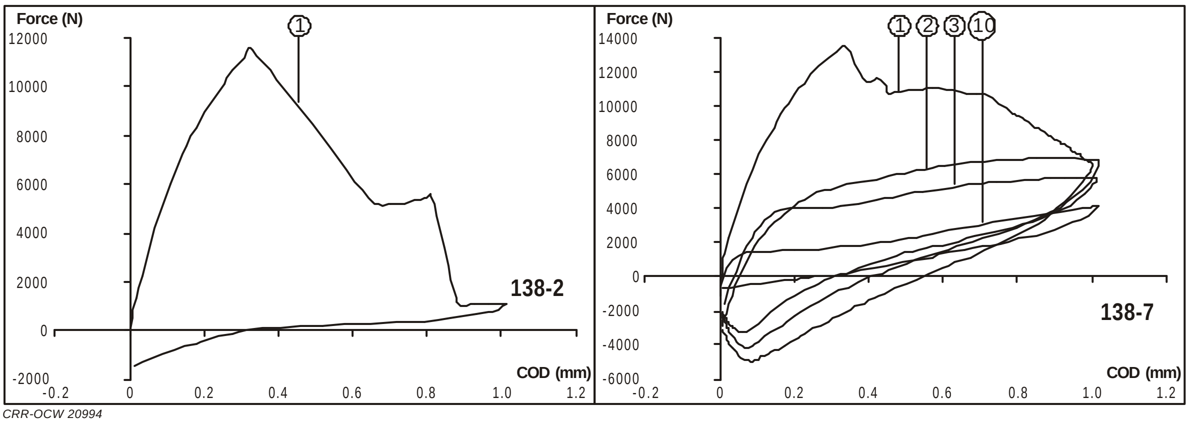
Table 4: Comparative table of maximum and minimum OVL

Sample	138-1	138-2	138-3	138-4	138-5	138-6	138-7	138-8
Max. OVL (mm) Cycle 1	0.20	-	0.14	0.11	0.20	0.25	0.15	0.28
Max. OVL (mm) Cycle 2	0.20	-	0.14	0.10	0.20	0.24	0.19	0.28
Max. OVL(mm) Cycle 3	0.19	-	0.14	0.10	0.20	0.25	0.24	0.29
Max. OVL (mm) Cycle 10	0.19	-	0.14	0.09	0.20	0.34	0.36	0.31
Min. OVL(mm) Cycle 1	-0.01		-0.03	-0.05	-0.01	-0.03	-0.02	-0.01
Min. OVL (mm) Cycle 2	-0.01	-	-0.03	-0.06	-0.02	-0.05	-0.02	-0.02
Min. OVL (mm) Cycle 3	-0.01	-	-0.03	-0.06	-0.02	-0.05	-0.03	-0.02
Min. OVL (mm) Cycle 10	-0.01	-	-0.03	-0.06	-0.02	-0.05	0.09	-0.03

Figure 3 shows the plots of the applied force versus COD. COD is the widening of the discontinuity and varies between 0 and 1 mm.



Tests at -10 °C



Tests at -15 °C

Figure 3: Force versus COD plots (cycle number in circles)

4.2. The effect of nonwoven fabrics

The nonwoven fabrics are impregnated by the elastomeric binder which is spread before and after placing the interface system. This leads to a shear deformable interlayer between the concrete base and the reinforcing grid, working as a stress absorbing membrane (SAMI). The reinforcing effect of the nonwoven fabric is negligible.

The plots in the left column of figure 3, at -10 °C, correspond with the interface systems with nonwoven fabrics, the plots in the right column with the interface systems without nonwoven fabrics. The effect is already clear in the first load cycle. The interface systems with nonwoven fabrics behave less stiff in the first cycle (initial slope of the curves is smaller). This is explained by interfacial sliding which allows for larger movements of the base layer. Since the test is displacement controlled, the maximum forces applied to the samples are smaller.

The samples without nonwoven fabrics (figure 3, right column) allow no interfacial sliding and hence induce larger forces in the very beginning of the test (initial slope of the curves is higher). A second difference with the plots in the left column is the sudden drop of the force in the first cycle. This was due to the formation of a horizontal crack at the interface, initiated at the tip of the discontinuity, as could be seen on the video images. In the absence of a shear deformable interlayer, the shear stresses in this zone become too high and a crack is initiated. The propagation of an interfacial crack leads to a reduction of the stiffness of the sample and a relief of the stresses, similar to the effect of interfacial sliding. Consequently, the crack stops to propagate when the shear stresses have sufficiently decreased. In the second load cycle, the plots are similar to the plots on the left hand side. The formation of an interfacial crack has indeed lead to a more "deformable" interface, implying a reduction of all the stresses.

