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THE EVALUATION OF PAVEMENT IN DESERT REGION IN LIBYA

HODNOCENÍ VOZOVEK V POUŠTNÍ OBLASTI LIBYE

SHORT VERSION OF PHD THESIS

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1 SUMMARY

Bituminous mixture pavements are subjected to deterioration and distress under the action of traffic loading and climatic factors. One of the dominant modes of pavement failures is a cracking. The evaluation of the bituminous pavement mixture is very difficult, complicated and laborious work. The complicity of the evaluation of the pavement structure due to the large number of variables involved in the evaluation of pavement mixture composition (bitumen, coarse aggregate, fine aggregate, and filler), keeping in mind their different properties (mechanical, physical and chemical) as well as the heterogeneous loading in addition to the climatic factors.

Bituminous pavement provides the vital part of Libyan over land transportation system. Huge investment has been made over the last 20 years in this field by the transportation authorities. In order to achieve the maximum cost benefit from this large transportation system and huge investments, efficient studies and evaluation before starting maintenance and rehabilitation work should be carried out. Cracks of the bituminous mixture pavement became the common main mode of highways deterioration in Libya, especially, the highways those located in the south region. The predominant mode failure and distress of Libyan highways is cracking, generally longitudinal and transverse cracking. Waddan – Sebha highway is one example of the Libyan roads, which has been severely distressed in the form cracking.

A new wearing course was laid in order to repair Waddan – Sebha Highway, but the cracks appeared very soon after. In this work, due to the large number of variables involved which make it difficult to stimulate all the real factors subjected and influencing the pavement through its service life, therefore, the researcher simplified the loading subjected to the pavement in order to characterise the pavement materials properties and to fined the main reason of pavement failure. The field specimens were cut randomly from the surfacing of Waddan – Sebha Highway, in the vicinity of area of severe cracking. In the road laboratory of the University of Technology Brno, the physical, Mechanical and especially functional properties of asphalt courses were measured. The tests results were evaluated by the Czech pavement design method modified for Libyan climate and conditions. The evaluation finds the main reason of the pavement failure. The laboratory full-scale measurements of asphalt courses were done. Functional tests confirmed good pavement resistance to effect of vehicle loading from the point of permanent deformation and fatigue of asphalt courses. The low temperature test found that the transverse cracks are caused by asphalt degradation. The reason could be the lower quality of the sandstone aggregate characterized with the value of water absorption, Los Angeles, Impact and crushing tests. The stress relaxation did not occur from the temperature of +25 °C. In low temperature tester the tensile strength was reached at

average temperature of -2.3 °C and this temperature occurs several times during the year.

The results were discussed and compared with other similar mixtures results from Czech Republic, Austria and Portugal.

2 STATE OF THE ART

Bituminous pavements are multi-layered system and layers are neither homogeneous nor isotropic or linear. They are constructed of non-homogeneous layers (base course and sub-grade). The loading (static, dynamic, long term, short term, etc) is depended on heterogeneous traffic: traffic volume (low, medium and heavy), the traffic loading (axle loading, axle configurations, tire configurations, tyre pressure, etc), traffic movement, (quick overdrive, uniform, slow, and continuous sequence, accelerating, breaking and stopping). The other elements such as nature of sub-grade (sand, gravel, silt, clay, silty-sand, sandy gravel, etc.), and the climatic factors (temperature, humidity, UV radiation, de-icing, acid rains, etc.) have their influence and effect on bituminous mixture pavement.

Due to the above-mentioned large number of variables involved, therefore, many causes of cracking, which differ from one location to an other are observed, resulting in more than one kind of distress and accordingly, there no exist any standard solution suitable for the phenomenon of the cracking and its mechanism.

Considerable scientific studies, papers and laboratory works on the evaluation of asphalt pavement have been made and published. We introduce hereafter only some of these works, which are similar or have direct relation to our work and summarized below.

