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Final report

Investigation on millability and recycling of glass fibre reinforced asphalt layers

Commissioned by: Saint-Gobain Adfors

This certificate includes 19 pages.

Contents

1 General details

Commissioned by:	Saint-Gobain Adfors Viktoriaallee 3-5 52066 Aachen
Date of order:	10.04.2012
Aim of order:	To investigate the influence of the asphalt reinforcement system GlasGrid® on the milling properties of asphalt and the recycling of reclaimed asphalt containing glass fibre in bitumen-based layers

2 Brief description of the scope of work

Asphalt reinforcements are being used more and more in present-day road construction. In addition to the known advantages of asphalt reinforcement, the question of the effects on reclaiming, especially when milling machines are used, is increasingly becoming the focus of discussions. One of the basic requirements for the large-scale use of asphalt reinforcements concerns deconstruction of the asphalt surface and recycling the reclaimed material in new asphalt mixtures.

At the Institute of Road and Traffic Engineering, RWTH Aachen, the influence of the asphalt reinforcement GlasGrid® GG200-8502 on the milling behaviour was tested under predefined conditions. This was carried out by laying the GlasGrid® on an existing asphalt base according to the appropriate, current installation recommendation and covering it with an asphalt overlay (SMA 8 S). After a period of about one week the asphalt overlay and the asphalt reinforcement were milled in a single process using a small milling machine.

The aim of the investigations was on the one hand to analyse the milling behaviour of a road surface strengthened through an asphalt reinforcement under aspects of mechanical and process technology and on the other hand to test the recycling of the milled material (containing glass fibre) in bitumen-based layers.

3 Investigations on millability

3.1 Test section of the Institute of Road and Traffic Engineering

The Institute of Road and Traffic Engineering, RWTH Aachen, has at its disposal a 26-meter long test section on which different road surfaces can be installed and deconstructed under realistic conditions on a width of 1 meter. Starting from an anti-frost layer, different road surfaces can be installed even exceeding those defined in the german engineer standards (RStO 01). The mixture is placed using a rail-mounted paver, compaction of the installed material is carried out by a tandem vibration roller. The paver is equipped with a high performance compaction screed so that by using two pressure plates it is possible to achieve a high level of pre-compaction. Through the targeted setting of special machine parameters of the paver and a corresponding coordination of the rolling pattern, while taking into account the test boundary conditions, not only typical practical installation procedures can be carried out but also test series for a targeted analysis of the installation technology.

In the course of the investigations on the milling behaviour of GlasGrid®-reinforced asphalt layers and their recycling (commissioned by Saint-Gobain Adfors), two asphalt layers (asphalt binder and wearing course) were installed and dismantled.

3.2 Installation of the asphalt construction

Based on an anti-frost layer and an existing asphalt base course, an asphalt binder layer of type AC 16 B S was installed on which the asphalt reinforcement was laid according to the installation instructions and sprayed with a bitumen emulsion U 60 K. After the emulsion broke the overlaying was carried out with a 4 cm-thick asphalt wearing course of type SMA 8 S.

The asphalt mixtures required for the installations were produced in a local mixing plant and transported to the test track of the institute in a suitable transport vehicle. As part of the quality control the delivered asphalt mixture was checked (visual inspection, temperature measurement). Then the paver was loaded with the mixture to be installed and the installation was carried out. For the installation a high performance compaction screed with two pressure plates was used, achieving high pre-compaction. The final compaction of both layers was carried out with a tandem vibration roller.

The installation of the 8 cm-thick asphalt binder layer (AC 16 B S) took place on 13.04.2012. The mixture was delivered and installed with a temperature of about 165 °C in optimum weather conditions. An average compaction degree of 99.0 % was achieved.

After it had been in place for a few days the installation of the asphalt reinforcement Grid followed on 18.04.2012 observing the laying instructions of Saint-Gobain Adfors as follows:

- Manual rolling out of the reinforcement grid on the asphalt binder layer
- Pressing down the grid using a compaction roller (see Fig. 2)
- Spraying with a bitumen emulsion U 60 K (spraying amount ca. 300 g/m²) (see Fig. 2)
- Waiting until the emulsion broke

The reinforcement was only laid along one side of the test section in order to gain additional milled material without glass fibre to produce a control mixture (reference) for the later investigations on recycling (see Fig.1).

Fig. 1: Pressing down the reinforcement laid along one side with a compaction roller with a close-up of the grid

Fig. 2: Spraying the GlasGrid with bitumen emulsion U 60 K

After the asphalt reinforcement had been laid the surface was covered with a 4 cm-thick wearing course of type SMA 8 S on the same day (see Fig.3 and Fig.4). The mixture was delivered with a temperature of 180 °C. During the installation no adverse effects caused by the asphalt reinforcement were ascertained. There was only a slight, local rippling of the grid which however had no influence on the location accuracy. The check test delivered an average compaction degree of 101.1 %.

