Experimental and Analytical Approaches for Studying Reflective Crack Retardation

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ABSTRACT: Bituminous membranes technology has recently come into use in Israel in order to retard the process of reflection cracking in new asphalt overlays. Thus, in an effort to establish design criteria for this technology a simulation laboratory research was undertaken, aiming to achieve a mechanical simulation of fatigue crack propagation in asphaltic mixtures with Bituminous membranes as a function of the number of load applications. A number of experiments were conducted within this model, including the testing of sand-asphalt beams with 4 kinds of Bituminous membranes and with 2 kinds of sand-asphalt beams for control. From the test results one can conclude that the fatigue life is a function of the membrane's characteristics such as thickness, modulus of elasticity, and the amount of the modifier in the bitumen mass. The analytical model was based on variables which represents the experimental testing geometry, testing configuration and material properties. The stress intensity factor as related to crack propagation was correlated with this variables using finite element techniques.

1 INTRODUCTION

Among the many causes of structural pavement distress, a major one is related to the reflective cracking which occurs in the asphaltic overlay of existing cracked pavements. Even after 20 years of practical use and monitoring of the performance of the geotextile felts, the mechanism by which reflection cracking is retarded is yet to be fully understood. As a consequence , there are considerable differences, as reported by Maurer and Malasheskie ,1989), between the predictions derived from laboratory standard tests and the actual field performance. Obviously, these differences can also be attributed to the partial knowledge regarding the qualities required of the felt in order to obtain appropriate performance. This is witnessed by the conflicting variety of criteria and recommendations intended to determine the required properties of these felts, as reported by Koerner (1990).

Thus, it seems that one cannot accurately predict the performance of a specific felt without conducting advance fatigue experiments in a simple laboratory wheel tracking device. In light of the above, the objectives of this paper were to develop a simple laboratory fatigue test which will simulate field conditions as closely as possible on the one hand, and will differentiate between the efficiency levels of bituminous pre-coated geotextile felts on the other hand. For these objectives, 4 kinds of bituminous Polypaz felts, 3M, 3/250, 3/250, with reduced amount of polymer (3/250[x%]), and 4/180, were used, showing that their basic characteristics do not always indicate their final behavior.

2 THE LABORATORY TEST SYSTEM

The effect of different treatments in the interface between existing pavement surface and a new asphaltic overlay was experimentally evaluated by laboratory moving-wheel tracking device (originally introduced by Ishai et al ,1978). This device consisted of a metal rigid plate which moved back and forth between two horizontal plates. It consisted of an elastic rubber beam which served as a base to the asphaltic beam samples, as described in Fig. 1.

The asphaltic beam sample was repeatedly loaded by a pneumatic wheel 40 cm. in diameter and a tire pressure of 0.5 MPa. The number of loaded wheel coverages was 48 per minute (2880 per hour). The entire system was located in a closed room, thermally insulated and temperature controlled to a constant 25° C.

In order to examine the efficiency of the bituminous felts alone, it was decided to limit the scope of the laboratory investigation to one type of sand-asphalt mixture made of dolomite aggregate (were 100% passing sieve #10, 55% sieve #40 and 15% sieve #200) and 8% (Marshal test optimum content) of 60/70 bitumen content.

Preliminary tests were conducted in order to examine the possible correlation between the properties of the various felts and their retarding capability. These tests included the conventional standard tests and also the "Narrow Strip" tensile test, interface friction test, and the effect of the modifier amount on softening point (R&B test) of the bitumen mass. The characteristics of two out of the four felts mentioned before are given in Table 1. Fig. 2 presents the results of the "Narrow Strip" tensile test for all the felts examined in this work.

Table 1 and Fig. 2 indicate that a 3M type (made of fiber-glass) has a far lower strain resistance than the three other felts (made of polyester) which have closely identical tensile strain capability.
A direct shear test at the interface was also used in order to find out the differences in the possible performances of the various tested felts. The results of these tests are presented in Fig. 3, were the testing procedure was according to Uzan et al (1978). This figure indicates that there is no difference in the magnitude of the shear patterns and values of the three types of felts. These derived shear values at the interface were lower, as expected, that those of a tack-coat applied at the interface.

Table 1 Manufacturer's data regarding the characteristics of the different felts tested.

