Effectiveness of the Compactasphalt® Technology

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ABSTRACT

A society's future economic opportunities depend on the efficiency of its transportation system. At present, road problems are manifested in the form of deficiencies in smoothness, skid resistance, deformation resistance, and layer adhesion. Thinner top layers are more resistant to deformation but, at the same time, they are increasingly difficult to compact in compliance with requirements. Richter has achieved the solution by developing COMPACTASPHALT technology. It has been possible to reduce the thickness of the top layer because it shares, through the simultaneous paving with asphalt binder, the latter's heat potential. In this manner, the effect of bad weather conditions is reduced, and a safe, requirement-compliant compaction, combined with additional intensive interlocking of both layers becomes possible. Considerations on cost effectiveness point to the advantages of the technology, both for the client as well as for the contractor.

1 The road network of the Federal Republic of Germany

The guarantor of mobility in the Federal Republic of Germany is its road network, measuring approx. 626,000 km in length and having a gross fixed capital of more that € 470 billion and which, compared internationally, is well built. 91% of passenger transportation and 70 % of goods transportation are carried out over land. Of this amount of traffic, 70 % occurs over highways, federal roads and state roads which, in 2003, comprised an overall road network share of approx. 25 %. 95 % of the road network is built of asphalt. This network of roads forms the backbone of the economic power of Germany.

A road must provide a user with functional qualities such as road grip, smoothness, noise reduction, brightness, navigability and driving comfort during a pre-determined service life which will require, in turn, an outstanding and enduring structural quality. The structural properties to be achieved, i.e. weather-resistance and stability under load in high temperatures, elasticity and ability to release stress in low temperatures, wear-resistance and ample fatigue resistance are, next to the building material properties and the dimensioning of the road surface's individual layers (calculated on the basis of the expected traffic load), in direct correlation to the processing of the building materials at the construction site. They also affect the possible service life of these pavements whereby, according to *Thurner* [18], the quality of a road structure will be, in an ideal case, so homogeneous that no repairs will be necessary, and the structure will only require thorough maintenance at the end of its very long functional period.

A country's economic chances for the future depend directly on the capabilities of its traffic system and the competitiveness of its mobility industry. The overwhelmingly empirical science of road construction technology has been developed from a multitude of practical experiences acquired from diverse branches such as materials technology, machine construction technology, automotive engineering or, for instance, human reliability. According to *Huschek* [12], the next step is, „*especially in the spirit of empiricism (…), to ask the same basic question repeatedly, whether what has been tried-and-true until now can be perpetuated under new, harder conditions, or whether it appears advisable to contemplate new concepts*".

In the mid 1990s it became clear that the federal budgets would only find relief in the medium-term if growing demands were countered with the continuous further development of both asphalt materials and their compositions, as well as of paving technology. This led to the development of COMPACTASPHALT® technology.

2 The idea of the Compactasphalt

As pertains to layers, the classic construction of highly-stressed traffic surfaces in Germany is composed, pursuant to the „*Guidelines for the Standardization of the Paving of Traffic Surfaces – RstO 01*" [16], of 4 cm asphalt upper layers 0/11 mm and 8 cm asphalt binder layers 0/16 or 0/22 mm. The upper layers present a special problem, being that the multitude of tasks, such as compacting the subjacent layers which are rich in cavities, the smoothness, road grip, brightness, weather-resistance, and stability through flexibility, stability under load, and wear- and fatigue-resistance, require making truly diverse conceptual decisions. As a result, tasks such as compacting and stability under load work against each other. Conditional upon the compacting function, the upper layer is the layer that is richest in binding materials, while also experiencing the highest temperatures and stresses. Due to the thermoplastic properties of the binding material, the top-layer asphalt possesses the lowest-possible shear strengths in summer. Increasing the compaction by 1% increases the deformation-resistance by approx. 15-20 % which, in combination with a reduction in layer thickness, as well as compaction degrees $\geq$ 100 %, leads to an even clearer improvement.

To be able to achieve the required compaction degree in the field of at least 97 %, taking into account unfavorable weather conditions that can be expected, ample heat capacity is needed. Under this consideration, and especially to avoid the shattering of particles during the compaction process, the effect of the temperature is met with a standard layer thickness of 4 cm.

