Report Number 97-20

MINNESOTA DEPARTMENT OF TRANSPORTATION

MnROAD
Office of Minnesota Road Research

PB98-128374

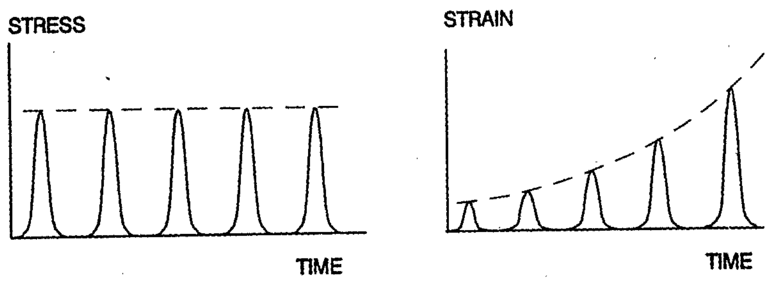

Figure 4. Schematic example of stress and strain behavior in a controlled stress mode of loading fatigue test.

Asphalt Mixture Laboratory Tests

Finnish National
Road Administration

Technical Research
Centre of Finland

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
MN/RC - 97/20		

4. Title and Subtitle	5. Report Date
ASPHALT MIXTURE LABORATORY TESTS	February 1997
	6.

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

11. Contract (C) or Grant (G) No.

12. Sponsoring Organization Name and Address

Minnesota Department of Transportation
395 John Ireland Boulevard Mail Stop 330
St. Paul, Minnesota 55155

13. Type of Report and Period Covered

Final Report - 1996 to 1997

14. Sponsoring Agency Code

15. Supplementary Notes

This report has also been published as Research Report nr. 395 by the Technical Research Centre of Finland.

16. Abstract (Limit: 200 words)

Technical Research Center of Finland (VTT) conducted wheel tracking and fatigue tests of Minnesota Road Research Project (MnROAD) bituminous mixtures as a result of the cooperation between Finnish National Road Administration (FinnRA) and Minnesota Department of Transportation (Mn/DOT). FinnRA funded the tests.

MnROAD, Mn/DOT's pavement testing facility, sent raw materials (aggregates and binders) and ready- made mixtures. In spite of the differences between Mn/ROAD and Finnish mixtures, the rutting of Mn/ROAD mixture measured by wheel tracking device was similar if compared to a dense graded mixture with binder of similar penetration. The Mn/ROAD mixture with low stiffness binder deformed much more and tested outside the Finnish specifications. However, it may be successful in Minnesota because of smaller axle loads.

The fatigue properties in strain control tested about the same as corresponding Finnish bituminous mixtures. However, the behavior in stress mode was different. The MnROAD fatigue line tested flatter than any Finnish bituminous mixture with straight run bitumen, and only some with polymer modified bitumen were similar. The report recommends careful analysis of the fatigue properties of Mn/ROAD pavement performance.

17. Document Analysis/Descriptors	18. Availability Statement
Mn/ROAD bituminous FinnRA wheel tracking asphalt rutting fatigue properties	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

ASPHALT MIXTURE LABORATORY TESTS MINNESOTA ROAD RESEARCH PROJECT (Mn/ROAD)

Final Report

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COMMUINITIES AND INFRASTRUCTURE
Road Engineering and Geotechnology

February 1997

Published by:
Minnesota Department of Transportation
Office of Research Administration
200 Ford Building
Mail Stop 330
117 University Avenue
St. Paul, MN 55155

EXECUTIVE SUMMARY

The Minnesota Department of Transportation (Mn/DOT) and Finnish National Road Administration (Finnra) have cooperated for several years. Both organizations work on the areas of cold climate, which gives a very good background to the cooperation.

The Minnesota Road Research Project (Mn/ROAD) is the largest Test Road since AASHO Road Test in 1958-60. It is obvious that one part of the cooperation would take place in connection to this Test Road. In Finland the Technical Research Center (VTT) is the main road research laboratory participating into the cooperation. The corresponding institute in Minnesota is the University of Minnesota (U of M).

In the early stage of the cooperation several visits were made on both sides. Some researchers from Minnesota have made three visits to Finland, one of those visits in the cooperation with the Finnish Pavement Research Programme (ASTO). Several researchers from Finnra, VTT, and the University of Oulu have visited the Mn/ROAD project.

The practical actions of the cooperation have been the exchange of some measuring instruments and instrumentation expertise. Thus Mr. Jari Pihlajamäki spent two months at Mn/ROAD in 1993 installing AC-response strain gages using retro-fit techniques and analyzing the basic data of those instruments.

The main effort this far has been the Fatigue and Wheel Tracking Tests of bituminous materials used at Mn/ROAD. These tests were funded by Finnra and they were carried out by VTT, because VTT has appropriate facilities. Mn/DOT sent the raw materials for two bituminous mixtures and one ready-made mixture.

This research report is the final report of those tests. The tests were supervised by Mr. Seppo Salmenkaita from Finnra, Mr. David Johnson from Mn/ROAD, and professor David Newcomb from U of M. At VTT Mr. Matti Huhtala was responsible for the tests. Mr. Harri Spoof performed the fatigue tests. Ms. Leena Saarinen made the general mixture and material analysis and performed the wheeltracking tests. This report is written at VTT by Matti Huhtala, Harri Spoof, Pekka Halonen and Leena Saarinen.

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CHAPTER 1: INTRODUCTION

During the ASTO-project (The Finnish Asphalt Pavement Research Programme) Technical Research Center (VTT) could considerably develop its research equipment used for bituminous material research. The development started from the preparation of samples (mixing, spreading, compaction). Besides the routine equipment the most important laboratory equipments are wear resistance by studded tires, static and repeated loading creep, wheeltracking and fatigue devices. Especially the measurement of permanent deformation and fatigue properties of bituminous mixtures demand special devices which are not available in every research laboratory.

The permanent deformation properties can be measured with Marshall-test, static and repeated loading creep and wheel-tracking tests. Marshall test is very simple and widely used in bituminous mixture design. Creep tests measure a clear material property but this basic property is not always well related to the rutting on the road. Wheel-tracking test demands a special device which simulates the situation on the road. A truck tire or more often a smaller tire which has, however, the same contact pressure is driven on the bituminous mixture and rutting is measured. The wheel-tracking test is not standardized. The sample size at VTT wheel-tracking test is larger than in any other routine test device, which makes the results more realistic.

When a truck moves on a road the bituminous course bends under it. Repeated bending causes fatigue cracks. The phenomenon is basically the same in metals like steel or aluminum.

Bending can be caused in laboratory by bending a bituminous beam with three or four point fixing or having the bituminous mixture beam on a rubber support and a vertical force cause bending in the middle of the beam. This set-up is realistic and simulates well the phenomenon. VTT uses six beams simultaneously which make the test time reasonable.

This report describes the bituminous mixture laboratory tests of two material used at Mn/ROAD. The materials are handled in chapter 2, permanent deformation in chapter 3, fatigue tests in chapter 4 and the results and discussion in chapters 5 and 6.

CHAPTER 2: MATERIALS AND COMPACTION

Materials

Three different asphalt mixtures used in Minnesota Road Research Project (Mn/ROAD) were sent to VTT in Finland for laboratory testing (Table 1). One mixture was sent as a "Ready Made" asphalt mixture (~450 kg in 24 barrels). This mixture was used in the fatigue tests. The other two mixtures were sent as raw materials. There were three different aggregates (~450 kg in 20 barrels) and two different bitumens (1 barrel each). These two mixtures were used in the deformation (rutting) tests.

Table 1. Materials sent from Mn/ROAD to VTT for laboratory testing.

MATERIAL	TYPES	NUMBER
Aggregates	BA 001 BA 002 BA 003	13 pcs 5 pcs 2 pcs
Mixtures	BM 001	24 pcs
Bitumens	AC 001 (AC 20) AC 002 (120/150)	1 pc 1 pc

The "Ready Made" mixture was extracted in order to get bitumen content, grading curves and bitumen penetrations (Table 2 and Figure 1).

Table 2. Binder tests made at VTT.