Property	Units	Standard	3/250*	3M*
Raw Material			Polyester	Fiberglass
Production Method	All	membranes	are	nonwoven
Membrane thickness	[mm].		3	3
Felt weight	[gr/m^2]		250	105
Tearing force in tension	[kg/cm^2]	DIN 52123 DIN 52133	20/17	15/15
Elongation in tension	[%]	DIN 52123	50/50	3/3
Stability under high temperature	[° C]	DIN 52133	+115	+115
Stability under low temperature	[° C]	DIN 52133	-20	-20
Type of polymer			SBS**	SBS**

* 3/250 - 3mm thick membrane with 250 gr/m polyester fabric reinforcement

** SBS - Styrene - Butadiene - Styrene

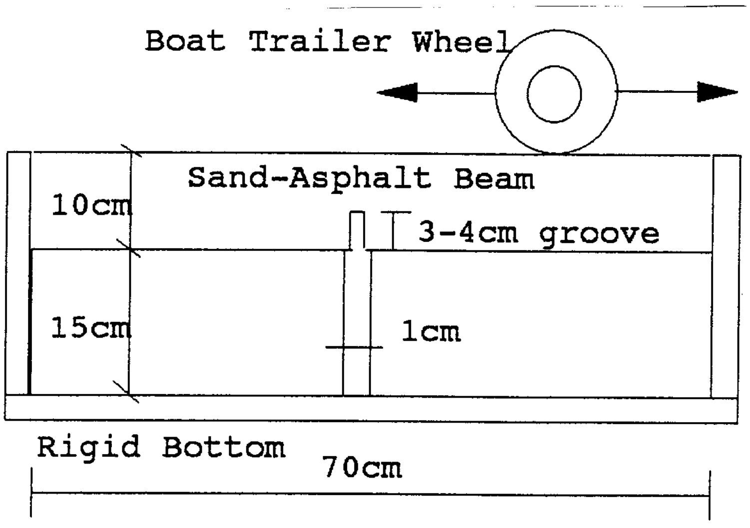

Figure 1 The laboratory Wheel - tracking device.

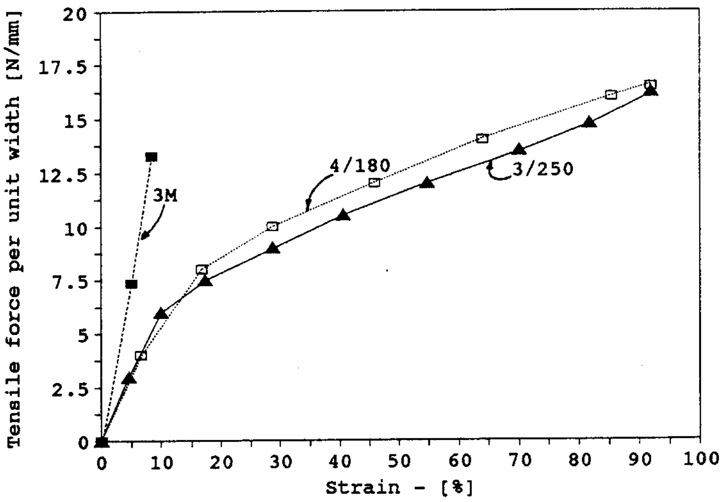

Figure 2 Narrow strip tensile tests results for three membranes.

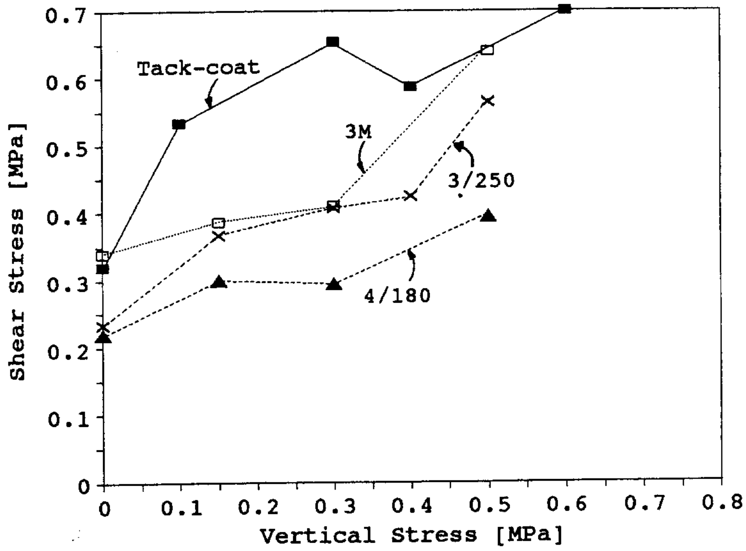

Figure 3 Direct shear tests for four interface treatments.

