Scottish Road Research Board

A MODIFIED APPROACH TO PAVEMENT DESIGN USING EME2

70058115
APRIL 2021

PUBLIC

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TYPE OF DOCUMENT (VERSION) PUBLIC

PROJECT NO. TS/TRBO/SER/2017/04/04

OUR REF. NO. 70058115

DATE: APRIL 2021

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QUALITY CONTROL

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks				
Date	06/04/2021			
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Signature	Khweir, Kadhim (UKKXK600) Digitally signed by Khweir, Kadhim (UKKXK600) DN: cn=Khweir, Kadhim (UKKXK600), ou=Active, email=Kadhim.Khweir@wsp.com Date: 2021.04.06 18:33:32 +01'00'			
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Authorised by	Michael Gordon			
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Project number	70058115			
Report number	R70058115_03			
File reference	EME2_Phase3R			

CONTENTS

EXECUTIVE SUMMARY

The Scottish Road Research Board commissioned WSP to consider how the UK pavement design process could be improved or modified to more accurately reflect the performance of material known as EME2. The request followed on from a previous study that highlighted that careful consideration needed to be given to quantifying the fatigue characteristics of EME2, as it differs from the reference material used in the current UK design.

The study was split into three phases that comprised a review of the development of the current UK road pavement design; a technical review of the design methods used in France and the USA; and the development of a modified design approach based on UK and international studies on the fatigue properties of asphalt materials. This report relates to the final phase of the project.

The consensus of both UK and international work was that materials rich in binder like EME2 are more resistant to fatigue loading than conventional materials. Numerous studies suggest that the extra binder contained in the EME2 will increase its fatigue life by at least 1.8 times compared to a conventional mixture like DBM50. The enhanced fatigue properties of EME2 are not taken into account in the current UK design method, and the introduction of the factor K_{Flex} in 2004 led to a reduction in fatigue life for stiff mixes such as EME2 when compared with DBM50.

Mathematical modelling work was undertaken to determine whether the existing UK fatigue equation could be adjusted to accommodate pavement designs utilising EME2 materials. The existing K_{Flex} factor was modified to better quantify the fatigue characteristics of EME2 for design purposes. The proposed new factor (K_{Flexm}) takes into account the influence of the binder content and the maximum aggregate size used in EME2.

It is recommended that the use of the K_{Flexm} factor be considered for use in Scotland, where asphalt producers find it difficult to meet the current compliance test requirements for stiffness modulus. The K_{Flexm} factor can be used to more accurately model the fatigue life of EME2 and reduce the current construction stiffness requirement. This provides a discretionary option that allows Transport Scotland to accept newly built pavements containing EME2 with reduced stiffness moduli.

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1

INTRODUCTION

1. INTRODUCTION

1.1. BACKGROUND

The Scottish Road Research Board (SRRB) commissioned WSP to review how the current UK pavement design procedure deals with materials that have different mechanical properties. Previous research has highlighted that material properties and pavement design requirements are closely linked, and any significant changes need be taken into account. Modern materials, such as EME2, are known to possess enhanced mechanical properties, and it is important that the design process reflects any improved performance. This is required to permit an accurate analysis of what pavement designs will provide the lowest whole life cost.

1.2. EME2

EME2 (Enrobé à Module Élevé) is a high strength, high performance, long-life asphalt originally developed in France. Compared to traditional UK materials, EME2 has a much higher binder content and lower air voids content making it more resistant to moisture damage. It is considered to be virtually impermeable when well compacted (Sanders *et al*, 2005). It also utilises an aggregate grading that is finer than that used traditionally in the UK and results in a densely packed aggregate structure with good aggregate interlock. The EME2 mixture (typically 10, 14mm & 20mm nominal size) is very cohesive and can be considered immune from segregation. It utilises a hardpaving grade bitumen, either Grade 10/20 pen or Grade 15/25 pen and provides enhanced mechanical properties, particularly dynamic stiffness modulus (load spreading ability) and resistance to fatigue.

1.2.1 Previous SRRB research

A previous SRRB study (McHale, 2017) examined the design and performance of EME2 in the Scottish context. The study looked at the mix exactly as specified in France, but also explored the use of softer binders to make it more suitable for use in the Scottish environment. The research study did not yield the results expected and showed that standard EME2 mixtures produced in Scotland possessed lower in-situ stiffnesses than mixtures produced in England. The study also highlighted that careful consideration needs to be given to quantifying the fatigue characteristics of EME2 as it differs from the reference material used in the current UK design, particularly in terms of binder volume. The study recommended that an improved model was required to predict the performance of designs containing EME2.

1.3. METHODOLOGY

The aim of the study was to consider how the pavement design process could be improved or modified to more accurately reflect the performance of EME2 base and binder materials. The approach involved splitting the study into three phases, as follows:

- Phase I
  - A literature review on the development of the current UK road pavement design methodology, including how material properties, such as fatigue resistance, are used in the analysis of pavements and the prediction of pavement life.

- Phase II
  - A technical review of the design methods used in France and the USA to determine whether alternative approaches could be incorporated into the UK method.
- Phase III
  - Development of a modified design approach based on studies that examined the effect of binder type and content.

This report relates to the final phase of the project and builds on the findings of the earlier work which are summarised below.

1.3.1. Phase I

The Phase I report (James, 2019) reviewed the present pavement design method used in the UK, including consideration of key material properties, such as stiffness and fatigue resistance. The report considers numerous key documents and studies that have shaped the development of pavement design methodology in the UK. The report highlights that the most recent update, known as the ‘versatile approach’ (Nunn, 2005) introduced Foundation Classes to enable for reductions in the more expensive surfacing layers. It also introduced a new design factor (K_{Flex}) for fully flexible pavements, which is intended to limit the amount of ‘flexing’ of the asphalt base. However, it is noted that K_{Flex} is a theoretical factor that depends upon the design stiffness of the asphalt base. The latest method still retains a simple layered linear elastic model to determine the strain at the critical locations, and the method is calibrated to LR1132 (Powell *et al*, 1984). As such, the current method represents a blend of practical experience (LR1132 historical trials) and structural theory. The review notes that more complex mechanistic models had not been sufficiently validated and that their use would require the introduction of new or complicated test methods to measure and provide additional input data. The report concludes that the current UK design method is conservative and does not easily lend itself to certain adjustments, e.g. the current method utilises a generalised fatigue relationship based on the performance of traditional materials, rather than the fatigue performance of modern materials such as EME2. The report recommended that pavement design models used in France and the USA should be examined to establish whether an alternative approach could be adopted.

1.3.2. Phase II

The Phase II report (James & Khweir, 2020) examined the current approaches to pavement design in France and the USA and compared them to UK practice. The main documents reviewed as part of the study were:

- French Design Manual for Pavement Structures; and
- Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures NCHRP 1-37A.

The study highlighted that predicting pavement performance is a very complex modelling task and this can be evidenced by the huge body of recent work that has taken place in the USA. Significant challenges in developing accurate predictions of pavement performance lie ahead when future traffic and climatic conditions cannot be controlled. All the design systems discussed in the report use linear elastic theory to calculate stresses and strains. However, it is recognised that the validity of using linear elastic modelling is questionable when some pavements fail due to top-down surface cracking rather than the predicted bottom-up cracking from the asphalt base layer. All the models examined require significant calibration factors to match actual and predicted performance. All the models rely on conservative, risk-based modelling to ensure that a significant proportion of pavements do not fail prematurely.

The French and US methods rely on relationships that were developed in the laboratory and are calibrated to the performance of pavements in service. In contrast, the UK method utilises results from full scale trials (undertaken in the 60s) that were compared against laboratory tests. The study contains a worked example that compares a hypothetical pavement design using the UK and French method. The aim of the example highlights the subtle differences in approach and any difference in the final pavement thickness. The report concludes that there are advantages and disadvantages to the UK, French and US systems, but no single approach presents a method of accurately predicting pavement performance in the field. Each method uses a statistical approach and the level of conservatism in design is specific to each country. Recommendations include developing an alternative approach that could consider using the K_{Safety} or K_{Flex} factor as a risk-based means of balancing stiffness values with improved fatigue performance gained from using material with a higher binder content and smaller aggregate sizes.

2

USE OF EME2 IN SCOTLAND

2. USE OF EME2 IN SCOTLAND

The SRRB commissioned a research study in 2014 to explore whether EME2 mixtures required to be modified for use in Scotland. The study was completed in two phases. The first phase comprised laboratory testing of a range of EME2 mixtures, and the second phase involved extracting cores from Scottish sites where the material had been used to assess its performance in service. The findings of the study are discussed below.

2.1. LABORATORY EVALUATION OF EME2 MIXTURES

Since the early days of the introduction of EME2 in Scotland, there was interest in the idea of using a softer grade binder than the commonly used grade of 15/25 pen. This was due to the perception that Scotland's climate was cooler than that found in France. Although areas of France can be exposed to similarly cold temperatures, the cooler mean annual temperature for Scotland means that there is concern surrounding the likelihood of colder laying conditions and the increased risk of inadequate compaction being achieved. A laboratory investigation was therefore carried out with softer paving grade bitumens (Grades: 30/45, 40/60 pen) which would reduce the risk of thermally induced damage under extreme weather conditions, and also facilitate compaction during construction.