High compactness can only be achieved with adequate paving thicknesses. In order to guarantee the compacting function of the upper layer, thinner layers would suffice, but due to compactibility atop a cold base, it is necessary to adapt the paving thickness of the binding-material-rich upper layer, which thus has a reduced shear strength, to the compaction willingness, which results in an increased tendency of the asphalt to deform under traffic loads. By using increasingly harder binding agents, the mixing and paving temperatures increase, and the final compaction to be achieved is influenced more heavily by unfavorable weather conditions.

In 1997, *Richter* and *Dietrich* [14] observed that one in every five upper layers that were applied in the months of October through December showed reduced compactions. Low compaction degrees and higher cavity contents negatively influence the deformation stability and favor the quick aging of the upper layer due to, among other things, the separation of the binding agent from the rocks and the formation of thermically-induced cracks. The durability of asphalt upper layers has been a growing problem ever since asphalts that counteracted the formation of grooves were created in the 1990s. With the axial creep test, *Huschek* [10] had already shown, in 1980, that the compaction state of an asphalt layer influences quite considerably, together with the mix composition, the mineral materials and the viscosity of the binding agents, the resistance to thermal distortion: If the compaction degree increases from 97 to 100 %, the resistance to thermal distortion will decrease by almost 50 %.

In 1988, *Huschek* [11] discussed a new road construction design which was to take into account increased traffic loads. However, the thinning of the upper asphalt layer, needed to further increase the resistance to deformation, in favor of a thicker lower layer, often failed due to the fact that thin upper layers made of deformation-resistant mixtures are only compressible upon a cold base under favorable weather conditions, and the increase in temperature of the mixture at the time of supply is subject to limitations due to the increasing oxidation of the binding material.
In a laboratory study using the Marshall hammer, *Richter* [8] documented the correlation between compaction (number of impacts) and asphalt temperature in an AB 0/11, B 65 mixture (Figure 1).

It is possible to see from the red curve that a 150° C mixture can be compacted with 100 impacts to more than 100 %. By reducing the temperature by 30° C to 120° C (blue curve), compaction degrees of approx. 98 % and void contents of 4 Vol.-% are achieved using the same compacting energy – a result that could actually be satisfactory. It is important to notice, however, that the same compaction level is reached at the higher temperature after only 25 impacts, meaning ¼ of the necessary energy!
This is the reason for which the compaction on the field starts, under adequate temperatures, with rollers with a low line load, and the risk of deformations and shear cracks can be clearly reduced by gradually increasing to heavier rollers. If the temperature drops to 100° C and below, the required compaction degree of 97 % Marshall can no longer be achieved, even with four times the compacting energy, and the void content approaches 8 Vol.-%. In this very normal case, an asphalt upper layer of inferior quality could result under unfavorable weather conditions.

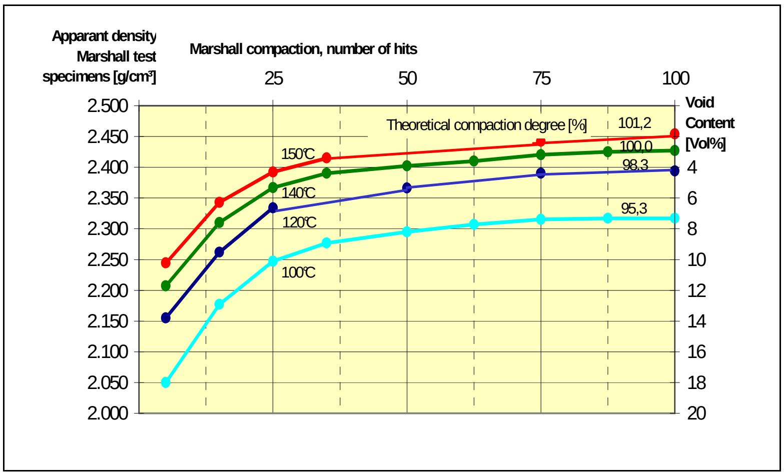
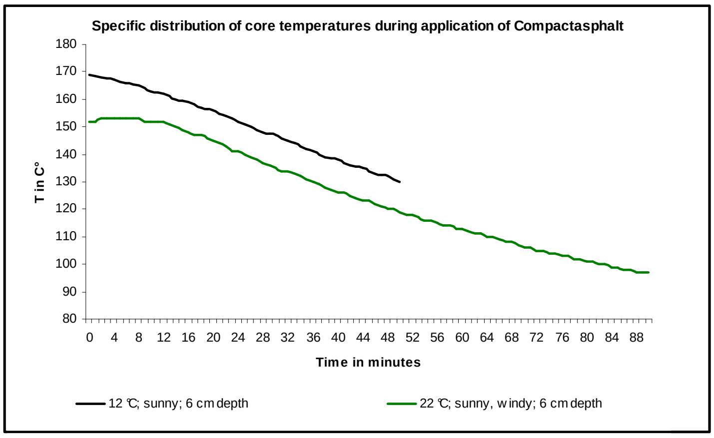