Fig. 3: Installation of the overlay using a rail-guided test paver and checking the layer thickness

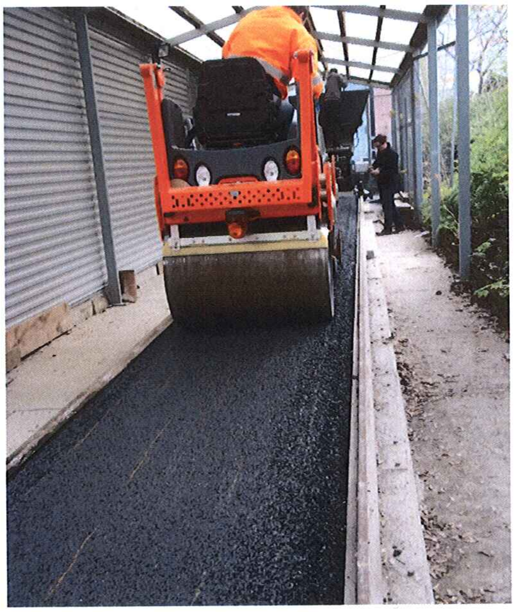

Fig. 4: Dynamic compaction of the wearing course using a tandem vibration roller

The layer structure of the asphalt superstructure is represented in the following illustration. The most important parameters of both kinds of asphalts are presented in Table 1.

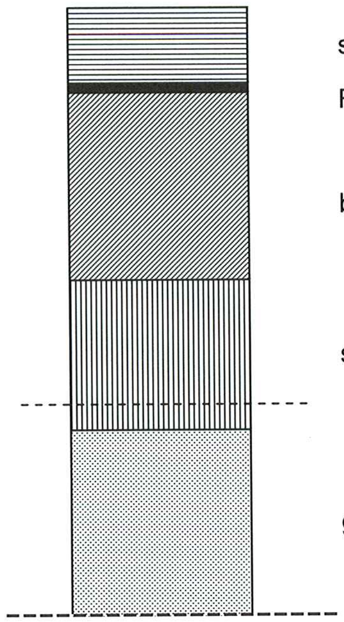

Fig. 5: Layer structure of the asphalt superstructure

Table 1: Parameters of asphalt mixture and layer

Feature	*Binder layer*	*Surface layer*
Type of mixture	AC 16 B S	SMA 8 S
Type of mineral	Basalt	Diabas
Type of binder	30/45	PmB 25/55-55 A
Layer thickness [cm]	8	4
Compaction degree [%]	99.6	101.0
Voids content [vol.-%]	6.3	1.4

3.3 Removal of the asphalt construction, milling tests

In order to test the influence of the asphalt reinforcement GlasGrid® on the millability of the asphalt construction a cross-layer milling depth of 6 cm was chosen so that the wearing course and the upper part of the asphalt binder layer including the asphalt reinforcement were picked up by the milling machine in a single process. The main emphasis was placed on the aspects of machine and process technology, for example fibres adhering to the milling drum.

For the milling tests a small milling machine with a milling drum width of 500 mm and a tool spacing of 8 mm was employed (see Fig.6 and Fig.7). A dosed quantity of water was injected in the area of the milling drum during the milling operation to reduce the dust emissions.

Fig. 6 : Employed small milling machine with a drum width of 500 mm

Fig. 7: Close-up of the milling drum with drilling bits

The milling process was carried out in two steps. First the unreinforced area was milled with the grid being partly cut due to the milling drum width. This circumstance made it possible to check, if the existing milling depth was sufficient to reach the reinforcement layer. Then the "pure" milled material, i.e. without glass fibre, was collected and stored in a dry place. Fig.8 shows the test section after this step had been carried out.

In the second step the reinforced area was milled (see Fig.9). The choice of a milling depth of 5 cm guaranteed that the milling drum extended into the upper part of the asphalt binder layer, thus ensuring complete removal of the asphalt reinforcement.