TRL Report PPR750 (Artamendi and McHale, 2015) describes the laboratory testing and results and discusses the findings to assess the influence of the softer grade binders on two EME2 mixture designs produced from two aggregates sources. The results consistently showed a trend for one of the sources to perform better than the other in terms of wheel tracking, stiffness and fatigue. The report stated that the most likely factor causing the difference was related to the filler type and fines content of the mixtures. The EME2 mixtures produced with the softer binders were considered to be equivalent in terms of design stiffness to conventional materials such as Heavy Duty Macadam (HDM50) and Dense Bitumen Macadam (DBM50), but lower than the stiffness expected for normal EME2. Results from the four-point bending fatigue tests suggested that all the EME2 mixtures would significantly reduce the risk of fatigue cracking in the road when compared to a traditional DBM50 material. The EME2 mixtures made with the hardest binder (15/25 pen) produced the highest stiffness, deformation resistance and best resistance to fatigue. Thermal testing such as fracture toughness and flexural strength at 0ºC indicated that there were no significant differences between the mixtures produced with different penetration grade binders.

The report also discusses the significance of new fatigue data collected as part of the study, and the potential implications of its use in current analytical pavement design. Past studies indicated that the volume of binder was the most crucial material parameter that influenced the fatigue life and that the fatigue life of asphalt mixtures containing a similar volume of a harder binder was not significantly different. As a result, similar fatigue characterisation for DBM50, HDM and HMB35 were adopted. The four-point bending test results in the study suggested that this relationship does not hold for EME2 mixtures.

2.2. IN-SERVICE PERFORMANCE OF EME2

TRL Report PPR829 (McHale, 2017) relates to the second phase of the project that assessed the in-service performance of EME2 materials located on three Scottish trunk road sites. The M876 was selected as it was believed to be one of the oldest EME2 sites in the UK, having been in service for over 10 years. The two other sites were located on the A9 at Bankfoot and Crubenmore, which were 6.6 and 4.1 years old, respectively. The latter site was selected because it utilised a softer binder (Grade: 30/45) and was considered to provide key information relevant to the first part of the study. Some of the data collected was also compared to information collected on EME2 samples taken from three Highways England (HE) sites.

The condition of the EME2 layers from the A9 sites were found to be in good condition. In particular, the appearance of A9 Crubenmore cores were noted to be very uniform and well bonded with no sign of voids. Some of the M876 cores showed signs of debonding between the binder course and base layers and were described to be dusty or gritty to the touch. The measured mean core depths taken from the core logs corresponded well to the design depths specified in the original contracts. Laboratory testing showed that the gradings of the EME2 mixtures from the M876 and A9 Bankfoot sites were found to contain an excess of fine materials, particularly on the 2mm and 75μm sieve.

The penetration and softening point of the extracted binders were broadly in keeping with the expected fall in penetration and increase in softening point that is expected following construction, i.e. there were no significant indications of ageing or hardening of the binders in service. The minimum richness modulus, an estimation of binder film thickness, was met on the A9 sites, but not on the M876. The M876 voids content at 5.3% was found to be close to the top end of the specified maximum of 6%. The EME2 materials sampled from the A9 sites produced mean voids content of 2.2% and 1.3%, indicating the material had been compacted to a higher standard.

The mean indirect tensile stiffness modulus (ITSM) of the binder course and base course materials sampled from the oil lane at the three sites ranged between 4GPa to 5GPa. This compares to a range between 7.7GPa to 9.2GPa for EME2 samples taken from the HE network. A comparison of stiffness for samples taken from the wheelpath and the oil lane showed that there was no significant difference in the stiffness values. This indicated that little or no deterioration of the material had occurred owing to trafficking in the wheelpath. Although the in situ ITSM values are considered to be low, they broadly compare with testing carried out at the time of construction and values determined on materials from Scotland tested as part of Phase I of the study. Using a relationship derived from Phase I of the study, the equivalent design stiffness ranged between 5GPa to 6.7GPa. This is below the long-term stiffness of 8GPa normally adopted for analytical design purposes.

Recommendations included investigating why the EME2 materials tested as part of this study produced significantly lower stiffnesses than EME2 materials produced in England. Results from the study highlighted the need to develop an analytical design method that expressly incorporates the fatigue performance of EME2 and is not skewed towards materials with high stiffness. The latter would provide a better model for predicting the performance of asphalt pavements and better assess the use of materials with enhanced properties such as EME2.

3

EFFECT OF BINDER CONTENT & TYPE

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3. EFFECT OF BINDER CONTENT & TYPE

3.1. REVIEW OF UK & INTERNATIONAL RESEARCH

The following paragraphs review research that has been carried out to assess the influence of binder content and binder grade on the fatigue properties of asphalt materials. The purpose of the review is to quantify the effect of binder content and grade, particularly in the context of using EME2 mixtures when compared to more conventional UK mixtures such as DBM50. Several of the studies have developed fatigue relationships and these have been used to predict the impact of using EME2, and how this could translate into an increase in the theoretical design life of a fully flexible pavement.

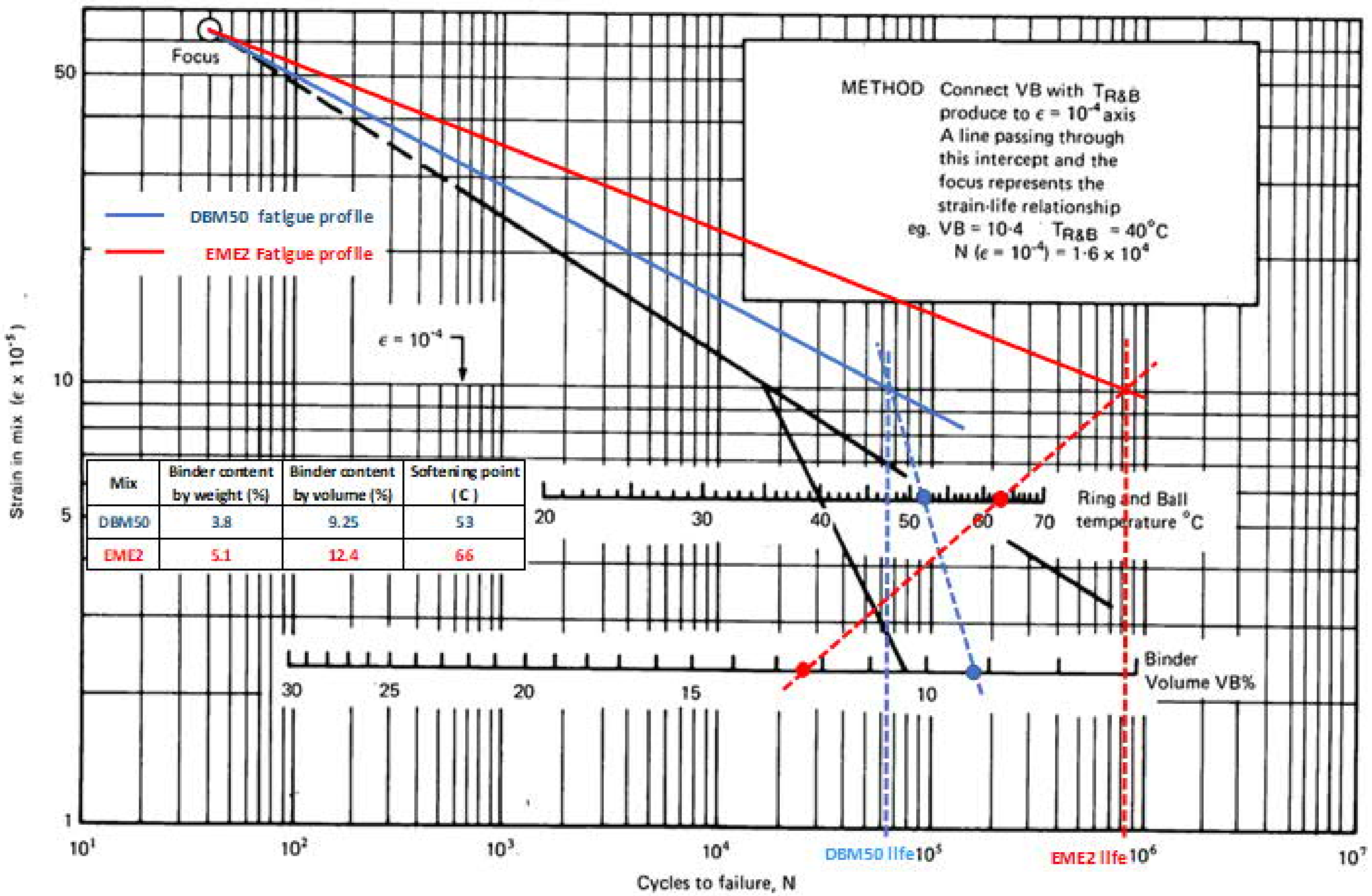
It should be noted that over the last 40 years, the fatigue performance of asphalt mixtures has been evaluated using a range of tests that either apply a constant load, known as controlled stress, or constant deflection, known as controlled strain. Test specimens and configurations also differ and include two, three and four point bending tests, and each laboratory test uses its own loading scheme with one temperature with no rest periods. As a result, the prediction of fatigue life can vary significantly dependant on the test used. As such, the review below focusses on the predicted trend or difference in fatigue life when an asphalt mixture such as EME2 is used.

