Mixing and compacting asphalt mixtures modified with silane molecules

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ABSTRACT

If chemically reactive silane molecules are added to a road asphalt mixture the performance properties change significantly. The additive coats the surfaces of the aggregate particles and forms a layer of 1 to 100 nanometres in thickness. Due to this effect, advantageous changes in asphalt performance behaviour are noticed such as consistent and higher compaction, and a highly reduction of binder stripping. This paper reports on workability observed during production of asphalt mixtures of the type AC 11 with 25/55-55 and AC 16 with 50/70 produced in laboratory with and without adding silane molecules. During mixing and compaction the power consumption was continuously recorded. During the mixing process it was stated, that if silane molecules were added, the time needed for coating the aggregate was reduced by 20%, while the power consumption of the mixing unit always remained at the same level. When temperature was reduced stepwise during the compaction process, from the standard mixing temperature of 135 to 95 degree Celsius for the AC 16 mixture, and of 145 to 105 degree Celsius for the AC 11 mixture respectively, compactability always remains at the same level. From this laboratory study it was concluded, that workability may be significantly improved through a silane additive.

Keywords: Additives, Asphalt, Density, Energy saving, Workability

1. INTRODUCTION

Road pavements in Germany are commonly made of hot asphalt mixture [1]. Conventionally, compaction temperature is in the range of 135°C to 160°C. A decrease in compaction temperature would lead to significant technical, economic and environmental advantages:

- The construction process would be less dependent on weather and season conditions;
- The compactibility would increase with potential benefits in terms of higher bulk density and lower air voids content resulting in a longer life time;
- A lower energy demand associated to lower natural resources consumption and exploitation.

One technique to achieve this is the use of wax based additives to modify the viscosity of bitumen. These additives were used in the recent past. For example, the German Federal Highway Research Institute (BASt) evaluated and monitored a number of tests sections where wax additives were used [2, 3]. Good workability was observed while the mixing temperature was reduced of 20 K. Performance tests showed good results, except in terms of low temperature behavior [4]. According to the BASt specification and recommendations, the use of these additives is required for mastic asphalt [3, 5]. However, for health and safety measures, the mixing temperature was reduced from 250°C to 230°C.

Alternative ways to reduce mixing temperature are the use of Zeolites [6, 7] or the Swedish KGO III technique by Karl Gunnar Ohlson [8]. Both techniques are unusual in Germany.

Organic silane, commonly used in semiconductor industry as coupling agents to facilitate the adhesion between bio-inert materials and specific polymer matrices, represents an attractive solution for improving the compaction process. This additive creates a stronger bonding effect of bitumen and aggregates [9, 10] based on an irreversible chemical reaction between silane and aggregate associated to the evaporation of a small amount of water. A known effect of the increased bonding properties is an improved water resistance as water cannot dissolve the saline-aggregate interaction [11].

In this paper the temperature reduction effect during mixing and compaction process of a commercially available silane additive is evaluated. The improved bonding effects and the minimum remaining amount of water (it is not a foamed bitumen) potentially lead to a consistent reduction of the viscosity in the hot asphalt mixtures during production. So a decrease in temperature for mixing and the following compaction processes should be possible. Due to the experience of poorer low temperature performance when using wax based additives, TSRSTs and USTs were conducted to evaluate the behavior of mixture containing silane.

2. MATERIALS AND EXPERIMENTAL PLAN

In order to evaluate the compaction resistance, an asphalt mixture (AC 16 B S) for binder course, as well as a mixture (AC 11 D S) for wearing course were produced in the ISBS laboratory. Both types of asphalt mixtures were prepared according to mix design conventionally used in Germany [5]. The two mixtures were designed with Gabbro aggregate, limestone filler and with two types of bitumen: one paving grade bitumen having penetration range 50/70 [12] and one polymer modified bitumen with penetration range 25/55 [12] and softening temperature of 55ºC (EN 1427, 2007), named 25/55-55. Silane additive was used in 3 out of 4 prepared mixtures. Table 1 presents the mix design for the asphalt mixtures used in the present research.