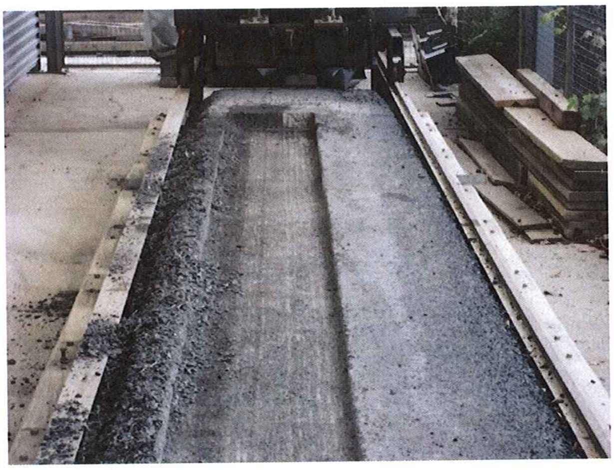

Fig. 8: Toolpath in the unreinforced area

Fig. 9: Milling the reinforced area

During the milling operation the milling behaviour was assessed from a process engineering point of view and afterwards the milling material was examined with regard to particle size distribution and the type and size of the fibre content in the reclaimed asphalt.

After carrying out the milling experiments both asphalt granulate qualities were available for later use in a new asphalt mixture (see section 4.1).

3.4 Results of the milling tests

The planned milling experiments and the target milling depths could be fully implemented. During the milling operation there were no adverse effects at all on the milling process from a process engineering point of view.

After the milling operation the milling drum was examined for adhering glass fibre strands. No strands got caught on the milling drum over a milling length of about 15 m (see Fig.10).

Fig. 10: Milling drum with drilling bits after the milling operation

Fig. 11: Milled material with glass fibre

The milled material had a fine particle size distribution, as can be seen in Fig.11, whereby the glass fibre strands which emerged during the milling process were evenly distributed in the reclaimed material. An analysis of 5 partial specimens yielded an average strand length of about 14 cm with a medial fibre content of 1 wt.-%. The strands were between 2 and 20 cm long.

On completion and evaluation of the milling tests there were no concerns whatsoever with regard to recycling milled material containing glass fibre.

4 Investigations on recycling

4.1 Investigation concept

Proving the safe recycling of milled material or asphalt granulate (AG) containing glass fibre (GF) was carried out on the basis of an asphalt binder mixture to which on the one hand asphalt granulate containing glass fibre and on the other hand asphalt granulate with no glass fibre was added. The version with no glass fibre represented the control variant (reference) which was compared with different asphalt versions containing glass fibre. The assessment criterion was the fatigue behaviour at low temperatures which was addressed by means of cyclic tensile tests.

4.1.1 Initial test for asphalt binder mixture AC 16 B S

The tests were carried out on an asphalt binder mixture of Type AC 16 B S with a glass fibre-free asphalt granulate (AG) proportion of 30 wt.-%. Using an asphalt wearing course mixture was not possible due to the permitted grain diameter of 11mm, as the reclaimed asphalt partially contained coarser grain fractions resulting from the milled asphalt binder layer.

The composition requirements corresponding to the german asphalt standards (TL Asphalt-StB 09) formed the basis for the initial test. According to these requirements the composition must be specified in such a way that it complies with a void content of the Marshall specimens between 3.5 and 6.5 vol.-% and at the same time a minimum binder content of 4,4 wt.-%. For the initial test therefore, based on a standard grading curve for the mineral aggregates (TL-Asphalt-StB 09, Tab. 6), the nominal composition was determined complying with the above-mentioned conditions. The parameters for the selected version are presented in Table 2.

Table 2: Compositional features of the selected mixture variant AC 16 B S

Feature	*Value*
Binder content [wt.-%]	5.0
Filler content [wt.-%]	5.5
Sand content [wt.-%]	23.0
Split content [wt.-%]	71.4
Bulk density asphalt [g/cm^3]	2.363
Maximum density asphalt [g/cm^3]	2.483
Void content MPK [vol.-%]	4.8
Fictive void content [vol.-%]	16.1
Void filling ratio [vol.-%]	69.9

For the purpose of dosing the fresh components the binder content of 6.1 wt.-% and the particle size distribution according to Fig.12 were determined for the reclaimed asphalt.