Ready made mixture:	Binder content (%) Penetration (25°C, 0.1 mm) Ring and ball softening point (°C)	5.9 63 49
Raw materials:	Penetration (25°C, 0.1 mm), AC 001 Penetration (25°C, 0.1 mm), AC 002	69 110

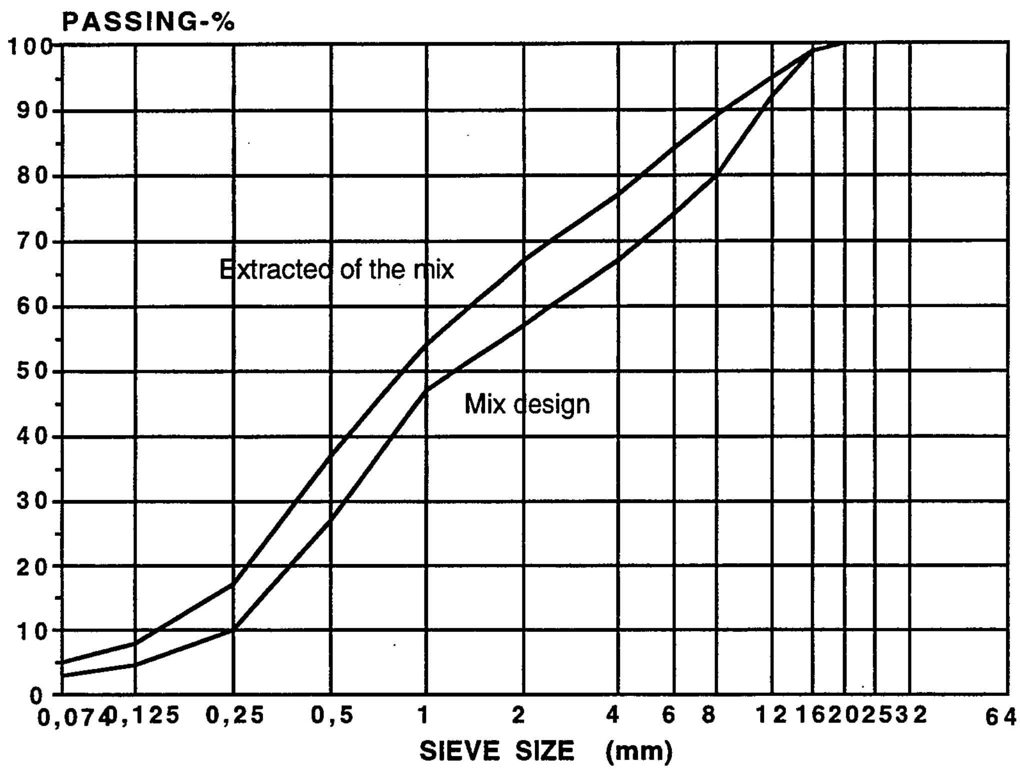


Figure 1. Grading curves of the mix design aggregate and the aggregate extracted from the mixture.

Compaction tests

Compaction tests where made by using three different compaction methods. The traditional Marshall method, the Finnish ICT-gyratory compactor and the VTT steel-tired roller slab compactor. More details of the equipments are presented in appendix 1.

Fatigue mixture compaction tests

Compaction tests of the "Ready Made" mixture were made in the gyratory compactor with a different number of revolutions (200-400 r.) and with the Marshall method (2*50 & 2*75 blows). Compaction temperature was 150°C. Target void content was 4.0%. Results of the compaction test for the "Ready Made" mixture is presented in Table 3.

Table 3. Results of the compaction tests for the "Ready Made" mixture.

Mixture properties	ICT gyr 200 r	ICT gyr 400 r	ICT gyr (400 r) weight/water	Marshall 2 x 50	Marshall 2 x 75
Bulk density, kg/m^3 Max. density, kg/m^3 Void content, %	2330 2456 5.1	2350 2456 4.3	2370 2456 3.5	2296 2456 6.5	2337 2456 4.8

After the compaction tests, slabs where made of the mixture. The sample size was 32 kg mixture for the slabs (500*420*60 mm) used in the fatigue tests. The "Ready Made" mixture was heated to 155-160°C and mixed in VTT:s laboratory mixer (appendix 1). Then the mixture was spread directly to a plywood-mold where it was compacted using the VTT steel-tired roller slab compactor (appendix 1). Compaction temperature was 135-140°C.

There were some problems in the beginning of compacting the mixture. The mixture did not compact adequately. The problems where solved by increasing of the amount of compaction passes from 20 to 30 passes. After 7.5...7.9 % of air void content was reached for the "Ready Made" mixture slabs. The result corresponded to the values (~7%) from the field tests made in Minnesota.

Compaction tests of deformation mixtures

A mix-design was made based on the Mn/ROAD information. Material proportions based on the mix-design are presented in Table 4. Aggregate gradation curves where the same for both mixtures (Figure 1).

Table 4. Material proportions based on the mix-design results.

Aggregates:	BA 001 BA 002 BA 003	74 % 16 % 10 %
Bitumens:	AC 001 (AC 20), High Stiffness AC 002 (120/150), Low Stiffness	5.3 % 5.9 %

Compaction tests of the two "Rutting Test" mixtures were made in the ICT-gyratory compactor with a different number of revolutions (80-400 r.). Results are shown in Table 5.

Table 5. Results of the compaction tests for the "Rutting Test" mixtures.

Mixture properties	ICT gyr 80 r	ICT gyr 200 r	ICT gyr 400 r	ICT gyr (400 r) weight/water	Voids (target)
HIGH STIFFNESS MIX:					
Bulk density, kg/m^3	2300	2350	2372	2394	
Void content, %	7.4	5.4	4.5	2.7	6.8
Binder content, w-%	5.3	5.3	5.3	5.3	
Density (aggr.), kg/m^3	2700	2700	2700	2700	
LOW STIFFNESS MIX:					
Bulk density, kg/m^3	2340	2375	2397	2400	
Void content, %	4.9	3.5	2.6	2.5	3.5
Binder content, w-%	5.9	5.9	5.9	5.9	
Density (aggr.), kg/m^3	2700	2700	2700	2700	

After the compaction tests, slabs were made of the mixtures. The sample size was 50 kg mixture for the slabs (700*500*70 mm) used in the deformation tests. The "Rutting Test" mixtures were heated to 155-160°C and mixed for 1 minute in VTT:s laboratory mixer (appendix 1). Then the mixture was spread directly to a plywood-mold where it was compacted using the VTT steel-tired roller slab compactor (appendix 1). Compaction temperature was 135-140°C. Normal VTT procedures were used (20 passes, 5 with vibration) in compaction. Results of air void content are presented in Table 6.

Table 6. Results of the compaction tests for the "Rutting Test" slabs.

Mixture	Void content	Target
High Stiffness Mixture, 5.3%	5.0 ... 10.0 (mean 7.3, n = 12)	6.8
Low Stiffness Mixture, 5.9%	3.0 ... 7.1 (mean 5.3, n = 12)	3.5

CHAPTER 3: DEFORMATION TESTS

Introduction

Rutting is one of the main problems of flexible pavements because of increased axle loads, tire pressures and heavy traffic. The need for permanent deformation resistant asphalt mixtures has significantly increased. Permanent (plastic) deformation is caused by heavy traffic especially at high temperatures. The possibility of deformation increases, when the traffic is slow and when the lateral distribution of vehicles is small.

Deformation properties of asphalt mixtures are tested in the laboratory at VTT by the Marshall method, static- and dynamic-creep tests or the wheel-tracking test. The wheel-tracking test is designed to simulate the heavy traffic loads on the road. The wheel-tracking test was used in this study .

Wheel-tracking test

In the wheel-tracking test an asphalt slab (700*500*70 mm) is loaded by a moving wheel (tire size 6.00 R 9) which moves forward and backwards over the slab. The device is located in a temperature chamber. A 10 kN wheel load, 0.7 m/s wheel speed and a test temperature of 30°C is used in the normal VTT procedure. The test runs for 14 000 passes which is approximately 6 hours. A laser device measures the cross profile from three different location of the slab at certain intervals. More details of the wheel-tracking device is presented in appendix 1.

Presentation of results

There are three different phases in the development of permanent deformation expressed as a function of the number of wheel passes:

- the initial stage when the slope of the curve quickly declines
- the part of the deformation profile when the slope remains quite constant
- the failure point (only if the mixture is poor).

Initial and total deformation is presented in Figure 2 as a function of wheel passes (no failure occurred).

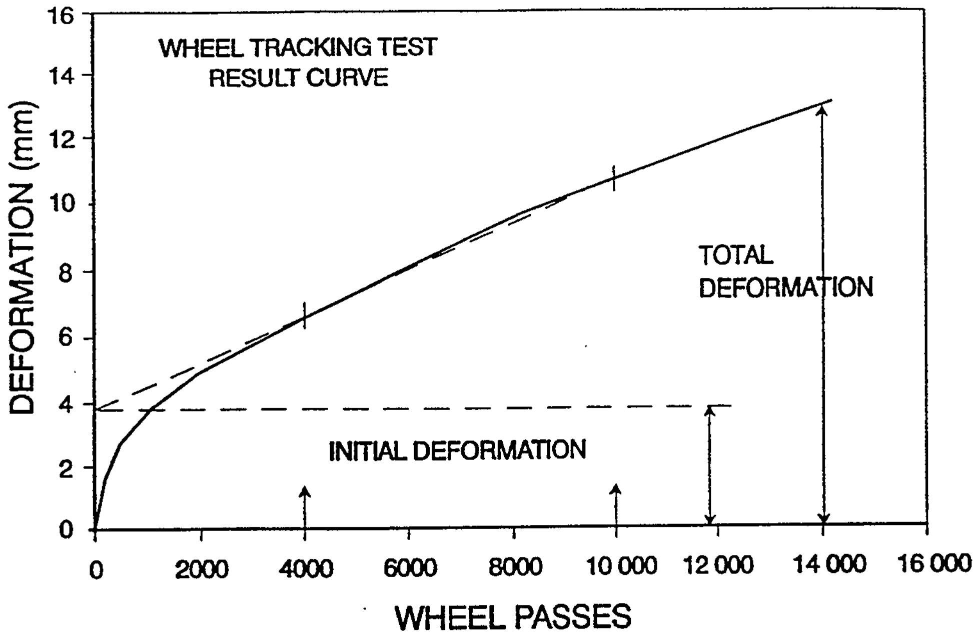


Figure 2. Schematic presentation of permanent deformation as a function of wheel passes.

