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Functional Durability-related Bitumen Specification (FunDBitS)

Correlations between bitumen and asphalt properties

Fatigue life

Deliverable D.2d
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Executive summary

In the FunDBitS project, the data that has become internationally available since the BiTVal project are being reviewed in order to develop performance-based bitumen characteristics which may be introduced into bitumen specification standards EN 12591, EN 14023 and EN 13924.

The relevant information available in the literature was already reviewed and summarized in the interim project report D.1. Possible correlations between the bitumen and asphalt properties related not only to stiffness were identified. Based on the findings five key asphalt performance-based and durability oriented characteristics were considered: permanent deformation (rutting); stiffness; low temperature cracking; fatigue cracking and binder/aggregate interaction.

Later on, possible correlations between the bitumen and asphalt properties were reviewed in terms of the extent to which the bitumen affects the asphalt, in particularly its durability and service life, with due consideration for the reliability of the test methods and presence of other factors on the asphalt properties. Particular reports to Deliverable D.2 of the FunDBitS project presents the review of the correlations between the referred five asphalt characteristics and bitumen tests/properties.

The presented report is a part of deliverable D.2 and deals specifically with the correlations between the asphalt fatigue life (which can be similarly to stiffness determined by several methods according to valid EN 12697-24 standard) and bitumen tests/properties related to fatigue behavior and performance-based characteristics like complex shear modulus or strain characteristics. Recommendation are given by the conclusions with respect to future steps and most suitable tests available so far.

It should be noted that the technical question of asphalt and bitumen fatigue behavior is a highly complex issue that is especially in terms of testing bitumen fatigue characteristics or the impact of ageing on fatigue the least attention from all assessed characteristics within FunDBitS project especially in the case of relation to a proper used of bituminous binders.

1. Introduction

The cracks due to mechanical fatigue depend on the road pavement structures (*i.e.* thickness of layers, stiffness modulus and the rheological characteristics of the materials), on the traffic (particularly heavy loaded vehicles), on the climatic conditions and on the time-dem´pendent evolution (ageing) of the characteristics of the bitumen.

The relevant asphalt test specimen tests on fatigue cracking as described in the interim report of FUNDBITS project D.1 is as follows:

- **Common test protocols**
  - Flexural loading
    - Four point loading (prismatic specimen)
    - Three point loading (prismatic specimen)
    - Two point loading (trapezoidal specimen)
  - Push-pull or tension-compression, (cylindrical specimens)
  - Diametric loading (cylindrical specimens)
- **Alternative test protocols**
  - Strain sweep test (EBADE)
  - Overlay tester (OT)

The relationship between the properties of the bitumen and the fatigue resistance of the asphalt mixture was studied in D.1 based on a vast literature review. Several bitumen properties have been analysed with various test methods, in order to identify if there are in existing studies and research works correlations between these properties and asphalt mixture fatigue resistance. The main laboratory tests in order to assess the bitumen properties which has been studied in D.1 are as follows:

- Dynamic shear rheometer test (DSR) : Linear viscoelastic properties (complex modulus (G*), phase angle (sinδ))
- Bending beam rheometer: low temperature stiffness and relaxation properties of asphalt binders
- Linear amplitude sweep test (LAS): fatigue stress/strain

2. Relation between the fatigue behaviour of bituminous binders and asphalt mixtures

2.1 General

Several studies have attempted to find a relationship between the bituminous binder and asphalt mixture fatigue properties. Chapter 8 of Report D.1 of this project is dedicated to an extensive literature review on the subject of fatigue behaviour. The fact that the binder quality has an impact on the fatigue performance of the asphalt mixtures is not negligible. Generally, the asphalt mixtures with higher bitumen content show a higher resistance to fatigue cracking. However, despite a vast literature review of numerous articles it was found out that it is very difficult to find a direct relationship between the fatigue properties of the binder and the asphalt mixtures. The main reason is that there is no proper binder test to describe the binder impact on fatigue properties of the asphalt mixtures, see paper 71 (Ballié et al., 2008). In this section, a summary of the findings on the relationship between the bituminous binder and asphalt mixture properties is given. Since the mixture stiffness is to some extend related to the mixture fatigue properties this relationship has also been mentioned in this chapter.

One of the binder properties which was found out to have a strong relationship to the mixture characteristics is the binder stiffness. In Paper 25 (Mangiafico et al., 2004) a strong linear relationship was found between the normalized binder complex stiffness modulus and the normalized mixture complex stiffness modulus. However this study failed to find a relationship between the fatigue properties of the binder and the mixture. The same relationship between the binder and mixture stiffness was found by Paper 272 (Pérez-Jiménez et al., 2014) using EBADE test protocol. This study also showed a relationship between the fatigue failure strain of the binder and the asphalt mixture.