Figure 1: Correlation between compaction and asphalt temperature in AB 0/11, B 65 mixture [8]

The mix temperature, regarded alone, is not able to solve the problem. Another decisive factor is the time available for the final compaction. *Dainess* [6] reported that the layer thickness affects the cooling time with the exponent 1.8. Thus, when the thickness of the upper layer was reduced in half, less than 1/3 of the time normally available for final compaction was available. Therefore, it was necessary to find a solution that not only enabled the application of a deformation-resistant upper layer mixture of low thickness, but that also affected the mechanical properties of the asphalt laid in such a positive manner, that a markedly longer durability could be expected. This is how the idea of COMPACTASPHALT was born.

Figure 2: Specific distribution of core temperatures during application of COMPACTASPHALT® (Excerpt) [20]



The thinner upper layer can benefit from the heat capacity of the simultaneously-applied lower layer (e.g. binder). In building classes *SV* to *II* [16], 10 cm binder- and 2 cm upper-layer materials are applied when using Compactasphalt technology. In contrast to standard construction methods (8+2) cm this leads to a tripling of the thickness of the upper layer, since a monolithic layer with a thickness of 12 cm is now present. This results in a more than 7-fold increase in the time available for final compaction, which enables the safe achievement of the required compaction degree. Figure 2 shows an excerpt from a series of temperature measurements during 2004 and 2005, during application of Compactasphalt® using modular finishers [20]. It is possible to recognize the gradual decline in the core temperature and to infer, based on the similar temperature progression during weather conditions favorable to paving, that a targeted sinking of the mixture temperature by 10-15° C, for example, under consideration of the project-specific conditions, would be absolutely possible without the need to use viscosity-reducing additives.

With this innovative construction method, not only is the time available for the final compaction markedly extended but, above all, a contribution is made toward the vertical compaction homogeneity. *Damm* presents in [7] a comparison of the thickness progression through the depth when applying two layers „*hot upon cold*" and „*hot upon hot*" (Fig. 3) and comments: „*In the first case, the thickness progression through the depth, following pre-compaction, is not homogeneous and is not fully compensated with the subsequent roller due to the loss in temperature: Thereby, the decrease in thickness through the cold base is especially detrimental. This presents clear disadvantages to the stability of the entire system.*"

The service life of an asphalt pavement is negatively affected by the influx of air (embrittlement of the binding material) and water (stripping).
At present it is possible to purposely place the void content of both layers at the lower limit, without being exposed to the risk of groove formation under volume-constant deformation, because a higher inner friction can also be mobilized with a higher compactness of the minerals.

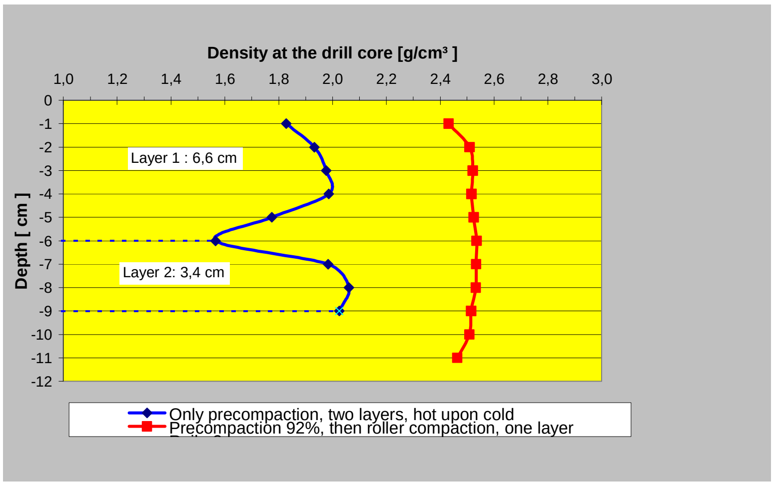


Figure 3: Thickness progression through the depth with two-layer (hot upon cold) and with one-layer (hot upon hot) application [7].