Table 1: Asphalt Mix Design

Type of asphalt mixture	AC 16 B S	AC 11 D S
Bitumen	50/70	25/55-55 A
Bitumen content*	4,3%	6,0%
Silane content * as function of bitumen content	0,10%	0,15%
Aggregates*	Gabbro	Gabbro
> 16,0 mm	2,8%	-
11,2 - 16,0 mm	28,5%	0,5%
8,0 - 11,2 mm	12,1%	20,2%
5,6 - 8,0 mm	12,8%	10,8%
2,0 - 5,6 mm	15,2%	23,3%
0,063 - 2,0 mm	22,0%	37,6%
< 0,063 mm	6,6%	7,6%

* % percentage with respect to the total material mass

The addition of Silane was carried out suing a special mixer with a Cowles agitator for producing emulsions (see Figure 1). Silane was mixed together with the bitumen and heated up to 160 °C for at least 10 minutes. The newly obtained bitumen was then added to the pre-heated aggregates in the mixer and the mixing process performed.

Figure 1: Cowles Agitator (Left) and Mixer Used (Right) for Blending Bitumen and Silane

Both asphalt mixtures were prepared with and without silane compound so that the plain mixtures could be used as control. In addition, different compaction temperatures were selected. Table 1 provides a summary of the experimental plan.

Table 2: Experimental Plan

ID	Asphalt Mixture	Bitumen	Silane	Compaction Temperature
1a	AC 16 BS	50/70	no	135 °C
1b			yes	135 °C
1c			yes	115 °C
1d			yes	95 °C
2a	AC 11 DS	25/55-55 A	no	145 °C
2b			yes	145 °C
2c			yes	125 °C
2d			yes	105 °C

The same compaction method (load, number of roll passes, etc.) was used for each mixture type; only compaction temperatures were different. Four asphalt slabs of sizes 300 x 260 x 40 mm³ and 300 x 260 x 50 mm³ were produced for each mixture AC 11 DS and AC 16 BS.

3. EXPERIMENTAL PROCEDURES

The mixing process was performed according to the current German Standard TP Asphalt-StB, part 35 [14] which based on the European standard EN 12697-35 [15]. During the two minute mixing, all eight asphalt mixture types were filmed and then the time for a specified coating percentage of aggregate was visually estimated. For evaluation, four degrees of coating were selected: 50%, 75%, 90% and 100%.

During the mixing process, the laboratory mixing device was used to record the torque of the mixing agitator attached to the driveshaft and of the mixing drum and the data converted into power [W]. The sum of the power from the agitator and drum are specified in a diagram over a two minute mixing duration. As an alternative representation, the accumulated power, energy, [Ws]=[J], is represented in another diagram.

The compactibility T was determined on the basis of the change in thickness of the Marshall sample during the compaction procedure according to German Standard TP Asphalt-StB, part 10 [16] which is derived from EN 12697-10 [17]. On the basis of the reducing sample thickness, due to the number of impacts, an exponential function can be determined whose parameter T provides an estimation of the material compactibility. Small values of T are typical of materials easy to compact, whereas larger values are representative of asphalt mixtures that require significant effort for achieving the desired compaction. In addition, bulk density, $\rho_{b,SSD}$ [18, 19], maximum density, ρ_m [20, 21], and air voids content V [22, 23] were measured for each asphalt mixture slab produced.

Two slabs of each asphalt mixture were cut into prismatic specimen with the dimensions of 40 x 40 x 160 mm^3 for AC 11 D S and 50 x 50 x 160 mm^3 for AC 16 B S. The specimens were subjected to low temperature tests according to EN 12697-46: Thermal Stress Restrained Specimen Tests (TSRST) and Uniaxial Tension Stress Tests (UTST). In TSRST the specimen is restrained and the two ends of the sample are kept at the same distance, while temperature is reduced with a rate of 10 K/h. As thermal shrinkage is prevented, a kryogenic stress develops until failure occurs. By recording the kryogenic stress, a curve of stress versus temperature, the failure temperature and failure stress can be specified. In UTST specimen is cooled down to test temperature avoiding any stress to builds up. Then the specimen is pulled until failure. The selected UTST temperatures were +20 °C, +5 °C, -10 °C and -25 °C; hence, a minimum number of 8 specimens were needed. For each temperature the maximum stress is recorded as tensile strength and all results are then used to generate the regression curve of strength as function of temperature.

