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PREDICTING THE PERFORMANCE OF STONE MASTIC ASPHALT

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Abstract

In analytical pavement design the two main criteria of pavement failure are fatigue cracking and permanent deformation. For permanent deformation the vertical strain at the bottom of the sub-base is held responsible whereas the horizontal strain between the bituminous and granular layers govern fatigue cracking. This paper investigates the generation of horizontal strain between the granular and bituminous layer of samples subjected to wheel-tracking tests. It examines the performance of traditional hot rolled asphalt in comparison to stone mastic asphalt. The process of measuring horizontal longitudinal strain in bituminous mixtures is outlined and results include graphs of strain measurement and rut depths. The improved rutting behaviour of SMA compared to HRA can be confirmed as well as a correlation of peak strain and rut depth development established.

Introduction

Road pavements throughout Europe are being subjected to higher loads through increasing axle and wheel loads as well as tyre pressures. A rise of the axle load limit to 130kN by the EU is planned (Der Spiegel, 1999). This may result in premature failure of the mixtures. Consequently new concepts are being sought to improve durability and longevity of the materials. Stone mastic asphalt has recently been introduced to the UK. This paper investigates the performance of SMA compared to HRA by measuring strains between bound and unbound materials of a pavement using a wheel-tracking apparatus.

Stone mastic asphalt

In the Scandinavian Countries as well as in Germany, SMA has been known since the early 1960's. In Germany SMA was developed to meet the demand for better wearing courses after the introduction of studded tyres. Although these are prohibited since 1975, SMA remains an acknowledged material especially because of the better stability compared to asphalt concrete and the lower cost compared to mastic asphalt. The increase in the use of SMA for Bavaria, the largest of the 16 German 'Länder' (states) by area, is shown in Figure 1.

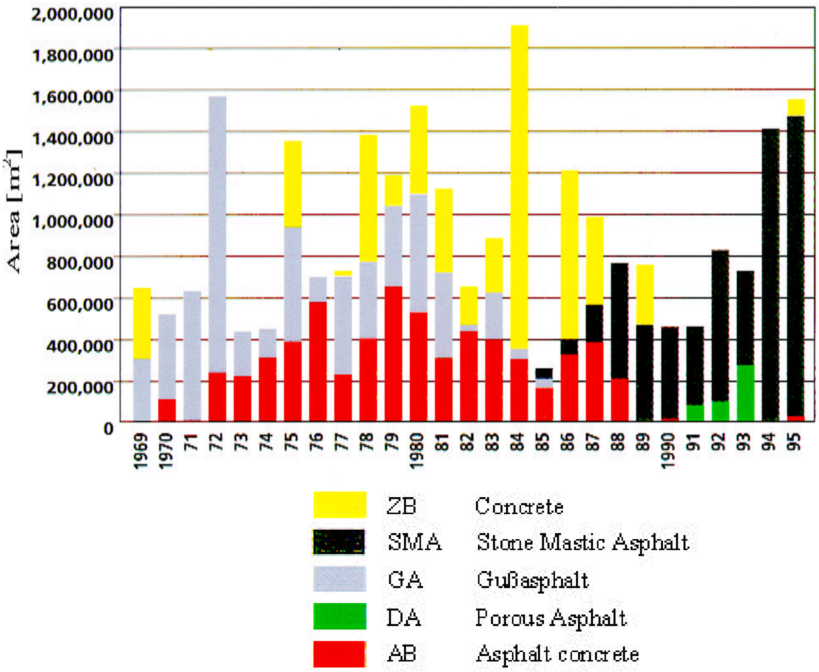

Figure 1 Increase of SMA on motorways in Bavaria

SMA is characterised by a gap-graded aggregate gradation. It consists of up to 80% by weight of coarse aggregate and up to 13% by weight of filler. The gap-graded aggregate mixture provides a stable stone-to-stone skeleton. Aggregate interlock and particle friction are maximised and give the structure its stability.

