Maintenance and Rehabilitation

Empirical Assessment of benefits provided by Asphalt Pavements with Inlay Systems

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Abstract

The structural maintenance of the existing traffic route network is one of the biggest challenges for the future. For this purpose, it is important to preserve the usability of the roads as long as possible by innovative construction methods. One conservation method that has been in use for more than 30 years is the use of asphalt inlay systems for rehabilitation of cracked road pavements. Initially, the paving fabrics and grids originally derived from geotechnics, were installed according to the trial-and-error method. This procedure resulted in damage for example because of lack of bond to the asphalt layers. In the meantime specialised asphalt grid systems were developed. Due to the reinforcing or stress-relieving effect of the inlays, the tensile stresses that occur in the area of the cracks are being absorbed and distributed, or decoupled from the new asphalt layer. In theory this will lead to a delayed crack propagation and a long-term crack-free road surface. However, still there is a considerable lack of confidence in these systems in the pavement society. In order to provide proof for the improved performance of asphalt pavements with inlay systems, the empirical background of the benefits and risks was researched by means of an extensive literature review complemented by an expert survey. The result of this practical evaluation is the documentation of the client's and customer's background with regard to the conditions of use for asphalt paving. 90 % of the participants believe that asphalt inlays can have a positive effect on durability of the pavement. Also, the reasons and motivations for using asphalt inlays and the satisfaction with effectiveness, constructions costs as well as the recycling ability of reclaimed asphalt was surveyed and analysed.

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1. INTRODUCTION

In Germany and Europe the structural maintenance of the existing traffic route network is increasingly becoming one of the greatest challenges for the future. For this purpose, it is of decisive importance to maintain the existing roads and preserve the usability as long as possible through innovative construction methods. A maintenance method is the use of asphalt inlay systems, to prevent reflective cracking in road pavements. Inlay systems currently are applied for prevention of reflection cracking. The reinforcing or stress-relieving effect of the inlays is intended to distribute and absorb the tensile stresses that occur in the area of the cracks and to disconnect them from the new asphalt overlay. This will lead to delayed crack propagation and thus to a long-term crack-free road surface. By avoiding the dismantling of existing fastening components and the possible extended service life, an important contribution to the saving of resources can be made. Despite a lot of research has been done in these field, the maintenance method is not fully accepted in the construction industry. So there might be other problems related to asphalt inlay systems, which were not covered yet by the published research. This paper summarises the existing research projects about the effect of asphalt inlay systems to pavements mechanical properties and durability. In order to identify open questions regarding practical application, the results of an expert survey conducted in German asphalt paving industry is discussed and open questions are identified empirically. The overall aim of the research project in which this study was one part is to proof the effect of asphalt inlay systems and to create a standard testing system for the performance evaluation and quality assurance of asphalt inlay systems.

2. STATE OF THE ART IN RESEARCH AND TECHOLOGY

Asphalt inlays have been used in road construction for more than 30 years. While in the beginning classical geogrids were used in asphalt, the properties of the asphalt inlay systems are now being optimized especially for the application in asphalt pavements. [1]

2.1. Definitions

Asphalt inlay systems are geotextiles and geotextile-related products which are placed in or under an asphalt layer. The different product types are defined as followed [2]:
Nonwovens are produced by the consolidation of mats (nonwovens) from filaments (continuous filaments) or staple fibres, which are heaped onto each other and arranged randomly. Bonding can be mechanical (e.g. by needling or sewing) and/or adhesive (e.g. by binder) or cohesive (e.g. by thermal action).
Grids are made of synthetic and/or natural fibre bundles, extruded polymer sheets or steel wire with different knot structures and opening widths. A distinction is made between woven and rustled, stretched and laid grids.
Composites are grids with laying aid and/or grids with non-woven fabric. Grids with installation aid are designed with an aid (e.g. thin fleece or plastic foils) to simplify installation. In the following, grids with installation aid are considered to be grids according to their function.

2.2. Research results

For validation of the promising effects of inlay systems, several research works were conducted in the past. In almost all the studies carried out the results are often depending on individual impacts like the fixing structure, the type of load, the test method and the asphalt layers used. These studies were evaluated regarding the durability effects on relevant pavement failure mechanisms.