Deformation test results

Mixture properties and wheel-tracking test results for the two "Rutting Test" mixtures are shown in Tables 7 and 8 and Figure 3.

Table 7. Mixture properties.

MIXTURE PROPERTIES:	High Stiffness Mixture	Low Stiffness Mixture
Binder content, w-%	5.3	5.9
Bulk density, kg/m^3 (ASTM D 2726, SSD)	2272	2301
Maximum density, kg/m^3 (modified ASTM D 2041 with shaker table)	2451	2430
Void content, % (ASTM D 3203)	7.3 (range 5-10)	5.3 (range 3-7)
VMA, vol.%	19	18
VFB, vol.%	61	71

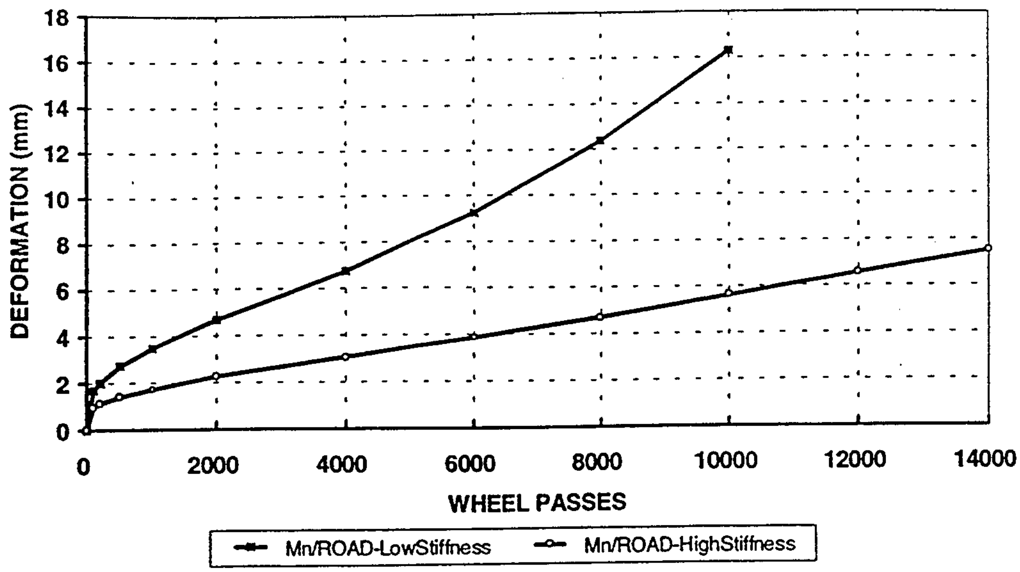


Figure 3. Rut depth progression during permanent deformation test, +30°C.

Table 8. Permanent deformation test results.

DEFORMATION RESULTS from the WHEEL-TRACKING TEST:	High Stiffness Mixture	Low Stiffness Mixture
- Initial Rut Depth, mm	1.4	~2
- Total Rut Depth, mm	6.1	(20
- Failure Time, number of wheel passes	-	~ 10000

The Low Stiffness Mixture failed during the test. After approximately 10000 passes the mixture started to crack and the test had to be stopped. The High Stiffness Mixture was significantly more deformation resistant with a total deformation of 6.1 mm. More detailed information about the test results are presented in appendix 2.

CHAPTER 4: FATIGUE TESTS

Introduction

Wheel loads caused by heavy traffic on the top of a asphalt pavement structure cause deflection of the pavement and induce stresses and strains at the bottom of the asphalt layer. These repetitive loadings will increase the deflections and decrease the pavement stiffness which will conduct increase in stresses and strains. After a certain number of load repetitions fine cracks will be initiated in the bottom of the asphalt layer. These cracks will propagate and penetrate through the whole asphalt layer until they are visual on the surface. This deterioration process is called fatigue. The fatigue criteria is applied in mechanistic design of asphalt pavement structures.

The repeated loadings can be simulated by laboratory tests. The test sample is loaded repetitively until failure occurs. Tests are usually controlled either with controlled stress or controlled strain mode of loading.

In the controlled stress mode of loading test, the load or stress is maintained constant during the whole test. That will effect an increase in the tensile strain in the bottom of the specimen during the test, due to decrease in material stiffness (Figure 4).

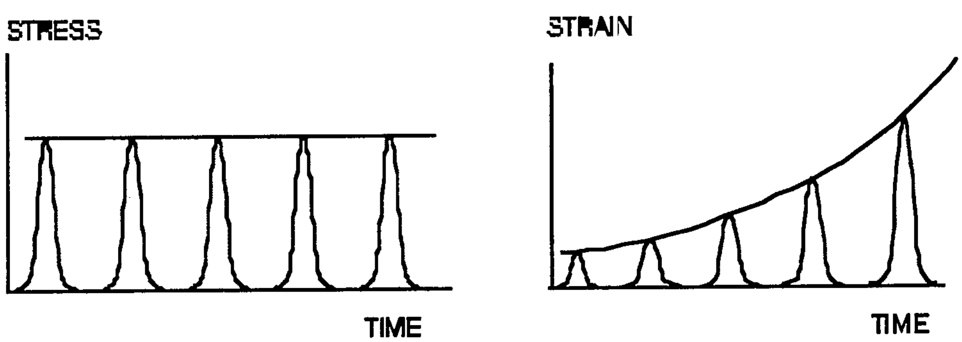


Figure 4. Schematic example of stress and strain behavior in a controlled stress mode of loading fatigue test.

In the controlled strain mode of loading test, where the tensile strain at the bottom of the specimen is maintained constant during the whole test, the behavior is different. The required load to generate a certain strain level will decrease during the test, due to decrease in material stiffness (Figure 5).

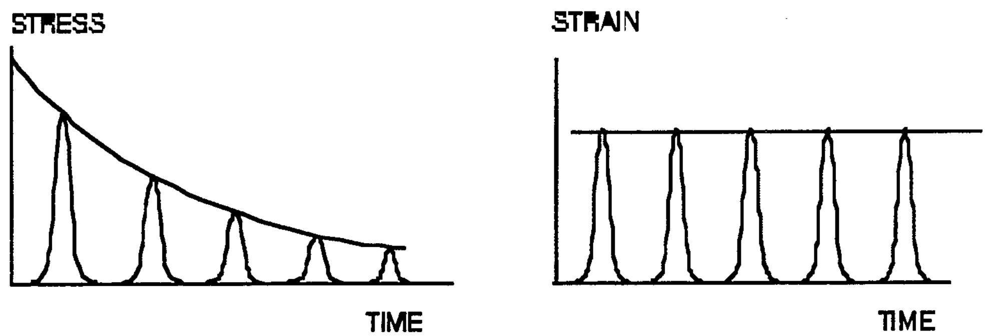


Figure 5. Schematic example of stress and strain in a controlled strain mode of loading fatigue test.

Because of the described material behavior, for a certain initial strain level, the maximum number of load repetitions to failure will be smaller for the controlled stress mode of loading test than for the controlled strain mode of loading test.

As above described the stress and strain relations are different in the various modes of loading. This is also the case out on the road in situ. Neither one of these two modes of loading will be exactly identical with the loading situation in the road under a moving wheel. That is why the tests always are made in both controlled stress and controlled strain mode of loading in the normal VTT fatigue procedure.

Fatigue test and equipment

Fatigue test equipment (appendix 1) is used for measuring the fatigue response of asphalt mixtures. The principle of the test is a center point loaded beam on a flexible rubber base. The beams (400*100*50 mm) are sawed out of slabs. The micro-computer controlled equipment is hydraulic and 6 independent tests can be done simultaneously.

Load is applied in the middle of the beam in 1 second cycles by using a loading plate. The haversine formed load cycle consist of 0.05 second loading time and 0.95 second rest period. During the rest period the rubber base returns the specimen back to its original stage.

On the specimens are two strain gages glued to detect failure and one to measure strain. Failure is defined as the number of load cycles when both strain gauges which detect failure are broken.

The equipment can be used either with controlled stress or controlled strain mode of loading. During the test computer stores data from applied force, measured strains and stiffness modulus. 6 - 10 test beams are needed to form a fatigue curve.

Presentation of results

Results form the fatigue tests are presented as equations and graphs. The fatigue equation is presented in formula 1.

$$N = a^{*} \left(\frac{1}{\varepsilon} \right)^{b} \qquad (1)$$

where	N	=	number of load cycles to failure
		=	initial tensile strain, µm/m
	a, b	=	material constants

In graphs fatigue results are presented in double logarithmic scales (Figure 6). The initial tensile strain (µm/m) is on the vertical axis and the number of load cycles to failure on the horizontal axis (appendix 3). All the points in the figures are representing one test specimen. The objective in the normal VTT fatigue procedure is to run the tests as follows:

- to get one specimen to last slightly more than one thousand load cycles
- to get one specimen to last about one million load cycles
- to get the rest of the specimens to last between one thousand and one million load cycles, until the number of specimens will be enough for establish a fatigue line.

Determination of the initial strain level is depending on the mode of loading of the test. The initial strain level in the controlled strain mode of loading is equal to the controlling strain level. In the controlled stress mode of loading it will be different because of the change in strain values during the test. In the normal VTT fatigue procedure the initial strain level is fixed to the strain value for load cycle number 200. This is due to the reason that there may be some instability in the beginning of a test. To be sure of equipment stability and to avoid problems in the determination of the initial strain value, it has been decided to use the load cycle number 200 as an initial stage.