Often, the interlocking of both layers is considered by builders of COMPACTASPHALT® pavements to be the primary goal. Additionally, higher and homogeneous transverse and vertical compaction of the upper layer and of the binder is achieved. The intensive interlocking is actually a positive side effect that guarantees the safe deflection of the shear forces from the traffic load toward the binder layer area. „*Since the upper layer cannot swerve sideways together with the base due to the interior interlocking, the formation of a groove due to defective layer adhesion can be excluded*" (*Damm*) [7]. A monolithic layer is formed, which is clearly shown in Figure 4. The layer borders become interleaved.

Due to the stronger compaction, the intensive layer adhesion, and the somewhat lower binding-material content, the asphalt's coefficient of elasticity is improved. A thinner upper layer increases not only the resistance to thermal distortion (of the entire system), it also enables the economical, unerring use of high-grade mineral materials in terms of brightening and polishing resistance, since an enduring road grip cannot be guaranteed by every stone.

The successful technical implementation of the concept was tied to the multi-stage development of specific machine- and process engineering (comp. [21]).

In 1993 *Richter* [8] had already described, in his patent specification, the simultaneous application of two differently-composed asphalts, in a heating procedure using only one finisher. The first Compactasphalt paving was produced in October 1995, at the highway A4, with a total length of 480 m. In the absence of the necessary technology, makeshift solutions were initially sought out.

Figure 4: COMPACTASPHALT® drill core – to demonstrate the intensive interlocking of the courses, a thin aluminium sheet was laid upon the binder prior to applying the upper-layer material.

A modular finisher that met *Richter*'s requirements was first used in December 1998, at the highway A7 near Kirchheim, over a length of 5,800 m. The advantages of this requirement-satisfying process became immediately evident: Stable paving conditions guaranteeing the consistent thickness of the upper layer, since both screeds are attached to the finisher's frame and it is the controllable quality of the base course that affects the smoothness and uniformity of the layer thicknesses for both layers. The overall flow of material was considerably easier to control. Even interruptions in the paving process did not necessarily lead to variations in the thickness of the upper layer. Subsequently, despite the diverse construction methods used, cross slope and crown profile changes did not pose any problems arising from the closeness of the two paving screeds. Thus, the procedural requirements necessary to guarantee the process stability were met.

After the *Hermann Kirchner* construction company was able to verify the process safety with a plenitude of paving actions, the following economically-important step was to make Compactasphalt® technology available to the general public, with the help of an industry partner.

By spring of 2004, *DYNAPAC* had developed a modular finisher of the 2nd generation for the application of Compactasphalt®, with the max. paving width of 11.75 m. Guaranteeing the consistent thickness of the top layer, paving widths of up to 13.25 m were achieved using this modular machine combination.

At present, three such units are used in Germany. Russia and China own one unit each – and further requests for quotations are pending. Overall, approx. 5 million m^2 of Compactasphalt® have been applied to date in Germany, 4 million m^2 of these were applied using *DYNAPAC* technology.

3 Advantages of this construction method

The *Highway Research Institute of the TU Darmstadt* [5] carried out various studies to assess the complete Compactasphalt® system with regard to its deformation properties and resistance to cracking.

Drilling cores (test specimens 1 - 4) were taken from the highway A5 after paving with Compactasphalt®, in order to study its complete structure with regard to deformation resistance. A core (test specimen 7), (see figure 6) was also taken from a conventionally-paved section, to be able to compare the stability of Compactasphalt® to that of conventional asphalt. Table 1, below, lists the types of mixes and the layer thicknesses required for the various construction methods.