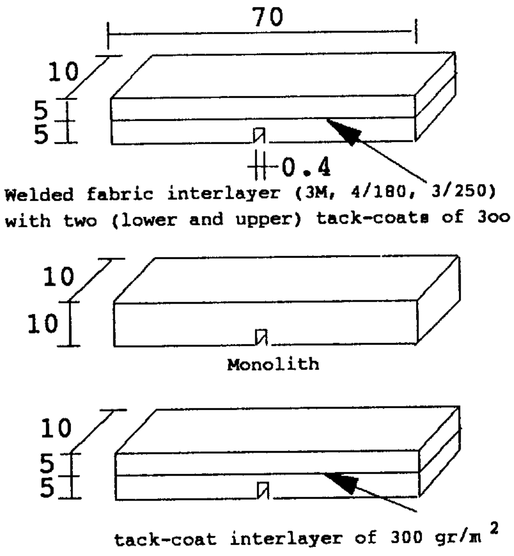

Figure 4 Flexural fatigue beam specimen.

The comparison of the efficiency of the different interface treatments was carried out with a laboratory wheel tracking device. While testing, the sample beam was confined by a vertical steel plate at both edges, in order to prevent any longitudinal movement relative to its rubber base and steel plate. The sand-asphalt beam samples were tested in three configurations (see also Fig. 4):

1. A monolithic beam, 10 cm thick;
2. Two 5 cm thick beams with a tack-coat interfaces;
3. Two 5 cm thick beams with a welded asphaltic membrane interlayer.

In all these beams, an artificial groove, 30-50mm. deep and 4mm. wide, was made at their center, along their entire bottom width. The edge of the groove was rounded. A separation of 10mm. was created between the rubber base plates directly under the presawn groove to simulate a crack that propagated from the bottom layers.

Test response in all experimental combinations is the rate of crack propagation with the number of the loaded wheel coverages. The propagated length of the cracking along both white colored vertical sides of the asphalt beam was monitored by a video camera and visually measured at given time intervals by means of a sophisticated magnifying set-up.

3 EXPERIMENTAL TEST RESULTS

Fig. 5 summarizes the major results of all beam configurations in the moving wheel tracking device. The results are expressed in terms of fatigue life and its coefficient of variation. It is important to note that a phenomenon of dual cracking was observed in some of the tests. This phenomenon is characterized by the propagation of a crack which begins at the edge of the artificial groove and at the same time, the propagation of a crack which begins on the upper surface. Germann and Lytton (1977) found the same phenomenon in their laboratory tests, it was also observed in in-situ test segments by Nunn (1989).

In this research, this phenomenon was observed in half of all beams which did not contain membranes, and took place in all beams which included membranes of all the various types. In order to demonstrate this phenomenon , Fig. 6 present the visual results of crack propagation vs. time as derived from two fatigue experiments conducted on sand-asphalt beams with 3/250 asphaltic membrane.

The term "UP" denotes the distance which the crack advanced from the edge of the groove upwards. The term "DOWN" denotes the distance advanced by an additional crack which began at the upper part of the beam and propagated downward. The relationship between the total length of the crack (the sum of "UP" + "DOWN" crack lengths) and the time elapsed since the beginning of the test was evaluated for each type of beam. The average time for all the 3/250 membrane types was multiplied by 2880 in order to obtain the number of tracking-wheel repetitions per hour.

4 EFFECT OF THE ASPHALTIC MEMBRANE

The results of the fatigue tests presented in Fig. 5 indicate that only the fatigue life associated with a 3/250 membrane is longer (3.8 time more) then that associated with the control tack-coat interface (which, as expected, is lower then the fatigue life of a monolithic beam).

Koerner (1990) provided a number of recommendations regarding the characteristics of asphaltic layer membranes in order to obtain optimal performances. Minimum requirements were specified for membrane strength, elongation, bitumen penetration and softening point. As can been seen in Fig. 2 and in Table 1 all membranes met the minimum requirements except for the 3M membrane whose strain behavior was far lower than required.