3.1.1. The effect of mix variables on the fatigue strength of bituminous materials

A laboratory study into the effect of mix variables on fatigue (Cooper and Pell, 1974) concluded that binder content was a primary factor affecting fatigue performance, and as the relative volume of binder was increased, a longer fatigue life was obtained for a given strain. The dynamic stiffness was also affected by the binder content, increasing as binder content was increased until it reached a maximum at a condition of maximum mix density. If the binder content was increased beyond this point the dynamic stiffness began to decrease. Binder type, or penetration grade, were also seen as key factors affecting fatigue performance on the basis of applied strain. Longer lives were obtained for a given strain with binders that had a higher ring and ball softening point temperature. Dynamic stiffness was also influenced by binder type, but in a more complex way owing to the speed of loading and temperature effects on binder properties.

The work produced a nomograph for the prediction of the fatigue performance of a bituminous material (see Figure 3-1 below). This nomograph was based on defining the volume of the binder and the softening point (Ring & Ball temperature). Both these values (the binder volume & the softening point) were plotted on the graph and connected to produce a straight line. A line connecting this intercept and the focus point represented the strain-life relationship or fatigue profile of the bituminous material.

This nomograph was used to create fatigue profiles for a typical DBM50 and EME2 mixture. Binder volume values were based on the standard binder content target values as defined by the relevant British Standard. Softening points for DBM50 and the EME2 binders were based on average standard values for 40/60 Pen bitumen and 15/25 Pen bitumen. It can be seen from Figure 3-1 that the nomograph predicts the EME2 material, with a target binder content of 5.1% and softening point of 66, to have a significantly higher fatigue life than that of the DBM50 mixture with a target binder content of 3.8% and softening point of 53.



Mix	Binder content by weight (%)	Binder content by volume (%)	Softening point (C)
DBM50	3.8	9.25	53
EME2	5.1	12.4	66

Figure 3-1 - Nomograph for Prediction fatigue life (Cooper & Pell, 1974)

3.1.2. A simplified design for bituminous pavements

Brown (1974) undertook a study to develop a new design method which produced three fatigue profiles for DBM200, DBM100 and Hot Rolled Asphalt (HRA) mixture. The fatigue profiles are reproduced in Figure 3-2. The HRA mixture exhibited a fatigue life that was more than 20 times the fatigue life of the DBM200 and more than 10 times that of the DBM100. The fatigue life for a range of initial strains of 60 to 200 microstrain were calculated and are shown in Table 3-1. The average ratio of fatigue life for this typical range of strain values was found to be 13.2 and 24.5, for HRA to DBM100 and for HRA to DBM200, respectively.

Table 3-1 - Fatigue life of HRA compared to DBM mixtures

Microstrain	Cycles to failure in Millions			Ratio: increase in life	
	Hot Rolled asphalt	DBM100	DBM200	HRA/ DBM100	HRA/ DBM200
200	2.70	0.26	0.13	10.3	21.4
150	8.77	0.76	0.39	11.5	22.7
100	46.25	3.44	1.87	13.4	24.8
80	115.47	7.89	4.44	14.6	26.0
60	375.67	23.03	13.59	16.3	27.6
Average ratio of HRA to the DBM				13.2	24.5

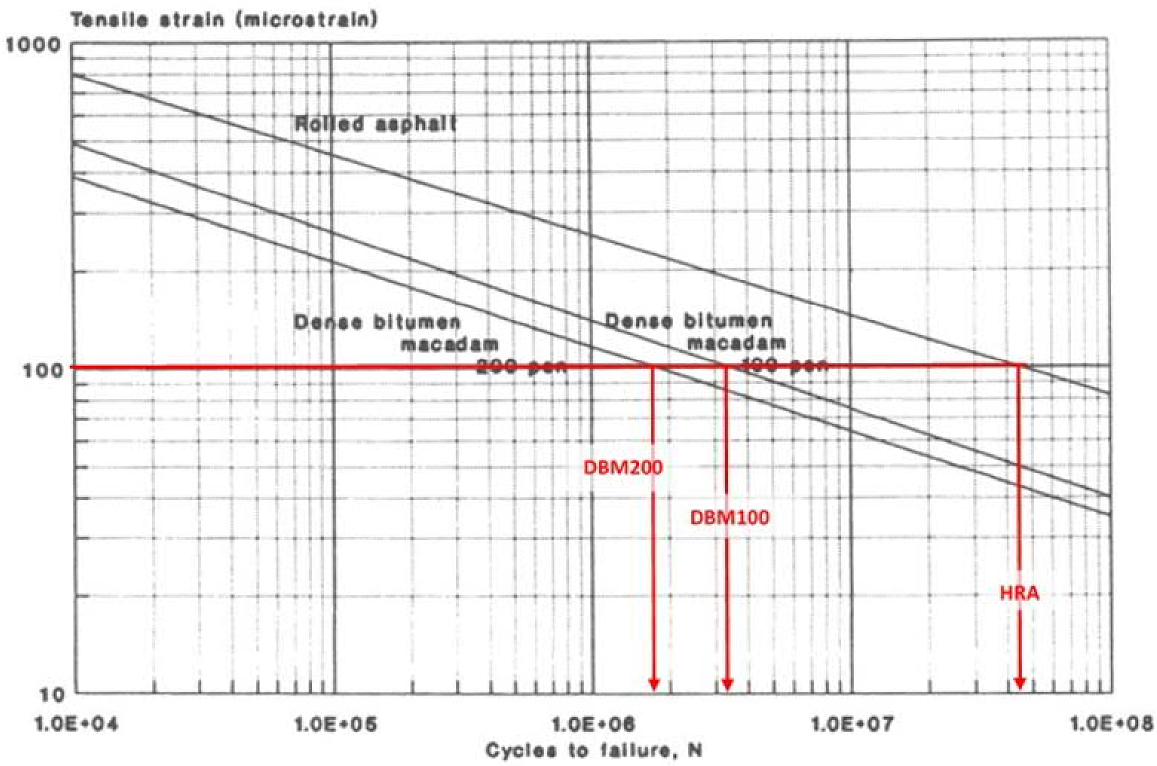


Figure 3-2 - Fatigue profiles for HRA, DBM100 & DBM200 (Brown, 1974)

3.1.3. Fatigue resistance for very heavy traffic

Pavement designs have historically been based on the cumulative number of standard axles predicted to pass over the pavement during its prescribed life. With the growth of goods traffic and the increase in vehicle weights, existing empirical design methods had to be supplemented by analytical techniques. Research in the 1980s enabled design standards to be revised to reflect these changes. New pavement designs, termed "unconventional pavement design" were proposed (Goddard, 1982). The designs comprised a surface course placed on a well compacted upper base of DBM and lower base of HRA. The rationale for this change was based on the better fatigue performance of HRA which had a high binder content when compared to the conventional DBM.

The design was predicted to have a fatigue life five times that of a conventional structure of the same thickness. This approach was used widely for the heaviest trafficked roads in the UK, including sections of the M6. The HRA material was placed in the zone where the structure is considered to be at the greatest risk of fatigue failure, i.e. the bottom of the base, where generally the highest horizontal tensile strains occur. The study recommended the use of HRA as a lower base for heavy traffic applications, as opposed to a conventional pavement using a DBM base. The study reported that for each 0.4% increase in binder content, the fatigue life could be increased by 45%. If this finding is applied to an EME2 mixture, which contains around 1.3% more binder than DBM50, then this translates to EME2 having 2.35 times the fatigue life of the DBM50.

3.1.4. The Structural Design of Bituminous Roads

The Transport and Road Research Laboratory (TRRL) produced its pavement design report LR 1132 in 1984 (Powell *et al*, 1984). This report incorporates the findings described above in regard to the superior fatigue performance of HRA over DBM. The report stated that the laboratory fatigue life of HRA at a given level of tensile strain is about twice that of DBM because of its higher binder content (Figure 3-3). The figure showed that for any strain value caused by traffic loading, the fatigue performance of the HRA is more than twice that of the DBM50.

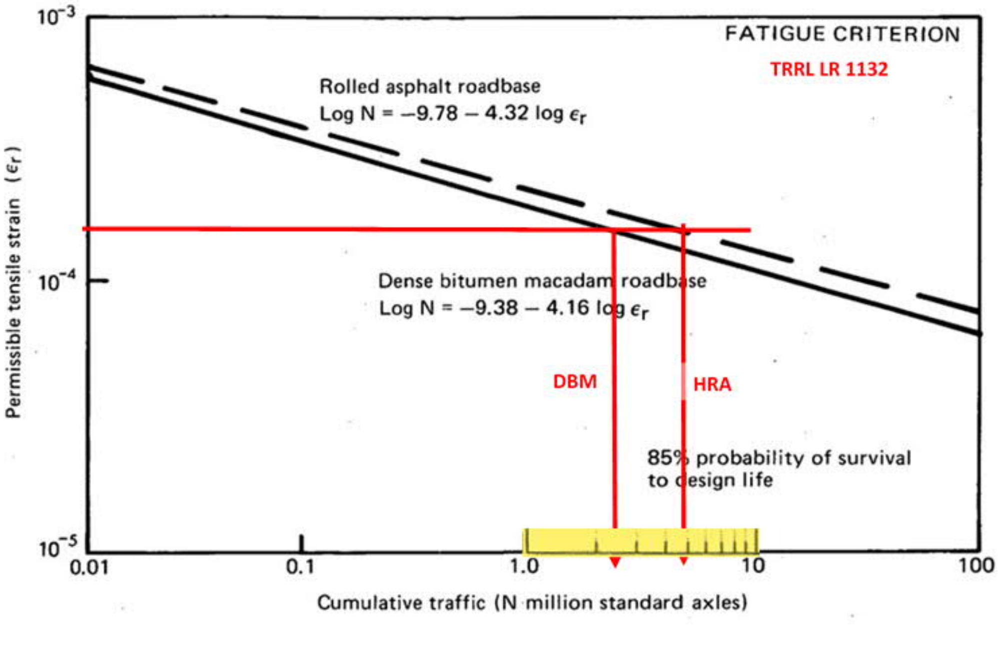


Figure 3-3 - Fatigue profiles for DBM & HRA mixtures (Power *et al*, 1984)