SMA contains voids between 2-4% by volume only. The remaining proportion of the mix is filled with mastic, which is a mixture of bitumen, filler, sand and stabilising additives. Stabilising additives can be organic or mineral fibres or polymers, either granular of in powder form. They stabilise the asphalt mortar and prevent binder run-off from the aggregate. Thus, they ensure the homogeneity of the mixture. Very common additives are cellulose fibres. They contribute to the volume of the asphalt mortar without making the mastic brittle or negatively influencing the properties of the bitumen.

Wheel-tracking tests

Hot rolled asphalt sample

Hot rolled asphalt is the traditional paving material in the UK. It is a gap-graded material with the gap between the fine and coarse aggregate. It contains mainly mortar, which is a mixture of bitumen, sand and filler. The coarse aggregate contributes to the stiffness of the asphalt. However, its main function is to extend the mortar, thus making the mix more economical

(Whiteoak, 1990). Stresses imposed on the pavement by the traffic are distributed mainly through the mortar, which means a high stiffness is required from the material.

HRA 30/14 samples were made according to BS 594 using 50 pen bitumen and Silurian greywacke aggregate from a quarry in Northern Ireland. The composition of the mix is summarised in Table 1. The samples were prepared by following standard procedures before pouring the mass into a mould, 300mm x 90mm x 40mm, and compacting it with a 17kg roller compactor. Density and void content were determined.

Table 1. Mix compositions [%]

	HRA 30-14	SMA 14	SMA 10
Bitumen	8.30	6.97	7.17
Fibres	0.00	0.33	0.33
< 20 mm	1.36	2.00	0
< 14 mm	27.50	41.74	3.62
< 10 mm	2.92	19.23	43.94
< 6.30 mm	0.24	8.49	17.26
< 2.36 mm	1.60	6.41	10.00
< 0.60 mm	26.80	2.32	3.58
< 0.212 mm	21.82	2.29	3.10
< 0.075 mm	9.46	10.23	11.00

Stone mastic asphalt samples

In a SMA mixture, the aggregate gradation is gap-graded with little aggregate in the 212ìm to 2.36mm range. This results in a very stable interlocking stone skeleton that gives the material its strength. The necessity to fill the voids between the aggregate requires a high amount of mortar. To prevent binder drainage from the aggregate fibres are employed which ensure the homogeneity of the mixture. A void content of approximately 4% prevents overfilling of the voids and ensures particle friction and stone-to-stone contact thus ensuring high resistance to rutting.

The stone mastic asphalt samples were prepared in a similar way to the HRA samples. Instead of 50 pen bitumen a softer 100 pen bitumen was used. Pelletised cellulose fibres were premixed with the bitumen. 14mm and 10mm SMA test samples were made as outlined in Table 1.

Preparation of samples for testing

Strain gauges are sensitive measuring devices and to ensure proper results the strain to be measured must be transferred faultlessly. Therefore, close and precise bonding between the strain gauge and the surface of the measured object has to be guaranteed. The surface must be smooth and absolutely clean.

A 70mm x 30mm piece of aluminium foil was glued onto the surface using CN bonding agent from TML. The same bonding agent was later used for the strain gauge. It was hoped to get more realistic results through the introduction of the aluminium foil for it could give the strain over an averaged area rather than an area with mainly stones or mainly mortar.

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A strain gauge type PFL-30-11 from TML and connecting terminals were applied using a technique described by Hoffmann (1996). Wires were soldered to the connecting terminal and, after the strain gauge was covered by a piece of plastic foil, the whole area was protected with strong tape. Before being subjected to the wheel-tracking test the 30mm thick samples were then placed in a steel mould on top of 70mm of sand. The test sample is shown in Figure 2.