4. RESULTS

4.1 COATING, POWER CONSUMPTION AND COMPACTIBILITY

The visually estimated times for different degrees of coating of the different asphalt mixtures investigated are presented in Table 3. The mixing processes of both asphalt types show that the asphalt mixture without silane (ID 1a and 2a) required a longer period for coating the aggregates compared the other mixtures containing the binding agent (ID 1b, 1c, 1d and 2b, 2c, 2d). This results lead to the conclusion that using silanes, a shorter mixing time will be needed.

Table 3: Estimated Times for Different Degrees of Coating in the Mixing Process.

Degree of coating	**Mixture AC 16 BS**				**Mixture AC 11 DS**			
	1a	**1b**	**1c**	**1d**	**2a**	**2b**	**2c**	**2d**
50 %	25 s	15 s	19 s	19 s	37 s	22 s	30 s	30 s
75 %	35 s	22 s	30 s	29 s	45 s	29 s	38 s	39 s
90 %	50 s	32 s	40 s	43 s	55 s	42 s	44 s	46 s
100 %	67 s	47 s	50 s	55 s	80 s	56 s	66 s	61 s

Figure 2 and 3 show, on the left side, the power consumption of the mixer in [W] versus time for the four different compaction temperatures of mixtures AC 16 BS and AC 11 DS, respectively. The corresponding accumulated power demand is plotted on the right side. The accumulated power demand for AC 16 B S indicates that mixtures prepared with silane require less mixing power. A similar behavior could not be observed for mixture AC 11 DS.

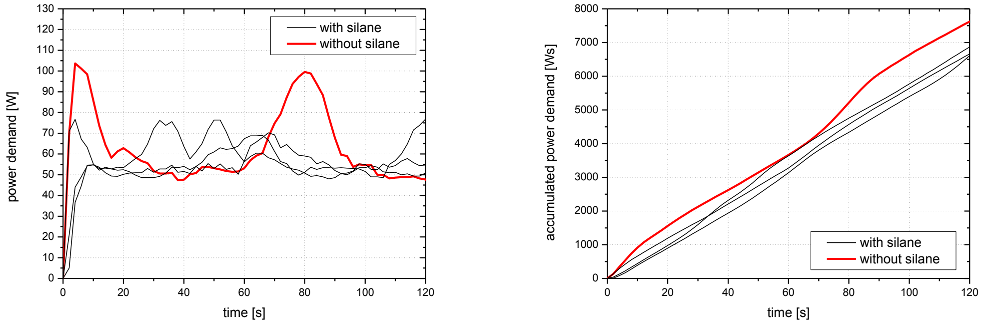

Figure 2: Recorded power demand [W] and accumulated power demand (right side) during the mixing processes for mixtures AC 16 B S.

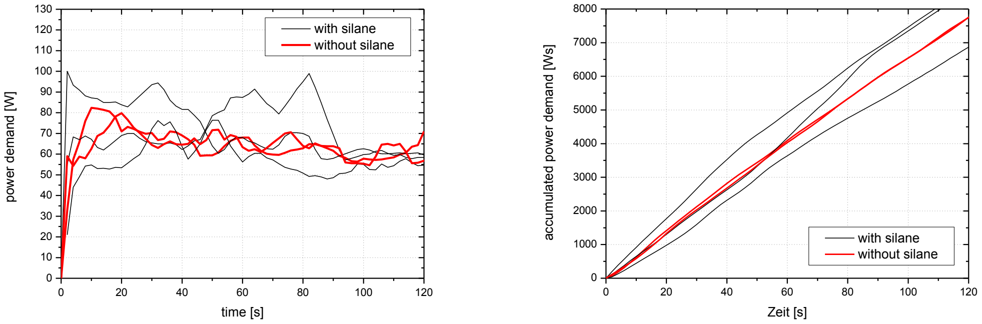

Figure 3: Recorded power demand [W] and accumulated power demand (right side) during the mixing processes for mixtures AC 11 D S.