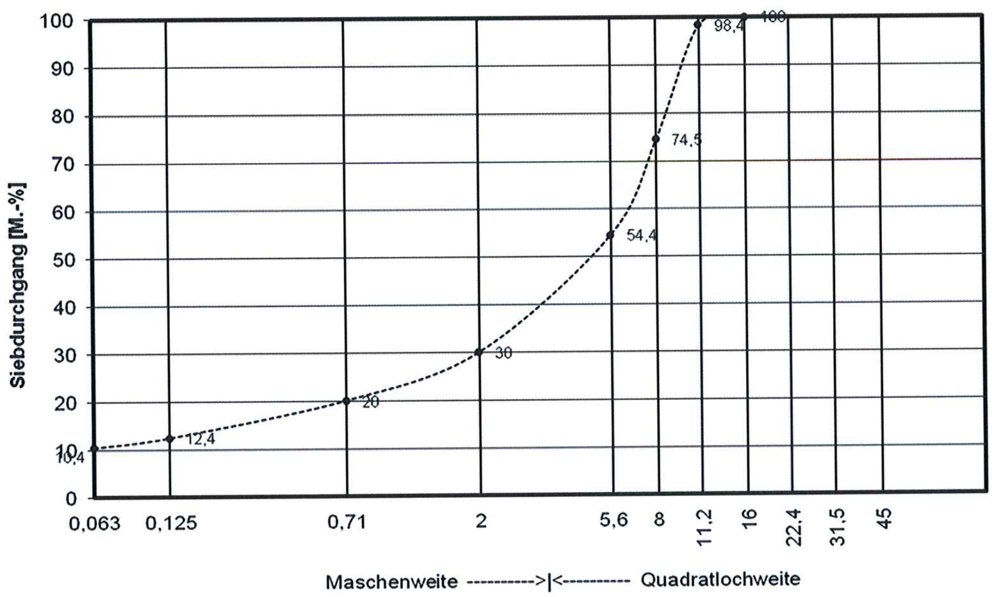

Fig. 12: Particle size distribution of the (extracted) reclaimed asphalt

A greywacke aggregate and a limestone filler were used as fresh components. A polymer-modified product PmB 25/55-55 A was chosen as binder.

4.1.2 Variants investigated

Based on the nominal composition of the control variant (30 wt.-% AG without glass fibre) a further six mixtures were produced with asphalt granulate containing glass fibre varying the following parameters:

- Amount of asphalt granulate (AG) added: 30, 20 and 10 wt.-%
- Final mixing time: 180 and 90 seconds

The following table provides an overview of the overall seven variants tested.

Table 3: Investigated asphalt variants

Variant	*Asphalt granulate proportion [wt.-%]*	*Glass fibre content in mixture [wt.-%]*	*Final mixing time [s]*
0	30	0	180
1	30	0.3	180
2	20	0.2	180
3	10	0.1	180
4	30	0.3	90
5	20	0.2	90
6	10	0.1	90

Due to the choice of the parameters 3 different questions could be examined, whereby the first was of fundamental interest:

1. Is there a difference when asphalt granulate containing glass fibre is added compared to using conventional asphalt granulate without glass fibre?
2. What effect does a different glass fibre or asphalt granulate proportion have?
3. Does a shorter final mixing time have a negative effect on the asphalt properties as a result of insufficient mixing?

While the significance of the first two points can be directly deduced, the influence of the final mixing time after adding the asphalt granulate is important with regard to economic aspects. A longer final mixing time means less output from the mixing plant, so the mixing should be restricted to the level which is necessary to achieve sufficient homogenisation.

In order to be able to compare the asphalt variants with each other in terms of these questions, the compositional equivalence had to be ensured. This was achieved through a corresponding dosage of the fresh components so that the nominal composition of the control variant was maintained for all the variants.

It was not necessary to prove the homogeneity of the asphalt granulate according to TL AG-StB 09, as a sufficient uniformity of the asphalt granulate could be taken for granted due to its known origin. Fig.13 illustrates both asphalt granulate qualities as they were reclaimed during the milling tests.

Fig. 13: Asphalt granulate without glass fibres (left) and with fibres (right)

4.1.3 Production of mixtures and specimens

The asphalt mixtures were produced in a laboratory mixer in batches of 50 kg per variant. The mixing process was carried out in the following steps:

1. Loading the hot mineral aggregates
2. Adding the filler
3. Mixing for 30 seconds
4. Loading the asphalt granulate (cold feed) and the glass fibre and mixing for 30 seconds
5. Adding the hot fresh bitumen and starting the final mixing time of 180 or 90 seconds

The temperature of the fresh aggregate was determined depending on the added amount of asphalt granulate according to the german guidelines contained in the instructions for the recycling of asphalt granulate (M VAG).

To determine the exact glass fibre content the glass fibre strands were detached from the asphalt granulate beforehand and weighted separately.

From the asphalt mixtures 320 x 260 x 50 mm^3 large asphalt slabs were produced under realistic conditions in the roller compactor (according to DIN EN 12697-33). The compaction was carried out force-controlled, so the compaction regime (number of roller crossings, maximum load) had to be individually adapted to ensure comparable void contents for all the asphalt variants tested. A check of the void contents resulted in void contents between 4.3 and 4.9 vol.-% for all the variants, so any differences in the test results can be attributed exclusively to the effect of the glass fibre.

Then the prismatic specimens needed for the fatigue testing were sawn out of the slabs measuring of 50 x 50 x 160 mm^3 and the volume density was determined. All of the 21 prisms (7 variants in triplicate) had volume densities of 2.37 ± 0.03 g/m^3 so they could be used for comparative tests.