Delay of reflection crack formation

In road maintenance, cracked carriageways are often the reason for a repair measure. If the cracked pavement is built over without repairing the cause of the crack, it is likely that the carriageway will crack again within a short period of time.
Various studies have shown a delay in the formation of reflection cracks using inlays. As an example, Canestrari et al. [3] performed four-point bending tests with cyclic loading and three-point bending tests with continuous loading on two-layer, beam-shaped specimens. In addition, shear tests were performed to investigate the influence of shear strength on the fastening properties. A geogrid with glass fibre reinforced polymer fibres and a geogrid with glass fibre and carbon fibre were used as inserts. The glass fibre reinforced polymer grid used is very stiff compared to the glass fibre carbon grid.
The shear tests showed that both grids reduce the bond shear strength to different degrees. The reduction in shear strength compared to specimens without asphalt reinforcement is only a few percent for the flexible carbon fibreglass grid. In contrast, the shear strength of the glass-fibre polymer grid is significantly lower. On closer inspection, it is also noticeable that the decrease in shear strength is greater at low temperatures than at higher temperatures.
Although increased stiffness was demonstrated for both grids in the bending tests, the failure machanisms and crack propagation were different. The specimen, reinforced with a carbon fibreglass grid, behaved in the cracked state similar to a specimen without asphalt inlay, resulting in a continuous vertical crack. The specimen equipped with the

glass-fibre polymer grid conducted the crack in horizontal direction. This resulted in many small cracks along the inlay and a failure of the layer bonding (see Figure 1).
Based on these test results, Canestrari et al. concluded that geogrids significantly increase the deformation resistance. Both grids increase the elongation stiffness of the system in the pre-crack phase, so that it can be assumed that the forces are introduced into the grids. A detachment effect therefore only occurs in the area of layer bonding failure. In the fracture phase, however, the grids behave differently. While a brittle material behaviour is still observed in the carbon-glass fiber grid, the glass-fiber-polymer grid produces a ductile behaviour. This change in properties leads to a significant delay in crack formation.
In addition to the laboratory tests, the crack formation was observed on a test track. The laboratory tests could be confirmed here, whereby the results can also be transferred into practice.

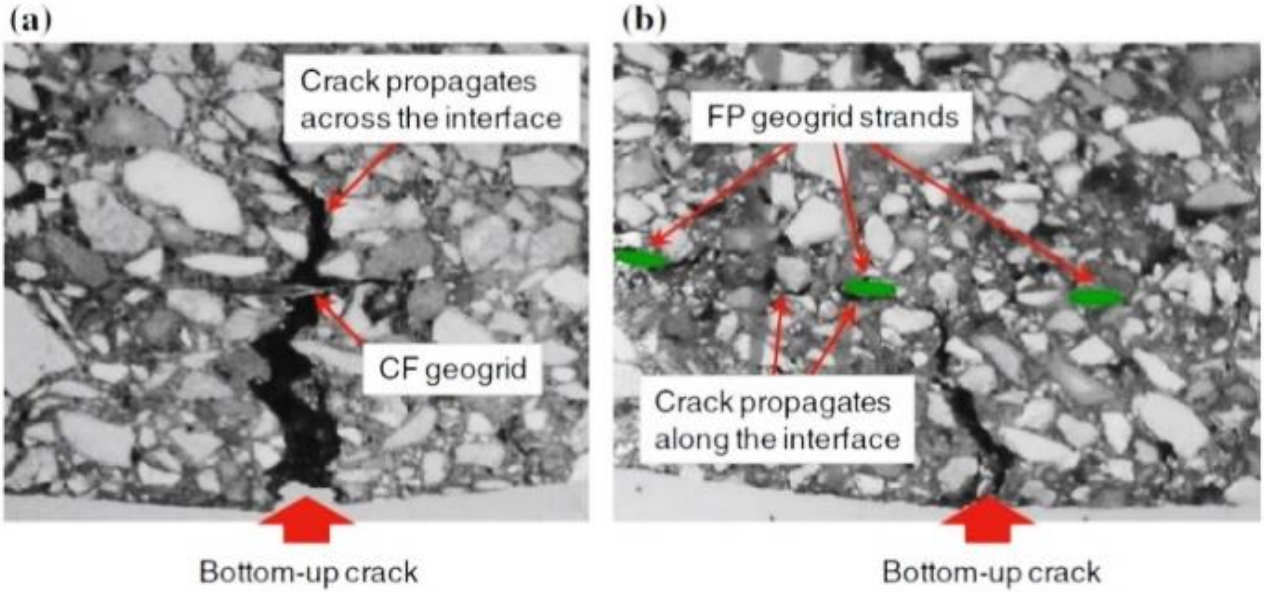

Figure 1: Reflection crack propagation when using different asphalt layers (Canestrari, Belogi, Ferrotti, & Graziani, 2015)

