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Warm Asphalt Mix – Technologies, Research and Experience

Mieszanki mineralno-asfaltowe na ciepło – technologie, badanie i doświadczenia

Summary

Caused by the demand for lower bitumen fume emissions, different Warm Asphalt Mix (WAM) technologies have been developed which enable to mix, transport, pave and compact asphalt at up to 40°C lower temperatures than usual. These technologies are based on three different principles:

- Modification of the asphalt mixing process, e.g. by using two bitumen types
- Introduction of water causing in-situ foaming of the bitumen
- Addition of substances, which decrease the viscosity of bitumen at the processing temperature

Additional benefits are energy savings, lower CO₂ emissions, reduced binder ageing and faster release to traffic due to shorter cooling time. Additionally, the viscosity reducing additives improve the resistance to permanent deformation due to increased stiffness of the binder at service temperature. The WAM technologies have been studied in extensive lab and field studies and proved the performance in long-term observation.

The new technology can not only improve the environmental impact of asphalt. Viscosity reducing additives offer a versatile tool to every asphalt designer.

Streszczenie

Wymóg ograniczenia emisji wycieków, wynikających z pracy z gorącym asfaltem, spowodował opracowanie szeregu technologii mieszanek mineralno-asfaltowych na ciepło (Warm Asphalt Mix WAM). Technologie te umożliwiają mieszanie, transport, układanie oraz zagęszczanie mieszanki w temperaturze niższej nawet o 40°C. Oparte są one na trzech różnych zasadach:

- modyfikacji procesu wytwarzania mieszanki, np. używając dwóch różnych asfaltów,
- wprowadzeniu wody powodującej pienienie się wewnątrz (in-situ) asfaltu,
- dodanie substancji obniżających lepkość asfaltu w temperaturze przetwarzania.

Dodatkowe korzyści to oszczędność energii, obniżenie emisji CO₂, spowolnienie starzenia lepiszcza oraz szybsze otwarcie jezdni dla ruchu, wynikające z krótszego czasu stygnięcia nawierzchni. Ponadto, substancje obniżające lepkość poprawiają odporność na trwałe odkształcenia zwiększając sztywność lepiszcza w temperaturze użytkowania. Wnikliwe badania laboratoryjne i terenowe udowodniły sprawność mieszanki w długoterminowych obserwacjach. Nowa technologia mieszanki mineralno-asfaltowej nie tylko jest bardziej przyjazna środowisku, ale również obniżając lepkość asfaltu staje się uniwersalnym narzędziem dla każdego projektanta mieszanki.

1 Introduction

Since the mid-1990-ies the European asphalt industry and meanwhile also the North American asphalt industry is confronted with demands for decreased bitumen fume and aerosol emissions and CO₂ emissions. The best option to fulfil these demands is to reduce the temperatures of asphalt production, transportation, paving and compaction. Different technologies have been developed which allow to produce asphalt layers at up to 40°C lower temperatures and to achieve the same asphalt quality as with conventional hot mix asphalt. These technologies, which are called “Low Temperature Asphalt” or “Warm Asphalt Mix” (WAM), can even improve some asphalt properties. This paper analyses the various technologies, reports on research results and ongoing field performance monitoring. The review of the individual processes may be incomplete, since the number of offered products is continuously increasing.

2 Warm Asphalt Mix Technologies

The temperatures during production, transportation, laying and compaction of asphalt can be reduced with the following proven technologies:

2.1 Modification of Process Technology

Modifications of the existing batch mixing plant technology allow a reduction of the mixing temperature without changing the components of the asphalt.

- KGO or “addition sequence” process
In the first step of the KGO process, only the coarse aggregates are blended with the bitumen until a homogeneous mix is obtained. The increased bitumen/aggregates ratio allows the mixing with cooler, i.e. higher viscous bitumen. In the second step the finer aggregates are added and can be dispersed into the pre-coated coarse mix.
- Two phase mixing process
In the first phase the aggregates are mixed with a soft bitumen grade. The low viscosity allows reducing the process temperature. In the second phase a hard bitumen grade is added and can be homogenized with the pre-coated aggregates at reduced temperature.

The feasibility has been demonstrated for both technologies and homogenous mixes with fully coated aggregates have been obtained. However, technical modifications of the mixing plants are necessary and the available time for transportation and paving is reduced since the rolling has to be completed at similar temperatures as with conventional asphalt.