To carry out the tension fatigue tests the samples were adhered to adapter plates in an assembly bench (see Fig.14). Care was taken to ensure an exact plane-parallel alignment of the plates to minimise stresses resulting from fixing moments.

Fig. 14: Mounting the test specimens in an assembly bench

4.1.4 Fatigue tests

The fatigue tests were carried out according to DIN EN 12697-46. Here prismatic asphalt test specimens are subjected to a pulsating uniaxial tensile load which consists of a constant temperature-related lower stress level (thermal stress) and a sinusoidal stress to simulate traffic load (mechanical stress) (see Fig.15 and 16). The result of the test is the tolerable alternation of load until the test specimen cracks, the so-called load cycles to failure. In addition conclusions on the ductile behaviour of the asphalt may be drawn by means of the deformation curve.

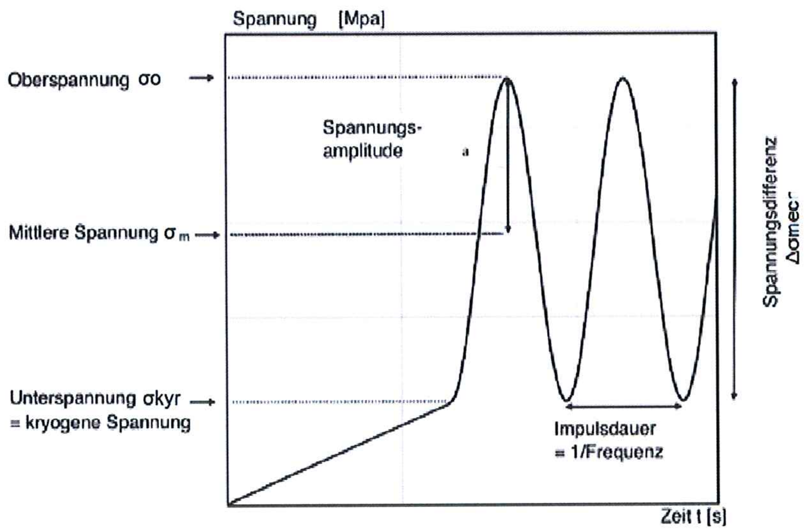

Fig. 15: Load scheme of the tensile fatigue test

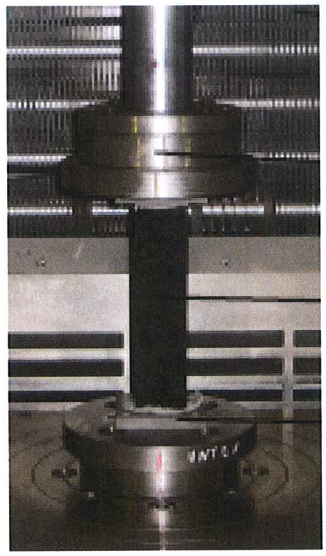

Fig. 16: Mounted test specimen

The tests were carried out at a frequency of 10 Hz in triplicate at 3 different temperatures. As experience has shown that the maximum load cycles to failure occur in the moderately negative temperature range, testing temperatures of +5 °C, -5 °C and -10 °C were chosen.

The thermal stresses for all the asphalt variants were set uniformly on the basis of empirical values due to the similarity of their compositions. The normal procedure demands that these tensile stresses are determined in advance through separate cooling tests. The mechanical stress was selected at 1.60 MPa according to the recommendation of DIN EN 12697-46. The test conditions are compiled in Table 4.

Table 4: Test conditions for the tensile fatigue tests

Temperature [°C]	*Test frequency [Hz]*	*Thermal stress [MPa]*	*Mechanical stress [MPa]*	*Total stress [MPa]*
5		0.08		1.68
-5	10	0.40	1.60	2.00
-10		0.80		2.40

The test chosen here represents to some extent a combined fatigue and cold test, as the conventional fatigue test is carried out at a temperature of 20°C where no thermally indicated stresses occur concerning relaxation ability.

4.2 Test results

As the main aim of the investigations is to prove the recycling of glass fibre reinforced asphalt, the control variant (30 wt.-% AG without GF) is first compared with the corresponding variant containing glass fibre with the same proportion of asphalt granulate.

Then the secondary questions on the influence of the amount of glass fibre and the final mixing time are addressed.

4.2.1 Control variant vs. variant containing glass fibre

The results of the tensile fatigue tests for both variants observed are illustrated in Fig.17. The diagram shows the load cycles to failure reached at the temperatures tested when the test specimens failed. The marked points represent the average out of three individual tests. The variance of the single values is indicated by means of an error bar for twice the standard deviation.