Kudrna [30] gives measured functional properties: complex stiffness modulus, fatigue properties, resistance to permanent deformation, and resistance to temperature cracking. The measured stiffness modulus and the fatigue properties were used in models expressed mathematically for prediction of the pavement serviceability at the end of the analysed period (usually 20 years). The mentioned evaluation enables to fulfil the requirement dealing with prediction of pavement failure up to 10 years of service. Kudrna and Urbanec [31] they have measured the stiffness moduli and phase angle within range of temperature that occur in the road at loading conditions corresponding to load speed in accordance with ČSN 73 6160 [12] and prEN 12697-26 [50]. Resistance to mechanical fatigue was measured according to the requirements of prEN 12697-24 [49]. Resistance to permanent deformation was measured in accordance with TP 109 [64]. Also the resistance to contractile flaw has been carried out to stimulate contractions of asphalt layers. Modified and unmodified bitumen were used, it was concluded that modified bitumen are preferred for higher resistance to contractile flaws. Schlosser et al [58, 59] stated that the new methods are applied to control viscoelastic materials. The tests can be static or dynamic; the dynamic test better evaluates the characteristics of the road construction materials. The dynamic test of the complex modulus enables to test the materials with frequency 6-20Hz. This frequency expresses the travelling of a car on a road surface. It was found that as temperature decreases, the complex modulus, and static modulus of deformation are increase, while phase shift decreases. Safwat F. [55] the stiffness modulus and fatigue properties of different types of bituminous pavement layers have been determined in the laboratory. Indirect tensile test (ITT) has been conducted primarily due to its advantages in practice. It has the benefit of using cylindrical specimens, which can be cored from pavement layers. It is concluded that the ITT, which is relatively simple and rapid to conduct, is also sufficiently accurate for routine measurements. Melanie, et al. [35], and Arand [3] reported that as an asphalt pavement cools down, thermal stresses build-up, ultimately leading to cracking when they exceed the available tensile strength of the pavement. The analysis data enables to determine the following parameters: the fracture temperature, the magnitude of the maximum strength reserve (difference between the maximum tensile strength and the thermal stress at any temperature), and the temperature at which this occurs. Collop and Cebon [7] have examined theoretically the possible mechanisms of fatigue cracking in asphalt pavements using linear elastic fracture mechanics (LEFM). Results indicate that longitudinal thermal fatigue cracking is unlikely to be due to stress intensity factors produced by the non-uniform transverse contact pressure, the fatigue cracking (both longitudinal and transverse) at the base of the asphalt layer is found to be mainly dependent on the magnitude of the normal contact pressure and the pavement geometry. Maarten and Jacobs [28] a substantial part of the damage of flexible pavements is caused by cracking of the asphalt concrete (AC) top layer. This damage is caused by crack growth from the bottom of the top layer (structural damage) as well as damage caused by process, which occur at the surface of the road structure (traffic loading, weather condition, aging by UV light, etc). Macro crack growth process was measured with a crack foil. It is concluded that the macro crack doesn't grow continuously. Mirza and Witczak [37] stated that as bitumen ages, binder and mix stiffness increase. This effect tends to increase rutting resistance of the mix and may be considered as benefit of ageing. On the other hand, hardening can be result in the development and/or acceleration of several distress types, such as disintegration and fracture from both fatigue and thermal cracking distress, which may lead to the failure of the pavement structure. Di Benedetto et al [13] on an homogeneous series of specimens, it has been possible to predict a fatigue damage of a stress controlled test from the results of a strain controlled test using the developed fatigue law. Anderson [2], ref. [25] and ref. [45] reported that cracking due to thermal cycling occurred in relatively mild climates such as Florida and Texas and therefore, cracking is not exclusively a cold-climate problem. Transverse and longitudinal cracks caused by the contraction and build-up of stresses in asphalt pavement layer with decreasing temperature. Most of these cracks are uniformly spaced. Cracking may result from temperature cycling or from a single temperature drop, also known as low temperature cracking. Arand [4 & 5] superposed the temperature induced stresses by the traffic induced stresses in order to calculate preciously the point of time of the first damage by cracking of real roads by the use of fatigue laws and Miner's hypothesis. Examples from the practice are given. Future design procedures for asphalt roads should more take into consideration the temperature induced stresses in road body. Vanelstraete, et al, [70] carried out the thermal shrinkage tests at low temperatures (below -5 °C in most cases) where the risk of cracking is the highest. The test can be carried out on a beam pavement maintained at constant length mounted to a rigid frame while changing the surrounding temperature at constant rate. Sybilski and Styki [63] in their work tested stiffness modulus of various bituminous mixtures were in repeated load indirect test (RLIT) at -10, 0, 10 and 20 °C. Variation of value of stiffness modulus and temperature susceptibility depending on mixture type and the gradation, rock type of mineral aggregate and bitumen binder was analysed. Bitumen binder has great influence on mixture stiffness modulus at a given temperature and variation of stiffness modulus with temperature - temperature susceptibility. It is desired that the mixture have high stiffness modulus at elevated service temperature, low temperature susceptibility and low stiffness, modulus at low service temperature. Isacson et al [27], Sybiliski [62], and Remašova [54] said that maximum resistance to transverse cracking is to be associated with aggregates that have high abrasion resistance, low freezing - thaw and low absorption, aggregate chemical structural, aggregate surface properties, properties of bitumen and presence of water contribute to create and keep adhesion bond. Carswell at al [6] presents a summary and main findings on a research carried out on fatigue characterisation of different mixes, with conventional and polymer modified bitumen. The conclusion was: increase the voids content leads to lower the fatigue response of bitumen performance; change of aggregate type or grading has small effect on fatigue response, increase of mix stiffness does not lead to poorer fatigue behaviour within the limits examined, while binder type has great effect on the laboratory fatigue performance. Roche and Marsac [54]; carried out bending fatigue tests of trapezoidal specimens at imposed strain, 25 Hz and ambient temperature on sand bitumen mixture at high strain level. The results obtained confirmed some already known results regarding the modulus variation curve during the fatigue test, namely a direct relationship between the transitional thermal period (temperature increase) and the first part of the modulus variation curve corresponding to a large decrease. Hopman [24] stated that the mechanics of asphalt pavements studies up to now do not fully take into account the visco-elastic properties of the bituminous mixes. Well-known and often used multi-layer programs like Bisar, (Circly and Moebius) take the bituminous mixes as being linear elastic. Other programs like Pace and Kenlayer do account for the visco-elasticity of the materials, but model the moving load as static loads (referring to their position at the surface) with in road and decreasing amplitude. VEROAD is an acronym for Visco-Elastic Road Analysis Delft and is an analytical linear visco-elastic multi-layer program, which takes fully account of both the visco-elasticity of the material and of actual movement of the load. Thus the mechanics of the pavements are best calculated. In the paper the application of VEROAD for some actual problems is discussed. Emphasis is laid on the extra insight in the pavement constructions that is gained above using linear visco-elastic multi-layer programs: time dependence of displacement stress and strain, permanent deformation and dissipated energy.

