Developing a catalogue for cold recycled pavement designs for Germany

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ABSTRACT: An overview of a conservative approach integrating Bitumen Stabilised Materials (BSM) into established German design practices. The structural equivalence of these designs to the existing standard German catalogue designs (RStO 12/24), is confirmed using the Mechanistic-Empirical design method. Bitumen stabilised material characteristics, Mechanistic-Empirical design steps, assumed inputs and the first results for the German catalogue are discussed. The increasing interest in BSM in Germany and the demonstrated financial and environmental benefits in several projects worldwide suggest BSM as a suitable base layer alternative.

1 INTRODUCTION

For the pavement design in Germany, there are two methods, analytical and catalogue. The catalogue method is described in *Guidelines for the standardisation of pavement's superstructure,* known as RStO with the latest version published in 2024 (RStO 12/24, 2024). The guideline has different tables which contain different designs for both flexible and rigid pavements. For flexible pavements, the RStO offers a variety of base and subbase alternatives (hot mix asphalt base, cement stabilised base, crushed stone and gravel layers).

Currently, RStO 12/24 does not include Bitumen-Stabilised Materials (BSM), which has not yet been implemented on a large scale in the German market. In response to the increasing interest in BSM in Germany and its globally demonstrated financial and environmental benefits, BSM base layers are being investigated as a cold recycling alternative.

2 WHAT IS BITUMEN STABILISED MATERIAL

BSMs are non-continuously bound materials composed of either 100% reclaimed asphalt pavement (RAP) material, graded crushed stone (GCS) or a blend of both, and treated with foamed bitumen or bitumen emulsion. The material is treated with a maximum of 1% active filler (hydrated lime or cement) and 1.8% - 2.2% net bitumen to produce a stress dependent material that performs similarly to a granular material in a pavement structure (Jenkins, 2000).

When manufacturing BSM with high amounts of reclaimed asphalt (RA >75%), the recovered binder is to be assessed to indicate the degree of oxidative aging. If the binder is considered active, the RA is to be blended with aggregates to ensure the binder does not form unwanted bonds within the material.

The BSM mix design and construction processes (TG2 Sabita, 2020) have been developed to limit the risk of producing a weakly bound material and ensure stress dependent material behaviour. This approach ensures that the failure mechanism of the BSM layer is permanent deformation (TG2 Sabita, 2020).

BSM is not only a cost-effective but also environmentally friendly approach due to cold mixing, in-situ application, reduced transportation as well as reduced virgin aggregate consumption compared to traditional asphalt. All these aspects reduce energy consumption and CO_2 emissions.

2.1 *The behavior of BSM*

BSM behaves similarly to unbound granular materials (stress dependent) but with considerably better cohesion and reduced moisture sensitivity. In contrast to hot-mix asphalt, the applied bitumen is distributed among the finer particles in a BSM, leaving the larger particles uncoated. The bitumen-rich mortar created between the coarse particles improves cohesion but has little influence on the internal friction angle, thereby maintaining the stress stiffening behavior.

The dispersed bitumen's visco-elastic properties provide BSM with its flexural strength and increased stiffness. The BSM maintains the granular properties of the parent material since the coarser aggregate particles remain uncoated and the bitumen is dispersed

as “spot welds” throughout the material. Therefore, since stiffness is stress dependent, BSM is not typically susceptible to fatigue cracking (TG2 Sabita, 2020).

2.2 *The benefits of BSM*

There are several advantages to recycling with BSM, such as reduced energy and natural resource requirements, an environmentally friendly approach, early trafficking following compaction that reduces traffic interruptions, and a significant decrease in heavy construction site’s traffic (TG2 Sabita, 2020).

2.3 *Foamed bitumen*

When water is injected into hot bitumen, a spontaneous foaming reaction occurs, resulting in foamed bitumen. The injected water quickly vaporises when it encounters hot bitumen, producing a large number of tiny bubbles that momentarily change the bitumen's physical characteristics. This foaming process occurs in an expansion chamber, where bitumen and water are injected under high pressure. The foam generated is inherently unstable and typically collapses within one minute.

During the mixing process, the bitumen bubbles burst, creating small bitumen splinters that disperse throughout the aggregate mix. These splinters adhere to the fine particles, forming various small spot welds in finer (-0.075 mm) fractions of the material. During compaction, the bitumen particles within the mastic are physically pressed against the larger aggregate particles, forming localized, non-continuous bonds (Wirtgen, 2012).

2.4 *Permanent deformation of BSM*

The material experiences both elastic and plastic strains during a load cycle (Theyse, 2007). Repeated loading causes unbound granular materials and BSM to deform due to the accumulation of residual plastic strain that remains after each load cycle.

3 MECHANISTIC-EMPIRICAL DESIGN STEPS

3.1 *BSM design approach*

The design process for pavements incorporating BSM is essentially the same as for all other pavement structures. Firstly, the required structural capacity is determined, and construction material availability is established. To classify the various materials, including the material that will be bitumen stabilised, site investigations and laboratory testing are conducted.