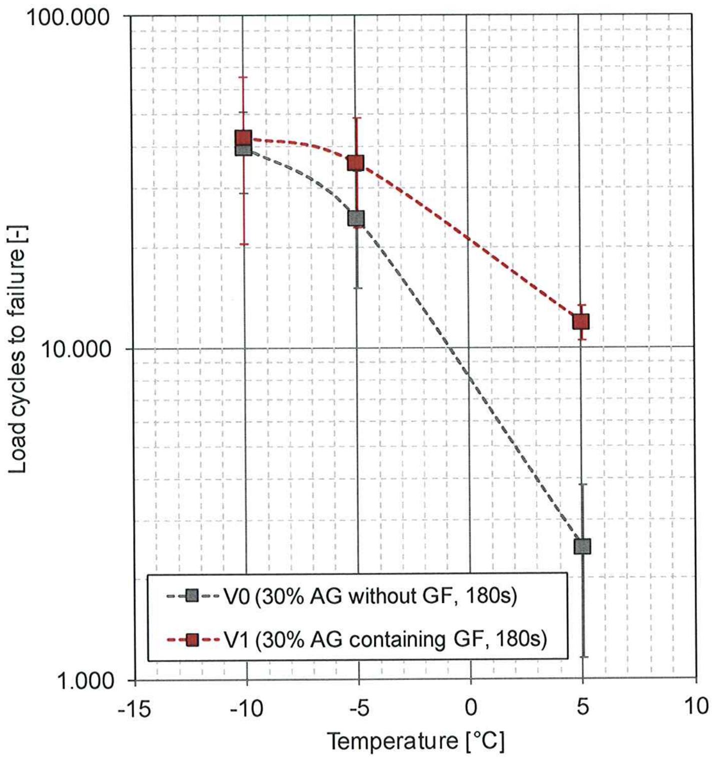

Fig. 17: Comparison of the load cycles to failure of control and glass fibre variants depending on temperature

It should first of all be noted that the load cycles to failure for the glass fibre variant are above those of the control variant across the whole temperature range. While the values at -10 °C are almost comparable, the difference increases with rising temperatures. At +5 °C the glass fibre variant performs considerably better.

When evaluating the results the following considerations should be taken into account:

1. Within the investigations no separate cooling tests were carried out to determine the mixture-specific thermal stresses but rather the same conditions were assumed for all the variants. Due to the uniform composition and the same asphalt granulate quality this is certainly acceptable at higher temperatures as the thermal stresses are negligibly small in this case and any differences which occur have hardly any effect. This however does not apply to the same extent for lower temperatures.

2. As the asphalt containing glass fibre tends to show a more ductile behaviour than the control variant, presumably less thermal tensile stress occurs here. So through the equal treatment of all the variants the load cycles to failure determined for the control variant are more likely to be overestimated and those for the glass fibre variant underestimated.

3. The strains which occur at low temperatures are very small. When the strains are so small there is reason to presume that the glass fibres elements are not activated and thus not involved in the stress transfer. This effect is possibly responsible for the small difference between both variants at low temperatures.

When summarising the above statements the conclusion can be drawn that if the same thermal stress state is assumed for both asphalts, the fatigue behaviour in the negative temperature range of the asphalt containing glass fibre is evaluated too low. If the tests were repeated with the individual (thermal) tensile stresses, it is highly probable that the asphalt containing glass fibre would perform better in contrast to the control variant even at low temperatures.

On the basis of these results it can be noted that the use of reclaimed asphalt containing glass fibre material has no negative effect at all on the fatigue behaviour at low temperatures. The asphalt containing glass fibre even tends to bear more load cycles and thus has a better fatigue behaviour.

4.2.2 Influence of glass fibre content and final mixing time

A subordinate investigation aim, based on the findings of the preceding investigations, was the influence of the amount of glass fibre and the final mixing period. Fig.18 first illustrates the results for the variation in the amount of glass fibre which was added to the reclaimed asphalt.