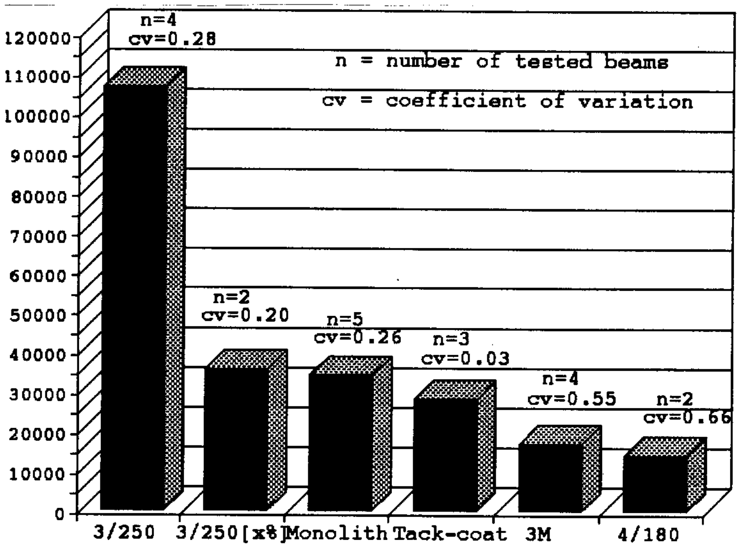

Figure 5 Summary of fatigue test results for all membrane types.

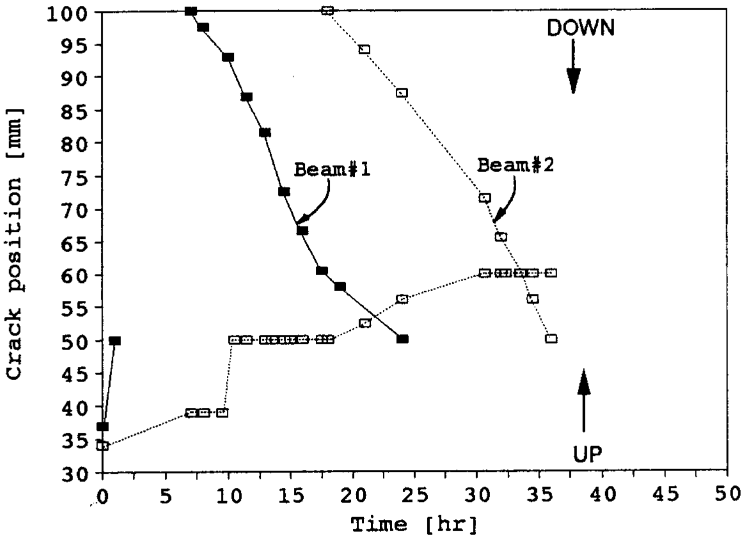

Figure 6 Crack position vs. wheel's travel time for beams with 3/250 membrane.

Accordingly, thefatigue life ratio obtained from the use of this membrane was very low - 0.60 . Furthermore, the qualities of the 4/180 membrane fulfilled all Koerner's requirements. As can been seen in Fig. 2 the tensile strain capacity of the 4/180 membrane was almost identical to that of 3/250 membrane. As can been seen in Fig. 3 the behavior of these membranes under shear was also almost identical (Kief et al ,1992)) and thus the difference in the fatigue life between the two membranes may stem from the difference in the thickness of the membranes. As can been seen in Fig. 7 there is an exponential relation between the amount of the modifier and the softening point. Thus the difference in the fatigue life between the 3/250 membrane and the 3/250[x%] membrane may stem from the difference in the reduced modifier amount in the membranes. As shown before, the laboratory simulation indicated that the use of membranes which meet accepted criteria can lead to significant retardation of reflection cracking (the 3/250 membrane), but also to earlier fatigue failure than expected in a conventional 50mm. asphaltic overlay layer (3M and 4/180 type membranes).