In order to determine a cost-effective mix and ensure reliable performance, a BSM mix design is performed. This process consists of sampling and characterisation, followed by mixing, compaction, curing, and testing to determine the optimum active filler and bitumen application rate. Table 1 provides the minimum requirements for Indirect Tensile Strength (ITS) tests (TG2 Sabita, 2022). The next step is to determine the shear properties (cohesion and angle of friction).

3.2 *Design for permanent deformation in BSM*

Traditional European and North American design philosophies solely evaluate the base layers and surfacing, ensuring the subgrade has sufficient cover to prevent deformation under load and protect the pavement layers from frost damage.

When unbound granular materials or BSM are applied as base or subbase layers in a pavement structure, it is imperative to determine the long-term permanent deformation of the layer as greater shear stresses on the pavement layers higher up in the structure result in significant plastic strain. The stress conditions within the layer are consequently examined while modelling a pavement with a BSM base layer.

The principal stresses in the BSM, along with the predetermined material properties, are used to calculate the ratio of applied stresses to the maximum failure stress. The calculated deviator stress ratio, combined with the material's density and moisture resistance properties, helps to estimate the number of allowable load repetitions that the layer can withstand before reaching the terminal level of permanent deformation.

The *Loudons* transfer function shown below was used in the analysis of the BSM layer:

$$N=10^{\wedge[A+B(RD)+C(RetC)+D(PS)+E(SR)}$$

RD = Relative Density % (typically 88%)
RetC = Retained Cohesion (from simplified triaxial test)
PS = Allowable Plastic Strain % (% of the layer thickness)
SR = Stress Ratio Parameter
A = 1.55 (constant for 90% reliability)
B = 0.10 (empirical constant)
C = 0.05 (empirical constant)
D = 0.10 (empirical constant)
E = -22.3333 (empirical constant)

The calculation of load repetitions to failure is performed using a Mechanistic-Empirical design approach, which relies on established material properties and data from extensive long-term pavement studies (TG2 Sabita, 2020).

4 DESIGN INPUTS FOR THE GERMAN COLD RECYCLED PAVEMENT CATALOGUE

The proposed pavement structures incorporating BSM were designed to have equal capacity as the standard load classes in RStO 12/24. The pavement

structures were modeled and analysed with Rubicon Toolbox® using Linear Elastic Theory.

BSMs are designed utilising the material's shear properties, the focus is on the angle of friction and cohesion of the material. Asphalt Academy guideline (TG2 Sabita, 2022), defines different classes for BSM with minimum requirements. For this study, class one BSM was selected based on the test results on mixes produced in Germany (Table 1).

Table 1. Minimum specification for BSM (TG2 Sabita, 2022)

Class	RAP (%)	ITS		Triaxial		
		ITS_{DRY} (kPa)	ITS_{WET} (kPa)	Cohesion (kPa)	Friction Angle (°)	Retained Cohesion (%)
BSM	< 50	225	125	250	40	75
	50-100	225	125	265	38	75

4.1 *Design traffic load*

The load class for a carriageway is usually determined by the design traffic load, as set out in Table 2. The 10-ton single axle, which is the standard design axle in Germany, used in the analysis.
While still providing adequate structural capacity, the pavement designs are intended to optimise the pavement structure for each load class.

Table 2. Relevant design traffic and assigned load class (RStO 12/24, 2024)

Equivalent 10-t-standard axles (million ESALs)	Load class
Above 32	Bk 100
From 10 to 32	Bk 32
From 3.2 to 10	Bk 10
From 1.8 to 3.2	Bk 3.2
From 1.0 to 1.8	Bk 1.8
From 0.3 to 1.0	Bk 1.0
to 0.3	Bk 0.3

4.2 *Material-specific properties*

4.2.1 *Asphalt*

For all pavement structures in all load classes, a 4 cm thick asphalt surface course was considered. In cases that a thicker asphalt was required, a minimum of 6 cm for binder and 8 cm for base layers were considered.

For all asphalt types a resilient modulus of 5000 MPa was considered. In Rubicon Toolbox®, the binder and surface courses were represented as a single layer. Poisson's ratio of 0.35 was considered for all asphalt types. The Shell Asphalt Fatigue transfer function (which is integrated in Rubicon Toolbox®) was considered to control the fatigue under the asphalt layer.

4.2.2 *BSM*

The BSM parameters for cohesion (C), angle of friction (φ) and retained cohesion were used as indicated in Table 3. Poisson's ratio of 0.3 was assumed and used for the BSM layer (Jenkins, 2000).

Table 3. BSM input parameters for design

Description	Parameter
Relative density	86%
Allowed deformation	5% of thickness
Retained cohesion	75%
Cohesion	250 kPa
Angle of friction	40°

The maximum acceptable in field resilient modulus for a BSM is normally considered 1000 MPa, contingent on the support conditions. Values of more than 1500 MPa have, however, been reported in completed projects. (Collings, 2015).