2.2 Water-based Technologies

Some WAM technologies are based on the introduction of water into the mixing process. The common principle is the generation of water steam which increases the volume of the binder and decreases its apparent viscosity. These effects allow asphalt mixing temperatures of 120-125°C and compaction temperatures of 90-95°C.

- Warm Asphalt Mix Foam
The WAM-Foam process uses a two-component binder system, similar like the two phase mixing process. In the first step the aggregates are coated with a soft binder and subsequently foamed, harder bitumen is added. This technology needs a modification of the mixing plant. However, in contrast to the other water-based processes, the dry aggregates are coated with bitumen before the water is introduced. This may be advantageous with respect to adhesion of the binder on the aggregates. The most trials and applications are located in Scandinavia where the process has been developed.

- Zeolites
Zeolites are added into the mixing plant and substitute a part of the filler. The structure of this synthetic sodium aluminium silicate mineral contains 21 wt. % water in small pores which is released upon heating within 2-3 hours. The evolving water steam causes a quasi in-situ foaming of the bitumen. In order to enable the addition of zeolite, the mixing plant has to be equipped with an additional storage silo and a feeding system. The zeolite technology is in use in Europe and has also been successfully demonstrated in the USA. The properties of the finished asphalt layers are not significantly differing from conventional layers.
- Wet aggregates
Instead of an additional mineral, wet sand is used to introduce water into the mixing plant. In interaction with added chemicals (surfactants) the released steam effects in-situ foaming of the bitumen. This process requires a plant modification.
- Emulsion technology
In-situ bitumen foaming can also be obtained by mixing bitumen emulsions with hot aggregates. This technology applies special emulsions with 30 % water content which are delivered and fed into the mixer at a temperature of ca. 90°C.

A common feature of water-based technologies is the limited duration of the effect, therefore the asphalt mix has to be paved and compacted soon after the production. The methods are proven for soft and medium bitumen grades.

2.3 Viscosity Reducing Organic Additives

Viscosity reducing additives are deformation resistant solids at service temperature which melt, depending on the type of additive, between 70 and 140°C. The melts are low-viscosity liquids which are homogeneously soluble in hot bitumen and can therefore quickly and easily be blended with bitumen and polymer-modified bitumen, e.g. by stirring. Significant viscosity reductions are obtained by adding 2-4 % into the bitumen. Because of the solubility of the additives, the viscosity reduced binders are hot storage stable and in contrast to other WAM technologies, the viscosity effect is permanent, even at asphalt recycling at the end of the service life of the layer.

During the cooling time of the paved asphalt the molten additives solidify to microscopically small, uniformly distributed particles which increase the stiffness of the binder, analogous to fibre-reinforced materials. Especially the benefit of improved stiffness at high service temperatures without significant changes of other properties opened up additional applications with only partial utilization of the temperature reduction potential.

The additives are either added as solids into the mixer, or as pre-blended, low viscosity binder. The latter is recommended in order to assure homogeneous distribution. Alternatively, asphalt mixing plants can be equipped with in-line dosage systems. One of the additives is also available as combined cellulose fibre/additive pellet for the production of warm mix SMA. Currently three classes of additives are in use:

- Montan Wax based additives
Montan wax (lignite wax) is extracted from special, waxy lignite. In chemical terms, montan wax consists mainly of fossil fatty acid esters. The pure wax melts around 75°C and therefore it is frequently blended with higher melting materials, such as amide waxes.
- Amide Waxes
Amide waxes are synthetic fatty acid amides with melting points around 140°C which are available under different trade names.

- **Fischer-Tropsch (FT) Wax (Sasobit®)**

FT wax is a blend of long-chain alkanes which is produced from synthesis gas (CO / H₂) with the Fischer-Tropsch process. This additive is a pure hydrocarbon without functional groups and therefore shows high chemical stability and ageing resistance. The pure wax melts around 100°C. However, when blended with bitumen, solvency effects shift the congealing temperature of the additive to about 80-85°C and allow asphalt compaction below 100°C. More than 7 million tonnes of hot mix have been modified by FT Wax over the last 6 years and have proven its benefit on each occasion.