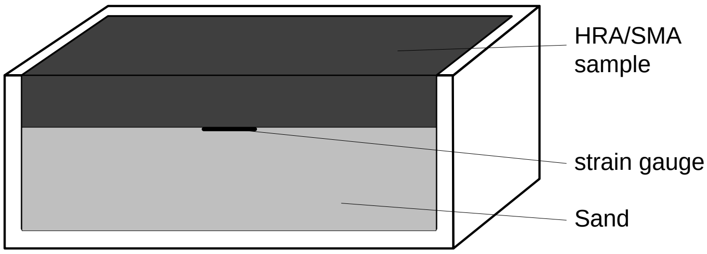

Figure 2 Sample ready for testing

For practical reasons strain measurements are almost always carried out using a Wheatstone bridge circuit. Strain gauges not only measure strain in response to any applied stress but also strain due to changes in temperature. In this case to eliminate any effects of temperature changes a dummy sample was used.

For this test set-up with an amplifier connected to the Wheatstone bridge circuit strain was calculated as shown in Equation 1.

$$e = \frac{V_{out}}{100 \cdot GF}$$ **Equation 1**

where: å = strain [-]
V_{out} = output voltage
GF = gauge factor

Test set-up

Wheel-tracking testing was carried out at 60ºC. A dummy sample was placed beside the test specimen to eliminate any environmental effects on the test sample. The wheel used was a solid rubber tyre with varying loads of 190N, 280N and 370N. Voltage signals from the strain gauges were recorded to a National Instruments data acquisition board using LabVIEW software.

Test conditions

Testing time was eight hours. However, some tests had to be terminated earlier because the wheel-tracking apparatus could not accommodate the rut depth created. Therefore, testing time was between four and eight hours, i.e. 12,000 to 24,000 wheel passes.

Measurements were taken of the air temperature every 15 minutes. The rut depth was monitored every minute for the first 10 minutes, every 15 minutes for the first hour and every 30 minutes thereafter. The strain gauge signal was read every 30 minutes for the length of one minute. This gave 50 wheel passes per reading. The accuracy was 100 points per second.

Results

Figures 3 to 5 show typical strain graphs for each material at 280N wheel load. The different plots show the strain gauge signal at different test stages. Each line represents one full cycle of the wheel-tracking apparatus, i.e. one forward and one backward movement. The peaks occur when the wheel is at the centre of the sample, directly above the strain gauge.

The signal obtained from the strain gauges may drift over time independent of the applied load. Although it was tried to minimise this effect it was not possible to eliminate it. Therefore, all curves were levelled at the mode value of a reading. This means any increase in basic strain due to deformation is not taken into account.

In Figure 6 the maximum peak strain values of a reading are expressed as percentages with the initial value obtained at the start of the test corresponding to 100%. Figure 7 shows the rut development of each sample over time and Table 2 indicates the simplified linear rutting rates.