After a sufficient number of tested specimens, usually between 6 and 10, the fatigue line will be calculated using normal linear regression techniques. The material constants (slope and position of the line) as well as information about correlations and deviations for the tested mixture will be obtained from these calculations.

Results

The Mn/ROAD "Ready Made" asphalt mixture was tested in the VTT fatigue equipment. It is also indicated as a "Low Stiffness Field Mixture". More details about the mixture are presented in chapter 2. The mixture was sent from Minnesota to VTT. After that the mixture was heated, mixed and compacted to slabs. Beams where sawn from the slabs, strain gauges where glued on the beams and the beams were ready for the test. Test were made in both stress and strain controlled mode of loading in two different temperatures, +15°C and +5°C. The results from the tests are presented in Figures 6-7 and Table 9. More detailed results are presented in appendix 3.

Table 9. Material constants and correlation coefficients from the fatigue tests for Mn/ROAD "Ready Made" low stiffness field mixture.

Mode of Loading	STRESS CONTROL			STRAIN CONTROL		
Temperature	log a	b	R	log a	b	R
+ 15°C	32.74	10.55	0.92	31.30	9.27	0.98
+ 5°C	27.43	9.44	0.97	28.77	9.12	0.99

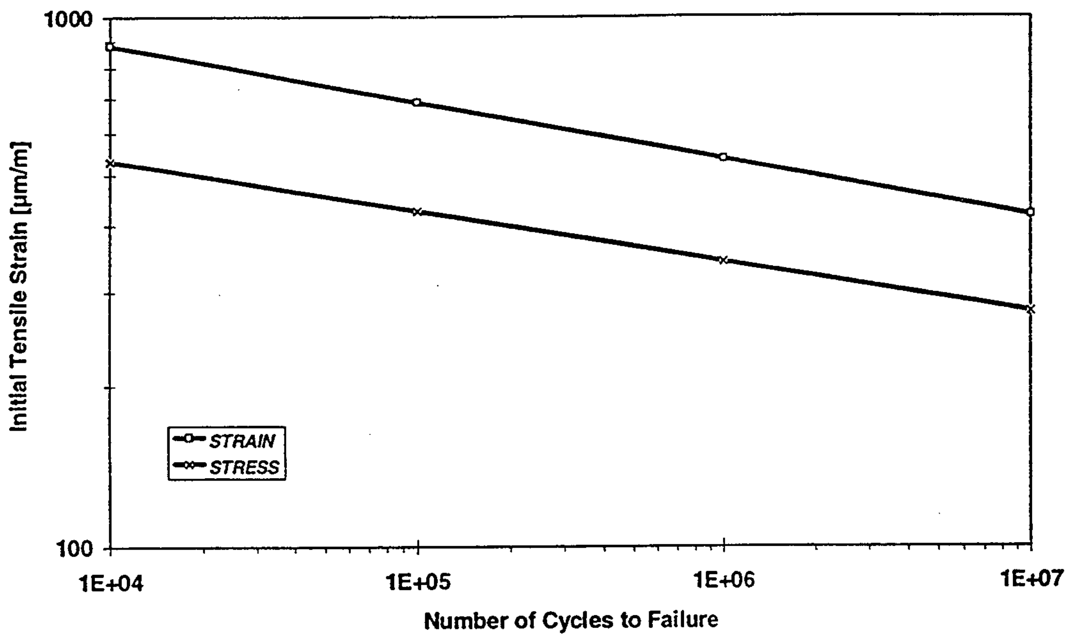


Figure 6. "Ready Made" low stiffness field mixture fatigue test results, +15°C.

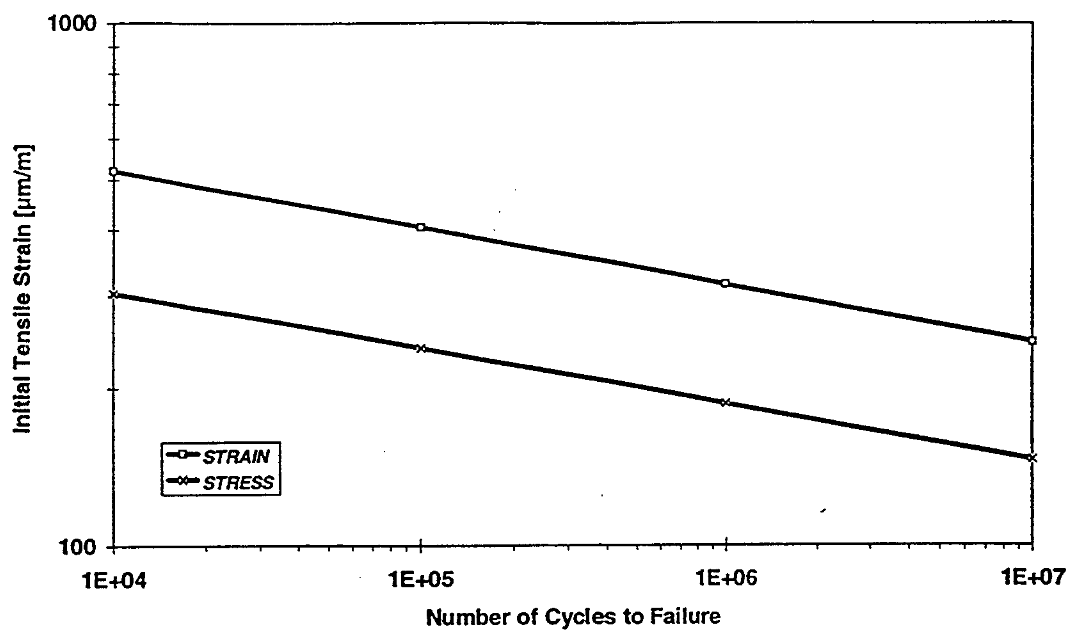


Figure 7. "Ready Made" low stiffness field mixture fatigue test results, +5°C.

CHAPTER 5: DISCUSSION

Permanent deformation

The deformation results are presented in Figure 3 and in Table 6. It can be seen in Figure 3 that the deformation of Mn/ROAD High Stiffness mixture (lower curve) develops first rapidly during the first 200 passes (the initial deformation which may be mainly postcompaction) and after that reasonably straight. That is a typical behavior in the wheel-tracking test.

Mn/ROAD Low Stiffness mixture (higher curve in Figure 3) behaves in a very different way. There is first similar but greater initial deformation and then there is a straight part up to about 6000 passes. After about 6 000 passes deformation accelerates or the curve bends upwards. The test has been interrupted at 10 000 passes. This kind of curve means that the mixture has failed, the test has been too severe for that mixture.

The Mn/ROAD mixtures are compared in Figures 8 and 9 to some Finnish bituminous mixtures.

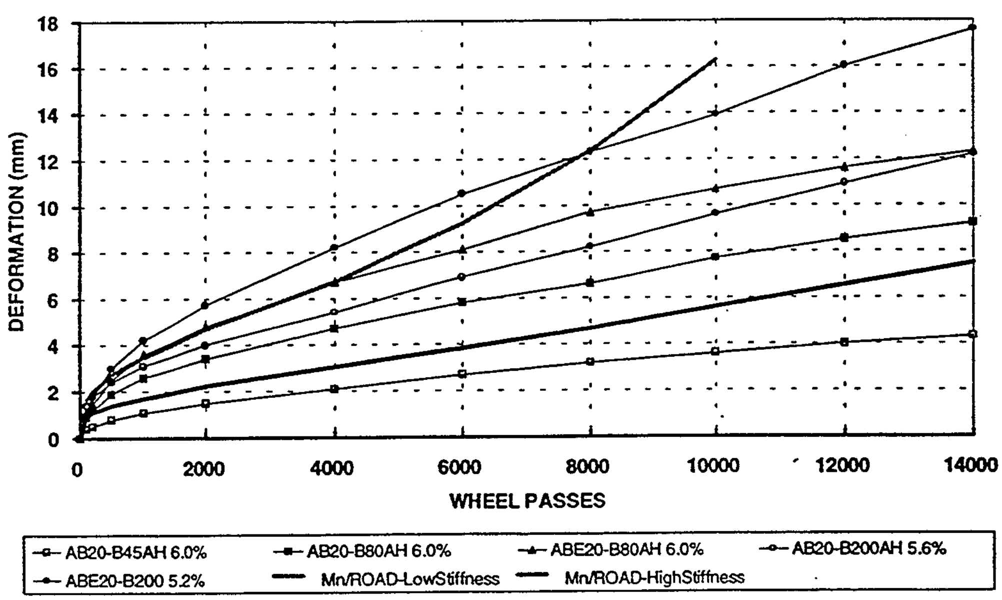


Figure 8. Comparation of deformation of mixtures, +30°C.