2.3.1 Influence on Binder Properties

In the following chapters the effects of viscosity reducing additives on binder and asphalt properties are discussed exemplarily for FT wax.

The ability to produce and lay asphalt mixes at decreased temperature is mainly based on decreased binder viscosity. Extensive investigations have shown that 3% FT wax decrease the viscosity of bitumen and of polymer-modified bitumen (pmb) by 13-29%, on average by 20%. As displayed by figure 1, the viscosity decreases approximately linear with increasing percentage of the additive. Figure 2 illustrates that the effect has been present in the complete investigated temperature range between 90 and 160°C.

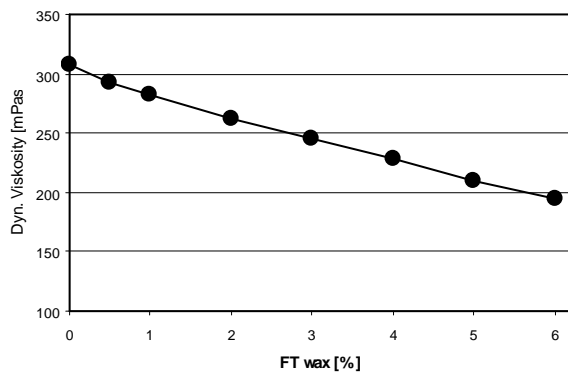


Fig. 1: Dynamic viscosity of bitumen 70/100 with increasing content of FT wax (Rotational viscometer at 135°C)

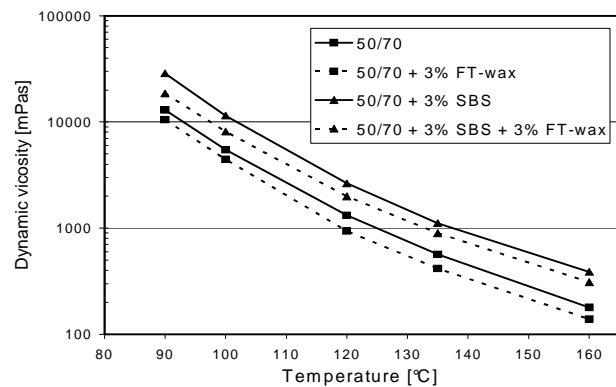


Fig. 2: Dynamic viscosity of neat and modified B 50/70 (Rotational viscometer)

Moreover figure 2 illustrates the enormous viscosity increase which is caused by the addition of SBS polymer and the viscosity reduction by the co-modification with FT wax.

At medium and high service temperature, the stability and durability of asphalt layers is decisively influenced by the stiffness of the binder. The stiffness is conventionally determined with needle penetration measurements and in performance related testing with the dynamic shear rheometer (DSR). As shown in figure 4, the additive decreases the penetration with increasing percentage of addition. The intensity of the stiffening effect is the higher, the softer the base bitumen is. An addition of 3% shifts the penetration to the next harder binder class. The German Petroleum Institute fundamentally investigated the influence of FT wax on the visco elastic properties of bitumen with DSRⁱ. Besides the complex modulus, the phase angle δ is a good measure for stiffness and elasticity of the binder.

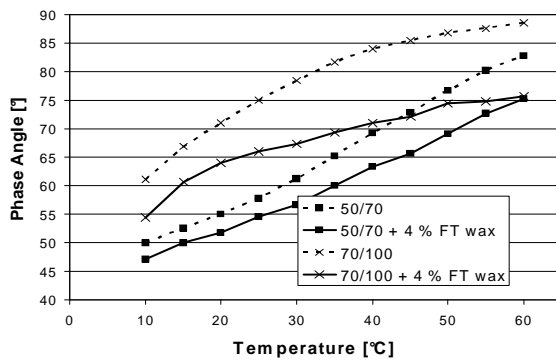


Fig. 3: Influence of FT wax on DSR phase angle δ at different temperatures

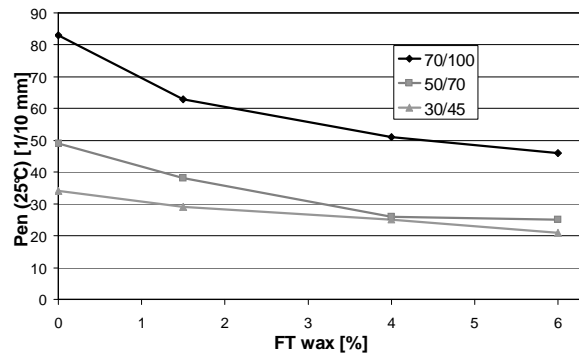


Fig. 4: Influence of TF wax on needle penetration at 25°C

Figure 3 illustrates that the additive decreases the phase angle, i.e. increases the stiffness. This effect is especially pronounced at high temperatures and therefore improves the deformation resistance of asphalt at high summer temperatures.