Similar investigations were also carried out by Vismara et al. [4]. The use of a polymer glass fibre grid led to a reduced layer bond. The results of fatigue tests in the form of cyclic loaded, notched, two-layer test plates show, analogous to [3], an increased crack resistance and a material behaviour changing from brittle to ductile.
Safavizadeh and Kim [5] carried out more detailed investigations on crack propagation. A method was developed for the description, modelling and prediction of the influence of asphalt inlay systems on crack opening under consideration of interfacial fatigue (cyclic shear stiffness) using 4 point bending tests.
Safavizadeh and Kim divided the crack propagation process into three phases. In the first phase, the crack develops and progresses to the asphalt inlay system. In the second phase, the crack is deflected horizontally due to the absorption of stresses by the grid and the resulting reduction of stresses at the crack edges. If the bond between the layers is not sufficient to transfer these stresses, a horizontal crack occurs and progresses. Horizontal crack propagation also relieves stresses and prevents vertical crack propagation. During this phase, no vertical crack growth takes place, which is why it is also referred to as the crack holding phase. In the third phase no further stress release is possible in the horizontal layer and the crack propagates vertically until the surface is reached.
Raab et al. [6] carried out tests with heavy traffic simulators on asphalt structures with three different asphalt inlay systems. The results show that the carbon fibreglass grid can significantly retard deformation and cracking. A polyester mesh also leads to improved results. Only the glass fiber grid in combination with a SAMI layer had no positive effect on deformation and cracking. This result is attributed to the poor bond between the layers and a delamination effect. Shear tests, identified reduced interlayer bond, which, however, is not below the relevant requirement value of 15 kN for the asphalt wearing course and asphalt binder course in any sample.
Montestruque et al. [7] investigated nonwovens and composites with polyester grids for road rehabilitation, on the basis of a test track and laboratory tests. In addition, the fatigue resistance of glass fibre strands and polyester fibre strands was tested in this study. On a laboratory scale, three different structures were tested using a modified tracking test. The results of the tests show that both structures with a SAMI layer and the fastenings with a SAMI layer and polyester grid delay crack formation and propagation. The results of the tests on fibre strands point out that glass fibres show much faster fatigue symptoms and cracks than polyester fibres under loads acting orthogonally to the fibre.
Further studies provide similar results, whereby the test configurations are often slightly changed. Khodaii et al. [8], investigated the temperature and layer influence in addition to the function of the asphalt inlay systems. Namir et al. [9] carried out studies on the behaviour of steel nets in asphalt pavements, which were also able to increase the bearable number of load cycles and reduce the rutting depth.

At the IFSTTAR [10] in France a full scale test was performed, accompanied by laboratory tests. The results show that the glass fibre grid used can delay the formation and propagation of reflection cracks.
In the project COST 348 [11] the experiences with asphalt inlay systems were summarized, which were available up to the year 2004. One finding from these data was that there is no generally accepted design method, but that steel grids and geosynthetic asphalt inlay systems improve the long-term behaviour of the pavement. This statement is based on practical experience gathered over 15 years.
Further publications show that asphalt pavements can significantly extend the service life of repaired road pavements [12–26].

Most important application of inlay systems within road maintenance is the reduction of reflective cracking form cracked sub-layers into new asphalt overlays, This crack prevention can be achieved by following methods:

1. In order to increase the tensile stiffness and strength at the bottom of the new asphalt layer, asphalt grids are installed. By high stiffness and strength fibres, horizontal bending stresses are transformed to the grids. This demands for a working interlock/bond between the grid and the new asphalt layer.
2. The installation of a stress-absorbing membrane interlayer (SAMI) between cracked and new layers, reduces horizontal stress. The use of nonwoven helps to increase the thickness of the SAMI. Thus the most important properties of non-wovens is its capacity to absorb bitumen.
3. By combination of non-woven and grids, the increased horizontal stress of the top asphalt layer due to reduced interlayer bonding is transformed to the grid system.
4. In new pavement structures, grids are applied at the bottom of the asphalt structure as reinforcement.