3.1.5. Development of a more versatile approach to pavement design

The versatile approach was introduced to give highway engineers a wider choice of materials and design configurations (Nunn, 2004). The report includes an adjustment to the bituminous roadbase fatigue formula, which was previously introduced in LR 1132 (Powell *et al*, 1984). The introduction of a material specific flexural factor, K_{Flex} , permits the use of base materials with different design stiffnesses. However, it has the effect of reducing the predicted fatigue life of pavement designs that use an asphalt base that has a high stiffness modulus. The formulae are reproduced below:

$$N / 10^6 = (\varepsilon_r / (K_{Flex} . K_{Safety} . 201 \times 10^{-6}))^{-(1/0.24)} \quad (1)$$

$$K_{Flex} = 1.089\ E^{-0.172} \quad (2)$$

Where, N is pavement life; ε_r is the microstrain value underside the base layer; K_{Safety} is 1, (no effect); and E is the dynamic stiffness modulus.

The newly adjusted fatigue formula, which incorporates the relationship detailed in LR 1132 with the K_{Flex} factor, is dependent on the stiffness modulus. The introduction of this factor has the effect of reducing the fatigue performance of EME2 without taking into consideration the high binder content of this material. It is noteworthy that LR 1132 provides two fatigue formulae: one for DBM100 and one for HRA50, but the Design Manual for Road and Bridges (DMRB), Pavement Design document CD 226 only uses the modified DBM100 relationship for DBM50 and the EME2 materials. It could be argued that the use of the HRA relationship is more appropriate when predicting the fatigue life of EME2 due to the high binder content of the material. Table 3-2 compares the estimates of fatigue life using the LR 1132 relationships for DBM100 and HRA50 with the K_{Flex} factor. If the HRA relationship is used for EME2 the fatigue life is increased by 70% to 90%.

Table 3-2 – Prediction of fatigue life for DBM50 and EME2 using DBM100 and HRA relationships (LR 1132) with K_{Flex}

Material	Stiffness modulus (GPa)	K_{Flex}	Micro-strain	LR 1132 Formulae		Ratio
				Fatigue life DBM100 (msa)	Fatigue life HRA50 (msa)	
DBM50	4.7	0.835	55	103.4	191.5	1.852
	4.7	0.835	60	72.0	131.5	1.827
	4.7	0.835	70	37.9	67.6	1.782
	4.7	0.835	80	21.8	37.9	1.744
EME2	8.0	0.762	55	70.7	129.0	1.825
	8.0	0.762	60	49.2	88.6	1.800
	8.0	0.762	70	25.9	45.5	1.756
	8.0	0.762	80	14.9	25.6	1.719
					Average ratio	1.80

3.1.6. The application of EME2 in flexible pavements

A study was undertaken (Sanders & Nunn, 2005) to compare the performance of EME2 with Heavy Duty Macadam (HDM50). As part of the study, the Indirect Tensile Fatigue Test (ITFT) was used to evaluate the EME2 and HDM50. Test results are summarised in Table 3-3 and Figure 3-4. The results are in line with similar studies which confirm the improved fatigue performance of EME2. However, the authors chose to not emphasise the significance by stating, "*ITFT testing has shown the EME class 2 material to perform slightly better in fatigue than a conventional HDM base material*". The results show that EME2 material is more fatigue resistant than the HDM material, and the difference in the fatigue performance of materials reduces with a reduction in tensile strain. The EME2 fatigue life ratio was at least 68% greater than the HDM value. Fatigue profiles for the two materials were created and are consistent with the other studies reviewed in this report.

Table 3-3 - EME2 fatigue tests result compared to HDM50

Microstrain	Laboratory fatigue life (msa)		Ratio
	EME2	**HDM**	**EME2/HDM**
150	0.0277	0.0118	2.34
100	0.1033	0.0505	2.05
80	0.2133	0.1121	1.90
70	0.3291	0.1807	1.82
60	0.5431	0.3136	1.73
55 (long life)	0.7206	0.4280	1.68
		Average	1.92

NOTE: The above fatigue lives are laboratory based and are well below the fatigue lives experienced for pavements in service. Laboratory life is based on specimens that are 40mm thick and subjected to continuous cycles of loading until failure. The tests present a condition when cracks begin to initiate but do not allow for crack propagation which will usually increase the life by more than 20 times. In addition, there are no rest periods or lateral wander in loading, which again tend to increase the life by a similar factor. The tests are designed to produce results within a reasonable time scales and are relatively intact at the end of testing. All these factors mean that the laboratory fatigue life could be increased by a factor from 400 to 1000 times when compared to real life situations.

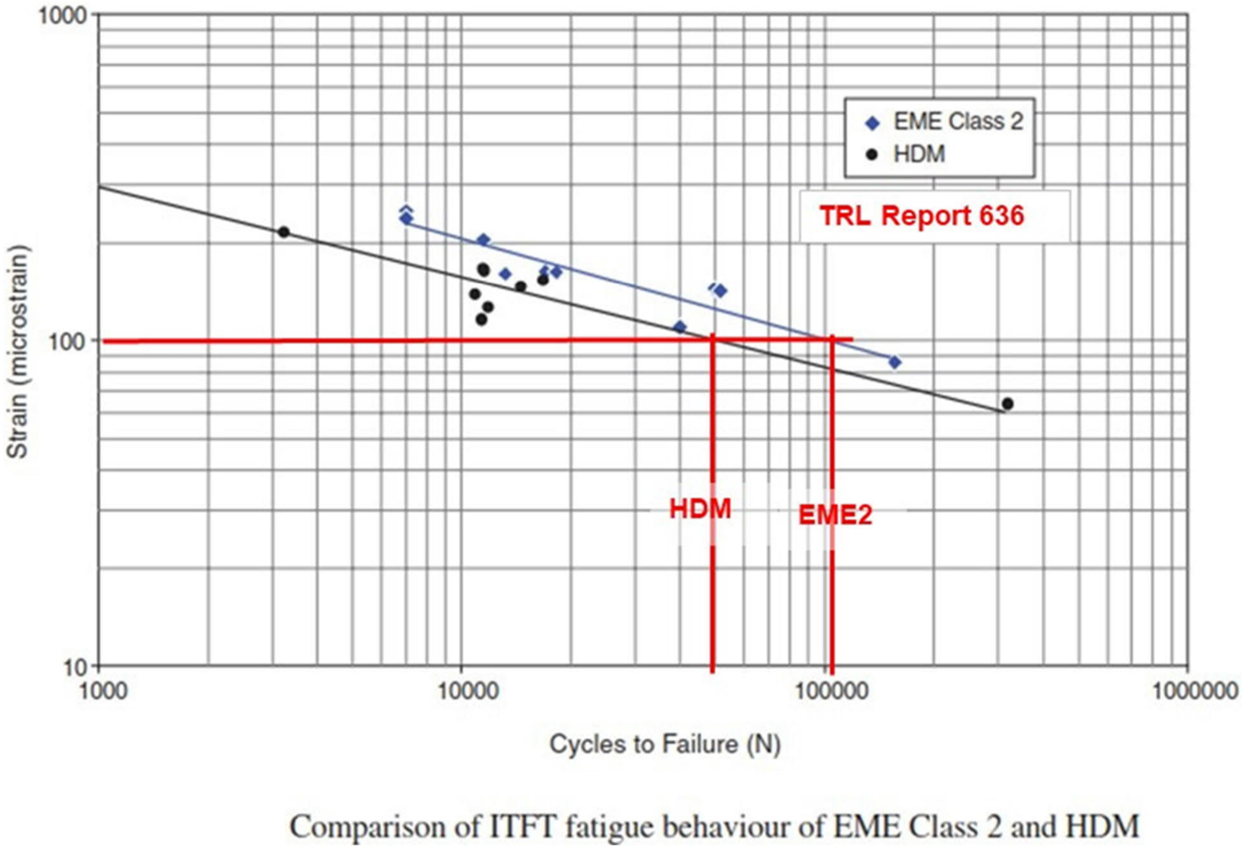


Figure 3-4 - Laboratory fatigue profiles of EME2 and HDM50 (Sanders & Nunn, 2004)

3.1.7. The Shell Method

Shell developed a software program for use in analytical pavement design (Shell, 1978 and Shell, 2011). The computer program BISAR (Bitumen Stress Analysis in Roads) is used to compute stresses, strains and displacements at any point in a pavement layer. To facilitate the generation of appropriate input data it incorporates the computer program BANDS (Bitumen and Asphalt Nomographs Developed by Shell) which includes bitumen stiffness, mix stiffness and mix fatigue.