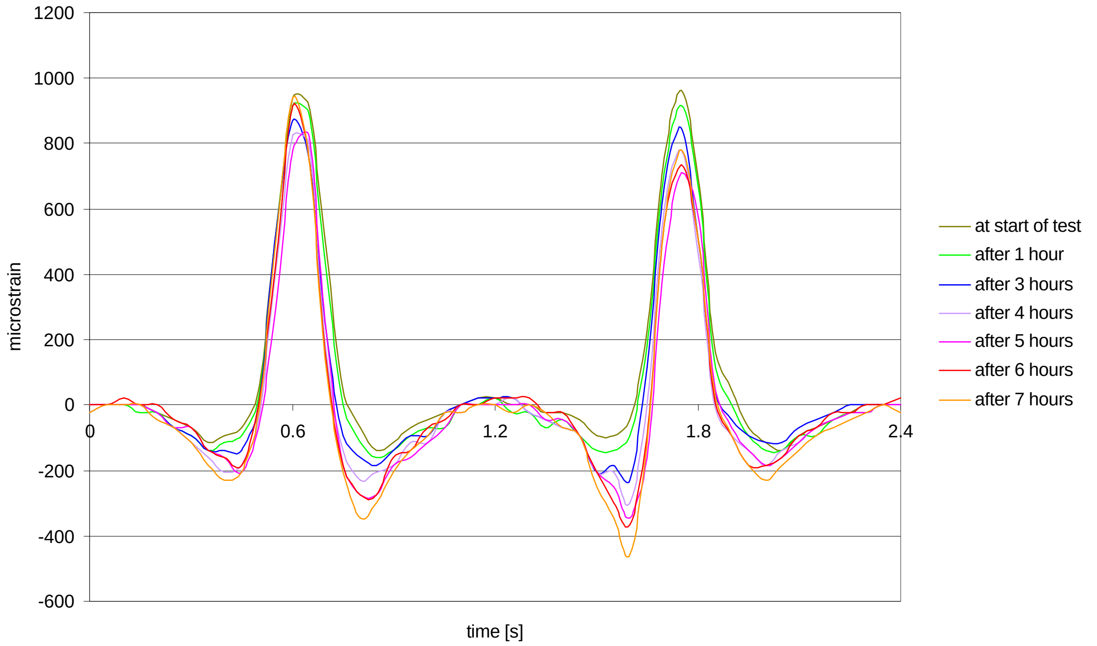

Figure 3. Strain development 10mm SMA at 280N load

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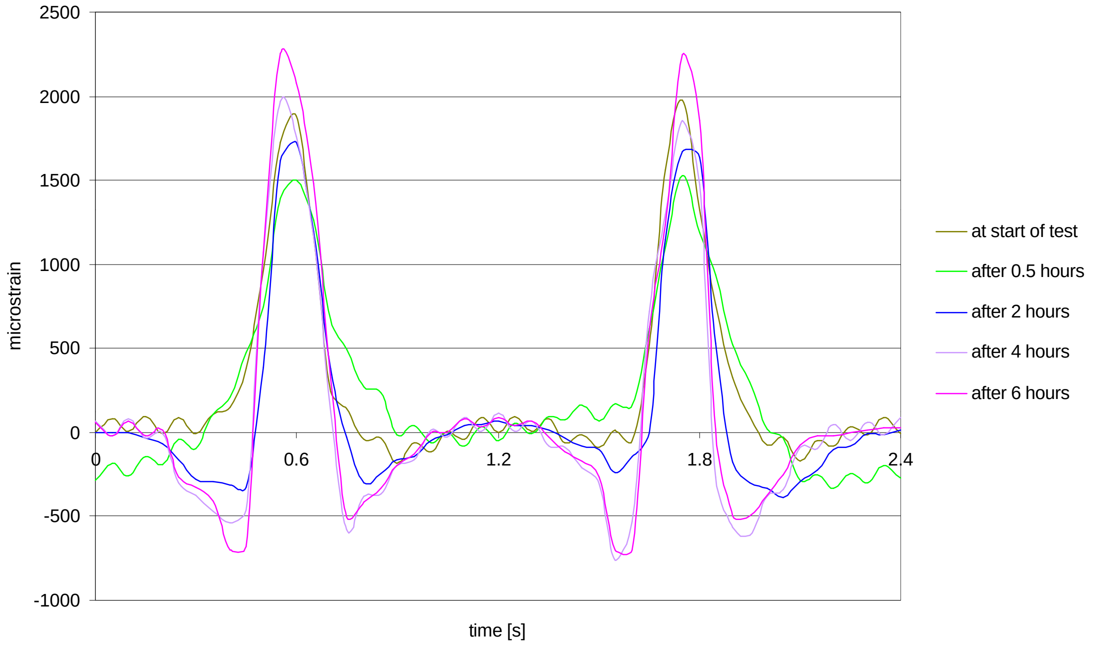