In 20 investigated studies a delaying of the in-situ cracking could be proven by the use of asphalt inlays. No improvement was achieved in three cases. The crack type was also investigated in laboratory studies:

Fatigue cracking:

- 42 inlay variants delay crack formation
- 3 variants have no positive influence

Bending tensile strength:

- 3 inlay variants increase the bending tensile strength
- No variant has a negative influence on the bending tensile strength.

Interlayer bonding:

- 28 variants reduce the layer bonding
- 1 variant has no negative influence on the bond of the layers

Increased bearing capacity

Generally it is agreed that inlay systems may hold the bearing capacity at a higher level over a longer period of time [2]. This is possible due to a better load-distributing effect and the stress absorption of the asphalt inlay system, which reduces the stresses acting on the base.
Raab et al. [27] state that - assuming a sufficient inter-layer bonding - asphalt grids reduce the vertical deformations of the asphalt construction and thus lead to an increase in system stiffness.
Four different asphalt inlay systems were used by Sobhan et al. [28] on a test track with two sections in each of which two areas were equipped with asphalt inlay systems. The results of measurements with a Falling Weight Deflectometer (FWD) show higher bearing capacity indicators in areas with grids than in the comparative pavements without grids. Another section was executed with a SAMI layer, here the load-bearing capacities determined by FWD measurements are lower than in the reference areas.
Correia and Zornberg [29] carried out large-scale laboratory tests in which the stresses and strains in the asphalt were measured at the depth of the asphalt inlay system. The results show that an asphalt inlay system can reduce both, stresses and strains. These reduced stresses and strains are based on increased structural stiffness of the pavement.

A quantitative improvement in bearing capacity by an asphalt inlay system has not yet been unequivocally proven. However, some studies indicate that grid products can positively influence the bearing capacity of a pavement.

- 6 Variants increase the load-bearing capacity
- 2 variants have no influence on the load-bearing capacity

Increasing the resistance to deformation

This reduction in total deformation can be achieved by measuring the rut depth and could be explained by stiffening the asphalt layers by increasing the shear deformation resistance.
Such a process would be an explanation for the reduced rut depth determined by Guler and Atalay [30]. By using different geogrids, which differ mainly in their tensile strength and elongation stiffness, Guler and Atalay describe a lower rut depth for some reinforced pavements than for comparable asphalt concrete structures without reinforcement. The effectiveness of asphalt grids in the maintenance of roads with deformations was also investigated in a diploma thesis at the Dresden University of Applied Sciences [31]. It was shown that asphalt grids can significantly reduce the rut depth. The authors come to the conclusion that the lower rut depth are caused by a stress distributing effect of the grid. In a study carried out at the IFFSTAR in France, no significant influence on the deformation resistance was found [10].
In a study from Switzerland, the formation of ruts was also investigated. Here the results are negative, Arraigada et al. [32] could not detect any improved effect against rutting. However, since the asphalt inlay system used was made with a SAMI layer, no improving effect was expected.
Kim et al [18] also investigated the influence of an asphalt inlay system on the deformation properties of the pavement. The results show a 23% and 48% decrease in deformation. Comparative measurements on an asphalt road in April and September [33] show similar results. The deformations, which occur more strongly due to warm temperatures during the summer months, are clearly less pronounced in the area of the sections with asphalt inlays than in the control sections.
Sanders [34] gives an explanation in which cases an asphalt inlay system can increase the deformation resistance. It describes a dependency between the position of the layer and the deformation resistance. For example, an inlay can increase the deformation resistance of an asphalt layer if it is placed in the area of the highest horizontal shear stresses. In addition to this position, a sufficiently high bond between the inlay and the asphalt is also necessary to achieve the desired effect.

