HIGH MODULUS PAVEMENT DESIGN USING ACCELERATED LOADING TESTING (ALT).

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ABSTRACT

In anticipation of the introduction of high modulus materials in the Swiss standards, a research project has been carried out for the evaluation of these bituminous mixtures. Three full-size test sections were built in a test hall for ALT named Halle-fosse: Two sections with two different high modulus bituminous mixtures (named EME, abbreviation of the French designation of the mixture: Enrobé à Module Elevé) as base layer, whereas the third section, used as reference, had a standard bituminous material base layer. The three structures were designed to have an equivalent fatigue resistance and were submitted to loading with a traffic simulator. This device, a truck axle, permits to simulate heavy traffic on roads. Strains were measured for different types of loading at different temperatures, in order to assess the response of the structure. Equivalency factors for both types of EME mixtures were established using, as a basis, the French design method.

1. INTRODUCTION

The Swiss standard design method for flexible pavements is based on the AASHTO-test results and uses the Structural Number and the equivalency factors for the various materials of the structure (SN_ 640324). Most of the bituminous materials have the same factor and the differences are mainly related to the position of the layer within the structure rather than to the mechanical properties of the mixtures (one for wearing course and one for the others layers of the flexible pavement). As a consequence, it is impossible to take into account the high performances of some mixes in the design method.

The program includes two stages: a laboratory study on the mix design with an assessment of the mechanical performances of the mixtures and then a full scale test, in order to evaluate their response and the behaviour of the test sections under different loading and temperature conditions. The project includes an assessment of the fatigue and of the rutting resistance (Perret, Dumont et al. 2001). This paper is focusing on some results from the first part of the experience, about fatigue, whereas the second part, about rutting, is presented in another paper in this conference (Perret et Dumont 2004).

Three test sections were built in a pit for the full scale test. They were designed to have an equivalent resistance to fatigue. Two sections have high modulus materials as base layer, whereas the third one, used as reference, has a standard Swiss bituminous mixture called HMT 22s. The two high modulus materials correspond to the EME1 and EME2 designation in the French standards. They have a high resistance to rutting and a high resistance to fatigue respectively.

The validation of the elastic-linear model used for the structure design is based on strain measurements in the bituminous layers. Thus, the lifetime of the different structures is assessed considering the thickness and the type of the material used as a base layer. This method makes it possible to calculate equivalency factors between various mixtures for different life stages using the Swiss standard bituminous mixture HMT as reference (SN_640431). Calculations were made at three temperatures for estimating the influence of this parameter. Also, diverse assumptions on the parameters introduced by the French method were made.

This paper describes the procedure used for assessing the equivalency factors of high modulus bituminous mixtures EME1 and EME2 designed according to the French design method (SETRA-LCPC 1994). It is focussing on the influence of the assumptions made for the material performances on the equivalency factors.

2. DESCRIPTION OF THE FULL SCALE TEST SECTIONS

2.1 Structures

Three full-scale test sections were built in the Halle-fosse at the Federal Institute of Technology at Lausanne, Switzerland. The structures are constituted with a flexible pavement of two bituminous layers (wearing course and base course), a subbase of unbound granular material and a subgrade of fine sand. The bottom of the pit is a concrete slab.

In the three structures, the kind of mixture and the thickness of the base course only vary. The thicknesses of the base layer are:

- 11 cm for the section with EME1,
- 14 cm for the section with HMT 22s,
- 7 cm for the section with EME2.

A detailled descrition of these three structures, with the thicknesses and the composition of the base layers, are given in another paper in this conference (Perret et Dumont 2004).

Strain and deflection data under different loading conditions (temperature, load intensity, inflation pressure and type of tires) were collected on the three structures and analysed (Perret 2003).

Strain measurements at the bottom of the base layers allow validating the linear elastic model used to calculate the equivalency factors. In general, calculations underestimate measured values for the sections with high modulus, whereas they overestimate them for the reference section with a HMT 22s base layer. However, variations between measurements and calculations stay small for the structures with EME1 with HMT 22s (approx. 10%). For the structure with EME2, variations are of the same range for temperatures of 5 and 15°C (about 15%), but they increase up to 25% at 30°C.

2.2 Mechanical performances of the bituminous mixtures used for the base layers

Binder of high modulus materials are low penetration grade bitumen. Depending on the content of the mastic (bitumen and fines), those mixtures show a high performance towards rutting (EME1) or towards fatigue (EME2). The composition of the 3 bituminous mixtures used as base course is given in table 1. The main properties of the binders are given in table 2.