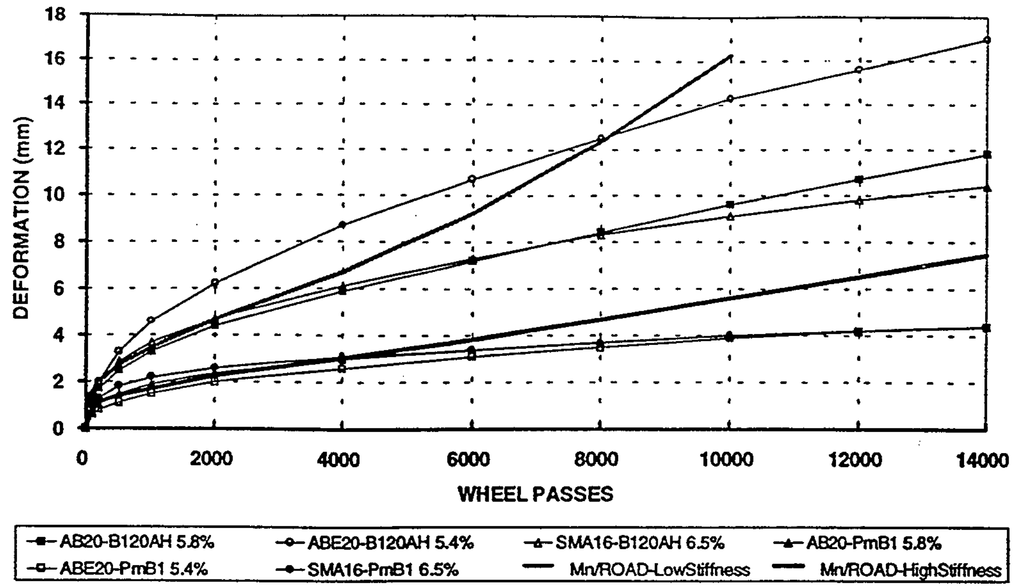


Figure 9. Comparation of deformation of mixtures, +30°C.

The abbreviations are:

- AB is dense graded asphalt concrete
- ABE is gap graded asphalt concrete
- SMA is stone mastic asphalt
- number after it is the maximum grain size in millimeters
- B45, B80, B120 and B200 are binders with respective penetrations
- AH is straight run bitumen from Saudi-Arabia, trade mark Arabian Heavy
- PmB1 is polymer modified bitumen number 1 (trade mark)
- percent presents binder content

Gradation envelopes are presented later in Figures 10 - 12.

The deformation curve of the Mn/ROAD High Stiffness mixture lies between the Finnish dense graded mixtures with bitumens B45 and B80. The softer bitumen B200 has naturally deformed more. Because the penetration of the binder in the other Mn/ROAD mixture is about 80, this Mn/ROAD mixture is more deformation resistant than the Finnish mixture with the same kind of binder. The reason is that more compaction work has been used. The Finnish mixtures have usually very low void content, 2 percent is a typical value.

The gap graded mixtures deform more than dense graded mixtures. They are good against studded tires because they have more coarse aggregates.

The Mn/ROAD mixtures are compared to the Finnish SMA and polymer-modified mixtures in Figure 9. The best mixtures are two polymer modified mixtures with very different grading curves or in that case aggregates have very little effect to deformation but the binder is decisive. The deformation properties of SMA and gap-graded mixtures are about the same if the binder is of the same penetration. The gap-graded with the softer bitumen is the worst.

The Mn/ROAD Low Stiffness behaves like the comparable AB20-B120 (about the same penetration) in the beginning but after 2000 passes it starts to deform more. Thus it has relatively good initial deformation capacity but after some deformation the aggregates move slightly, there may be some decompaction and mixture looses some of its stability.

Aggregates and mixtures are divided into performance classes I - IV in the Finnish Asphalt Specifications /1/. The permanent deformation classes are presented in Table 10. According to that classification the Mn/ROAD High Stiffness mixture would be in the class II and the Mn/ROAD Low Stiffness would be outside the classification.

Table 10. Permanent deformation classes of compacted paving mixes in Finland /1/.

Permanent deformation class	Rut depth in laboratory test Wheel tracking test, PANK 4205		Repeated loading creep test PANK 4208 Permanent strain (%)
	Initial rut depth (mm)	Final rut depth (mm)	
I	£ 1.0	£ 4.0	£ 2.0
II	£ 1.5	£ 8.0	£ 3.5
III	£ 2.0	£ 12.0	£ 5.0
IV	£ 3.0	£ 16.0	£ 6.5

These classes are not directly connected to the amount of traffic but the designer of the bituminous mixture must judge it. SMAs and good quality asphalt concretes are usually in class I, normal asphalt concrete in class II but in certain cases also in class III like the reference mixture of the ASTO Asphalt Pavement Research Programme (permanent deformation about 10 mm). Gap graded mixtures are usually in class III. Polymermodified mixtures fall usually in class I.

The mean annual temperature in Minnesota is about the same as in Finland but the summers are warmer and winters colder. The axle loads in Minnesota are smaller than in Finland (11.5 tons in certain cases on driving axle, 10 tons on single axle, 18 tons on tandem axle). Thus it is likely that the Low Stiffness mixture is good in Minnesota but would not be in Finland.

The grading curve of Mn/ROAD mixtures are presented in Figure 1 and the envelopes of the grading curves of the Finnish dense graded, gap graded and SMA mixtures in Figures 10 - 12. The Mn/ROAD mixture is very different from any Finnish mixture, there is much more sand (0.25...1.0 mm) than in the Finnish mixtures. It makes the compaction more difficult and their void content is much greater, 5.3 and 7.3 percent (Table 6) than the Finnish mixtures which often lies around 2 percent.

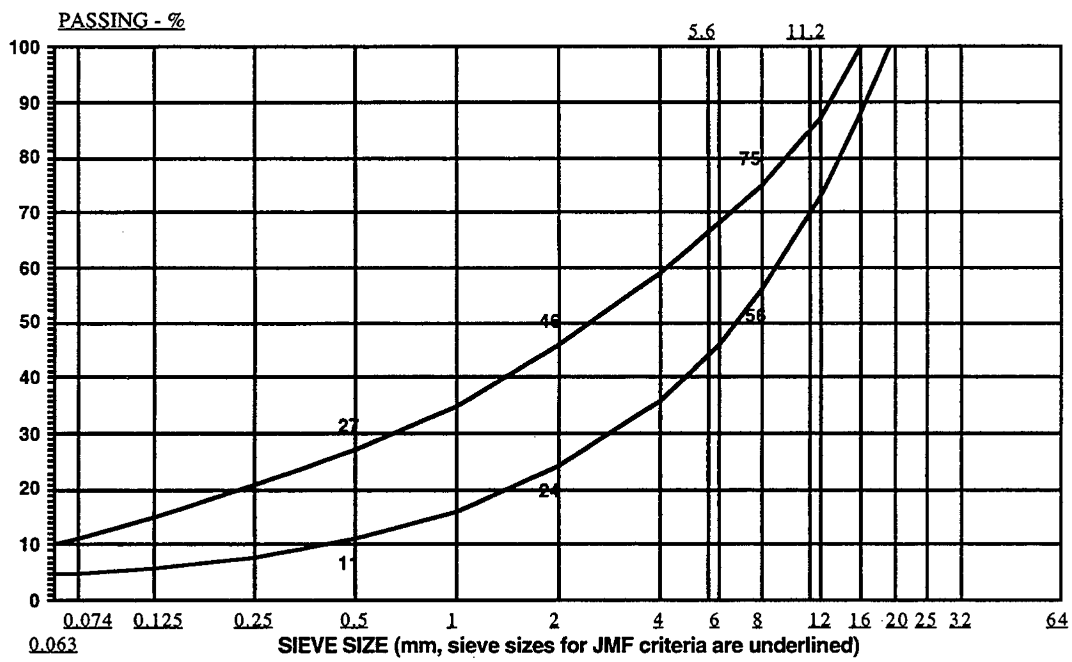


Figure 10. Gradation envelope of Finnish asphalt concrete AC16.

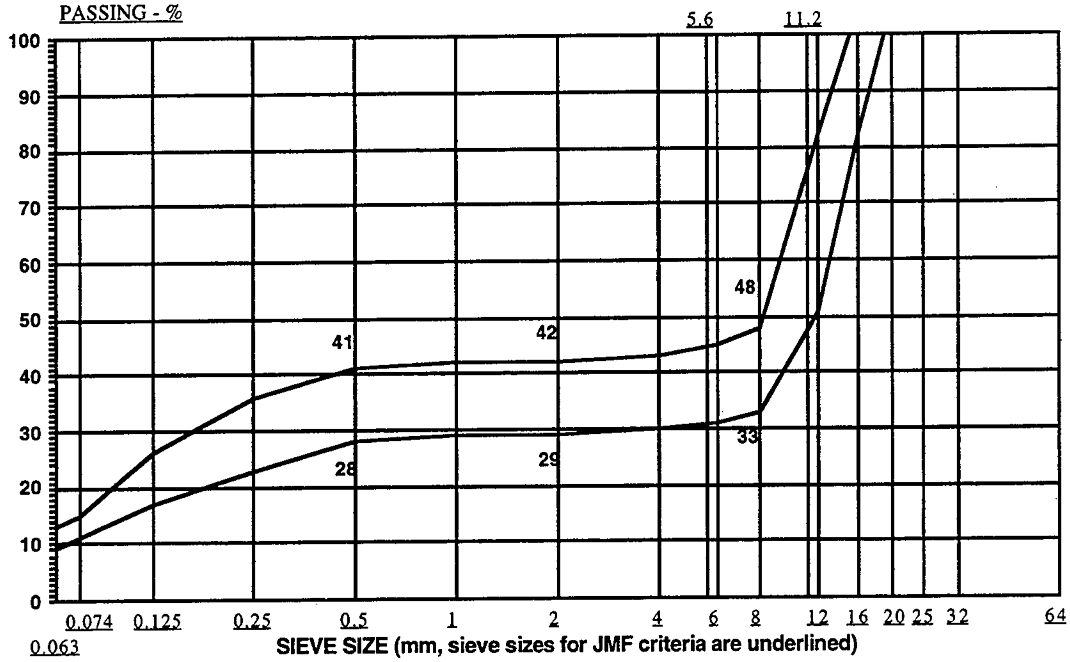


Figure 11. Gradation envelope of Finnish gapgraded asphalt GAC16.