2.3.2 Influence on Asphalt Properties

The viscosity reducing and stiffening effects of FT wax on the binder are expected to result in analogous effects in asphalt. Numerous laboratory investigations have been performed. The effect of reduced binder viscosity on the compaction resistance of SMA, which is known to be difficult to compact, has been evaluated with the method of Arand and Renkenⁱⁱ. This method is based on detecting the decreasing height of the specimen after each blow of the Marshall hammer. The results in table 1 demonstrate the decreasing compaction resistance with increasing percentage of the additive and the resulting decreased voids percentage in the asphalt.

Tab. 1: Compaction resistance of SMA 0/11 S in dependence of FT wax content in bitumen 50/70

FT wax [%]	0	2.0	4.0
Compaction resistance D	41.6	39.7	33.0
Voids [%] after 100 blows	6.80	4.77	2.03
after 200 blows	3.5	1.70	1.87

Lawrenceⁱⁱⁱ demonstrated with asphalt binder course mix 0/16 S, which is also difficult to compact, the influence of the additive on the volumetric density of Marshall specimens (Table 2). Based on the number of blows that were necessary to obtain the compaction degree of 100 % for asphalt mix without additive, the mix with 3 % FT wax showed a 2 % higher compaction degree at the same number of blows; simultaneously the Marshall stability increased by 19 %. These results indicate the potential of viscosity reducing additives for ensuring optimal compaction even of asphalt mixes which are difficult to compact. Huschek^{iv} pointed out that the reduction of the compaction degree by 2 % causes a loss of stability at elevated service temperatures by 30 %.

Tab. 2: Influence of FT wax on volumetric density and Marshall stability of asphalt binder course mix 0/16 S; binder content 4.2 %; compaction temperature 135°C; 2 x 50 blows.

	0 % FT wax	1.5 % FT wax	3 % FT wax
Density [kg/m ³]	2.439	2.473	2.505
Compaction degree [%]	100	101	102
Marshall stability [kN]	9.0	9.8	10.7

Gussasphalt (mastic asphalt) is produced and applied at temperatures up to 250°C. Because of the high bitumen fume emission level at such temperatures it is of special interest to decrease the temperature of mastic asphalt. Laboratory tests and the practical experience of the last years have shown that the addition of 3 % FT wax on top of the usual bitumen content allows to decrease the production temperature by 30°C and more. The potential for temperature reduction of individual asphalt mixes can be determined in the lab by measuring the resistance to stirring. Figure 5 displays such measurements for mastic asphalt GA 0/11 and GA 0/11 + 3 % FT wax (based on bitumen content). The upper dotted horizontal line in the figure at 275 Ncm indicates the limit for processability, the line at 230 Ncm indicates the limit of good processability.

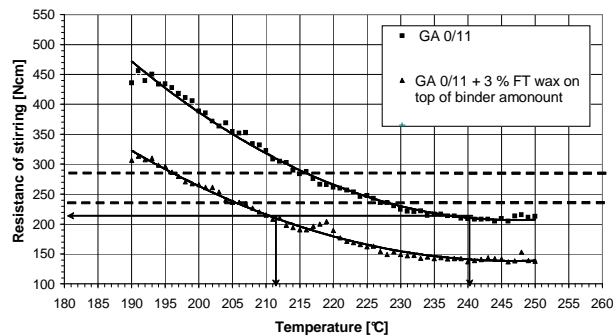


Fig. 5: Influence of FT wax on the resistance of stirring of mastic asphalt GA 0/11