At further cycling, the samples with nonwoven fabrics all remained intact. They were loaded for more than 40 cycles, until the behaviour was stable. The same applies for sample 138-5. The two other samples without nonwoven fabrics began to show a crack in the asphalt, sample 138-6 after 12 cycles and sample 138-8 after 7 cycles. Sample 138-6 eventually failed in cycle 44. Figure 4 shows a picture taken in this cycle, at maximum opening of the discontinuity.

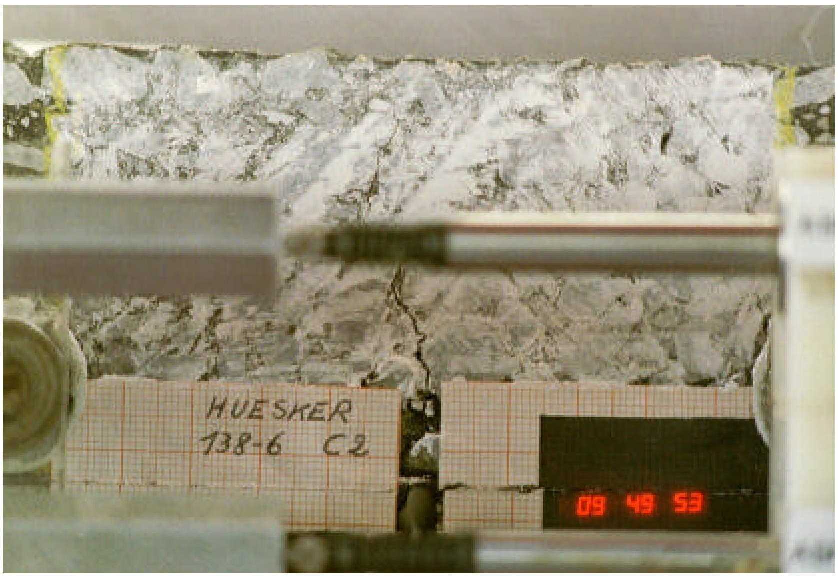


Figure 4: Sample 138-6 in cycle 44

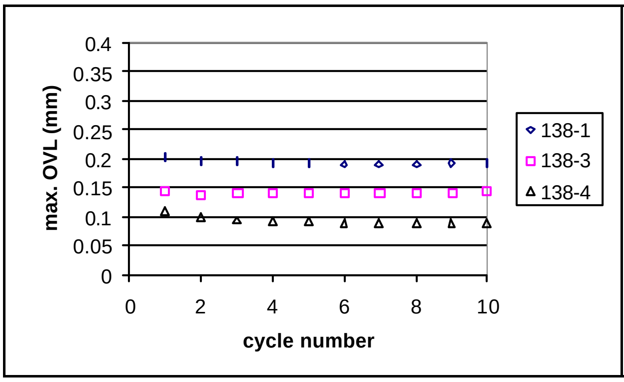
4.3. The effect of the stiffness of the grid

Because of the nonlinear stress-strain relation of grids, the stiffness is usually characterized in terms of strain at nominal strength (the higher this strain, the lower the stiffness). Of the three types with nonwoven fabrics, type 1 contained the grid with the smallest stiffness, while type 2 and 3 both had the same stiffness. Although all three interface systems behaved well during the test, there are a few differences that can be related to the grid stiffness.

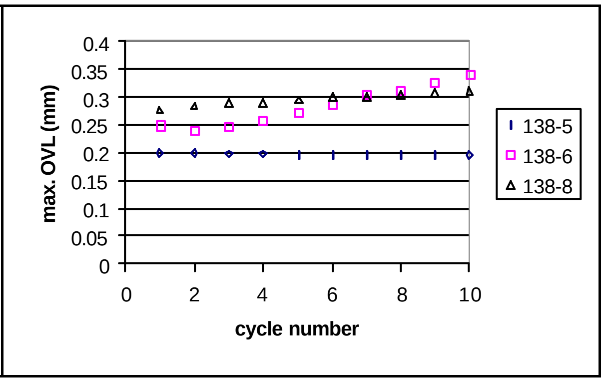
Figure 5 shows the plots of the maximum value of OVL versus the cycle number, for the tests at -10 °C. OVL is the relative displacement between two points on the asphalt overlay, situated 2 cm above the discontinuity (see figure 2). This displacement is proportional to the average strain in the zone between the two points. The maximum OVL is attained at maximum opening of the discontinuity. When there is a high degree of interface sliding and there are no cracks in the asphalt, OVL is small. Also, the initiation and propagation of cracks in the asphalt is seen by a sudden increase of OVL.