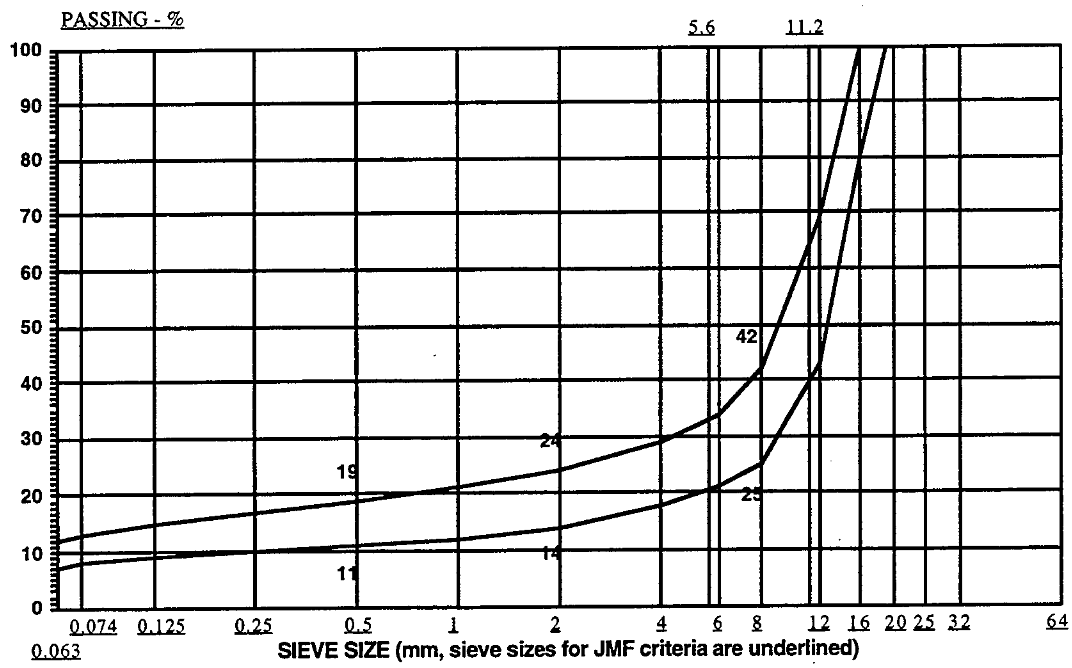


Figure 12. Gradation envelope of Finnish stone mastic asphalt SMA16.

The measured and calculated laboratory results are presented in Table 7. Voids in mineral aggregate (VMA) are 18 and 19 percent, typical values for the Finnish mixtures are 14-15 percent. Voids filled with bitumen (VFB) are 61 and 71 percent while the Finnish values are often 80 - 90 percent.

Compaction of Mn/ROAD mixtures was more difficult both in gyratory compactor and when slabs were made. The compaction properties were also clearly different from the mixes used in Finland. Not only compaction (density) is measured but also shear force (or more exactly shear moment) is measured during the gyratory compaction. The development of shear during the compaction of Mn/ROAD mixtures was different. The shear force usually increases and then decreases (Figure 13). If the decrease is very remarkable there may be later difficulties with permanent deformation (curve A in Figure 13). The shear forces in Mn/ROAD mixtures did not decrease (Figure 14) but kept more or less constant during the compaction (compare to curve C in Figure 13).

Shear forces cannot be interpreted well. If the force decreases too much the permanent deformation properties may be poor. As the force decreases it may mean that the coarse aggregates have found their stable positions and after that the only compaction happens within fine aggregates. Mn/ROAD mixtures has so much sand that the coarse aggregates mainly do not touch to each other and thus there is no change in compaction itself.

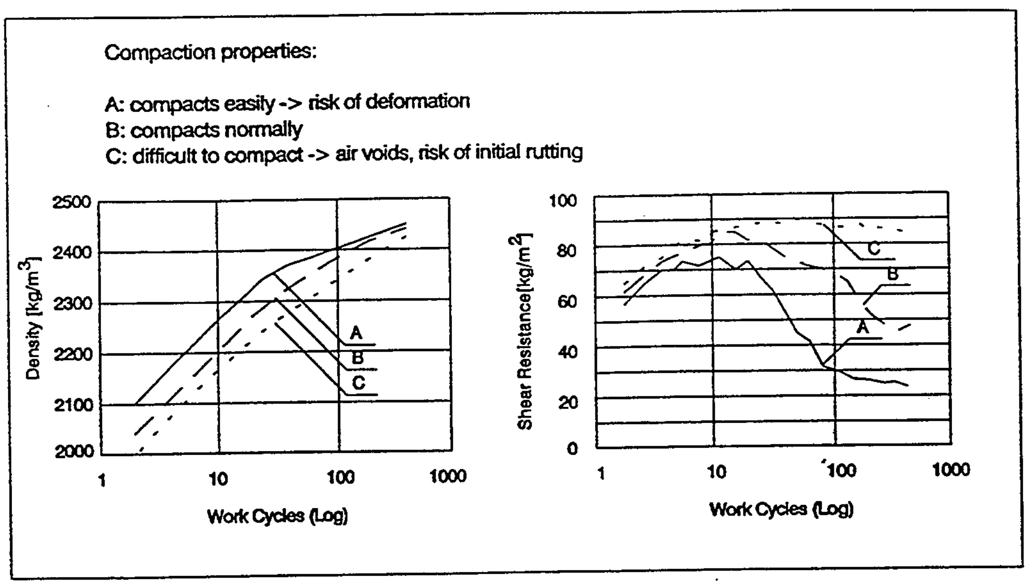
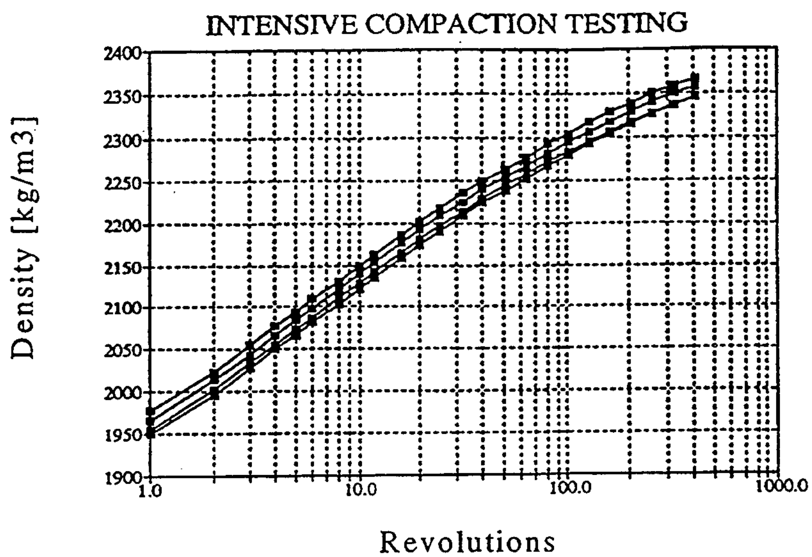


Figure 13. Schematic example of the development of shear and density during gyratory compaction of asphalt mixtures.

Thus the Mn/ROAD mixtures are clearly different from any Finnish mixtures. Asphalt mixtures have usually long traditions and later it is difficult to know the reasons for the development of the mixtures. The Finnish mixtures have typically been very dense and void content low. The reason has been to make mixtures which tolerate well the Finnish climate; water does not penetrate into the pavement. The control of quality has mainly based on the control of void content. Later the wear caused by studded tires was counteracted with good quality of coarse aggregate; there should be as much as possible coarse aggregate which lead to great maximum grain sizes and gap graded mixtures. The permanent deformation properties became important later. The Finnish aggregates are usually relatively rough on the surface. The availability of good quality aggregates has been good until the present time except for only certain areas. The maximum temperatures may be relatively high but only during short periods. It is usually during the vacation time when the amount of heavy traffic is at its lowest.

It is clear that the Mn/ROAD mixtures have also long traditions but it is unknown to us. The reason for the use of relatively high amount of sand may be due to the poor availability of the aggregates and based also on clear economical reasons.