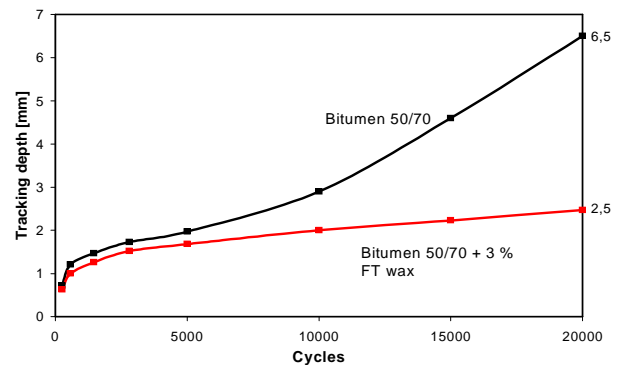


Fig. 6: Hamburg wheel tracking test (steel wheel; 700 N load; water bath at 50°C); SMA 0/11 S

It can be read from the diagram that for a desired resistance of 210 Ncm, which allows smooth paving, the additive shifts the temperature from 240 to 211°C.

Stiffening effects of the additive should result not only result in changed binder properties but also in improved mechanical properties of asphalt layers. This assumption has been confirmed by wheel tracking tests. Figure 6 shows that the tracking depth of SMA 0/11 S has been significantly reduced by modifying the bitumen with 3 % FT wax.

The stability of mastic asphalt can be evaluated with the static indentation test at 40°C, or more realistic with dynamic indentation tests at 50°C. The test results in figure 7 and 8 verify the improved resistance to permanent deformation at elevated temperature.

Besides the stability at high service temperatures also the low temperature properties are crucial for the durability of asphalt. Since the low temperature behaviour of asphalt is not only

determined by the binder properties but also by binder content and particle-size distribution of the aggregates it is recommendable to analyse the complete system.

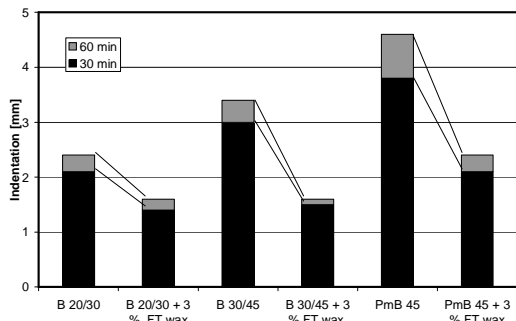


Fig. 7: Indentation at 40°C (DIN 1996-13); GA 0/11

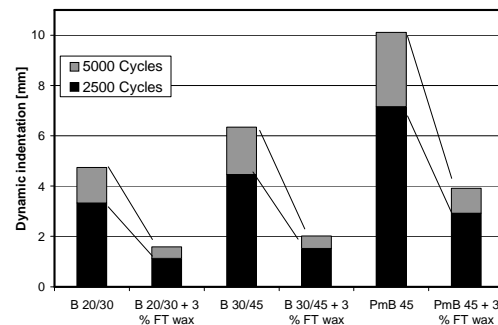


Fig. 8: Dynamic indentation at 50°C; GA 0/11; piston 2500 mm², haversine pulse 875 N for 0.2 sec and 1.5 sec relaxation

In Germany the asphalt cooling test according to Arand^v is considered to be the most appropriate method to analyse the low temperature properties of asphalt. This test is performed with 4x4x16 cm asphalt specimens which are cooled down at a rate of 10 K/h. During this procedure the length of the specimen is kept constant. The thermally induced tensile stress and the fracture temperature are recorded. In practical experience, thermally induced cracks appear at least 10°C lower than in this lab test. Table 3 shows some test results which indicate that the additive has no significant influence on the low temperature behaviour which is rather determined by the base bitumen.

Tab. 3: Results of the asphalt cooling test at 10 K/h

Asphalt mix - Binder	Max. thermally induced tensile stress [N/mm ²]	Fracture temperature [°C]
SMA 0/11 S - B 50/70	4,4	-25,5
SMA 0/11 S - B 50/70 + 3 % FT wax	4,5	-24,5
SMA 0/8 - B 70/100 + 2 % FT wax	4,3	-24,4
SMA 0/8 - B 50/100 + 3 % FT wax	4,2	-24,5
SMA 0/8 - PmB 80 + 2 % FT wax	5,1	-32,8
SMA 0/8 - PmB 80 + 3 % FT wax	5,1	-32,2
ABi 0/16 - B 70/100 + 2 % FT wax	4,8	-25,1
ABi 0/16 - B 70/100 + 3 % FT wax	4,7	-24,9
GA 0/11 - B 30/45	6,0	-26,5
GA 0/11 - B 30/45 + 3 % FT wax	5,9	-25,5
GA 0/11 - PmB 45	6,8	-30,0
GA 0/11 - PmB 45 + 3 % FT wax	7,0	-30,0