The compactibility for both types of asphalt mixtures with respect to compaction temperature is shown in Table 4. Despite different compaction temperatures, the compactibility, T, shows no significant differences. Overall, asphalt mixture AC 16 B S requires slightly more compaction effort compared to AC 11 D S.

Table 4: Asphalt Mixture Compactibility, T, as Function of Compaction Temperatures.

ID	Asphalt Mixture	Compaction Temperature	Compactibility T
1a	AC 16 BS	135 °C	41,6Nm
1b		135 °C	43,5 Nm
1c		115 °C	42,8 Nm
1d		95 °C	41,3 Nm
2a	AC 11 DS	145 °C	37,3 Nm
2b		145 °C	34,2 Nm
2c		125 °C	36,5 Nm
2d		105 °C	36,5 Nm

4.2 AIR VOIDS

In Table 5, bulk density and air voids content, obtained from the slab samples produced for each mixture type, are specified in terms of mean.

Table 5: Bulk Densities, Maximum Densities and Air Voids Content of the Asphalt Mixture Slabs Produced at Different Compaction Temperatures.

Asphalt mixture	**AC 16 B S**				**AC 11 D S**			
ID	**1a**	**1b**	**1c**	**1d**	**2a**	**2b**	**2c**	**2d**
Compaction Temperature °C	135	135	115	95	145	145	125	105
Bulk Density g/cm³	2,511	2,508	2,506	2,513	2,508	2,500	2,491	2,483
Max. Density g/cm³	2,684	2,711	2,713	2,688	2,618	2,615	2,627	2,622
Air Voids Content Vol.%	6,4	7,5	7,6	6,5	4,2	4,4	5,2	5,3
Mean Max. Density g/cm³	2,699				2,621			
Mean Air Voids Content Vol.%	7,0	7,1	7,2	6,9	4,3	4,6	5,0	5,3

Table 5 indicates that the maximum density of each asphalt mixture type is consistently similar either with or without silane additive. The air voids contents determined for the asphalt mixture AC 11 D S were all within the German repeatability accuracy of r = 1.1 Vol.% and can be assumed as statistically equivalent. However, the tendency of increasing air voids contents with reducing compaction temperature can be recognized. For the asphalt mixture AC 16 B S, the air voids percentage calculated with the average maximum density is also within the German repeatability accuracy. If the maximum density of the individual mixture types is used, the repeatability accuracy limit is slightly exceeded.

4.3 LOW TEMPERATURE BEHAVIOR

In figure 4 and 5 the results of the UTST and TSRST are presented as function of temperature. Significant kryogenic stress starts to build up at 10 °C, and increases with decreasing temperature, up to failure below - 20 °C. The tensile strengths (point markers) are connected by a regression line for each asphalt mixture to show their temperature dependency. All asphalt mixtures show a maximum of tensile strength around -10 °C. Comparing both asphalt mixture types, the tensile strength of AC 16 B S doesn't reach the level of AC 11 D S and its maximum is slightly shifted to higher temperatures.