Figure 4. Strain development 14mm SMA at 280N load

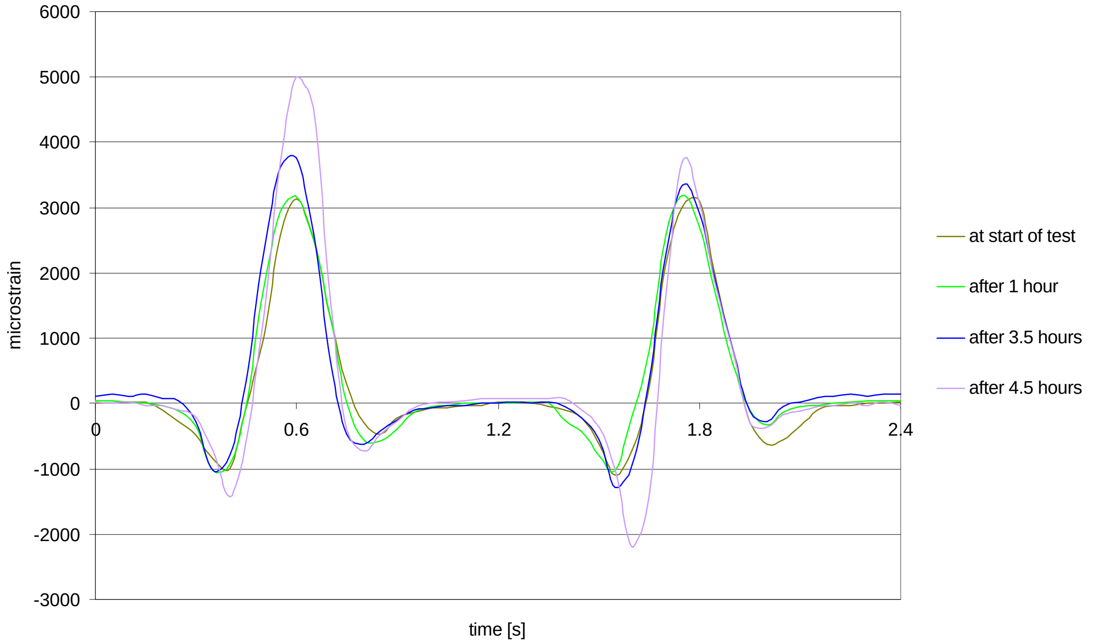

Figure 5. Strain development HRA 30/14 at 280N load

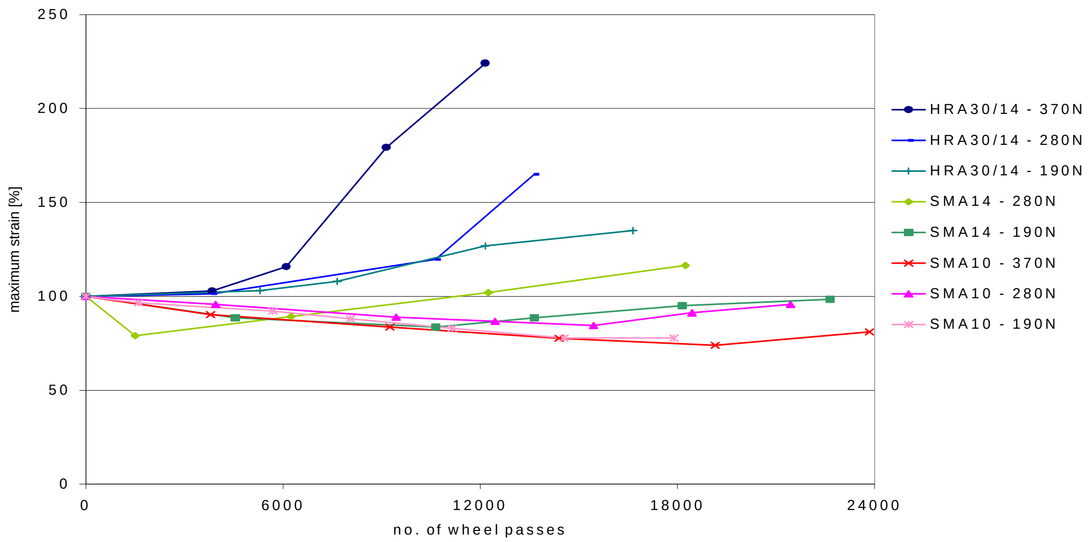

Figure 6. Peak strain data

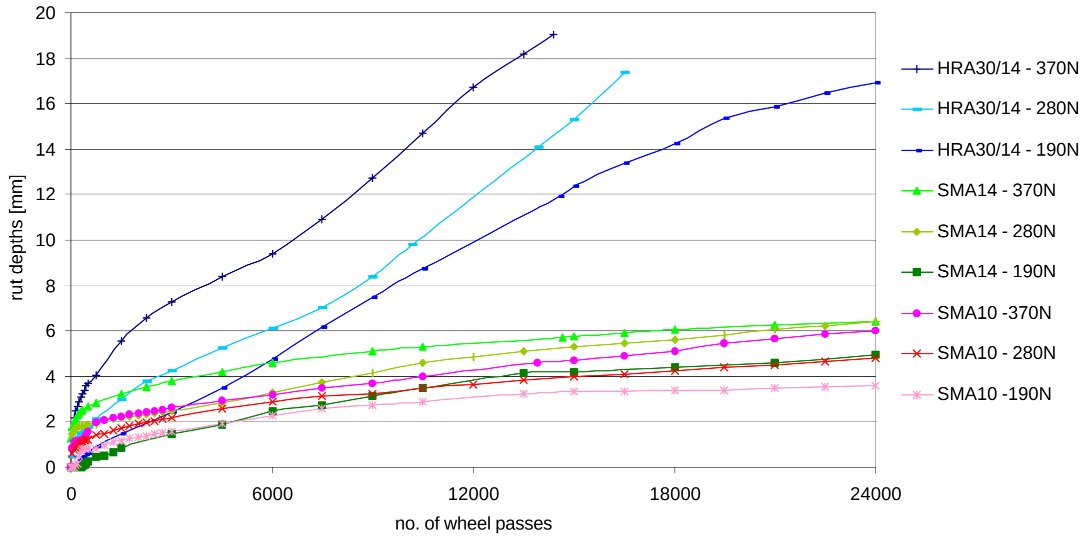

Figure 7. Rut depth data

Table 2. Rutting rates of test samples in mm/h

Wheel load	HRA 30-14	SMA 10
190 N	2.12	0.45
280 N	3.16	0.60
370 N	4.01	0.75

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Discussion

All of the strain signal graphs show one cycle of the wheel-tracking device, i.e. a single forward and back movement of the wheel. The peaks represent the wheel directly above the strain gauge on top of the sample. Whereas the zero readings correspond to the wheel being at each end of the mould. All readings were levelled out at the mode value of a series, which means that any strain due to permanent deformation was not considered. Thus, only the peaks are compared.

Figure 5 shows the strain signals obtained for the HRA 30/14 sample tested with a wheel load of 280N. A steady increase over testing time can be observed. At the end of the test a maximum peak value of 5181 ìstrain was obtained. For the 14mm SMA sample the final peak strain value was 2368 ìstrain (45.7% of HRA). The 10mm SMA sample showed the best rutting behaviour and the final peak strain value was 986 ìstrain (19% of HRA).

From examining Figure 6 where all maximum peak strain values are expressed as percentages it becomes apparent that the difference between peak values for the three HRA samples become bigger the higher the wheel load. All SMA samples, however, show a completely different behaviour. Here the peak values actually decrease for a good part of the test before eventually beginning to rise. The curves in Figure 6 correspond well with the plot of the rut depth development shown in Figure 7.

Conclusions

- Stone mastic asphalt shows excellent rutting behaviour with wheel tracking rates only 20% that of HRA.
- Peak values of strain correspond well with rutting behaviour.
- Peak strain values for HRA increase during the test period, SMA peak strain values decrease for a considerable amount of time before rising.
- There appears to be less strain in the SMA mixes than that of the HRA.

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