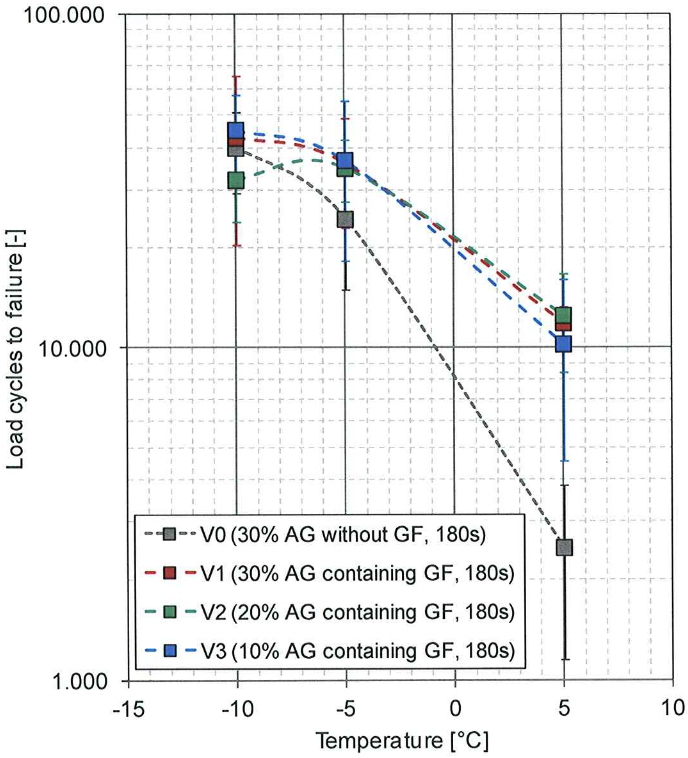

Fig. 18: Influence of the glass fibre content and the asphalt granulate proportion on the load cycles to failure at different temperatures

The test results lead to two interesting conclusions:

1. Even a small amount of glass fibre increases the tolerable load cycles noticeably.
2. A further increase in the amount of glass fibre does not lead to significant improvements, as all three glass fibre variants yield comparable results.[1]

Accordingly the statements made in the previous section apply to the same extent to all three glass fibre variants. None of the glass fibre variants perform worse than the control variant under the same production conditions.

In a last step the final mixing time was halved in order to allow an assessment of the effect on the homogeneity of the mixture. This also yielded interesting results which are summarised in Fig.19. The control variant is represented in addition to the 3 glass fibre variants, even though a direct comparison cannot be made due to the different final mixing times.

[1] The slightly lower number of load cycles of the variant V2 at -10 °C also lies within the precise reproducibility for this test.

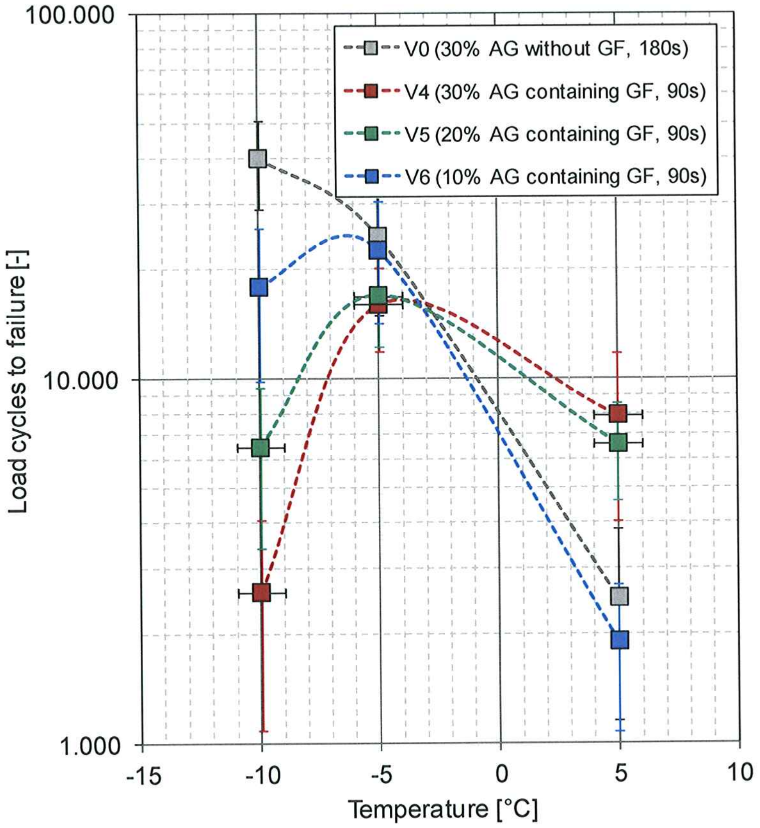

Fig. 19: Influence of the asphalt granulate proportion on load cycles to failure with a shortened final mixing time

The following conclusions can be drawn:

1. Overall all the load cycles to failure are below the values for the corresponding glass fibre variants with a longer final mixing time (see Fig.18). This indicates that a mixing time of 90 s is not sufficient for thorough mixing in terms of both the asphalt granulate and the fibres.
2. While the difference at +5°C and -5 °C is only relatively small, the values for -10 °C decrease significantly compared to the variants with a longer mixing time. The reason for this cannot be established conclusively. The susceptibility at low temperatures however is known to be particularly pronounced as in this case even the smallest imperfections in the asphalt test specimen can lead to premature failure.
3. Against the results for the long mixing time, there is an influence of glass fibre content. This however is not further analysed here, because of the insufficient homogenization of the mixture (see point 1).