Another import parameter which was found out in Paper 62 (Jiménéz et al., 2008) is the critical strain/deformation of bituminous binders in a DSR test. The critical strain is the strain measured in DSR test, at which the ratio of the fatigue strain to the load cycles starts to increase with a high rate. It was concluded by the authors that for bituminous binders with the same modulus the higher their critical deformation is the better their behaviour under fatigue.

In Paper 175 (Clopotel et al., 2012) a relationship was found between the stress/strain response of the mixture and the binder to the accelerated fatigue test. The stress-strain response of the binder was analysed, performing linear amplitude sweep (LAS) test protocol while EBADE test protocol was used for the mixture. These relationship are shown in the **Chyba! Nenalezen zdroj odkazů.**.

In Paper 71 (Ballié et al., 2008), an empirical relationship was obtained between binder properties and ε_6 value of the fatigue test. The obtained relationship is based on multivariate statistical processing, and is presented as:

Log10(FATIGUE)=2.0216+0.09641*Ex_IPpfeif+0.02939*log10(Ex_all_rupt)

Ex_IPpfeif = Pfeiffer Index (i.e. penetration at 25°C and the ring and ball softening point)
Ex_all_rupt = binder elongation at break in the direct tensile test

The estimated value of ε_6 calculated from the binder variable values is between 1.7*FATIGUE and 0.85*FATIGUE (*i.e.* around ±15 µdef for ε_6 centred on 100). It was observed that FATIGUE behaviour of asphalt mixtures with special binders and polymer modified binders is superior to the behaviour of the pure (paving grade) bitumen based asphalt mixtures. Moreover it was mentioned that no relationship was found the mix fatigue strain (ε_6) and the binder complex modulus (G*); the associated phase angle or with the variable G*sin (δ).

It can be seen that despite the efforts of Paper 71 in obtaining a relationship between binder properties and mixture fatigue characteristics, the uncertainty of the relationships is too high. Moreover, these relationships were purely empirical and were based on only one type of binder where only its nature was changed.

In Table 0-1 some of the relationships which were found in the literature are presented. It can be noticed that the correlation between the binder and asphalt mixture stiffness is relatively strong. This relationship becomes even stronger in higher temperature or lower load frequencies acting on an asphalt mixture. The reason for this is simply the fact that in higher temperatures, the asphalt mixture obtains more of its mechanical behaviours from the binder while in lower temperature range it is the aggregate structure that becomes the dominant component.

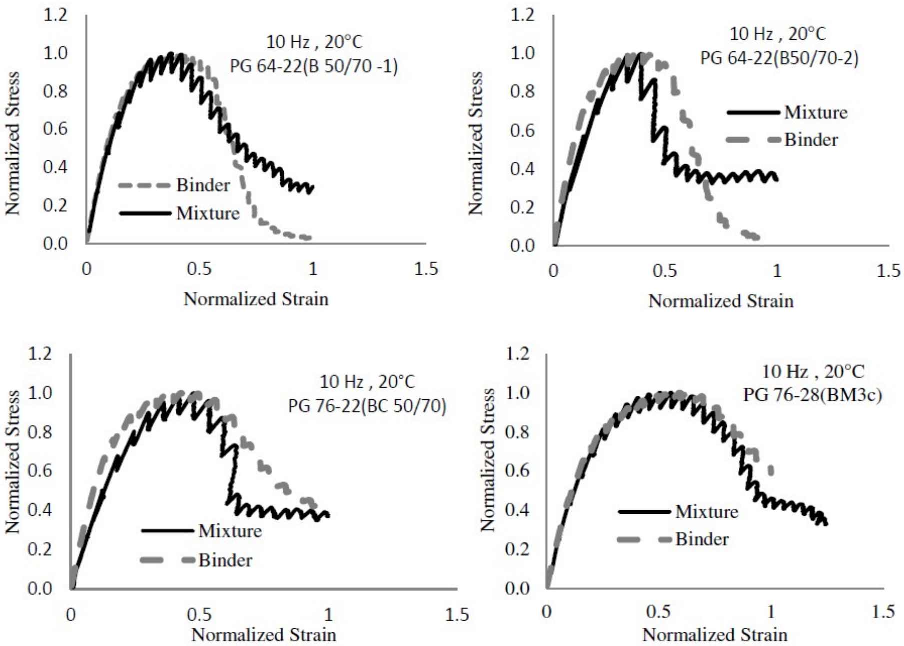

Figure 1-1: Mixture (EBADE) and binder (LAS) normalized stress-strain response to3 accelerated fatigue (Paper 175)