For comparison purposes, a typical DBM50 and EME2 material have been modelled using BANDS to determine their fatigue life. The range of binder and air void contents used in the calculations reflect the different mix designs that are typically encountered in the field with these mixtures, i.e. for different aggregate types. Typically, DBM50 has a residual air void content which is higher than EME2. This is reflected in the standards which allow DBM50 to have a maximum air void content of 1% higher than EME2. It is well understood that the EME2 material will respond more readily to the compaction effort to produce a layer which will be on the lower side of the void content range than DBM50. Both materials were modelled using UK design parameters, such as temperature of 20ºC and a speed of loading of 5Hz. The individual mix properties used were as follows:

DBM50

- Penetration value = 40Pen
- Softening point = 53ºC

EME2

- Penetration value = 15Pen
- Softening point 66ºC

- Penetration index = -1.0
- Binder volume 7.5% to 10.5%, Binder content by weight 3.8% ± 0.6
- Void content range 4% to 7%

- Penetration index -0.3
- Binder volume 12% to 14%, Binder content by weight 5.1% to 6.1%
- Void content range 2% to 5%

Calculations were carried out over a range of strain values from 55 to 75 microstrain, which are typically associated with long life pavements. Table 3-4 shows that the EME2 material is predicted to have two to three times the fatigue life of DBM50.

Table 3-4 - Fatigue life of EME2 compared to DBM50 (Shell Method)

Bitumen Stiffness MPa	Bitumen volume (%)	Aggregate volume (%)	Void content (%)	Mix Stiffness MPa	Fatigue Strain (µ)	Fatigue Life (msa)	Fatigue ratio of EME2/ DBM50
DBM50							
38.80	7.50	85.50	7.0	6570	55	101	N/A
38.80	7.50	85.50	7.0	6570	65	43.6	N/A
38.80	7.50	85.50	7.0	6570	75	21.3	N/A
38.80	9.00	85.50	5.5	6300	55	239	N/A
38.80	9.00	85.50	5.5	6300	65	104	N/A
38.80	9.00	85.50	5.5	6300	75	50.6	N/A
38.80	10.50	85.50	4.0	6080	55	503	N/A
38.80	10.50	85.50	4.0	6080	65	218	N/A
38.80	10.50	85.50	4.0	6080	75	107	N/A
EME2							
122.00	12.00	83.00	5.0	9630	55	401	3.97
122.00	12.00	83.00	5.0	9630	65	174	3.99
122.00	12.00	83.00	5.0	9630	75	85.1	4.00
122.00	13.50	83.00	3.5	9630	55	685	2.87
122.00	13.50	83.00	3.5	9630	65	297	2.86
122.00	13.50	83.00	3.5	9630	75	145	2.87

Bitumen Stiffness MPa	Bitumen volume (%)	Aggregate volume (%)	Void content (%)	Mix Stiffness MPa	Fatigue Strain (μ)	Fatigue Life (msa)	Fatigue ratio of EME2/ DBM50
122.00	15.00	83.00	2.0	9640	55	1110	2.21
122.00	15.00	83.00	2.0	9640	65	481	2.21
122.00	15.00	83.00	2.0	9640	75	235	2.20

3.1.8. The Asphalt Institute & Others

The Asphalt Institute (AI, 1982) and many others (Finn *et al*, 1977; Wojciech, 2018; Huang, 2004; and Athanassios, 2015), have advocated the use of the AI fatigue life prediction model which accommodates the effect of a higher binder content. The model consistently predicts better fatigue performance for mixtures with high binder volumes and low air voids when compared to a low bitumen volumes and high air voids.

The binder content (volume of binder, Vb) and air voids (Va) in the mix can be expressed as Voids Filled with Binder (VFB), where VFB = Vb / (Vb + Va). The combined effect of binder content and air voids in the mix, in the form of percent voids filled with binder (VFB), has been considered as a useful parameter in fatigue life prediction models. The factor C in the following equation represents the improvement in fatigue life due to the VFB.

$$N_f = 18.4\ C\ (0.004325 \varepsilon_t^{-3.291})\ (E^{-0.854}) \quad (3)$$

$$C = 10^M \quad (4)$$

$$M = 4.84\ (VFB - 0.69) \quad (5)$$

$$VFB\ (VFB = V_b / (V_b + V_a) \quad (6)$$

Where, N_f is the pavement life; ε_t is the Strain value; E is the dynamic stiffness modulus; and C is a factor for the effect of binder volume on the fatigue life.

Table 3-5 and Table 3-6 show the results of calculations using the model when applied to a typical DBM50 and EME2 mixture. As explained above, voids in the EME2 are less than the DBM50 and these have been taken into consideration during the modelling.

The calculations are based on an assumed aggregate bulk specific gravity of 2.75 and 1.03 for bitumen. Additional information, such as bitumen content, aggregate content, density, air voids content, average VFB, M and C factor are presented in the tables.

In the USA mixtures would be expected to have a C factor ≥ 1.0. It can be seen that the average fatigue factor, C, for DBM50 is 0.735. This value means that the binder contents found within the range of a UK standard DBM50 mixtures are predicted to provide a lower fatigue performance than a standard American mixture. In fact, many of the binder contents, with the exception of a binder content of 4.7%, are below what would be expected and the overall average is around 73% of the standard value. In contrast, the average C value for EME2 was found to be 2.556. This value means that the binder content of the EME2, along with good control on air voids content, leads to a fatigue performance more than that of a standard American mixture (2.556 or 255% of the standard value). When the average C factors for EME2 and DBM50 are compared, the EME2 mixture is 3.47 times better than the DBM50. This translates to a significantly increased prediction of fatigue life (N_f) which is consistent with other findings in this study.

Table 3-5 - DBM50 mixture with different mixture content

Bitumen content (%)	3.2	3.5	3.8	4.1	4.4	4.7
Aggregate content (%)	96.8	96.5	96.2	95.9	95.6	95.3
Max. Asphalt density (ton/M^3)	2.61	2.60	2.59	2.57	2.56	2.55
Void content	**Mixture density at different voids content (ton/m^3)**					
3%	2.53	2.52	2.51	2.50	2.48	2.47
5%	2.48	2.47	2.46	2.45	2.43	2.42
7%	2.43	2.42	2.40	2.39	2.38	2.37
	Void in Mineral Aggregate (%)					
3%	10.9	11.6	12.3	12.9	13.6	14.3
5%	12.7	13.4	14.1	14.7	15.4	16.1
7%	14.5	15.2	15.9	16.5	17.2	17.8
	Void Filled with Bitumen (%)					
3%	72.4	74.1	75.5	76.8	78.0	79.0
5%	60.6	62.7	64.4	66.1	67.5	68.9
7%	51.9	54.0	55.9	57.6	59.2	60.7
Average VFB	61.6	63.6	65.3	66.8	68.2	69.5
M factor	-0.36	-0.26	-0.18	-0.10	-0.04	0.03
Factor for the effect of bitumen content on fatigue, C =10^M. **Average = 0.735**	0.440	0.546	0.661	0.786	0.919	1.060

Table 3-6 - EME2 mixture with different mixture content

Bitumen content (%)	5.1	5.3	5.5	5.8	6.0	6.2
Aggregate content (%)	94.9	94.7	94.5	94.2	94.0	93.8
Max. Asphalt density (ton/M^3)	2.53	2.53	2.52	2.51	2.50	2.49
Void content	**Mixture density at different voids content (ton/m^3)**					
2%	2.48	2.48	2.47	2.46	2.45	2.44
4%	2.43	2.43	2.42	2.41	2.40	2.39
6%	2.38	2.37	2.37	2.36	2.35	2.34
	Void in Mineral Aggregate (%)					
2%	14.3	14.7	15.2	15.8	16.3	16.7
4%	16.0	16.5	16.9	17.6	18.0	18.4
6%	17.8	18.2	18.6	19.3	19.7	20.1
	Void Filled with Bitumen (%)					
2%	86.0	86.4	86.8	87.4	87.7	88.0
4%	75.1	75.7	76.3	77.2	77.8	78.3
6%	66.3	67.1	67.8	68.9	69.5	70.1
Average VFB	75.8	76.4	77.0	77.8	78.3	78.8
M factor	0.33	0.36	0.39	0.43	0.45	0.47
Factor for the effect of bitumen content on fatigue, C =10^M. **Average = 2.556**	2.13	2.28	2.44	2.67	2.83	2.98

3.2. DISCUSSION

The studies reviewed in this chapter included both UK and international research that relates to the prediction of fatigue life of asphalt mixtures. All the studies agree that a high binder content and low air voids will improve the fatigue performance of asphalt mixtures, which typically translates into an increased design life. Table 3-7 provides a summary of the reviewed studies.

Table 3-7 – Summary of fatigue study findings

Research study	Fatigue study finding
Cooper & Pell, 1974	Nomograph predicts the fatigue life for EME2 to be at least one order of magnitude higher than DBM50.
Brown, 1974	Fatigue profile for HRA (*similar to EME2 with high binder content*) at least one order of magnitude higher than DBM100 & DBM200.
Goddard, 1982	Binder content finding applied to EME2 translates to 2.35 times the fatigue life of the DBM50.
Powel *et al,* 1984 (LR 1132)	Fatigue performance of the HRA is more than twice that of the DBM50.
Nunn, 2004 (TRL 615)	TRL 615 formula predicts EME2 to be 1.8 times higher the DBM50.
Sanders *et al,* 2005 (TRL 636)	ITFT shows EME2 fatigue life to be around 1.92 times higher than HDM50.
The Shell method (Band Software)	EME2 material is predicted to have two to three times the fatigue life of DBM50.
The American Asphalt institute & others	EME2 mixture is 3.47 times better than the DBM50.