Each of the rut formation tests was carried out on test specimens from the complete system (asphalt binder layer and top layer), in a rut formation device at 50 °C under water. Illustration 6 shows the results of the tests. The test specimens 1 - 4 for Compactasphalt® showed less rut depth after 19,200 passes than test specimen 7 for the conventional construction method, which reached a rut depth of 8.0 mm. With the Compactasphalt® construction method, the individual values for test specimens 1 - 4 were between 3.4 mm (test specimen 2) and 5.5 mm (test specimen 3). A comparison of both construction methods shows that the rut depth of 5.5 mm for the conventional asphalt (grey) was achieved after 8,300 passes, thus demonstrating in the rut formation test that it is significantly more susceptible to deformation than the combined layers of Compactasphalt®.

***Tab. 1:* Types of mixes and target layer thicknesses required for the various construction methods used in the highway A5 [5] segment**

Type of mix	Paving method: „hot on hot“ Compactasphalt®		„hot on cold“ conventional asphalt	
Top layer	SMA 0/8 S	(2 cm)	GA 0/11 S	(3.5 cm)
Binder layer	ABi 0/22 S	(10 cm)	ABi 0/22 S	(8.5 cm)

The fatigue strength of asphalt layers can be tested using the tensile/swelling test. Here, the lateral strain is the decisive criterion as concerns the formation of fatigue cracks. Tests by *Hou* [9] have shown that strain rates are the most significant characteristic when assessing the resistance of asphalt to crack formation. The asphalt layer can only bear a large number of stress cycles without any damage, at low strain rates.

All values for Compactasphalt® and conventional construction methods were above the critical lateral strain rate of $15 * 10^{-6}$. It can be concluded from this fact that none of the road surface pavements is prone to the formation of cracks.

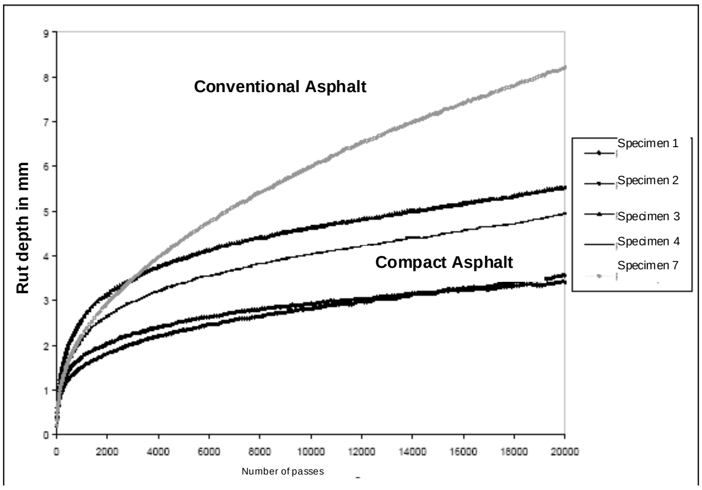


Fig. 6: Rut formation test on the test specimens (water bath, 50 °C) [5]

Cores taken in autumn 1998, within the scope of a road restoration carried out on the highway A8 section by Contwig-Walshausen, were tested in the shear test device. The following paving variations were used on the segment being restored: „*hot on hot*“, „*hot on warm*“, and conventional asphalt paving. Structural data and test results can be found on table 2.

<u>Tab. 2:</u> Structural data for the highway A 8 Contwig-Walshausennt, and average shear forces ascertained at the top/binder layer levels [5]

	Paving methods		
	“hot on hot“ Compactasphalt®	“hot on warm“	“hot on cold“ conventional construction method
Top layer	2.0 cm SMA 0/8 S	2.0 cm SMA 0/8 S	3.5 cm SMA 0/8 S
Binder layer	8.0 cm ABi 0/16 S	8.0 cm ABi 0/16 S	8.5 cm ABi 0/16 S
Base course	12.0 cm ARB 0/32 CS	12.0 cm ARB 0/32 CS	10.5 cm ARB 0/32 CS
∅ Shear force Top/Binder layer	37.6 kN	32.8 kN	32.6 kN

The cores associated with the „hot on hot“ paving method (Compactasphalt®) show, on average, the highest shear force with 37.6 kN. With the „hot on warm“ and conventional paving methods, average shear forces of 32.8 kN and 32.6 kN were still ascertained. In the update to the Fact Sheet on the Construction of Compactasphalt Pavements [13], a recommendation will be given on the extent to which a determination of the bond between both inner interlocked layers is actually required, using the testing technology available to date.

Overall, test results have documented the excellent stability of Compactasphalt®. In terms of deformation resistance and layer adhesion, the method is clearly superior to conventional construction methods.