3 PROBLEM DESCRIPTION AND SCOPE OF WORK

This chapter is divided into two main parts; the first is a description to the problem, while the second part is defining the scope of the work, which carried out during this evaluation.

3.1 Description of the problem

In 1983, 364 km of the road in the north-south direction of the central part of Libya, between the towns of Wadan and Sebha, were put into operation. The Holland Inter-Beton Company built the road and the Road Institute from Belgrade worked as the consulting company. The road is of the type with 11.5/110 km/h with two traffic lanes of the width of 7.5 m, and 2 x 1.5 m of paved shoulders. The pavement consists of wearing course of asphalt concrete with the thickness of 50 mm, binder course of asphalt concrete with thickness 60 mm and granular base course 0/32 with thickness 20 mm sand, silty sand and gravel are in the sub-grade. The geographical condition of the road is predominately flat with some hills and mountains ranges. The hot-arid climatic region lies mostly between 15° and 45° both north and south (see Figure 3.1) [9, 14, 20].

After ten years of exploitation, wide working cracks with bumps developed on the edges of the cracks has been appeared [44, 68]. Waddan – Sebha highway has been studied and evaluated, partial repair work has been carried out. The conclusion of this evaluation summarised by ETEP [9], as follows: the pavement damages cannot be correlated to any improper material characteristics and/or construction techniques, but should be traced to subsoil conditions. This type of pavement failure is seen in many highways in Libyan Desert, e.g. (Waddan – Sebha highway Ajdabiya-Jalo, and Ajdabiya –Kufra highway).

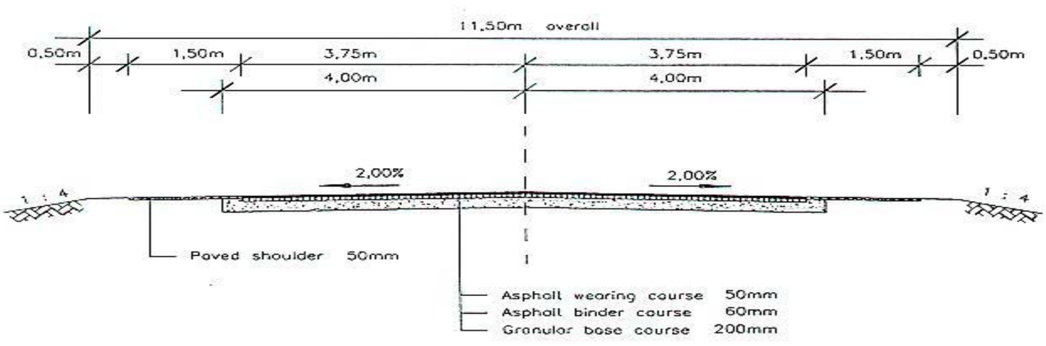


Figure 3.1 Waddan – Sebha Highway pavement cross-section

The study and evaluation that, has been carried out by ETEP [9] on Waddan-Sebha highway did not answer the question and find the main reason of the pavement failure, because their evaluation based only on the determination of the bituminous mixture composition, which is insufficient to evaluate the mixture properties. The ruptured sections of the road were partially repaired by the replacement of new wearing course, but the cracks appeared again very soon. The photo in in Figure 2.2 hereafter documents the condition of the ruptured road.

Figure 3.2 Longitudinal and transverse cracking appears again after repair work

Bituminous pavement materials are susceptible to cracking due to many causes (fatigue, shrinkage, sub-grade movements, environmental and ageing effects, poor construction quality, etc.). As a result of these causes and according to the nature, condition of stresses and loading subjected to the pavement during its lifetime. Thermally induced cracking of asphalt pavement layers may be a problem in cold regions as well as in areas with great variation in daily temperatures. During mid day the pavement surface can be heated by the solar radiation up to 70 °C, and during night it can be cooled down to about freezing in some extreme cases.

We expect that; the high solar radiation (UV-Ultra Violet) together with very low humidity (desert region) is causing faster than in the other region oxidation of the bitumen. Oxidised bitumen is much stiffer, and therefore, the bituminous mix becomes less viscous and plastic (more brittle). The above mentioned ageing process results in increasing the stiffness of the mix, which in turn leads to slow the relaxation of the stresses, and accordingly the bituminous mix starts to behave as rigid layer, and the observed cracks closely representing the thermal cracking pattern of concrete pavements.

As the temperature drop even by a single shock, the stiffness of the mix reaches a higher value, the strain in turn became intolerant, and the cracks start to be initiated. As the low temperature cycles repeated, the thermal stress reaches or may exceed the tensile strength of the asphalt mixtures, and accordingly the cracks started to propagate down wards to the full depth of the pavement.

The above-mentioned reasons have led the researcher to study and evaluate this phenomenon and try to find the main reason or reasons of this pavement failure especially from functional properties point of view.