Overall the results are very systematic and allow room for further interpretations which should however be substantiated by further investigations, particularly with regard to low temperature behaviour.

4.2.3 Summary of the results

Due to the fact that particularly the results in the negative temperature range contain some uncertainties as a result of the uniformly applied thermal tensile stresses for all the variants. Fig.20 shows the results for the highest tested temperature, namely +5°C. At this temperature it can be assumed that the thermal stresses are practically negligible and thus the results can easily be compared with each other.

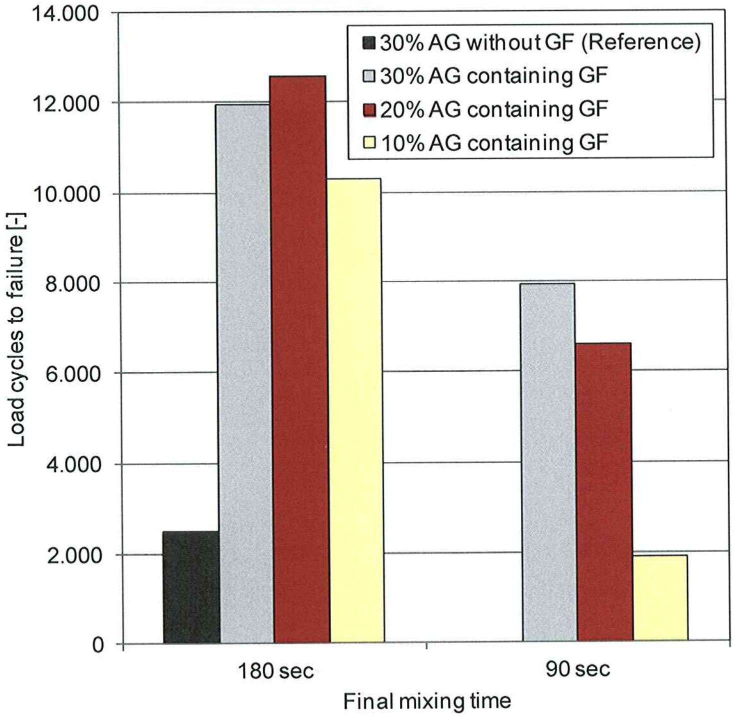

Fig. 20: Comparison of variants by number of load cycles to failure at a temperature of +5 C

To sum up, the following statements can be made on the basis of the data collected:

- A direct comparison between the control variant without glass fibre and the corresponding variant containing glass fibre shows that the glass fibre variant has a more favourable fatigue behaviour. The prerequisite is a sufficient final mixing time.
- The amount of glass fibre-modified asphalt granulate added has no significant influence on the fatigue properties. All the variants investigated (10 wt.-%, 20 wt.-% and 30 wt.-% AG) tolerate more load cycles than the control variant and thus exhibit better fatigue properties.
- Halving the final mixing time results in lower load cycles numbers due to insufficient homogenisation, while the fatigue behaviour improves slightly with an increased proportion of asphalt granulate. A direct comparison with the control variant is however not possible in this case due to the differing final mixing times.

5 Overall assessment

In order to assess the milling behaviour and the recycling of glass fiber reinforced asphalt (GlasGrid GG 200-8502) milling tests and comparative asphalt tests were carried out using the reclaimed milled material. The investigations yielded the following key results:

- On the test section of the Institute for Road and Traffic Engineering, RWTH Aachen, the asphalt reinforcement was milled together with the asphalt overlay and the upper part of the asphalt binder course in a single operation. No adverse effects on the milling operation caused by the asphalt reinforcement were ascertained.
- In the course of the asphalt technological investigations the reclaimed asphalt containing glass fiber (milled material) was used in a new asphalt binder mixture which was tested with regard to its fatigue properties in low temperatures. The fatigue criterion was the number of bearable load cycles gained in tension fatigue tests. In comparison with a control mixture containing the same proportion of asphalt granulate without glass fiber, there were no adverse effects when the material containing glass fiber was used. In fact even a tendency towards a slightly better fatigue behaviour was detected.

Harmless recycling of glass fiber reinforced asphalt can be considered as proven on the basis of these results if sufficient homogenisation of the resulting mixture is ensured. There are no concerns whatsoever with regard to using glass fiber in a wearing course either. It must however be borne in mind that the fiber material could partly be exposed on the surface, although this is probably only a temporary problem, since the fiber strains will be removed by traffic loading.

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Dr.-Ing. Christian Schulze	Dipl.-Ing. Dipl.-Wirt.-Ing. André Meyer

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