Mechanical properties of the bituminous mixtures were assessed on specimens cored in the sections. Requirements in the French standards concern:

- richness modulus
- Duriez test
- complex modulus at 15°C and 10 Hz
- fatigue resistance at 10°C and 25 Hz.

In addition, LCPC rutting tests were carried out on the three mixes.

Test results are summarised in table 3 and compared with the requirements of the French standard.

		HMT 22s	EME1	EME2
Richness modulus	**Test**	2,5	2,7	3,5
	Standard	-	>2,5	>3,4
Complex modulus at 15°C, 10 Hz, (MPa)	**Test**	7'500	15'200	15'500
	Standard	-	14'000	14'000
Fatigue resistance ε_6 at 10°C, 25 Hz, (µ strains)	**Test**	94	133	143
	Standard	-	100	130
Fatigue regression line slope at 10°C. 25 Hz (-)	**Test**	-0,18	-0,16	-0,17
	Standard	-	-0,20	-0,20
Rut at 30'000 cycles, 60°C, (%)	**Test**	5,7	2,3	7,1
	Standard	-	< 8	< 8

Table 1: Test results on mixes used as base layers

Modulus and fatigue tests were carried out on trapezoidal specimen with the LCPC two-point bending test device. Fatigue is defined with two parameters of the fatigue curve in a log-log representation: the value of ε_6, corresponding to the strain to apply in order to have a failure after 10_6 cycles, as well as the slope of the regression line. For this last value there is no particular requirement, but the French standard provides a default value to use for design.

The high modulus materials placed in the test sections comply with all the requirements provided in the French standard (Duriez tests were not carried out). As expected, EME1 shows a better rutting resistance whereas the EME2 provides a better resistance to fatigue.

3. PAVEMENT DESIGN WITH THE FRENCH METHOD

The two criteria used in the French design method are:

- limitation of the horizontal strain at the bottom of the bituminous layers
- limitation of the vertical strain at the top of the subgrade.

Both limitations are related to the number of cycles (passes of a load) during the considered lifetime of the pavement structure. In all cases that have been assessed, the critical design criterion was the limitation of the horizontal strain at the bottom of the bituminous materials.

The relation between the admissible horizontal strain at the bottom of the bituminous layer $\varepsilon_{t,ad}$ and the number of cycles NE is the following:

$$\varepsilon_{t,ad} = \varepsilon(NE,\theta) \cdot k_r \cdot k_c \cdot k_s \tag{1}$$

with:

$$\varepsilon(NE,\theta) = \varepsilon_6(10°C{,}25HZ) \cdot \left(\frac{E(10°C)}{E(\theta)}\right)^{0.5} \cdot \left(\frac{NE}{10^6}\right)^b \tag{2}$$

and:

k_r: risk coefficient adjusting the strain value to the risk chosen according to factors of a confidence interval around the thickness of the layers and around the result of the fatigue tests

k_c: coefficient adjusting the computation model to the behaviour observed on real pavement

k_s: reduction coefficient taking into account a lack of uniformity in the bearing capacity on a soft subgrade

Equation (2) allows taking into account a variation of the fatigue resistance ε_6 considering temperature θ with the respective values of the E modulus. The influence of the frequency is neglected.

Coefficients k_r are calculated with the slope and the standard deviation of the results from the fatigue test at failure. Coefficients are different for each material.

The coefficient k_s doesn't depend on the type of bituminous mixture and is the same for the three materials.

The value of the coefficient k_c for high modulus materials (EME1 or EME2) is 1,0. It is significantly different from the value of 1,3 applied to traditional mixes (GB1, GB2 or GB3 in the French standards), which are assumed to be similar to the Swiss standard mixture HMT 22s.

By calculating horizontal strains for a reference load, it is possible to calculate the number of cycles leading to failure using relation (3).

$$NE = \left[\frac{\varepsilon_6(10°C,25Hz) \cdot k_r \cdot k_c \cdot k_s}{\varepsilon_{t,adm}} \cdot \left(\frac{E(10°C)}{E(\theta)} \right)^{0.5} \right]^{-\frac{1}{b}} \tag{3}$$

For a defined load, temperature and material, the number of cycles depends only on the strain value at the bottom of the bituminous layer, which is function of the thickness of the layers. It is then possible to calculate the number of loads in relation to the thickness of the base layer of the three different test sections assessed in the Halle-fosse.