Asphalt inlay systems cannot reduce or delay the development of deformations in the asphalt layer caused by consolidation (post-compaction). However, the total deformation over several layers could possibly be reduced. The evaluation of the studies shows:

- 16 variants increase the deformation resistance
- 5 variants have no influence on the deformation resistance

2.3. Effect of asphalt inlay systems

In table 1, the results obtained from the literature review are summarised. The numbers identify the number of inlay systems which affected the various failure modes positively or negatively.

Table 1: summarised results of the literature review

Damage	Effect		
	positive	none	negative
reflection cracking	20	3	0
fatigue crack formation	42	3	0
bending tensile strength	3	0	0
layer Bonding	0	1	28
bearing capacity	6	2	0
deformations	16	5	0

In addition to the material properties, the effect of the inlay systems also depends on many parameters with impacts shown in Figure 3.

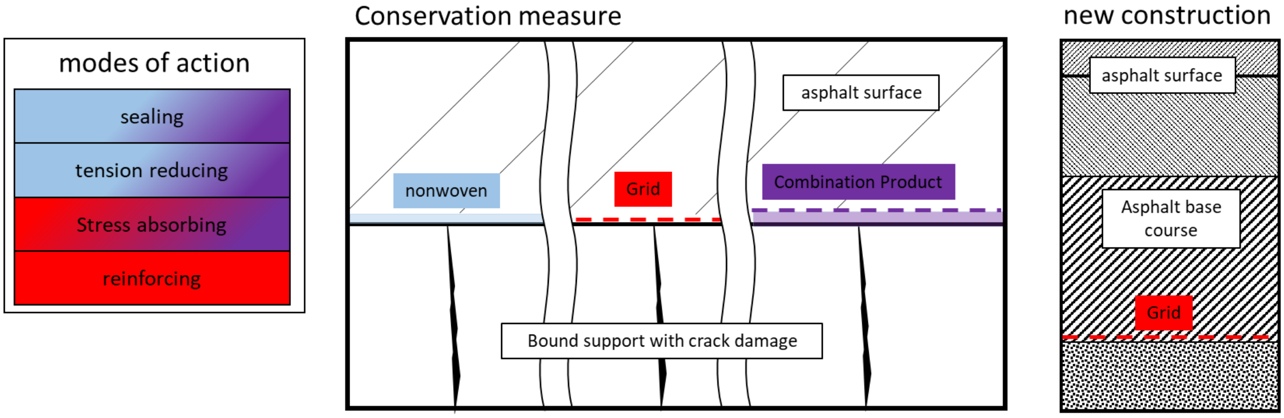

Figure 2: Asphalt inlay positions

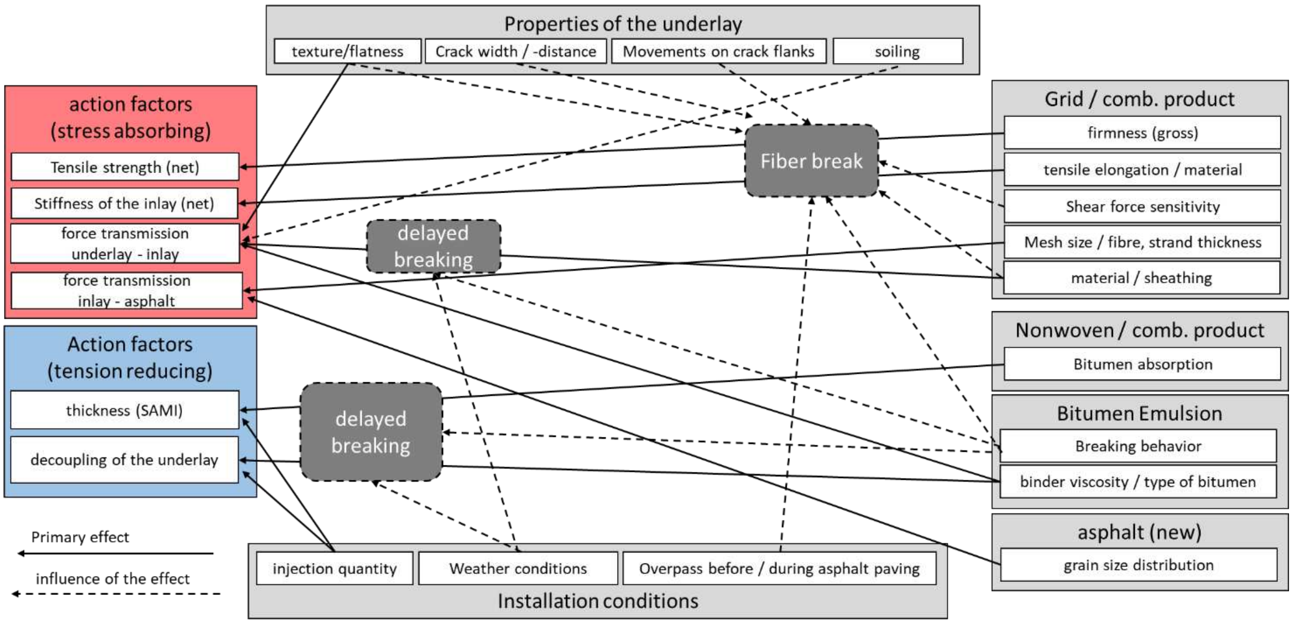

Figure 3: Effects on the functionality of asphalt inlay systems

3. EMPIRICAL ASSESSMENT

To obtain effectiveness, limits of use, as well as the requirements for the installation design of asphalt inlay systems, an expert survey was performed. The result of this practical evaluation is a documentation provided by the clients and contractors existing experience background with regard to the operating conditions for Asphalt paving. A total of 73 German experts shared their experience regarding asphalt inlay systems in the following areas:

- General experience in use of asphalt inlay systems
- Influences on the mode of action of asphalt inlays
- Experience in dismantling and recycling of asphalt layers with asphalt inlays

3.1. General experience with the use of asphalt inlay systems

In the first part of the survey, basic data were asked as to what kind of information could be obtained about the experiences of the respondents. In addition, the selection reasons and expectations for the inlay systems can be determined.