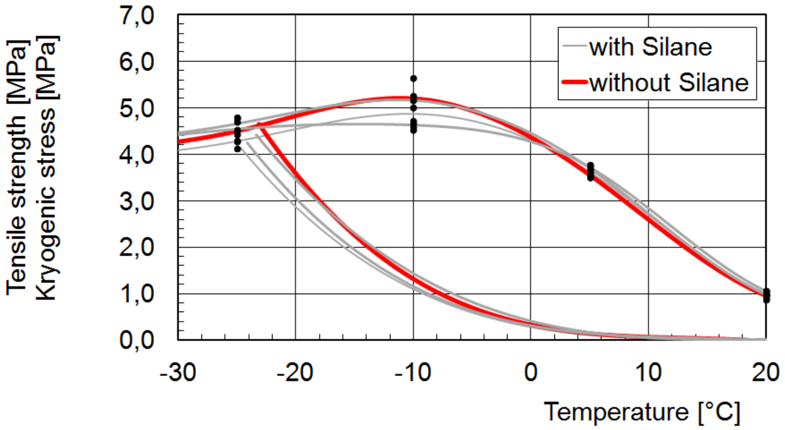

Figure 4: Results of UTST and TSRST: Tensile Strength and kryogenic Stress as function of temperature for mixtures AC 11 D S.

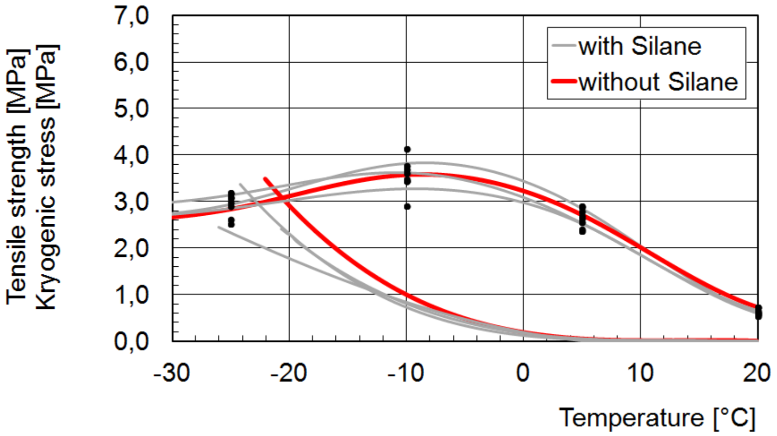

Figure 5: Results of UTST and TSRST: Tensile Strength and kryogenic Stress as function of temperature for mixtures AC 16 B S.

Regarding the tensile strength, both figures show no differences between the asphalt mixtures with or without silane. All results are scattering in a range where no significant difference could be observed.

The kryogenic stresses show small differences. The asphalt mixture with silane shows an explicit tendency of lower kryogenic stress at lower temperatures with respect to the asphalt mixture without silane (black line in figure 4 or 5). As there's no distinct trend for failure temperature or failure stress, only the trend of lower kryogenic stresses can be noted.

5. SUMMARY AND CONCLUSIONS

In this research the influence of the silane binding agent on the mixing process and to compaction properties of asphalt mixture and their impact on low temperature behavior was investigated. For this purpose, two typical asphalt mixtures used in Germany, one for wearing course and one for binder course, were prepared. During the mixing processes, the power consumption of the laboratory mixer was recorded and the time that the degrees of coating of 50 %, 75 %, 90 % and 100 % were reached was recorded. In addition compactibility and air voids content was measured. Prismatic specimens were cut of the slabs and TSRST and UTST were conducted.

The following conclusions can be drawn:

- Coating requires, on average, 20 % less time when using silane.
- Less power consumption was observed for binder layer mixture when adding silane to the mix design.
- The compactibility does not show any difference for both asphalt mixture types with and without binding agent.
- The maximum density of the asphalt mixtures produced can be considered equivalent, while the bulk densities of the roller compacted mixture slabs indicate minimal differences.
- An effect of compaction temperature on air voids content was observed only for the wearing course mixture with increasing values for lower compaction temperatures. Nevertheless, the variation of air voids content was not very remarkable.
- The low temperature behavior was not affected from silane addition. In case TSRST slightly better results were observed.

Overall, when including silane in the mix design, aggregate coating time is reduced as well as compaction temperature resulting in air voids contents comparable to those obtained without binding agents. A negative impact to low temperature behavior can be avoided.

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