However, one should point out that the number of cycles is very sensitive to the coefficients values because they are elevated at a power of about 5 (-1/b). This means that the lifetime of pavement structures strongly depends on the value of the three coefficients k_r, k_c and k_s. For a better understanding , the effect of the coefficient k_c on the equivalency factors is presented in this paper.

4. EQUIVALENCY FACTORS

4.1 Approach

The approach to determine equivalency factors has four stages:

1. calculation of admissible strain at the bottom of the bituminous layer for various thicknesses of the base layer and for each material; calculations are made with the multilayer software Noah (Eckmann 1997) and by considering linear elastic behaviour for all materials
2. calculation of the maximum number of loads that can be applied on the structure in relation to the admissible strain and to the various thicknesses of the base layer considered for each materials
3. evaluation of the relation between the maximum number of cycles that can be applied and the thickness of the base layer (by regression)
4. for different loadings (corresponding to the traffic classes of the Swiss standards), determination of the ratio between the required thickness of the base layer with EME and the required one of the base layer with conventional materials.

The ratios determined in stage 4 are equivalent factors for high modulus materials.

As the temperature strongly modifies the strain amplitude in flexible pavements (in particular in the bituminous layers), calculations were made for three temperatures (5, 15 and 30°C) corresponding to the temperatures applied on the test sections during the full-scale tests.

Moreover, ratios were calculated with two sets of data for the bituminous mixtures:

1. mechanical properties provided in the French standards
2. mechanical properties provided by the laboratory test.

Finally, the influence of the coefficient k_c is assessed by considering the same value for all materials instead of using various values, as considered in the standards.

4.2 Material elastics properties

Elastic properties of subbase and subgrade materials are the same for all calculations. According to the French standard, the subbase is divided into two layers of 20 cm, the upper one having a stiffer modulus. Subbase and subgrade modules were obtained with plate tests. They are in accordance with the recommendations of the French design method.

The bituminous materials modulus depend on the temperature. As explained previously, we used data from laboratory tests results and from the French standards.

The modulus values taken into consideration for the different layers are summarised in table 4. Modulus value of MR 11 and HMT 22s correspond respectively to BBM and to GB 2 or 3 standard values considered in the French design method.

		5°C	**15°C**	**30°C**
MR 11	**Test**	14'700	8'800	2'700
	Standard	9’400	5’100	1’300
HMT 22s (GB2 or 3)	**Test**	12’500	7’500	2’450
	Standard	15’000	9’000	2'700
EME1	**Test**	20’100	15’200	6’850
	Standard	20’000	14’000	6’000
EME2	**Test**	21’500	15’500	6’550
	Standard	20’000	14’000	6’000
Subbase	**20 cm up**	360		
	20 cm down	180		
Subgrade		90		
Concrete		20’000		

Table 2: Elastic modulus considered (MPa)

4.3 Structure lifetime considering the thickness of the base layer

Modelled structures correspond to the ones tested in the Halle-fosse, except the thickness of the base layers which is variable: the wearing course is 3 cm thick and the subbase is made with 40 cm of unbound material. Horizontal strains at the bottom of the base layer are calculated considering a variation of the base layer thickness between 7 and 21 cm.

The Lifetime of the structures, expressed by the total number of loads applied up to failure, is assessed using the equation (3). A regression between the number of loading NE and the thickness h of the base layer, using an exponential law equation (4) is then carried out.

$$NE = C_1 \cdot e^{C_2 \cdot h} \tag{4}$$

C1 and C2 are regression constants.

The inverse function of (4) provides the thickness of the base layer in relation to the number of loads.

$$h = \frac{1}{C_2} \cdot \ln\left(\frac{NE}{C_1}\right) \tag{5}$$

Initial calculations, called “standard” are purely theoretical, which means that all properties of the bituminous materials are provided by the French design method. Reference materials from the French guide are GB 2 or 3. Second calculations, called “laboratory tests”, are made using the material properties issued from the laboratory tests.

The equivalent standard axle load (ESAL) considered corresponds to the one taken into account in the French design method, as an axle load of 13 tons applied on dual tires with an inflation pressure of 6,62 bars. Swiss traffic classes consider ESAL of 8 tons (SN_640320). Therefore, we used a power law to express traffic in ESALs of 13 tons load. The considered design lifetime expectancy is 20 years. The thickness of the base layer were calculated for traffic classes T3 to T6 , (see details in table 5).