It is pleasing to note that more than half of the 73 participants came from the field of clients and contractors, the other participants being engineering offices, asphalt manufacturers, inlay manufacturers and suppliers as well as testing institutes and scientific institutions. About two thirds of these participants have already supervised more than 10 projects with asphalt inlays and thus have sound experience with the construction method. The projects supervised are spread across all road types and traffic loads.

The participants were asked whether they considered it possible to extend the service life by using asphalt inlays in maintenance and new construction measures. 90% of the respondents mean that the use of asphalt inlay systems in maintenance measures can extend the service life. In the case of new construction measures, only 63% of respondents believe that an extension of the service life is possible. An analysis of the responses by actor groups also shows that

asphalt manufacturers are less convinced about the use of asphalt inlays to extend the service life than installers, engineering consultants and manufacturers of inlays.
The use of asphalt inlays in practice is manifold; the most common use of the inlays is for the rehabilitation of crack-damaged surfaces. They are also used more frequently when a further lane is added. Also as causal damage of the fastening which leads to the use of the inserts, crack damages (net cracks and individual cracks) were indicated by the majority. In some cases, however, the inlays were also used by the respondents due to deformations, load-bearing capacity problems and patches.
There can be several reasons why a particular inlay is selected. The interviewees stated that 62 percent of the reasons for their use were advices from the manufacturers and their own experience. In addition to these, well-known references, advice from engineering offices and a literature study are further reasons for the selection. The main grid materials applied are glass fibres and plastic fibres (PP/PET/PVA). Occasionally, carbon or basalt fibres are also used. Other fibre materials only have very small market shares.
Reasons cited for dissatisfaction include construction progress, weather conditions, installation and product selection, as well as inadequate advice and transparency. The inter layer bond was also mentioned more often as a reason for dissatisfaction with asphalt inlays, but it is possible that this dissatisfaction results from the requirement values specified in the regulations.