3.2 Aims and Scope of the work

The scope of the work includes evaluation the following:

1. Environmental influence and loading
2. Control testing of bituminous mixture composition and densities analysis.
3. Stiffness modulus measurement.
4. Permanent deformation (rutting) evaluation.
5. Fatigue characteristics evaluation.
6. Low temperature-cracking testing evaluation.
7. Evaluation of pavement by Application of Linear Elastic Module (LAYEPS - Programme).
8. Discussion and comparison with other similar mixtures testing results from Czech Republic, Austria and Portugal.

In this work real field pavement samples were tested and evaluated according to American and Czech testing methodologies, the testing and evaluation was carried out as described in chapter 4.

4 USED ELABORATION METHODS

4.1 Environmental characteristics

The main features of hot-arid areas are a long hot summer (over 100 days a year), a high ambient temperature (the absolute temperature being in excess of 40 °C and the average daily temperature in hottest month being over 20 °C), a low average relative humidity (less than 50 %), occasional rains, dry wind and dust storms [60]. The average air temperature of 8 0C to 10 °C in January and 28 °C through 30 °C in July characterize the hot arid climate region. The extreme temperatures exceed 50 °C in summer and the minimum extreme temperature reach –6.8 °C. The average yearly rainfalls are from 0 to 50 mm in the north and 0 to 10 mm in the south. The air humidity is 30 % to 50 %.

4.2 Traffic loading

The road is one of the main roads connecting the north of Libya with the south is loaded by the medium up to heavy traffic. The designed traffic load was specified as 2.5 millions repetitions (EAL) of the designed axle of the mass of 82 kN.

4.3 Testing Programme

The aim of this section is to present the testing and evaluation programme which were performed in the laboratory of the roads department, Faculty of civil engineering University of Technology Brno. As it has been stated earlier real field samples of asphalt pavement mixture from hot arid climatic region (Waddan-Sebha highway) was tested and evaluated. The evaluation carried out according to the testing evaluation chart, Figure 4.1.

4.4 Coring of the Samples

The undisturbed field samples were cut randomly in the vicinity of area of severe cracking, from the road surfacing (wearing coarse) by using diamond disk asphalt cutter. The samples were taken from a distance about 147 km from Sebha at location: (490+000). The test specimens were prepared having dimensions of 250 x 50 x 50 mm, carefully packed and transported to the laboratory.

4.5 Inspections and Control Testing

The Specimens were tested for inspection and control of mixture composition and gradation of the used aggregate. The following tests were carried out: densities tests (bulk specific gravity, max theoretical density), extraction test for mixture gradation and determination of bitumen content in the mixture, the aggregate results from the extraction test is going to be tested for sieve analysis. The bitumen was recovered from the bitumen solution results from the extraction test by rotary evaporated method. The recovered bitumen was tested for the mechanical properties. The following tests were carried out: penetration test, softening point test (R&B), and ductility test. From the density values the voids in mineral aggregate (VMA), air voids in mix (Va), volume of bitumen in mix (VB), and volume of aggregate in mix (VA) were estimated (see section 5.1).