Classes	Daily ESAL (8 to)	Number of loads (13 to)
T3	300	314’000
T4	1’000	1’130’000
T5	3’000	3’140’000
T6	10’000	11’300’000

Table 3 : Swiss traffic classes, expressed in 13 tons for a period of 20 years

A graphical representation of the results, with a semi-logarithmic scale, is given in figure 2. The thickness corresponding to the Swiss design method (CH HMT) is also plotted on the graphs corresponding to the “standard” initial calculations.

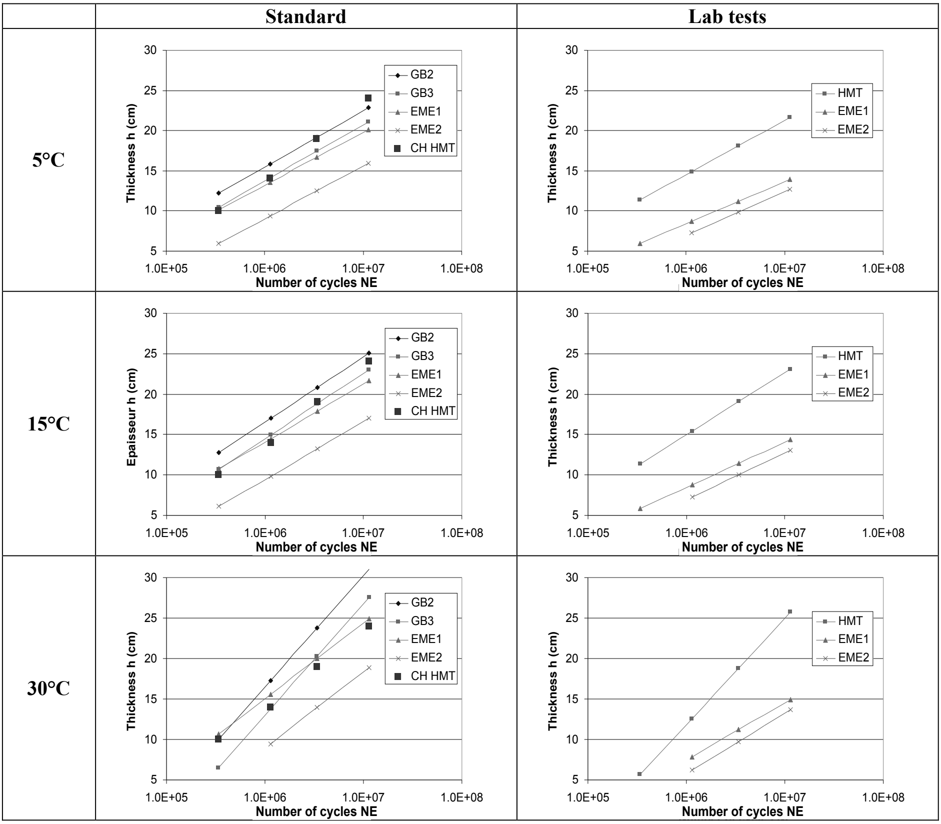

Figure 1: Thickness h of the base layer related to the number of loads NE

The calculations based on the “standard” properties provide the same range of thicknesses for the base layers as the ones based on the Swiss design method, except for the EME2, for which thicknesses are logically smaller.

For a large number of cycles, the required thickness of the base course generally increases with the temperature. With the French design method, an increase of the temperature means a reduction of the modulus, which implies an increase of the strains in the bituminous layers. On the other side, fatigue resistance also increases with the temperature. The present results show that with the raising of temperature, the augmentation of the fatigue resistance doesn't compensate the increase of the strains due to the reduction of the modulus.

Looking at the figures above in the "standards" column, we notice that the results for GB2 and GB3 have parallel curves, just like EME1 and EME2. This means that the slopes of the curves only depend on the modulus of the bituminous materials of the base layer. This observation is clearly confirmed when looking at the regression coefficients C_1 and C_2 calculated for the various situations considered (see table 6).

	5°C		15°C		30°C	
	C_1	C_2	C_1	C_2	C_1	C_2
GB2	6'210	0,328	8'970	0,285	63'700	0,167
GB3	11'200	0,328	16'200	0,285	115'000	0,167
EME1	9'650	0,351	10'900	0,328	25'000	0,246
EME2	42'800	0,351	48'100	0,328	111'000	0,246
HMT 22s (test)	6'830	0,343	11'800	0,297	128'000	0,174
EME1 (test)	24'400	0,441	31'400	0,410	88'200	0,326
EME2 (test)	53'400	0,422	66'700	0,393	169'000	0,308

Table 4: Regression coefficients between thickness h and number of loads NE

Coefficients C_2 are similar when the modules of the base layer are analogous. Looking at equation (5), this coefficient is inversely proportional to the slope of the curves in the semi-logarithmic representation as used in figure 2. The tendency is that a reduction of the modulus leads to a reduction of the values C_2, which means an increase of the slope in figure 2.