Based on laboratory and process engineering tests, the following are the advantages of the Compactasphalt® construction method:

- savings on material costs,
- significant extension of the time available for final compaction,
- reduction of bad weather influences,
- possibility to reduce the mix temperatures,
- better durability through the intensive interlocking of both layers,
- higher heat stability compared to conventional paving methods, as well as
- a marked reduction in paving times.

In consideration of the high paving qualities achieved comprehensively by using modular finishers, and a process safety that has been extensively tested and proven over a period of many years, the manufacture of Compactasphalt® pavements has been integrated in the *ZTV Asphalt-StB 07* [22]. With this method, driving over the lower hot layer is fundamentally forbidden.

4 Focus on maintenance

Under the point of view of minimizing the life-cycle costs of traffic roads, the advantageous application of Compactasphalt® [19] should not only be reserved for highways and federal roads. This is only possible when more competition is made possible in the market, with no restrictions, at the quality level that has been achieved to date. Here, *DYNAPAC* will make a technically and economically innovative contribution with a 2.55-m module that is compliant with regulations:

- Compactasphalt® can be offered and applied in conformity with the requirements of *ZTV Asphalt-StB 07* [22]: **no passing over the hot sub-layer**.
- The machine's technical solution to paving with Compactasphalt® is applicable without limitations, and is not limited by problems resulting from changes in inclination or paving widths, or by problems that diminish the safety of the process.
- Both paving screeds are coupled in succession to the frame of the modular finisher. This meets the identically-defined conditions whereby it is possible to achieve a consistent thickness of the upper layer applied, independent of the load-bearing performance of the hot base.
- In recognition of the studies by *Tappert* [17] and *Arand* [1,2], the use of higher compacting screeds should continue to be carried out in moderation, since their effect on the mechanical properties of the binder layers applied has not been scientifically secured.
- The support frame is a minimally-modified serial finisher that is predominantly used for standard construction methods and which can be converted into a modular finisher, when necessary, at low cost. This guarantees a high degree of utilization.
- Both material containers, which are arranged in immediate succession, facilitate the mixture logistics and minimize the risk of interruptions during paving.
- The use of a modular paver allows for the use of paving-improving additives and/or low-viscosity asphalts in the binder area.
- When paving with Compactasphalt®, a second paver is not blocked, and can be used for other activities.
- Only one crew is needed to operate the modular finisher.
- The purchase of a DF 145 CS paver is linked, at the same time, to the possibility of being able to pave Compactasphalt®. Optionally, the paver can be prepared, prior to delivery or at any later time, for attaching of the modular components at low cost.

Fig. 7: Compactasphalt® paver DF 145 CS + TP2500 module

The modular paver shown in Fig. 7, with a paving width starting at 2.55 m has the same basic principle as the 3,0m module, which has already provided valuable knowledge. The concept is rounded off with very short equipping times, a compact assembly, and very good visibility.

5 Forecasted service life

Richter [15] considers the durability of conventional wearing courses to be about 12 years. Compactasphalt® built with modular finishers and subjected to heavy loads for years display outstanding stability. It can be expected that by applying this construction method under comparable conditions, the useful life of wearing courses can be doubled.

DYNAPAC had the opportunity to lay newly-developed open-porous asphalt (popcorn), two-layered, in thicknesses of 35 and 20 mm, with grain diameters of 12.5 and 9.5 mm, respectively, for the *State of Georgia Department of Transportation*, at the testing site of the *National Center of Asphalt Technology* (*NCAT*). The paving field used is part of a 2.7 km long circuit, and had a width of 5.40 m and a length of 65 m (Fig. 8 and 9).

Fig. 8: View of the testing site of NCAT. 24 months of constant loads atop the testing fields. (Photo: NCAT)

Fig. 9: View of the NCAT test section (Photo: NCAT)

The objective was to achieve the maximum possible void content during paving, from a technical viewpoint.
In the most extreme case, 18 vol.-% was achieved with the conventional method. This challenging paving action worked perfectly. After completing the test section void contents between 22 and 24 Vol.-% were achieved.

Following completion of all individual fields using the most diverse mixture compositions, the test program was launched in September 2006, in the course of which a traffic load produced in 15 years would be simulated within 2 years. To this end, trucks loaded with steel plates, each pulling 2 trailers, drove over the testing area daily (Fig. 9).