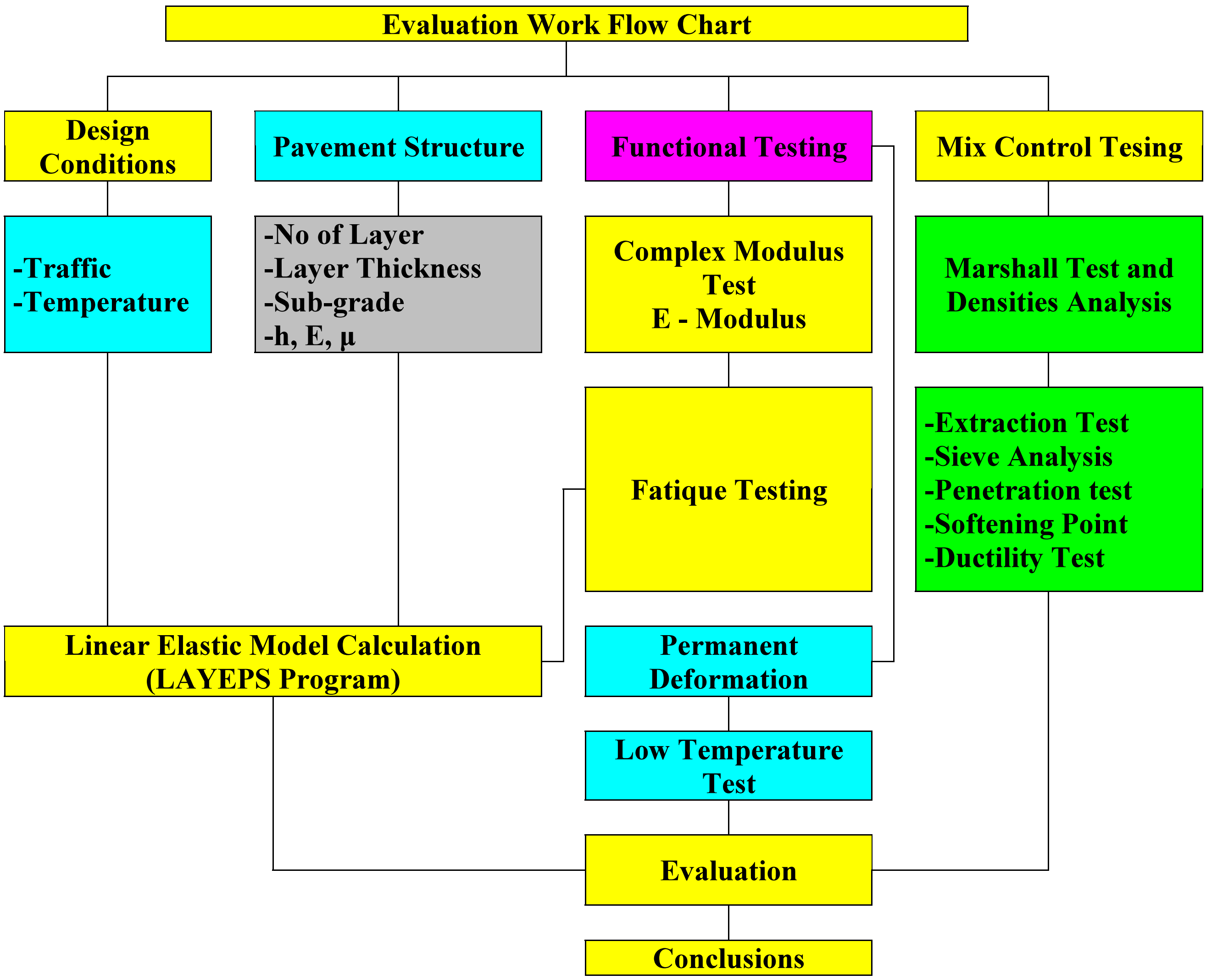


Figure 4.1 Flow chart for the pavement testing and evaluation

4.6 Functional Testing

The undisturbed field samples were tested from functional point of view. The following tests were carried out: complex stiffness modulus test, fatigue test, shrinkage test and the rutting test. The functional testing results are presented in the bituminous mixture functional testing (see section 5.2). During this study the air and pavement temperature in different layers were also measured.

4.7 Pavement Evaluation

The values of the modulus of stiffness and fatigue properties, which result from the functional testing, were used for the evaluation of the bituminous mixture failure due to the repeated loading of traffic. For the pavement evaluation the design model as LAYEPS [32] programme was used. The programme is calculating multi-layered half space according to the Czech Technical Recommendation 77 [65], modified for Libyan climatic and conditions.

5 MAIN TEST RESULTS

The field samples were tested for mechanical control testing and functional testing.

5.1 Mixture Control Testing

5.1.1 Densities voids analysis

The pavement samples were analysed for densities; the bulk specific gravity of the samples were averaged 2.23, maximum theoretical density (MD) 2.33 and the bulk specific gravity (BSG) of total aggregate 2.48. The average percentage of voids in mineral aggregate (VMA) and the air voids (Va) in the pavement were found to be 14,8 and 4.3 respectively. The results of the evaluation carried out after 15 years as well as the results during construction are shown in Table 5.1.

Table 5.1 Marshall test results during construction and after 15 years of service

Properties	Units	During construction		During the Study
		Sandstone Mix.	Basalt Mix.	Sandstone Mix. after 15 Years
Bitumen Content by weight	[%]	6.2	6.9	5.9
Bit. Content by Volume	[%]	10.7	13.0	10.2
Bit. Absorbed by Aggregate	[%]	1.8	1.48	1.7
Voids Ratio	[%]	4.6	4.2	4.3
Voids in Mineral Aggregate (VMA).	[%]	14.3	17.2	14.8
Voids Filled by Bitumen (VFB)	[%]	74.8	75.5	68.9
Marshall Stability	[kN]	18.0	18.3	39.5
Flow	[mm]	3.02	3.3	2.7

5.1.2 Asphalt mixture compositions

It was stated that; the evaluated asphalt mixture represent the type of asphalt concrete of the grading 0/22 in the wearing course and grading of 0/32 for the binder course. The wearing course differs from the binder course only by the maximum grain size and the lower content of bitumen (5.3 %), that corresponding to the grading. Therefore the only wearing course was evaluated in the whole work[42]. The aggregate mechanical properties for both materials sandstone and basalt, which were used in the road construction, have been re-evaluated in Libya (STFA construction company laboratory). The results of mechanical properties evaluation showed large variations in the materials (sandstone and basalt) mechanical properties as shown in Table 5.2.

Table 5.2 Mechanical properties of aggregate

Test	Units	Sandstone Materials	Basalt Materials
Los Angeles	[%]	35.9	18.0
Water absorption	[%]	3.2	1.8
Impact Value	[%]	31.0	12.0
Crushing Value	[%]	22.0	13.0
Ten Percent Value	[kN]	148.0	277.0

5.1.3 Mechanical properties of recovered bitumen

Toluene solvent was used to perform the extraction test, in order to determine the bitumen content and mixture gradation, the bitumen was recovered from the extraction solution by rotary evaporated, the bitumen content obtained (5.7 %), well agreed with the report [53] presented by the general road department, the recovered bitumen was tested to evaluate its rheological properties such as penetration, softening point (R&B), and the ductility test, the test results are shown in Table 5.3.

Table 5.3 Mechanical properties of recovered bitumen

Test	Units	Original Bitumen	Result after 15 Years.
Penetration test	0.1 [mm]	60 / 70	11.0
Softening Point (R&B).	[^{0}C]	46 / 54	75.7
Ductility	[cm]	≥ 100	6.5

The bitumen content recovered from the pavement samples extraction solution was in close agreement with average about 0.3 % less than the bitumen content during construction. The bitumen recovered from the pavement samples indicate that; as would be anticipated, bitumen hardening has been occurred as a result of mixing, storage, laying, and finally as a result of being subjected to environmental during its service life.