The summarised findings in Table 3-7 provide a strong basis for adjusting the fatigue equation in a way that positively reflects the contribution of higher binder contents as well as the binder type. In addition, EME2 utilises smaller aggregate and a finer grading that reduces the occurrence of segregation that often takes place when using DBM mixes.

It is important to reiterate that findings tabulated in Table 3-7 are based on different approaches to predicting fatigue life. Some of the studies are based on site gathered data and others are based on laboratory testing. The laboratory studies are based on different specimen orientations, shapes and sizes, as well as different apparatus. It appears, however, that there is a consensus that the fatigue life improves markedly with an increase in binder content particularly with a finer grading such as an EME2 mixture.

Following the introduction of EME2 to the UK, it is unclear why its enhanced fatigue performance was not acknowledged and allowed for in design calculations. It is possible that a conservative approach may have been adopted for the following reasons:

- Enhanced fatigue performance was regarded cautiously and a reduction in layer thickness could lead to premature failures, particularly with a highly stiff material;

- the improvement in fatigue life was not regarded to be significant enough to warrant a change to a well-established fatigue formula that had been used by the road industry for some time; and
- the need for a trial period to allow industry time to assess and understand the process of mixture design, production and then laying, in order to be successfully adopted in the UK.

Chapter 4 describes an adjustment that could made to the current fatigue life equation that would acknowledge the higher binder content used in EME2 and provide a better prediction of fatigue performance and design life. For the reasons stated above, a conservative approach has been adopted to ensure that an increase in fatigue performance for EME2 mixtures is controlled. As such, it seems appropriate to adopt the lowest fatigue ratio found from the reviewed studies, i.e. the increase will not exceed 1.8 times the fatigue life of the DBM50.

4

MODIFIED FATIGUE LIFE CALCULATION

4. MODIFIED FATIGUE LIFE CALCULATION

4.1. K_{FLEX} FACTOR

Based on the findings presented in Table 3-7, mathematical modelling work was undertaken to determine whether the existing fatigue equation could be adjusted to accommodate pavement designs utilising EME2 materials. As stated in the last chapter, the K_{Flex} factor was introduced as part of the calculation to determine the fatigue life of a pavement and was adopted by the DMRB standard, CD 226 Design of new pavement construction. The justification for using K_{Flex} is stated in TRL 615 (Nunn, 2004) as "The use of this criterion [K_{Flex}] will ensure that pavements with stiff asphalt bases do not flex as much as pavements with a less stiff asphalt base".

The K_{Flex} factor is solely a function of the dynamic stiffness modulus value, i.e. as the stiffness value increases the fatigue life decreases. As EME2 mixtures have a significantly higher dynamic stiffness modulus, the introduction of the K_{Flex} has had a negative effect on predicted fatigue life. The design value for the dynamic stiffness modulus for EME2 is 8000MPa, compared to 4700MPa for DBM50. Once the K_{Flex} factor is applied, the fatigue life for EME2 is reduced by 32%, when compared with standard DBM50. This is contrary to the fact that the fatigue performance of the EME2 will be better owing to its high bitumen content, finer grading, low air voids content and low penetration value.

In order to balance the original K_{Flex} criterion and the benefits of an EME2 material, a modification to the K_{Flex} formula is suggested. The modification concentrates on the significant positive effect of the high bitumen content, and to a lesser extent on the advantage of the finer grading when compared to DBM50. Mathematical modelling was carried out to adjust the present K_{Flex} formula by adding two additional parameters. One parameter is for the binder content and the second parameter is for the maximum aggregate size (either 20mm, 14mm or 10mm for EME2).

In proposing this change to the K_{Flex} equation it is assumed that:

- Smaller maximum aggregate sizes are associated with higher binder contents;
- the EME2 mixture is properly designed to determine the optimum binder content, i.e. an increase in binder content beyond the optimum may have an adverse effect;
- binder content increases will improve fatigue properties but will not necessarily increase the stiffness modulus; and
- as the nominal maximum aggregate size decreases, fatigue properties will improve due to the cohesiveness of the mix and reduced potential for segregation.

In order to limit any increase in fatigue life in line within the summary shown in Table 3-7, i.e. 1.8 times the fatigue life of the DBM50, it was decided to adopt an increase in fatigue life by up to 60% for increased EME2 binder content; 10% for maximum aggregate size; and the combination of the two parameters, binder content & maximum aggregate size to a level not greater than 80%.

The new proposed K_{Flex} formula, K_{Flexm} is as follows:

$$K_{flexm} = (2270/A)^{0.02}\, E^{-0.653/BC} \qquad (7)$$

Where, E is dynamic stiffness modulus, A is maximum aggregate size and BC is the binder content.

Table 4-1 shows that when the new formula (K_{Flexm}) is applied to a typical DBM50 material it will produce a similar value to the original TRL 615 formula. However, the new equation will have a positive effect if the pavement design incorporates an EME2 material.

Table 4-1 - DBM50 fatigue life before and after the K_{flexm} modification

Stiffness Modulus (GPa)	Binder content (%)	Maximum aggregate size (mm)	K_{flex}	Stain value (microstrain)	Fatigue life (msa)
DBM50 with K_{Flex} before modification using Equation 1 & 2					
4.7	N/A	N/A	0.835	55	103.40
4.7	N/A	N/A	0.835	65	51.61
4.7	N/A	N/A	0.835	75	28.46
4.7	N/A	N/A	0.835	100	8.60
DBM50 with the new K_{Flexm} using Equation 1 & 7					
4.7	3.8	32	0.835	55	103.50
4.7	3.8	32	0.835	65	51.65
4.7	3.8	32	0.835	75	28.48
4.7	3.8	32	0.835	100	8.61

Table 4-2 shows predictions of fatigue life for EME2 using the existing TRL 615 formula (Equation 1, incorporating KFlex) and using K_{Flexm} (Equation 7). It can be seen that, dependent on binder content and aggregate size, the use of K_{Flexm} increases the predicted fatigue life of the EME2.

When the values are compared to the predicted fatigue life for a DBM50 shown in Table 4-1 above, the increase ranges between 3.9% and 37.6%, which is significantly less than the minimum increase of 80% reported in literature (Table 3-7). However, if the predicted fatigue life for EME2 using K_{Flexm} is compared with the previous equation incorporating KFlex, then the life increased 52% to 101% for stiffness modulus values of 8000MPa to 6000MPa respectively, which is more significant.

Table 4-3 shows the effect of using the K_{Flexm} factor with a range of bitumen contents. As expected, a very high binder content of 6.5% increases the life more than a low value, such as 5.1%. However, when compared to a DBM50, the increase in fatigue life does not exceed 50% and as such remains a conservative estimate. However, when EME2 life with K_{Flexm} Compared with life with the standard KFlex again the effect is significant (an increase of 66% to 119%).

Table 4-2 - EME2 fatigue life before and after the K_{Flexm} modification

Stiffness Modulus (GPa)	Binder content (%)	Maximum aggregate size (mm)	K_{Flex}	Stain value (microstrain)	Fatigue life (msa)	Fatigue life	
						Compared to DBM50 (%) (cf. Table 4-1)	Increase using K_{Flexm} (%)
EME2 with K_{Flex}							
8	N/A	N/A	0.762	55	70.67	68.3	N/A
8	N/A	N/A	0.762	65	35.27	68.3	N/A
8	N/A	N/A	0.762	75	19.45	68.3	N/A
8	N/A	N/A	0.762	100	5.88	68.3	N/A
EME2 with the new K_{Flexm}							
8	5.1	20	0.842	55	107.48	103.9	152.1
8	5.1	20	0.842	65	53.64	103.9	152.1
8	5.1	20	0.842	75	29.58	103.9	152.1
8	5.1	20	0.842	100	8.94	103.9	152.1
7	5.3	14	0.871	55	123.62	119.6	174.9
7	5.3	14	0.871	65	61.70	119.6	174.9
7	5.3	14	0.871	75	34.02	119.6	174.9
7	5.3	14	0.871	100	10.28	119.6	174.9
6	5.5	10	0.901	55	142.26	137.6	201.3
6	5.5	10	0.901	65	71.00	137.6	201.3
6	5.5	10	0.901	75	39.15	137.6	201.3
6	5.5	10	0.901	100	11.83	137.6	201.3

Table 4-3 - EME2 fatigue life with K_{Flexm} for a range of binder contents

Stiffness Modulus (GPa)	Binder content (%)	Maximum aggregate size (mm)	K_{flex}	Stain value (microstrain)	Fatigue life (msa)	Fatigue life	
						compared to DBM50 (%) (cf. Table 4-1)	Increase using K_{Flexm} (%)
6.75	5.1	20	0.861	55	117.66	113.8	166.5
6.75	6.5	20	0.907	55	146.48	141.7	207.3
6.75	5.1	14	0.867	55	121.21	117.2	171.5
6.75	6.5	14	0.914	55	150.89	145.9	213.5
6.75	5.1	10	0.873	55	124.65	120.5	176.4
6.75	6.5	10	0.920	55	155.18	150.1	219.6

4.2. DESIGN CHART FOR EME2

Based on the preceding chapter, there is potential to use the K_{Flexm} factor to better quantify the fatigue characteristics of EME2 for design purposes. In Scotland, some EME2 material has not met the target Indirect Tensile Stiffness Modulus (ITSM) value of 5500 MPa, which is required to ensure the long-term design stiffness value of 8000 MPa is achieved. However, as discussed in this report, the current design process does not make an allowance for a material such as EME2, which differs significantly from the standard reference DBM material used in current design. It is therefore possible that the K_{Flexm} factor can be used to take account of the increased fatigue life of EME2 and reduce the current construction requirement of dynamic stiffness modulus value.