For the systems with nonwoven fabrics, table 4 and figure 5 show that OVL is largest for the interface system with the lowest stiffness (sample 138-1). This could be expected: a lower stiffness leads to larger strains. Still, the strains are small and no sudden increase is noticed.

For the interface systems without nonwoven fabrics, it is the system with the lowest stiffness that has the smallest value of OVL (sample 138-5). For the high stiffness interface systems (samples 138-6 and 138-8), OVL is larger and shows a steady increase. This increase is explained by the growth of a vertical crack in the asphalt layer. Due to the high grid stiffness, the interfacial shear stresses are higher and more easily lead to de-bonding between the different layers.



systems with nonwoven fabrics



systems without nonwoven fabrics

Figure 5: Maximum OVL versus cycle number

Another interesting observation, related to the grid stiffness, can be made in figure 3. The compressive forces are smaller for the low stiffness interface (sample 138-1) than for the high stiffness interfaces (samples 138-3 and 138-4). The compressive force is the force required to bring the discontinuity back to its initial width. Sample 138-1 thus behaves in a more elastic way, which is typical for undamaged samples. Samples 138-3 and 138-4 require larger compressive forces, which could be explained by the fact that these samples present more de-bonding at the interface. This is again explained by the high stiffness modulus of the grid: since the tensile strains in the asphalt layer are smaller, the interface is subjected to higher shear stresses and interface de-bonding is more likely to occur. This implies that a very high stiffness is not always beneficial. The stiffness should be sufficiently high to keep the tensile strains and stresses in the asphalt below the ultimate values. On the other hand, when the stiffness is too high, the shear stresses and strains at the interface may lead to de-bonding at the interface.

4.4. The effect of temperature

Two samples of type 1 were tested at a lower temperature, -15 °C instead of -10 °C. In table 2, it is seen that both samples tested at -15 °C failed during the experiment. No failure occurred for type 1 at -10 °C.

The efficiency of reinforced asphalt is thus highly sensitive to the temperature. While the asphalt sample with interface system of type 1 performed well at -10 °C, an identically fabricated sample failed at -15 °C. A more appropriate choice of binders for both asphalt and interface could solve this problem. If the elastomeric binder at the interface were replaced with a softer binder that behaves less brittle at -15 °C, the interface would be more shear deformable and the system would perform better. Temperature is thus a major factor in the selection of the binders.

It is interesting to note that both samples tested at -15 °C were prepared identically and subjected to the same test conditions. Still, the crack propagation in these samples was different, due to the heterogeneity of the material and the stochastic nature of damage propagation. One of the samples tested at -15 °C already failed in the first cycle. The damage scenario was as follows: first, a horizontal crack occurred at the interface (force drop at constant OVL), followed by a vertical crack throughout the asphalt layer (force drop at rapidly increasing OVL). The other sample only experienced the first damage mechanism in cycle 1. In the following cycles, a vertical crack appeared and propagated in a more gradual way. The crack had grown to the top in cycle 12.

5. CONCLUSIONS

An experimental program was carried out with the aim of comparing the efficiency of different types of reinforcing interface systems for the prevention of reflective cracking due to thermal variations at low temperatures.

The combination of a reinforcing grid with a nonwoven fabric, placed according to the procedure described in this paper, performs better than a plain reinforcing grid, placed according to the Belgian standard tender specifications. No cracks were visible at the end of the test cycles. The nonwoven fabric, impregnated by the elastomeric binder, works as a stress absorbing membrane that reduces the stresses in the reinforced asphalt overlay. Only sample 138-5 is performing in a similar manner as the combined systems.

Of the combined systems, the one with a grid with lower stiffness is showing a more elastic system behaviour, while the systems with stiffer grids show more plastic system behaviour.

In the absence of a stress absorbing interlayer, horizontal shear cracks are more easily initiated at the tips of joints or cracks. The use of very high stiffness reinforcements is not always beneficial, since in those cases the interface is more subjected to shear stresses and potential interface de-bonding. This may evolve in other types of damage than reflective cracking.

The climate in which the system is to be applied is one of the most important factors in the selection of the binder used for the impregnation of the nonwoven fabric. The tests have shown how seriously a decrease of the environmental temperature from -10 °C to -15 °C affects the behaviour of the reinforced asphalt system.

The thermal cracking test is a powerful tool in the development of new and better performing interface systems. A qualitative comparison of different systems provides good insight in the behaviour of reinforcing interface systems and the evolution of damage. However, knowing the stochastic character of crack propagation in such complex and heterogeneous structures, the quantitative results of one single test on a specific system should always be considered with due caution.

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