5.2 Functional Testing Results

5.2.1 Stiffness modulus (E^*) measurements

The test specimens of dimension 53 x 53 x 300 mm were cut randomly from the surfacing of the evaluated pavement (wearing course), in the vicinity of the area of severe cracking at ch. (490+000) for the sandstone pavement mixture, while the basalt pavement mixture samples (same grade and source of bitumen) were taken from Al Jufra 1500 housing unit roads project. The measurement of the complex modulus (**E***) was carried out according to ČSN 73 6160 [12] in compliance with the prEN 12697-26 [50], the samples were tested in two point bending (2PB) arrangement. The frequencies of cyclic loading were 1, 2, 5, 10, 15, and 20 Hz. The temperature applied for both sandstone and basalt mixtures were –10 (-5), 0 (10), 25 (30), and 45 (40) °C respectively. The maximum strain in the specimens was up to 5. 10^{-5}. The results of both sandstone and basalt mixtures are presented in graphically in Figures 5.1 and 5.2.

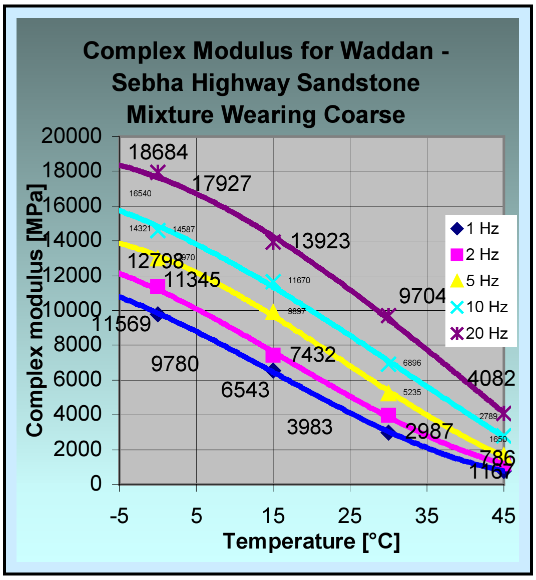


Figure 5.1

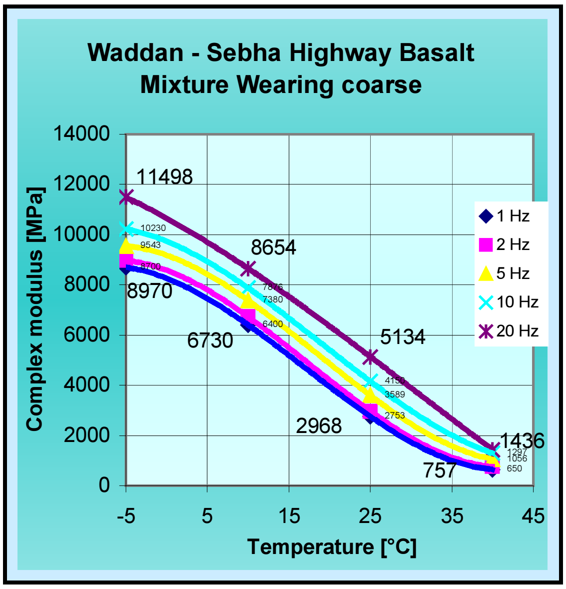


Figure 5.2

Figure 5.1 Complex modulus-temperature dependence for sandstone mixture at different frequencies

Figure 5.2 Complex modulus–temperature dependence for basalt at different frequencies.

5.2.2 Permanent deformation

For the determination of the resistance to permanent deformation the test slab has been prepared from the samples lined up side by side in the mould of small rutting tester (wheel tracking tester), and the specimens were tested in accordance to prEN 12697-22, the results are shown in Figure 5.3 [48].