3.2. Influences on the mode of action of asphalt inlays

In the second part of the survey, more specific questions about the effect and arrangement of asphalt inlay systems were asked. Thus the level of knowledge of the interviewees on these subjects will be.
First, the basic mode of action of asphalt inlay systems was determined. This showed that most of the respondents had theoretical background knowledge and were able to understand the difference between stress absorbing and stress reducing systems and to allocate the required layer variants to the respective effect. Only about 10% of the respondents gave implausible answers. Due to the different materials and their properties, it was of interest which product properties the survey participants would prefer in the superstructure of a cracked base. The following preferences were determined:

- Rather low stiffness preferred (38% / 62%), clients and contractors rather low stiffness, manufacturers rather high stiffness (presumably costs)
- About 30% of the respondents are of the opinion that there is no influence of the mentioned parameters on the effect. Since this value is constant across all parameters, it can be assumed that the answers come from the same people.
- Tensile strengths of 50-100 kN and mesh widths of 2-4 cm are preferred.
- The respondents favoured the fibre materials glass, plastic and carbon with a similar percentage.
- More than 50% of the participants favoured bitumen for the coating of the fibres. Only 10% of the respondents would choose a synthetic coat.
- 65% of the respondents prefer a grid with a laying aid.

A controversial topic in connection with asphalt inlay systems is layer bonding. After the first part of the question dealt with the general effect of asphalt inlays on the bond of layers, this part will provide further insights into the influence of the properties of the bond of layers on durability. Of the survey participants, 16 out of 69 have the opinion that poorer bond is the reason for reduced durability. That the inserts do not influence the bond think 6 out of the 69 respondents. The clear majority of the respondents think that asphalt inlay systems are the reason for lower bonding, but that`s not the reason for a reduced durability.

3.3. Experience in dismantling and recycling of asphalt layers with asphalt inlays

The dismantling as the first part of recycling is a central point in the material cycle and should run as easy as possible. Asphalt pavements are usually milled, as this is the most cost-effective and quickest method of deconstruction. The milling of the inlays is considered possible by 70% of the participants with a milling horizon below the inlay. With a milling horizon at the depth of the inlay, only 10% to 30% of the participants believe that milling is possible, depending on the inlay product. As a basic principle, milling is not possible for many participants in the case of plastic grids and fleece as well as composites than for glass products.
The recycling of the milled asphalt must be possible in order for the construction method to be economical. In principle, the opinion of the participants is divided here, half of the participants think that it possible to prepare and recycle the asphalt. 66% of these participants think it is possible to use the granulate with inlay residues for glass products, about 33% with plastic or fleece and composites. Glass products are generally considered to be less problematic to reuse. Subsequently, the survey participants were asked for their opinion on improved performance properties of asphalts with inlay residues. A large majority finds that the performance properties are not improved by fibre residues. Only in the case of glass meshes about 25% of the participants of the opinion that there is an improvement in the performance properties.
An evaluation of the general satisfaction with the dismantling of the fasteners is different in the different groups of actors, while the inlay manufacturers and suppliers are quite satisfied, the installers, asphalt manufacturers and clients

are dissatisfied. The contractors/construction companies are slightly more satisfied. In general, there is little satisfaction with dismantling and recycling.

4. Conclusion

One of the main tasks of asphalt inlay systems is to delay or prevent reflection cracks in traffic areas. In order to understand the mode of action, a comprehensive analysis of the technical literature was first carried out. Many of the studies considered, comparative investigations of asphalt paving systems and conventional asphalt systems were carried out under laboratory and practical conditions. As a result, the studies almost exclusively prove the positive effect of asphalt inlay systems with regard to the delay of reflection cracking. In a performed expert survey in which the clear majority of the participants have specialist knowledge of asphalt paving with inlay systems and viewed as a whole, there was a clear approval for the use of asphalt inlay systems in maintenance measures. Asphalt manufacturers are more reluctant to use asphalt inlays, which might be mainly due to problems with the recycling of asphalt granulate with residual inlay fibres.
Manufacturers and researchers agree on the fact that the installation must always be carried out by professional in order to achieve a high-quality result. The manufacturer's installation instructions should always be followed exactly to guarantee the bond of the layers and a position of the inlay in the fastening corresponding to the function.
Additional results of the expert survey were, that asphalt inlay systems are used in all load classes and that already experiences with these constructions exist in the road industry. The satisfaction with the inlay systems is similar between client and contractor. Overall, the expectation is slightly higher than the satisfaction. Almost only poor satisfaction is reached for dismantling and recycling of asphalt paving with inlays, there is a need to develop a process that allows the economical reuse of asphalt granulate with inlay residues. For this purpose, valuable research in the field of dismantling and recycling is necessary.

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