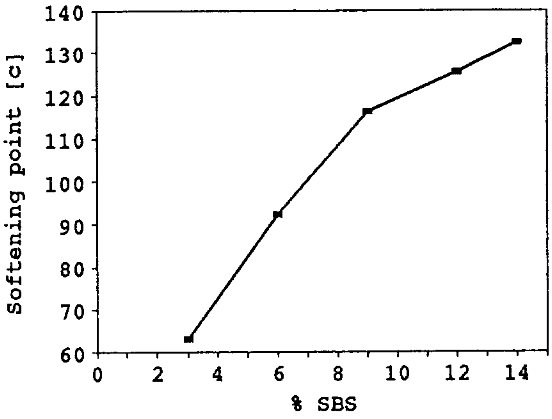

Figure 7 Modifier amount vs. softening point

5 THE ANALYTICAL MODEL

Parallel to the experimental system, an analytical finite element model was also developed (Altus et al ,1992). It aims toward finding the correct material and geometrical variables that will lead to the maximum resistance to fatigue failure of the composite structure. For simplicity the materials are analyzed as linear elastic. It was found that the K_I value, Stress Intensity Factor (SIF), is a function of the following basic parameters: Membrane layer thickness (0, 2, 4mm.), stiffness (10, 15, 20MPa), and crack length (a=30-46 by 4mm). All layers were in full contact and the model was symmetric.

The effect of membrane layer thickness on K_I is seen in Fig. 8. The influence of the soft membrane layer is pronounced only when the crack tip is close enough to the interface, meaning that the strengthening effect will not be seen for small cracks.

The effect of membrane layer stiffness on K_I is seen in Fig. 9 for t=4mm. As above, the influence is pronounced for large enough cracks. Moreover, the stiffness of the soft layer must be much lower then the asphalt concrete in order to have a significant effect.

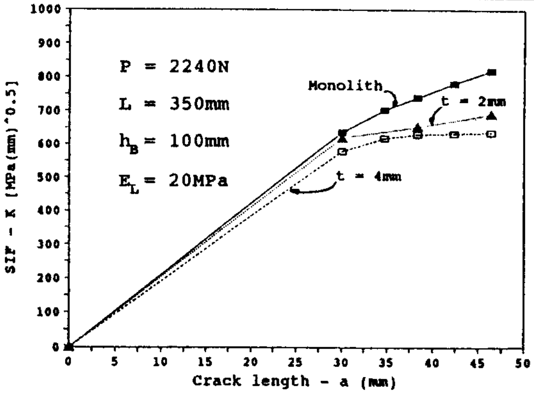

Figure 8 Effect of membrane thickness on K_I

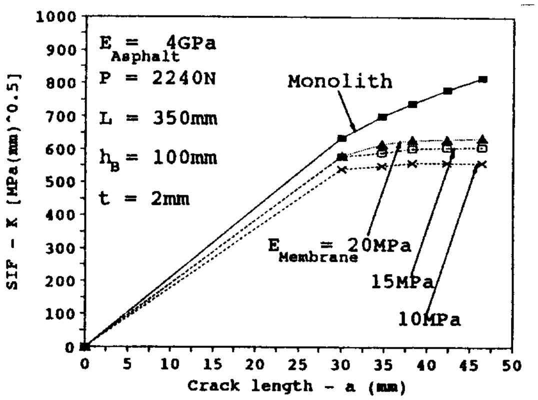

Figure 9 Effect of membrane stiffness on K_I

6 CONCLUSIONS

The following are the major conclusions derived in this work:

1. It is difficult to determine in advance the performance quality of a certain membrane without conducting preliminary fatigue tests.
2. the fatigue life of an asphaltic overlay is a function of the membrane's characteristics; including its modulus of elasticity, (i.e., a membrane with a low strain capability significantly decreases the fatigue life) its thickness, (i.e., the thicker the membrane the shorter its fatigue life) for two membranes with identical strain capacities, and the amount of the modifier in the bitumen mass, (i.e., the same membrane with a lower amount of modifier significantly decreases the fatigue life).
3. It was found that "sandwich" beams with the 3/250 membrane (composed of polymer-modified asphalt and reinforced with polyester geotextile fabric) presented by far the highest potential for crack retardation as compared to monolithic beams, tack-coated beams, or beams with inferior membranes.
4. The interpreted analytical model successfully defined the quantitative relationships between the testing and material variables and the rate of crack propagation. It clearly showed that the soft membrane layer in the interface cane significantly reduce (at given conditions) the Stress Intensity Factor, and thus increase the pavement potential for crack retardation.

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