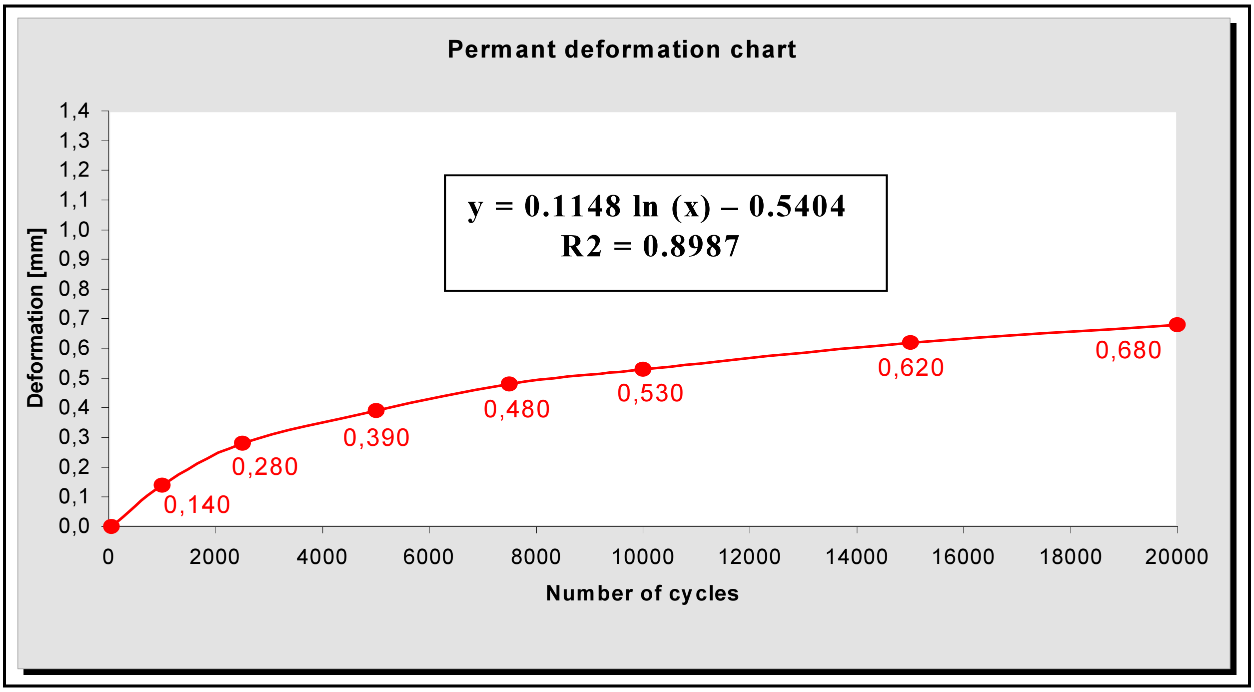


Figure 5.3 Permanent deformation test results for sandstone mixture.

5.2.3 Fatigue characteristics testing

The fatigue characteristics were determined according to ČSN 73 6160 [12], in compliance with prEN 12697-24 [49]. The loadings with harmonic repeated force at constant frequency of 25 Hz, in frame of 10^3 to 10^7 load repetitions were used. The specimens were of trapezoidal shape. The prediction of the fatigue life is made to the conventional concept of the maximum horizontal strain in the asphalt layer; this method is conventionally used to calculate the fatigue life according to the Wőhler relation (5.1).

The testing device is controlled by computer unit, the testing was done in strain control condition, the number of load repetition to failure is defined by the moment of half of the specimen initial stiffness modulus (**E***). The testing temperatures were 10 ^{0}C and 30 ^{0}C (25 ^{0}C) at constant frequency of 25 Hz, for both bituminous mixtures sandstone and basalt respectively; long-term tests were performed during days and nights. The test results are given in Figures 5.4.