Research has shown that where a laboratory measured resilient modulus is set as a minimum value it will lead to increased binder and filler contents, which in turn leads to weakly bound materials that lose the required stress dependency and exhibit fatigue behavior (Austroads, 2022).

To ensure a conservative approach for design, an assumed in field resilient modulus of 900 MPa was applied in the model when only one BSM layer was used. For configurations with two BSM layers, the resilient modulus values of 700 MPa and 900 MPa were used.

The BSM layer must have a minimum thickness of 10 cm to allow for practical construction considerations. If the BSM thickness exceeds 20 cm, it will be constructed in two layers to ensure uniform compaction on the thicker layers.

4.2.3 *Anti-frost layer and subgrade*

The anti-frost layer in the RStO 12/24 guideline has different thicknesses according to the frost penetration depth of each region in Germany. As a conservative approach for pavement design, the thickness of anti-frost layer was selected as 30 cm. Based on the RStO 12/24, a plate-load based stiffness (E_{V2}) of minimum 120 MPa should be reached on top of this layer (except for Bk 0.3, which 100 MPa is acceptable).

For subgrade, RStO considers a minimum resilient modulus value of 45 MPa.

The resilient modulus of the anti-frost layer was calculated as 200 MPa, over the subgrade with a resilient modulus of 45 MPa to reach the desired E_{V2} value of 120 MPa. The cohesion of 30 kPa and friction angle of 40.5° were selected as other input parameters for the anti-frost layer's material in the Rubicon Toolbox®.

Poisson's ratio of 0.49 was considered for both subgrade and anti-frost layers, as 0.5 is not permitted in the Rubicon Toolbox® as an input parameter.

5 FIRST RESULTS

The first catalogue design focused on BSM alternatives to hot mix asphalt base layer. As mentioned above, load classes Bk 1.0 to Bk 100 were based on a plate-load stiffness of E_{V2} = 120 MPa under the BSM, while load class Bk 0.3 was based on E_{V2} = 100 MPa. In practical cases, it can happen that the bearing capacity under the recycling horizon is less than 120 MPa; therefore, as the next step of this study, other E_{V2} values will be considered too.

The developed catalogue design alternatives incorporating BSM are listed in Table 4 to Table 7 for each of the load classes in RStO 12/24.

Table 4. BSM and standard RStO catalogue, Bk 100 & Bk 32

Load class (million ESALs)	Bk 100 (> 32)		Bk 32 (10-32)	
	RStO 12	BSM	RStO 12	BSM
Asphalt surface	12 cm	10 cm	12 cm	10 cm
Asphalt base	22 cm	8 cm	18 cm	8 cm
BSM	-	20 cm	-	15 cm
Bearing capacity beneath the BSM layer, E_{V2} = 120 MPa				

Table 5. BSM and standard RStO catalogue, Bk 10 & Bk 3.2

Load class (million ESALs)	Bk 10 (3.2-10)		Bk 3.2 (1.8-3.2)	
	RStO 12	BSM	RStO 12	BSM
Asphalt surface	12 cm	10 cm	10 cm	10 cm
Asphalt base	14 cm	-	12 cm	-
BSM	-	20 cm	-	15 cm
Bearing capacity beneath the BSM layer, E_{V2} = 120 MPa				

Table 6. BSM and standard RStO catalogue, Bk 1.8 & Bk 1.0

Load class (million ESALs)	Bk 1.8 (1.0-1.8)		Bk 1.0 (0.3-1.0)	
	RStO 12	BSM	RStO 12	BSM
Asphalt surface	4 cm	4 cm	4 cm	4 cm
Asphalt base	16 cm	-	14 cm	-
BSM	-	25 cm	-	20 cm
Bearing capacity beneath the BSM layer, E_{V2} = 120 MPa				

Table 7. BSM and standard RStO catalogue, Bk 0.3

Load class (million ESALs)	Bk 0.3 (<0.3)	
	RStO 12	BSM
Asphalt surface	4 cm	4 cm
Asphalt base	10 cm	-
BSM	-	20 cm
Bearing capacity beneath the BSM layer, E_{V2} = 100 MPa		

6 CONCLUSION

Integrating BSM as a cold recycling alternative is advantageous due to the financial and environmental benefits demonstrated in several projects across the world and caters for the growing interest in BSM in Germany. One of the main requirements for implementing this material in German pavements is to establish an accepted pavement design method. This paper aimed to present the first results of a plan to address this requirement.

The pavement structures presented in this study offer a conservative approach as the first step of a plan to integrate BSM into well-established design procedures in Germany. The Mechanistic-Empirical design method from Asphalt Academy is the existing international method for structural design of pavements with BSM (TG2 Sabita, 2022), which is founded on long term performance of BSM pavements and validated through different projects worldwide. This method was used to design the proposed pavements for different loading classes of the existing German catalogue design. The first validations were performed through accelerated pavement tests in outdoor testing facility of BASt (Kalantari, 2023). By having the first catalogue, it is now possible to construct more pilot projects and gather performance data for further validation.

The next step is to extend the catalogue by considering other bearing capacity levels beneath the BSM layer.

7 REFERENCES

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