Table 0-1: Correlations found between bituminous binder stiffness and permanent deformation behaviour of asphalt mixtures

Paper	Correlated data	Type of correlation	Data sets	Constant *a*	Constant *b*	R^2	*Comment*
Paper 025 (Mangiafico et al., 2012)	Normalized bitumen E* *vs* Normalized asphalt E*	Linear (y= a + bx)	12	0.2911	0.75	0.92	
	b *vs* ε_6			No correlation was found			
Paper 272 (Pérez-Jiménez et al, 2014)	Binder initial complex modulus *vs* Initial complex modulus mixture	Linear (y= a + bx)	9	10.156	7820	0.59	
	Failure strain of the binder *vs* Failure strain of the mixture			0.0118	1e-4	0.579	
Paper 175 (Clopotel et al., 2012)	Fracture energy binder *vs* fracture energy mixture	Linear (y= a + bx)	10	N/A	N/A	0.7718	
	Displacement @ max load binder *vs* displacement @max load mixture		7	N/A	N/A	0.65	T = -15 and 5 °C
			5	N/A	N/A	0.92	T = 5°C
Paper 71 (Ballié et al.,2008)	Asphalte modulus E* *vs* binder modulus G*	Linear (y= a + bx)	10	N/A	N/A	0.98	-10°C, 10Hz
			10	N/A	N/A	0.99	+30°C, 10Hz
	Phase angle of asphalt *vs* phase angle of binder		10	N/A	N/A	0.93	+15°C, 10Hz

2.2 Effect of modified binder on the fatigue cracking of asphalt mixtures

One of the solutions to improve the asphalt mixture performance in fatigue is to modify the binder. The modification can either be done by polymers or adding chemical or organic additives to the bitumen or asphalt mixture. Several studies have investigated the impact of modified binders on the mixture characteristics. The polymer modified bitumen (PMB), for example, has been used for decades as a solution of rutting and cracking problems generated by the passage of the heavy loaded vehicles and high ratios of traffic.

SBS polymer is one the most common solutions for improving the asphalt mixture performance in terms of less rutting and better fatigue resistance which has been used for many years. Different studies (c.f. papers 24, 34, 94, 248) have investigated the effect of using SBS modified binder on fatigue resistance of the mixtures.

The effect of modifying the bitumen with crumb rubber has been investigated (c.f. paper 34, 45). The crumb rubber is an interesting solution from ecological point of view, since it reduces the waste tyre and at the same time improves the fundamental engineering properties of asphalt mixtures. The use of crumb rubber modified bitumen has been examined through laboratory tests in order to verify the stiffness properties and the fatigue resistance of bituminous mixtures in base and wearing courses (Paper 36). The asphalt rubber concrete presented an increased fatigue life, both before and after aging. Moreover, in each type of mixture, the hard modified bitumen led to an improved fatigue life compared to the soft one.

Polyphosphoric acid (PPA) is one of many additives used to modify and enhance paving grade bitumen. Since the early 1990s, PPA has also been successfully used across the United States in combination with different polymer modifiers (c.f. Paper 58, 59, 69, 98). Typically, the use of PPA reduces the penetration value of the bitumen leading to change the penetration classification of the PPA modified binder as well as increasing in various extend its softening point. The PPA modification increases the stiffness of the binder without affecting the low temperature properties. In the laboratory tests conducted in Paper 59, it was shown that the combination of PPA with SBS can provide fatigue resistance similar to the bitumen which is solely modified with SBS. Using PPA can help reducing the dosage of SBS while keeping the performance comparable as using SBS alone (Paper 98).

Moreover an attempt was made by Paper 26 (Eckmann et al., 2012**)**, in order to find a correlation between binder performance indicator and fatigue behaviour of asphalt mixtures, when cross-linked polymer modified binders were used. It was concluded that although cross-linked polymers give a significant contribution to the fatigue resistance but no direct correlation was observed between the polymer content and the pavement performance.