3 Field Experience

Numerous field tests have been performed under supervision of local road authorities with the different WAM technologies in which mostly a single technology has been compared to standard asphalt. However, the German federal road authority (BaSt) initiated two extensive field tests with accompanying lab work in order to compare different technologies; a mastic asphalt study was carried out on the motorway A1 and a rolled asphalt study on the A 7. Table 4 shows some results. Aims have been to evaluate on the one hand the potential for temperature reduction and on the other hand the properties of the paved asphalts.

Tab. 4: Results from the comparative WAM mastic asphalt study (GA 0/11 S, Motorway A 1)

Binder	B 20/30 (Reference)	B 20/30 + 3 % FT wax	B 20/30 + modified montan wax	B 30/45 + amide wax
Rutting depth at 40°C, rubber wheel	2.9 mm	1.1 mm	1.0 mm	2.2 mm
Indentation test at 40°C, 30 min	3.6 mm	1.7 mm	4.6 mm	3.2 mm

Moreover the authority initiated a long-term observation of seven test section in order to investigate the performance and durability of WAM layers after 5-7 years service life in comparison to related control sections containing bitumen 50/70 respectively PmB 45A. The practical experience confirmed the lab results regarding the deformation resistance and other properties of the asphalt and enabled even further temperature reductions than concluded from lab tests. Table 5 gives an example of the energy savings, which have been realized by temperature reduction.

Tab. 5: Natural gas consumption during asphalt mix production (zeolite technology)

	Binder course mix ABi 0/22	SMA 0/8 S
Conventional; gas consumption [m ³ /h]	778	609
WAM; gas consumption [m ³ /h]	493	435

However, it has also been learned that the paving temperature of WAM has to be reduced in order of avoid detrimental over-compaction and that the application of tack-coat and the production of joints needs special care.

The German worker protection agency measures the bitumen fume and aerosol emission during many WAM pavements; the average results are listed in table 6.

Tab. 6: Fume and aerosol emissions from paving, worker at spreader bar, 95 percentile [mg/m³]^{vi}

	Conventional (160-180°C)	WAM, average 130°C
Rolled asphalt	10.4	0.6 – 6.9
Mastic asphalt	40.6	WAM (220-230°C) 1.7 – 11.1

Warm asphalt mixes are also a proven technology for paving temperature sensitive bridges. Temperature reduction opened up possibilities for additional benefits such as reduced wear and tear of the mixing plants, less thermal ageing of the binder during mix production and faster traffic release due to shorter required cooling time. This has been used for night paving of motorways in UK and USA and for night paving at Frankfurt airport during normal operation of the runway. The variety of opportunities resulted in continuously increasing acceptance and application of WAM technologies.

4 Outlook

Warm asphalt mixes have been applied on many occasions and have shown that our industry can contribute to lower emissions and energy savings. The need for lower emissions and reduced energy consumptions will be a major driver for new technologies such as WAM. However, field experience has shown that other advantages are important factors as well. The new technology offers a versatile tool to every asphalt designer. Lower mixing and paving temperatures allow a faster traffic release, therefore important road sections can be built in full depth over night.

Organic additives have been successfully used as compaction aids. Very stiff mixes such as hard PmB or SMA can be laid even by hand without lacking in compaction and increase the productivity of our working crew. Asphalt can also be laid at lower ambient temperature which

could extend the working season, therefore increase the productivity of our asphalt mixing plants.

Using new technologies we are also able to transport asphalt over longer distances. We can reach areas which we could not reach before.

Organic additives have shown impressive results when used to improve the resistance to permanent deformation. The ban for heavy trucks during day time could be history.

Special attention should be given to use of WAM as a co-modifier of PmB, either as an compaction aid or for heavy duty pavements. The combination of WAM and SBS can result in asphalt pavements which are nearly as hard concrete but still have the flexibility and modularity of asphalt. This concept has been successfully applied on container terminals, airport pavements, industrial areas and major intersections.

5 Literature

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