Analytical designs were carried out to model the existing DMRB chart for EME2 material. The analytical work was based on using the standard design value of stiffness modulus of 8000 MPa for EME2, and the TRL 615 fatigue profile, including the K_{Flex} factor. In addition, an EME2 with a lower stiffness modulus of 6750 MPa and a fatigue profile created using K_{Flexm} was calculated. The K_{Flexm} factor was applied to a conservative scenario where the material comprised a 20mm maximum aggregate size and binder content of 5.1% on a Class 3 Foundation. The outcome of the analytical process is shown in Table 4-4 and Figure 4-1. It can be seen that the design data produces a slightly higher design life than the values provided by the nomograph in CD 226 but overall it fits reasonably well with the existing methodology. This approach could be used to reduce the current compliance ITSM testing of stiffness modulus from 5500 MPa to 4650 MPa. A suggested revision to the requirements is shown in Table 4-5.

Table 4-4 - EME2 design life before and after fatigue profile modification

Thickness (mm)			Life (msa)		
Total asphalt	**Surface Course**	**EME2 base & binder course**	**DMRB Chart**	**EME2 with stiffness of 8000 MPa using K_{Flex}**	**EME2 with stiffness of 6750 MPa using K_{Flexm}**
200	30	170	10.2	12.46	13.00
210	30	180	15.6	16.82	17.46
220	30	190	22	22.55	23.26
230	30	200	29	29.96	30.75
240	30	210	40	39.54	40.39
250	30	220	52.5	51.78	52.65
260	30	230	68	67.30	68.22
267	30	237	80		
270	30	240		87.00	87.80

Note: the new long-term design stiffness modulus of 6750MPa for EME2 is based on minimum bitumen content of 5.1% & max aggregate size of 20mm,

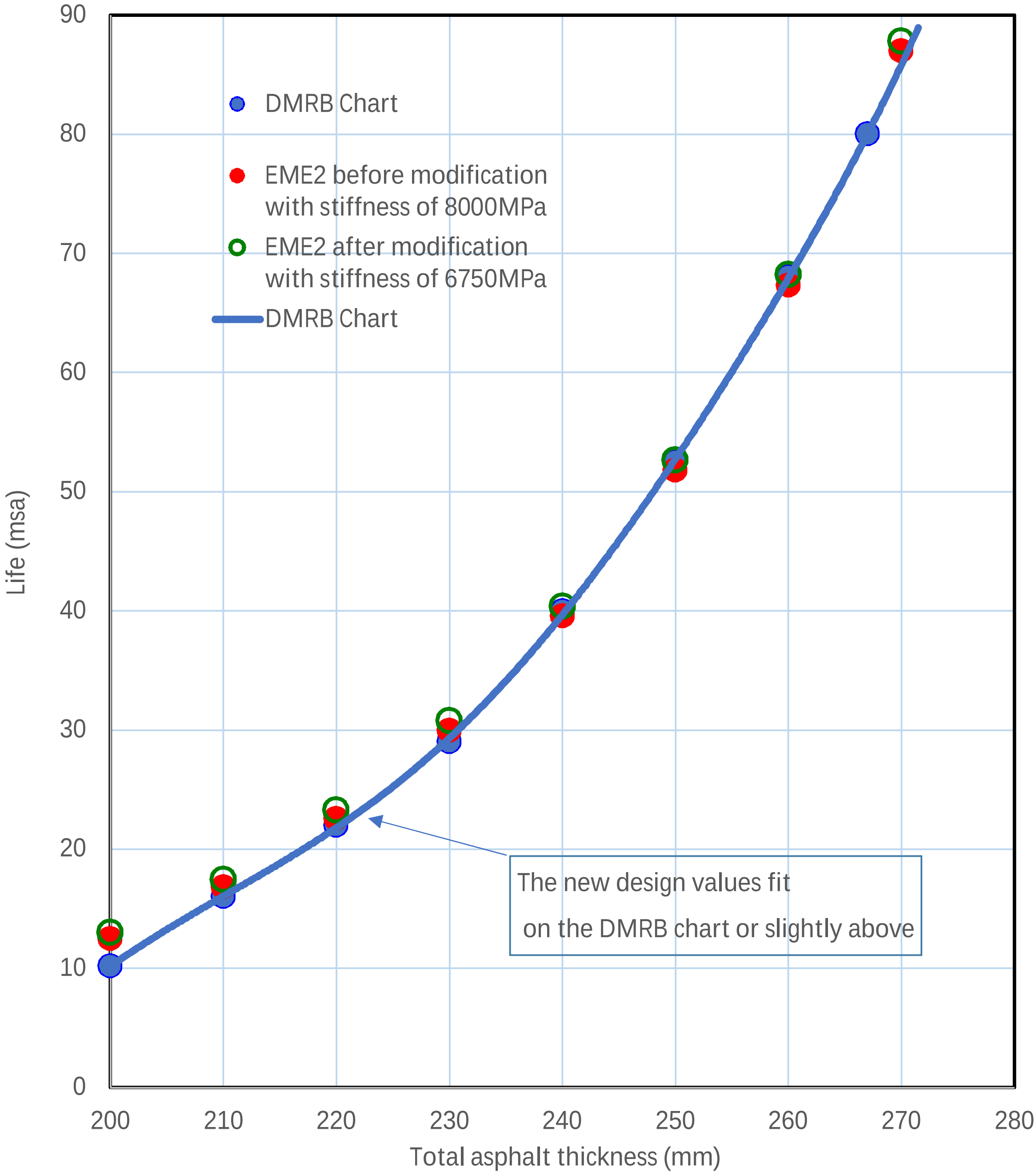


Figure 4-1 - Pavement design with EME2 before and after modification

Table 4-5 - New suggested EME2 design dynamic stiffness modulus

Dynamic stiffness modulus (MPa)	Existing requirement		New requirement	
	Design value	Testing value (ITSM)	Design value	Testing value (ITSM)
Minimum value (MPa)	8000	5500	6750	4650
Average value (MPa)	8000	6000	6750	5100

It is important to highlight that if the K_{Flexm} factor were to be adopted to recalculate fatigue life, it should not be used to reduce the design thickness stated in DMRB CD226 without further validation of the theory. It is recommended that the adjustment could be used as a discretionary option to allow Transport Scotland to accept newly built pavements containing EME2 that achieve reduced stiffness moduli when compared against the current requirement.

5

ALTERNATIVE APPROACHES TO FATIGUE

5. ALTERNATIVE APPROACHES TO FATIGUE

5.1. FATIGUE LIFE CONCEPT

It is universally recognised that when repeatedly loaded, most materials will begin to deteriorate even if the loads are significantly smaller than the ultimate strength of the material. If an asphalt pavement is properly designed and well-constructed, there is a theory that if the strains generated by traffic loading are low enough then failure by the classic fatigue mechanism will not occur. However, the converse is true in that poorly designed pavements, e.g. too thin or poorly constructed, will experience strains that are sufficiently high to cause fatigue failure.

5.1.1. Endurance limit

The endurance limit can be defined as the tensile strain below which a material can endure an infinite number of repeated load cycles without exhibiting failure. In particular, strain levels change with the asphalt layer thickness, i.e. thicker pavements give lower strain values, and other mechanical properties.

A number of research projects have investigated the performance of in-service pavements to provide evidence for an endurance limit. A comprehensive field investigation on the performance of thick asphalt pavements was undertaken in the UK in the 90s (Nunn *et al*, 1997). The study led to the concept of long-life pavements, which was based on the finding that roads do not need to be constructed thicker than that required by the current standard for 80 msa to achieve a very long structural life. Although the term endurance limit is not used, the threshold of 80 msa is indirectly defining an endurance limit. The design life of 80 msa corresponds to a strain level of 70 microstrain using the standard TRRL 1132 fatigue equation for DBM. It is noteworthy that with the introduction of K_{Flex} factor, the endurance limit is further reduced to around 53 microstrain for pavements utilising an EME2 as the base layer.

Researchers in the USA (Carpenter, 2006; Carpenter *et al,* 2003) believe an endurance limit exists. Their findings were based on a comprehensive study which included a large number of asphalt mixes that confirmed the endurance limit to be around the 70 microstrain level. The research showed that for all the mixtures tested there was a limit below which the fatigue curve flattened. This testing did not establish a specific strain level, but the range appears to be in the region of 70 to 100 microstrain. This finding was not totally new in the USA, and corroborated work (Monismith *et al*, 1972) that showed that there appeared to be a strain below which there was no fatigue damage and proposed 70 microstrain as the likely endurance limit.

Figure 5-1 shows the results of fatigue testing on 21 asphalt mixtures (Carpenter, 2006), which confirmed earlier work (Carpenter *et al*, 2003) based on 12 mixtures. The highest strain values were related to the polymer-modified mixtures which provides support to the impact of the binder type on the endurance limit. In the UK, polymer modified binder is not typically used in the production of asphalt base, so the 70 microstrain is still the most relevant. The study found that the influence of ‘Rich Bottom Base’ mixtures (binder rich mixes) on fatigue resistance was positive but regarded by the researcher to be marginal. The work also showed that an increase in the stiffness modulus would reduce the fatigue endurance limit but not below the threshold of 70 microstrain.