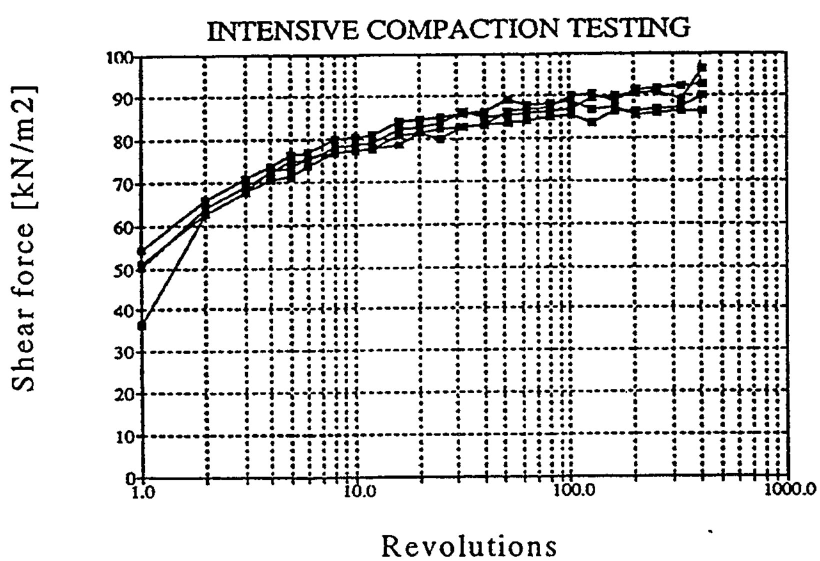


Figure 14. Development of shear and density during compaction of Mn/ROAD asphalt mixture.

Fatigue properties

The results of fatigue tests are presented in Figures 6 and 7. In spite of the difficulties in compacting the results are good; nicely on the straight lines (correlation coefficients 0.92 - 0.99, Table 9). Only from six to seven samples were needed for reliable results.

As temperature is warmer, in this case 15 °C, the lines are at higher position than in lower temperatures, in this case 5 °C. The difference between these lines is very typical.

Because of the nature of stress and strain control the fatigue curve from strain control tests are higher. The difference of strain and stress controlled samples is same kind as in normal Finnish bituminous mixtures.

Strain control fatigue curves are compared to several Finnish mixtures in Figure 15. The Mn/ROAD mixture is very close to the Finnish AB20-IV B-120 AH 5,8 %. The abbreviations have been explained earlier in chapter 5.1. AB20-IV is used in our previous Asphalt Specifications and means that mixture is dense graded, the grading curve lies well within the present grading envelope. IV mixtures have been the most common dense graded mixtures in Finland.

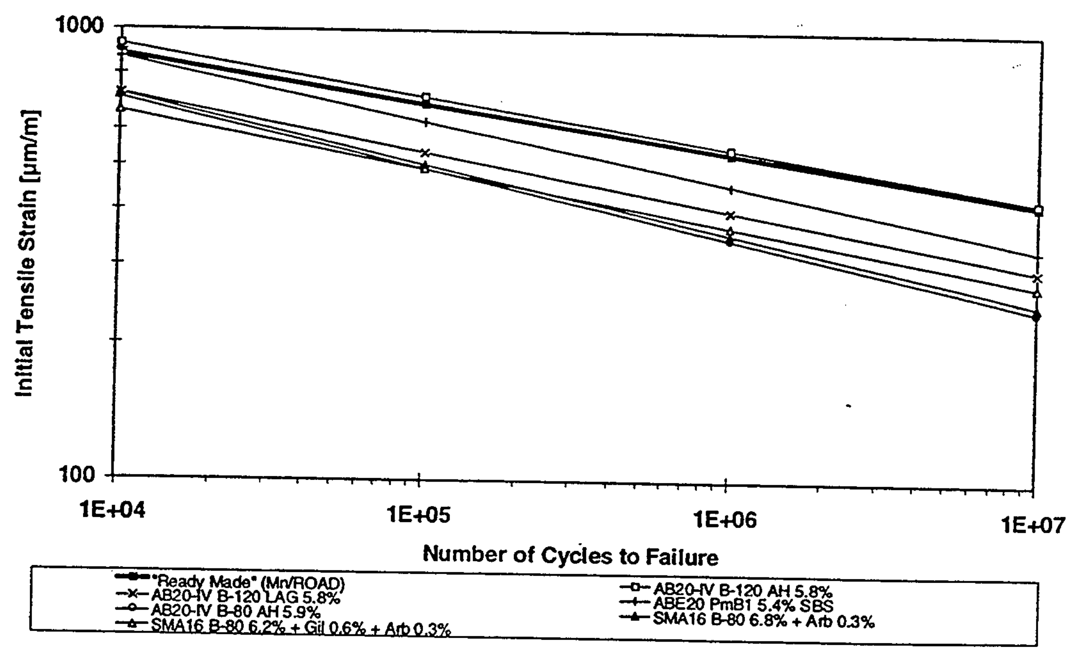


Figure 15. Comparation of fatigue properties of mixtures (strain-control), +15°C.

AB20-IV B-120 LAG 5.8 % is the same mixture as the previous one, but the binder is from Venezuela, trade mark Laguna. Thus simply the origin of bitumen may have relatively great effect on the fatigue properties.

If the binder is harder the fatigue curve is lower like the AB20-IV B-80 AH (the temperature has the same effect). SMAs with Arbocel (fibers) and Gilsonite (natural bitumen without fines) make the mixtures stiffer and fatigue curves lower. There are many kind of polymer modified bitumens and often they behave in very different way compared to straight run bitumens. In this case they have behaved like straight run bitumens but are lower.

Stress control fatigue curves are compared to several Finnish mixtures in Figure 16. The fatigue line of the Mn/ROAD mixture is flatter and close to polymer modified bitumen, while the other lines are well comparable to the stress control lines.

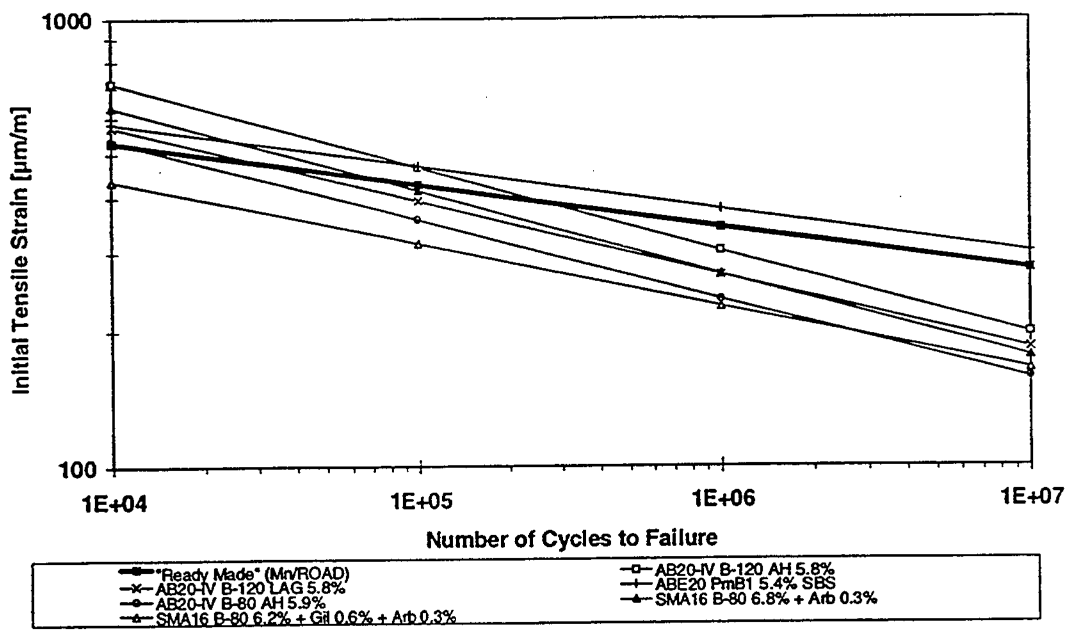


Figure 16. Comparation of fatigue properties of mixtures (stress-control), +15°C.

The slope of the curve is related to the power in so-called fourth power rule which is used in estimating the effects of different axle loads to the pavement performance. The inverse of the regression coefficient is close to that but it must be kept in mind that there are other factors which have effect, like stress dependency of unbound materials and subgrade, dynamic loadings, the criterium for the cracking and the final state of the pavement.

The inverse of the regression coefficient is usually for Finnish mixes around 6 - 8. These coefficients are depending on the test procedure. The indirect tensile test gives values around 3-4, four-point beam test around 4-5 and the bituminous beam on the rubber support 5-8.

In the indirect tensile test the material is assumed to behave as elastic material. Bituminous mixture is relatively far from that and thus the test is unrealistic and not close to the real life under the traffic load. The specimens are easy to make and the test easy compared to other fatigue tests.

The four point bending test is a pure fatigue test. The beam is bended similarly on both sides and there is no vertical compressive stress unlike in the pavement under the traffic load. The load in the test is usually sinusoidal form without any rest periods.

The beam on rubber support is realistic because there is both tensile stress at the bottom of the bituminous sample and there is vertical stress on the surface. The sample bends only in one direction and the rubber pushes it back to original position. The strains due to the loading in the tests are very similar to the transverse strains at the bottom of asphalt layers in real pavements as a truck passes the strain gage (see for instance /2/). As a vehicle passes a strain gage there is always compression first and then tension and after the pass compression once again. The compression is, however, only 10 to 30 percent of the tensile strain (depending on the temperature and pavement structure) and thus far from sinusoidal form.