4.4 Results for equivalency factors

The slopes of the function h = f(NE) are not similar for all the bituminous materials considered. Therefore, equivalency factors depend on the number of loads considered in the calculations. These factors are determined with equation (6) and for the number of cycles (NE) corresponding to the limits of the traffic classes .

$$EF = \frac{h_{EME}}{h_{HMT}} = \frac{\frac{1}{C_{2EME}} \cdot \ln\left(\frac{NE}{C_{1EME}}\right)}{\frac{1}{C_{2HMT}} \cdot \ln\left(\frac{NE}{C_{1HMT}}\right)} = \frac{C_{2HMT}}{C_{2EME}} \cdot \frac{\ln\left(\frac{NE}{C_{1EME}}\right)}{\ln\left(\frac{NE}{C_{1HMT}}\right)} \qquad (6)$$

The equivalency factors for EME1 and EME2 are calculated with the French design method by considering the results with GB2 and GB3 materials. GB3 (standard properties) and HMT 22s (lab properties) are used as reference materials. Equivalency factors are given in figure 3, considering temperature and traffic class .

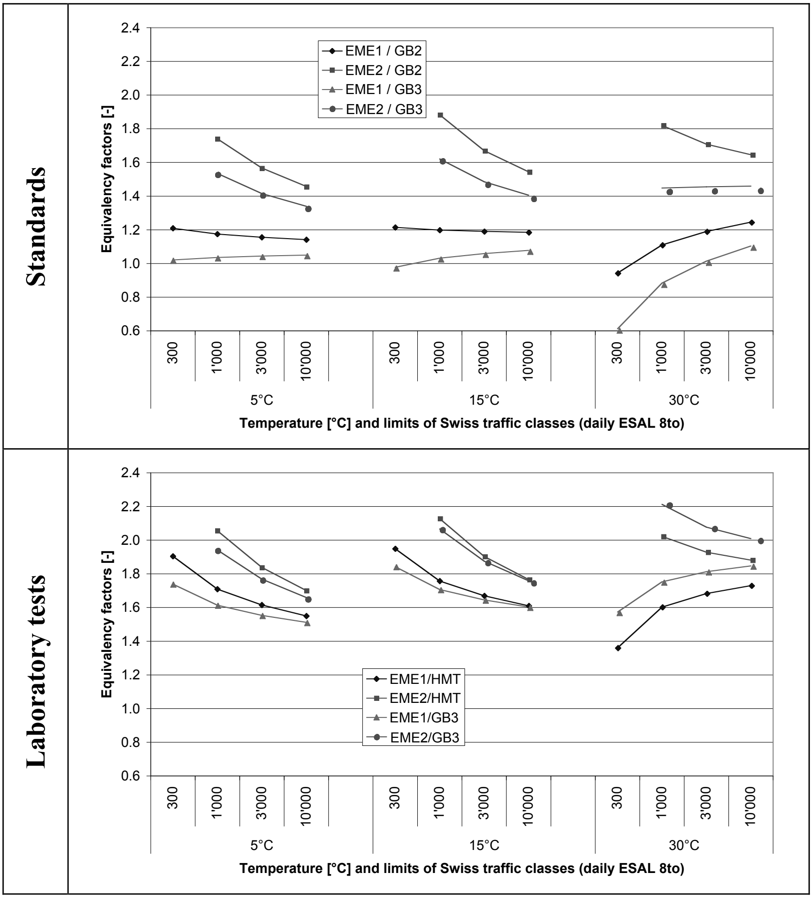

Figure 2 : Equivalency factors considering temperature and traffic class

The equivalency factors for EME1 and EME2 resulting from the calculations are summarised in table 7, It is assumed that high modulus bituminous mixtures are essentially used for high traffic.