After 24 months of applying constant loads, the void contents and the initial evenness in this field were just the same as on the first day. Two additional fields were paved during the application process, using the same materials and a “hot upon cold“ method, but their results were less promising.

The results reinforce the prediction that, with Compactasphalt® technology, it is possible to adapt the useful life of the top layer to the useful life of the binder layer. The economic considerations in the following chapter are guided by this assumption.

6 Economic considerations for using a modular paver with a basic working width of 2.55 m

The benefits of the Compactasphalt® construction method have operational and economic aspects.
While the operational benefits manifest themselves through the effective use of personnel, technology and materials, the economic efficiency lies primarily in the extension of the lifespan of traffic surfaces, and therefore in the clear reduction of lifecycle costs. In the case of operator models, there are direct benefits during paving as well as benefits that arise in the long term.

Based on a simplified cost calculation, the *Technical University Darmstadt* [5] concluded that Compactasphalt® technology becomes operationally effective starting at a paving area measuring approx. 12,400 m^2. In 2004, *Bippen* [3] compared the Compactasphalt® paving method with conventional paving, using a specific construction project as an example (the German highway A31) and calculated the operational benefit. Under the specific construction site conditions, and taking into consideration that the building company had used this new technology for the first time, he reported savings of 75,900 € for this project, emphasizing that it would have been possible to increase the benefit to 170.200 € with changes in the technological process. The calculated breakeven point for Compactasphalt® technology for this construction project was approx. 11,000 m^2.

Construction site parameters			
Cross-section		RQ 20	
Constr. catergory		I	
paving width	m	7,50	
paving length	m	2.000	
pav. thicknesses		conventional	CA
SMA 11 top l.	cm	4,0	2,0
AC 22 binder l.	cm	8,0	10,0
AC 32 base c.	cm	18,0	18,0
sep. base c.		2	2

Material costs (free to construction site)		
SMA 11 top l.	€/t	75,00
AC 22 binder l.	€/t	48,00
AC 32 base c.	€/t	32,00
Benefit from mix substitut.	%	80

Available mix quantity			
spec. Weight	kg/m^3	2.400	
		conventional	CA
SMA 11 top l.	t/h	120	55
AC 22 binder l.	t/h	200	275
AC 32 base c.	t/h	300	300

Fig. 11: Construction-related parameters of the calculation

Times for setting up and shutting down			
		convent.	CA
Setting up			
	workers	3	4
	hs	5,0	5,0
total	hs	15,0	20,0
Shutting down			
	workers	3	4
	hs	4,0	4,0
total	hs	12,0	16,0
Total sum	**hs**	**27,0**	**36,0**
Crane expenditure			
Time expend.	hs		3,0
Hourly rate	€/hs		150,00

Transportation expense			
Simple transportation costs, simple trip	€	1.000,00	
		convent.	**CA**
Delivery	unit	3	4
Return transp.	unit	3	4
total	**unit**	**6**	**8**

Fig. 12: Equipment-related technical parameters of the calculation

Within the scope of this treatment, the possible economic advantages will be presented using a fictitious construction project by way of example. Figures 11 - 13 are based on the corresponding calculation support documents.

	Unit		conventional total	conventional per m²	constr. comp. CA total	constr. comp. CA per m²	PPP project CA total	PPP project CA per m²
Planned paving area	m²		**15.000**					
Equipment-related costs (performance-dependet)								
Equipment costs	€		8.406	0,56	6.845	0,46	6.845	0,46
Fuel costs, total	€		4.671	0,31	4.272	0,28	4.272	0,28
Labor costs for paving, total	€		14.784	0,99	10.218	0,68	10.218	0,68
Set-up costs, total	€		810	0,05	1.530	0,10	1.530	0,10
Transportation costs	€		6.000	0,40	8.000	0,53	8.000	0,53
Sum of performance-dependent costs	€		**34.670**	**2,31**	**30.866**	**2,06**	**30.866**	**2,06**
					-10,97%		-10,97%	
Special effects		yes/no						
Material costs (savings from side offer)	€	1			-15.552	-1,04	-15.552	-1,04
Application costs top layer/binder layer	€	1			-3.000	-0,20	-3.000	-0,20
Speed-up premium	€					0,00		0,00
Functional construction method	€	1					-177.845	-11,86
No renovation of top layer after 12 yrs.	€	1					*-177.845*	
No traffic safety costs after 12 yrs.	€							
Sum of special effects	€				**-18.552**	**-1,24**	**-196.397**	**-13,09**
Sum of performance-dependent costs minus special effects	€		**34.670**	**2,31**	**12.314**	**0,82**	**-165.531**	**-11,04**
Discounted cost attenuation	€				**22.357**	**1,49**	**200.201**	**13,35**