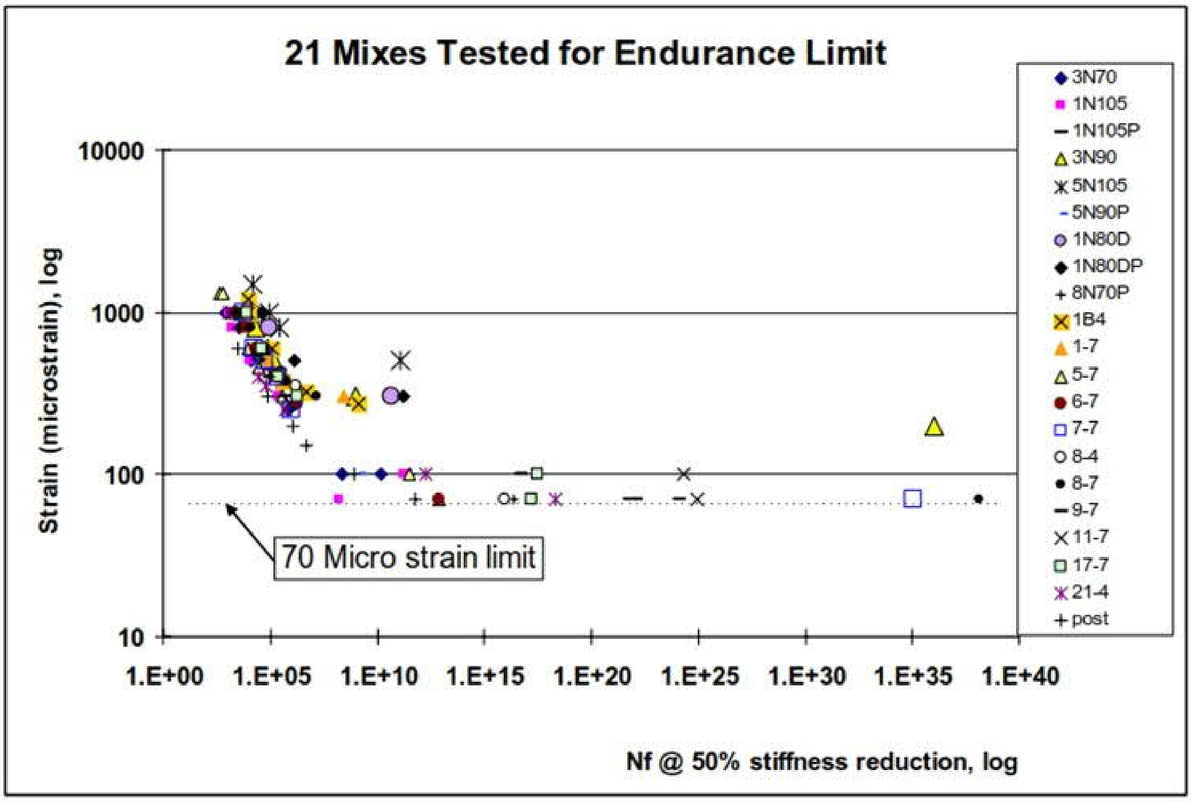


Figure 5-1 - Fatigue endurance tests (Carpenter, 2006)

From the literature review it appears that there are various methods of allowing for an asphalt fatigue endurance limit in pavement design methods. These typically include limiting the strain values by ensuring an adequate pavement thickness. Comprehensive studies in America (Witczak 2013) and Australia (Jameson, 2016) investigated how laboratory beam fatigue damage varies with test temperature, binder types, mix volumetric and rest period between loading pulses. From the relationships derived from the testing, the findings were that endurance limit strain increased with:

- increasing temperature;
- increasing rest period between load application during fatigue test up to about 5 seconds;
- increasing binder content;
- decreasing mix and binder stiffness; and
- decreasing air voids.

Figure 5-2 shows the influence of all of the above parameters for asphalt mixes made with Superpave performance grading PG 64-22 bitumen. The mixture is intended for use where the average seven-day maximum pavement temperature is 64°C and the expected minimum pavement temperature is -22°C.

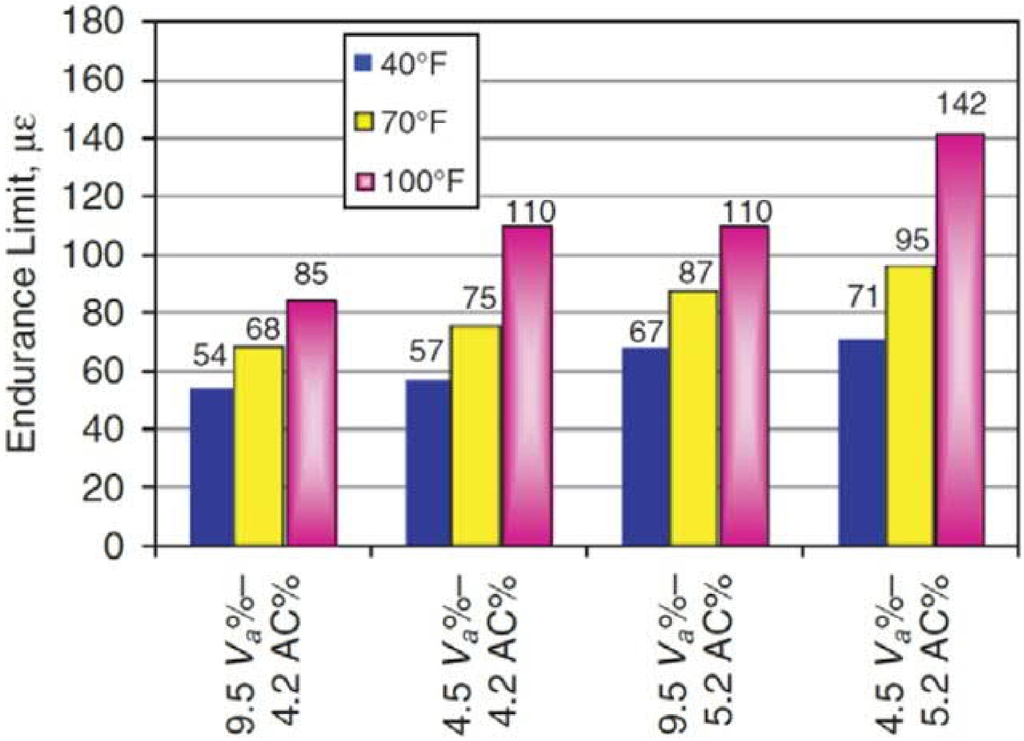


Figure 5-2 - Beam endurance limit strains for 5 seconds rest period (Witczak *et al*, 2013)

5.1.2 Future Work

The endurance limit concept potentially provides an alternative methodology to accurately model the performance of EME2 in Scotland. Further work would be required to investigate its relevance in flexible pavement designs.

It would also be beneficial to further monitor and analyse the as-built and in-situ stiffness and fatigue life performance of EME2 from sites across the network.

6

CONCLUSIONS & RECOMMENDATIONS

6. CONCLUSIONS & RECOMMENDATIONS

Fatigue loading is generally recognised as the weakening of a material caused by repeated loading or flexing. For asphalt pavements, excessive flexure can result in the gradual deterioration of material leading to structural damage and the growth of cracks. In pavement design methods, fatigue is an important property as it relates to the calculation of design life. A review of UK and international work on the fatigue properties of asphalt materials produced the following conclusions:

- Materials rich in binder like EME2 are more resistant to fatigue damage than conventional materials such as DBM50.
- EME2 typically contains around 1.3% more binder than DBM50 which is considered to be an important parameter in improving fatigue properties.
- UK and international literature suggests that the extra binder contained in the EME2 will increase its fatigue life by at least 1.8 times compared to a conventional mixture like DBM50.
- The above finding was irrespective of the testing methodology, apparatus, and specimen type used to determine the fatigue life.
- The enhanced fatigue properties of EME2 are not taken into account in the current UK design method, and the introduction of the factor K_{Flex} led to a reduction in fatigue life for stiff mixes such as EME2 when compared with DBM50.
- Significant research programmes in America and Australia appear to confirm the existence of an endurance limit, which is defined as the tensile strain below which a material can endure an infinite number of repeated load cycles without exhibiting fatigue failure.
- The endurance limit is regarded to be around the 70 microstrain level and there are various methods to ensure this value is not exceeded through increasing pavement thickness or altering mix properties.
- The endurance limit concept would require a more detailed investigation to determine its relevance and whether further benefits could be gained from this approach.

Mathematical modelling work was undertaken to determine whether the existing UK fatigue equation could be adjusted to accommodate pavement designs utilising EME2 materials. The existing K_{Flex} factor was modified to better quantify the fatigue characteristics of EME2 for design purposes. The proposed new factor (K_{Flexm}) takes into account the influence of the binder content and the maximum aggregate size used in EME2.

It is recommended that the use of the K_{Flexm} factor be considered for use in Scotland, where asphalt producers find it difficult to meet the current compliance test requirements for stiffness modulus. The K_{Flexm} factor can be used to more accurately model the fatigue life of EME2 and reduce the current construction stiffness requirement. This provides a discretionary option that allows Transport Scotland to accept newly built pavements containing EME2 with reduced stiffness moduli.

K_{Flexm} factor could be used to more accurately model the required thickness of EME2 pavements that meet the current stiffness criteria, further research is required in this area.

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