Typically fatigue curves are higher for samples on rubber support than for four point bending or indirect tensile tests where those are generally lowest. The strains are calculated from zero level and the real movement from compression to tension on sinusoidal form test is double compared to values calculated from zero level. It has been found at VTT that generally the fatigue curves tend to be flatter if the curves are higher. The data is too small and scattered in order to be sure about this phenomenon.

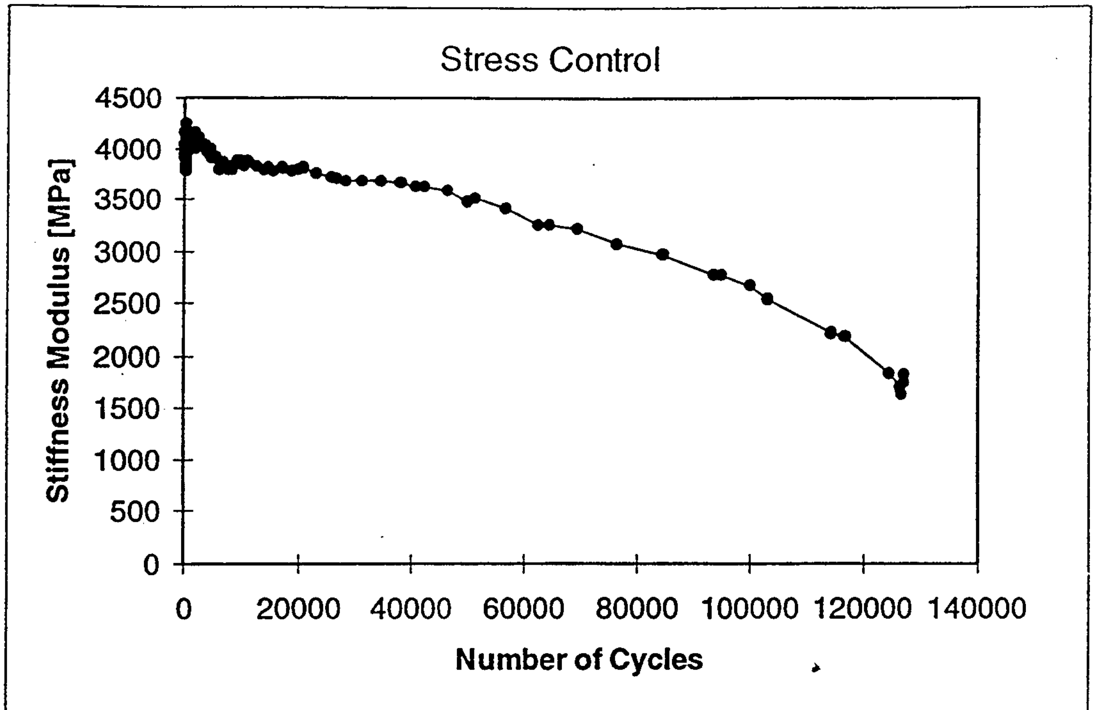
Rest periods between loadings has remarkable effect on fatigue properties if the rest period is less than about 1 second but very little effect if the rest period is longer than 1 second. The VTT fatigue test applies loading in one second cycles. One cycle consists of 0.05 second loading time and 0.95 second rest period.

As it was found that the fatigue curve from stress control test of Mn/ROAD mixtures deviates so much from others there was lot of interest to check that nothing has gone wrong. The strain measurement system was checked (strains are always measured, not calculated like in some other tests) and some tests were made with absolutely same material as earlier. This repeated test gave exactly the same results as one year earlier.

Because modified bitumen may cause very different slope the binder was extracted from the mixture and the penetration and the ring and ball tests were made. The results gave typical values for straight run bitumens.

The change of moduli during the test were typical to those seen earlier. Some examples of the evolution in stress and strain controlled tests is different as can be seen in Figure 17.

After all these checks it was clear that the behavior of Mn/ROAD mixture is different in stress mode. The reason may be the high amount of sand. The coarse aggregate has very few contact points between each other and the sand dominates in contacts. This makes the crack propagation slower.



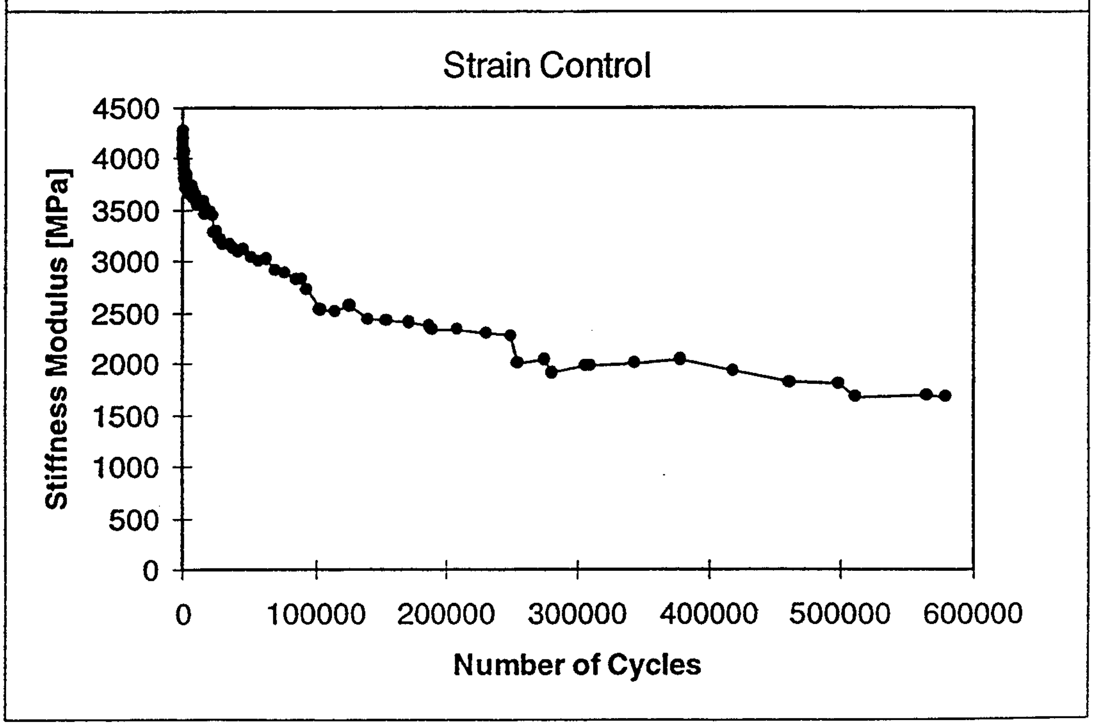


Figure 17. Examples of stiffness evolution during the fatigue test ("Ready Made" low stiffness field mixture, +15°C).

CHAPTER 6: CONCLUSIONS

Technical Research Center of Finland (VTT) made wheeltracking and fatigue tests of Minnesota Test Road (Mn/ROAD) Bituminous Mixtures within the co-operation between Finnish National Road Administration (Finnra) and Minnesota Department of Transportation (Mn/DOT). The tests were funded by the Finnra. Despite of the geographical distance this co-operation succeeded well.

The bituminous mixtures of Mn/ROAD and those used in Finland are different what was found in preparation of samples. Mn/ROAD sent raw materials (aggregates and binders) and ready made mixtures. Compaction was more difficult than compaction of Finnish mixtures. Traditionally Finnish mixtures are easy to compact. If mixtures are easy to compact they may also easily deform. Bituminous mixture design is a compromise between very many factors and there is no absolute truth for instance, what is the importance of compaction.

In spite of the differences between Mn/ROAD and Finnish mixtures the rutting of Mn/ROAD mixture measured by wheeltracking device was similar if compared to dense graded mixture with binder of similar penetration. However, the Mn/ROAD mixture with low stiffness binder deformed much more and was outside the Finnish specifications. It may be, however, successful in Minnesota because of smaller axle loads.

The fatigue properties in strain control were about the same as corresponding Finnish bituminous mixtures. However, the behavior in stress mode was different, the fatigue line was flatter than any Finnish bituminous mixture with straight run bitumen, only some with polymer modified bitumen were similar. It means that in cases where stress control is important, some overloads may cause excessive cracking and on the other side the pavement may be very successful with smaller loads. In general, stress control is valid if the bituminous part of the road forms an important part of the structural capacity and strain control if the main part of the structural capacity is from unbound layers. Neither stress control nor strain control corresponds with reality which is somewhere in between. Careful analysis is recommended as the fatigue properties of Mn/ROAD pavement performance will be analyzed.

As the results from Mn/ROAD will be compared to Finnish circumstances careful analysis shall be made. In many cases the difference due to different bituminous mixtures has no effect but in certain cases it may change conclusions. No general rule cannot be given at the present time.

CHAPTER 7: REFERENCES

1. Finnish Asphalt Specifications 1995. Finnish Pavement Technology Advisory Council PANK. Helsinki 1995. 67 p. ISBN 951-97197-3-3.

2. Huhtala, M., Alkio, R., Pihlajamäki, J., Pienimäki, M. & Halonen, P., Behavior of Bituminous Materials Under Moving Axle Loads. Asphalt Paving Technology 1990, vol 59. Annual Meeting of the Association of Asphalt Paving Technologists, February 1990, Albuquerque, New Mexico. pp 422-442.