	EME1	**EME2**
Standards	1,1 to 1,2	1,4 to 1,6
Laboratory tests	1,6 to 1,8	1,7 to 2,0

Table 5: Equivalency factors for EME1 and EME2

A first observation shows that equivalency factors calculated with “standard” material properties are always smaller than the ones calculated with” lab. tests” properties. This is due to the fact that the material properties (modulus and fatigue resistance ε_6) of EME1 and EME2 provided by laboratory tests are higher than the ones given in the standard design method. In the contrary, the modulus of the HMT 22s is significantly smaller than the “standard” stiffness property of GB2 or GB3. One can conclude that the calculation considering material properties provided in the French design method is safer.

The equivalency factors for the two high modulus bituminous mixtures EME1 and EME2 are clearly different and, based on the fatigue resistance criterion, EME2 has logically higher factors compared to EME1. Differences are larger when the factors are calculated with the “standard” properties. This is mainly explained by the large difference between the two values ε_6 for fatigue resistance considered in the French design method (respectively 100 and 130 microstrains for EME1 and EME2), whereas this difference is not so important for the results from the laboratory tests (respectively 133 and 143 microstrains). Factors are naturally larger when using GB2 as reference.

The results provided by the laboratory tests on the HMT22s and the GB3 show a difference of behaviour versus temperature. If the equivalent factors are more or less similar at 15°C, there is a clear difference between them at the two other temperatures considered. At low temperature (5°C), equivalency factors are greater using HMT22s as reference when the situation is the opposite at high temperature (30°C), where factors with HMT 22s are smaller. This situation shows that a reduction of the GB3 modulus with the temperature is larger than for HMT 22s (see table 4).

The variation of the equivalency factors considering the traffic level is greater at high than at low temperature. This variation is explained by the larger difference of the slope of the functions h = f(NE) presented on the figure 2.

Equivalency factors are generally greater at high than at low temperature, but variations are really small for the highest traffic class. One can assume that equivalent factors are independent from the temperature for a high traffic level , which corresponds to the application field of high modulus materials.

For low traffic classes, equivalency factor values for EME1 are smaller than 1,0 when considering “standard” properties. This is a paradoxical situation, as modulus and fatigue resistance of EME1 are both greater compared to GB2 or GB3. This is due to the values of the coefficient k_c proposed for GB (1,3) and for EME (1,0), which are different one from another. Looking at equation (3), this difference seriously handicaps high modulus materials compared to traditional ones.

5.4 Effects of the coefficient k_c on the equivalency factors

The number of cycles, and indirectly the equivalency factors strongly depend on the value of coefficient k_c that is taken into consideration. Therefore, new calculations (based on standards) neglecting this coefficient were carried out. As an assumption, all base materials have a same value k_c equal to 1,0. A graphical representation of these results is given in figure 4.

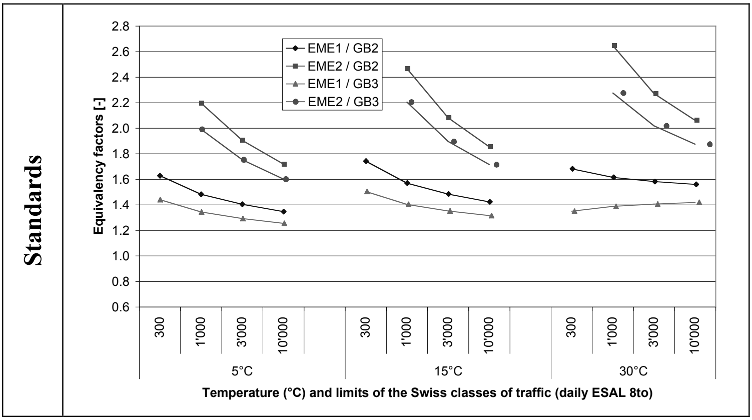

Figure 3: Equivalency factors considering temperature and traffic classes, with the same value for k_c for all bituminous mixtures

The comparison of figure 3 and figure 4 clearly shows how coefficient k_c "penalises" high modulus materials: using the same values for coefficient k_c, equivalency factors vary from 1,3 to 1,5 for EME1 and from 1,6 to 2,1 for EME2.

6. CONCLUSION

This research shows that high modulus materials designed to have a high rutting resistance (EME1) don't allow an important reduction of the thickness of the base layers (equivalency factors lightly greater than 1,0), if the calculations are carried out by using material properties proposed in the French standards. On the other hand, high modulus materials EME2 designed to have high fatigue resistance allow a reduction of about 30% of the thickness of the base layer (equivalency factors of about 1,5), based on the same hypothesis.

Equivalent factors assessed with properties provided by laboratory tests are significantly larger than the ones considering "standard" properties. This means that EME properties provided by the French standards are cautious regarding real properties of those mixes.

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