Fig. 13: Economic consideration from the point of view of the contractor and PPP project

The assumed construction-related parameters are shown in Fig. 11. In construction category I, two driving lanes totaling a width of 7.50 m are to be renovated along a length of 2,000 m. The assembly of the asphalt layers adds up to (18+8+4) cm under the conventional construction method. In a Compactasphalt construction carried out as a side offer, the layer thicknesses for the binder and top layers were modified by 2 cm each. It was presumed that the contractor can achieve a benefit of 80 % from the mixture substitution for the top layer. In this example, the mixture quantities available are identical for each variation. As pertains to the discounts to be undertaken, an annual price increase of 2.0 % and an inflation rate of 1.0 % are assumed. The renovation of the top layer that will be required after 12 years when using a conventional construction method is presently estimated at approx. 11.00 €/m^2.

The paving and compaction technology was classified according to *BGL 2001* [4]. For space reasons it is not possible to include an illustration here. The module was classified as a comparable paver, though with a 10 % reduction since an undercarriage is not necessary.

In order to determine the calculatory equipment costs, 50 % each was selected for depreciation and repairs. Personnel costs are assumed at an average of 30.00 €/h. Based on experience, the effective utilization of the paving technology increases with the use of a feeder, from 45 min/h to 55 min/h. In the present example and based on practice, no feeder was taken into account for conventional paving. When Compactasphalt® paving is carried out, it is to be assumed that the corresponding feeding technology is also used when applying the base layer.

The average fuel consumption was assumed at 0.170 l/kW.

According to experience, conventional paving requires one trip less each for transportation of the technology.

Preparation of the modular paver requires the use of one crane (approx. 3.0 hours), and is linked to an additional manual expenditure of approx. 9.0 man-hours (Fig. 12).

Figure 13 provides the results of the economic considerations from the point of view of the construction firm and in special cases from a *PPP* project.

The shortened paving times provide the contractor, despite the necessary additional expenditures from equipping and transportation costs, and without taking into account special effects, with an approximate cost reduction of 11 % when using the Compactasphalt® construction method. Based on the example, an attenuation of costs by an additional 1.24 €/m^2, to 1.49 €/m^2, compared to 2.31 €/m^2 with conventional construction, is to be expected if special effects should be attained from material substitution and from the costs saved on application on the top area. The breakeven point for the Compactasphalt® construction method lies, in the present case, at 6,300 m^2 (840 linear m), and it lies at 1,628 m^2 (217 linear m) under consideration of the special effects.

If the project should be considered under the conditions of a *PPP* project, an additional special effect (discounted) would also play an important role: It would not be necessary to renovate the top layer 12 years after paving. The savings from road safety costs cannot be expressed as a round sum and thus have not been taken into consideration. The result of the examination yields a discounted cost attenuation of approx. 200,200 €.

The profitability of this method already becomes a reality after the first few meters have been paved.

The advantages of the Compactasphalt construction method present themselves differently for the client, depending on whether the project was tendered or awarded as a side offer. In both cases, the benefit arises from the non-necessity to renovate the top layer during the useful life of the binder layer. If the construction was tendered, the client also enjoys the advantages gained from the mixture substitution and from the application savings.

7 Conclusions

The paving of Compactasphalt® using modular pavers was accompanied in years past by considerable research expenses. The asphalt-related technological advantages are undisputed. Now it depends on opening up to this procedure the possibility of broad application, especially in the area of maintenance. The economic study conducted for a fictitious construction site allows for the expectation of above-average operational and economic efficiencies. In concrete cases, project-specific discrepancies will occur by necessity.

In addition to the savings in blocking costs, the economic advantages arising from having less construction sites has not been included in the considerations:

- less traffic jams,
- fewer accidents,
- reductions in time loss and
- a lower CO_2 burden.

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