2.3 Binder ageing effect on fatigue cracking of asphalt pavments

In Paper 143 (Baek et al., 2012) the phenomenon of oxidative ageing is examined in terms of its effect on the dynamic modulus and fatigue performance of asphalt mixtures. In general, the stiffness of the asphalt mixture increases with ageing time over all of the frequency range. Cyclic fatigue tests were conducted for all four aged mixtures under CS (controlled stress) and CX (controlled crosshead) cyclic conditions. In this paper the different testing modes resulted in opposite fatigue performances. e.g. the STA (short term ageing) mix shows better performance in CX tests, while the LTA3 (long term ageing, 85 °C during 8 days) mix shows better performance in CS tests.

In another study the fatigue life of different mixture with aged an un-aged binders was determined in the laboratory, using 4-point bending test. It was found out that although the stiffness changes with ageing of the binder, the value of the fatigue life stayed unchanged for the test specimens.

3. Conclusions on relationships between bitumen properties and resistance to fatigue cracking of asphalt mixtures

The fact that binder characteristics can affect the fatigue resistance of the asphalt mixture is not negligible. However, despite the emphasize of many studies on finding a relashionship between the binder and mixture fatigue properties, very little information on this correlation is available and found in research. There are no existing data and correlation comparing binders and asphalt mixtures from real pavement structures. Furthermore, no direct relationship between the binder ageing and asphalt mixture was found according to the performed literature review. One of the main explanations for this can be lack of appropriate test methods for characterising binder fatigue properties since the current rheological test methods are restricted to the domain of linear viscoelastic behaviour under small deformations. A future research work is in this respect urgently needed in order to develop binder tests for better assessing the binder fatigue properties and further develop relatioships to correlate this to mixture fatigue properties.

4. References for fatigue cracking

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Paper 025 **Mangiafico, S, H di Benedetto, C Sauzeat, F Olard, S Dupriet, L Planque and R van Rooijen (2012).** Effect of reclaimed asphalt pavement on complex modulus and fatigue resistance of bitumens and asphalts. *E&E2012*.

Paper 026 **Eckmann, B, M Mazé, S Largeaud and S F Dumont (2012).** The contribution of cross-linked polymer modified binders to asphalt performance. *E&E2012*.

Paper 034 **Dreessen, S, T Gallet, A G Dumont and M Pittet (2012).** Durability study: field experience of long-term evolution of SBS polymer modified binder. *E&E2012*.

Paper 036 **Pasetto, M, and N Baldo (2012).** Fatigue behaviour and stiffness properties of asphalt rubber mixtures made with steel slags. *E&E2012*.

Paper 045 **Vasilica, B, G Georgeta and S Elisabeta 92012).** The effects of rubber powder on the performance of pavement asphalt. *E&E2012*.

Paper 058 **Baumgardner, G, J V Martin, R B Powell and P Turner (2008).** Polyphosphoric acid and styrene-butadiene-styrene block co-polymer modified asphalt: Evaluation of paved section at the NCAT test track built in 2000 and 2003. *E&E2008*.

Paper 059 **Bennert, T, and J V Martin (2008).** Polyphosphoric acid in combination with styrene-butadiene-styrene co-polymer: Mix fatigue resistance and permanent deformation evaluation. *E&E2008*.

Paper 062 **Pérez Jiménez, F, O J Reyes-Ortiz, R Miró Recasens and A Hernàndez-Noguers (2008).** Relation between the fatigue behavior of asphalt binders and bituminous mixtures. *E&E2008*.

Paper 069 **Such, C, J-V Martin, S Périgois and N Picard (2008).** Properties and performances of asphalt binders nd asphalt mixes modified with polyphosphoric acid. *E&E2008*.

Paper 071 **Ballié, M, E Chailleux, P Dumas, B Eckmann, C Leroux, B Lombardi, J-P Planche, C Such and J-C Vaniscote (2008).** Charachteristics of bituminous binders and their consequences on the mechanical performance of asphalts. *E&E2008*.

Paper 094 **Olard, F (2011).** Innovative design approach to high-performance asphalt concretes with long-life base and binder courses by use of aggregate packing concepts and polymer-modified binders. *TRB2011*.

Paper 098 **Li, X, N H Gibson, T R Clyne, E N Johnson and M E Kutay (2011).** Laboratory evaluation of asphalt binders and mixtures containing polyphosphoric acid. *TRB2011*.

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Paper 248 **Scholten, E, W Vonk and R Kluttz (2013).** The dawning of a new era of pavement design. *REAAA2013*.

Paper 272 **Pérez-Jiménez, F, R Botella, R Miró, A Paez-Dueñas, F J Barceló-Martínez and V Carrera (2014).** Binder, mastic and mixture fatigue characterization using a cyclic uniaxial strain sweep test. *TRB2014*.