$$\log(\varepsilon_0) = A + \mathbf{b} \cdot \log N \qquad (5.1)$$

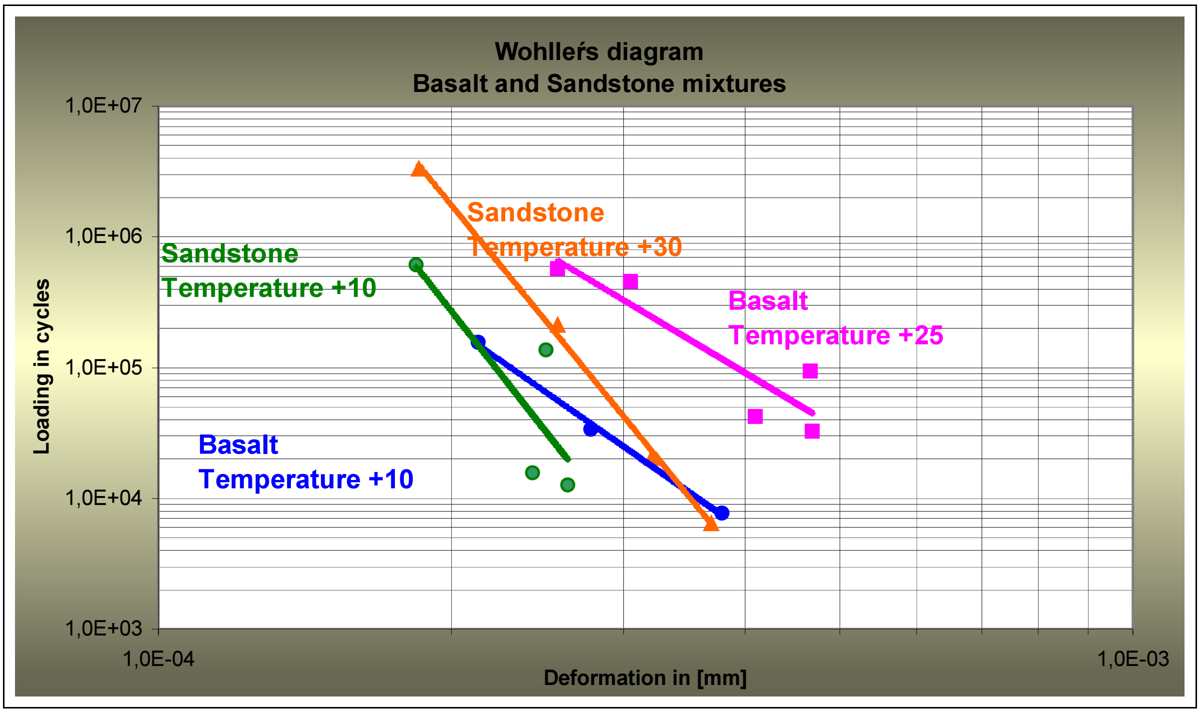


Figure 5.4 Fatigue life for both sandstone and basalt mixture

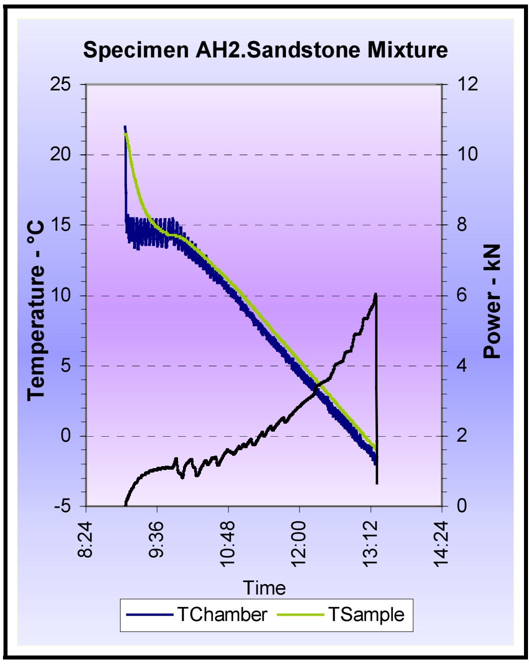
5.2.4 Resistance to low temperature cracking

The low temperature cracking resistance has been measured in the low temperature device, which has been constructed in the year 1999 in the University of Technology Brno.

The testing was performed at controlled temperature-sinking rate of –5 °C per hour. The test specimen was beam of dimension 50 x 50 x 250 mm affixed (by epoxy adhesive) and mounted to the equipment. The specimen length is kept constant length ($\varepsilon_T = 0$) during the cooling (no temperature dilatation). As the temperature decreases, the induced (built up) thermal stress in the specimen increases, and as the temperature continues to decrease the built up stress accordingly increases up to certain value (σ_{cr}), when the thermal stress is more than or equal to the specimen tensile strength, at this moment the specimen reached its critical stress (σ_{cr}) corresponding critical temperature (T_{cr}) and the specimen is broken. The moment of cracking is recorded as quick decreasing of the power. Six specimens of sandstone (Waddan-Sebha), while three specimens of basalt mixture (1500 housing project roads- Al Jufra) were tested in the same equipment with the same arrangements and testing conditions.

The basalt mixture has small deviation in the aggregate gradation, and contains the same bitumen source and grade (60/70 pen). It was found that the sandstone mixture average cracking stress (σ_{cr}) 2.2 MPa and the average cracking temperature (T_{cr}) –2.3 °C. The basalt mixture average cracking temperature (T_{cr}) is equal to -22 °C, and the average fracture stress (σ_{cr}) is 2.7 MPa. The summery of both bituminous mixture results are graphically presented (see Figure 5.5 and 5.6). The tests show that the basalt mixture has good resistance to low temperature-cracking keeping in mind its age.

The low temperature testing showed that the relaxation of sandstone mixture did not occur from the beginning of the testing, i.e. from the fixing of the test specimen into the measuring device at temperature + 25 °C. During the test with low decreasing rate of temperature -5 °C /hour a crack appeared at temperatures only slightly under freezing point The temperature data of this region specify that the temperature fall under freezing point occurs several times during each year. On the other hand the basalt mixture shows good resistance to low temperature cracking with an average temperature value equal to – 22 °C corresponding to value 2.7 MPa of thermal cracking stress.



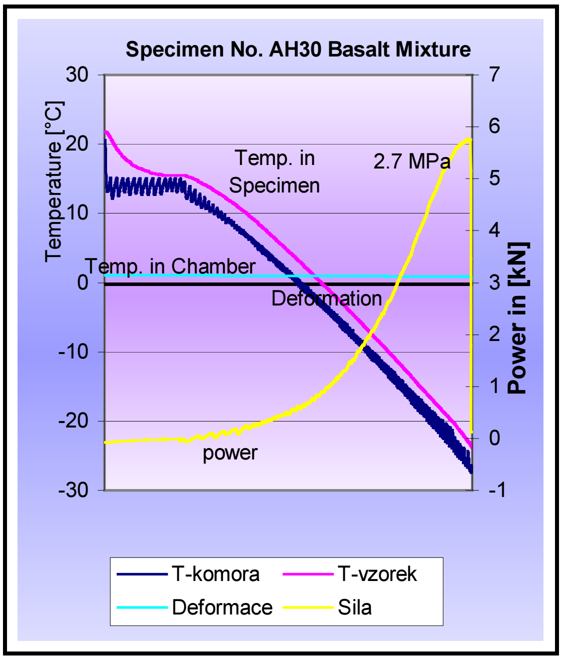


Figure 5.5 **Figure 5.6**

Figure 5.5 Low temperatures cracking results for sandstone.
Figure 5.6 Low temperatures cracking results for basalt mixtures.

5.3 Testing results discussions

For comparison and discussion the results of the measurements; the characteristics of the bitumen after the extraction from the experimental section in Portugal [30] are used, besides that the Czech bitumen A-P 65 (semi-blowed bitumen 60/70 pen) of the same range of characteristics was used too.

The dependence of a similar mixture prepared in laboratory with bitumen A-P 65 of Czech origin as well as the mixture from the experimental section manufactured in Portugal [30], are shown in Figure 5.7. The comparison showed that the evaluated section Libya has high modulus of stiffness. The lowest modulus has the Czech mixture prepared in laboratory, while the experimental results from Portugal section located in between.

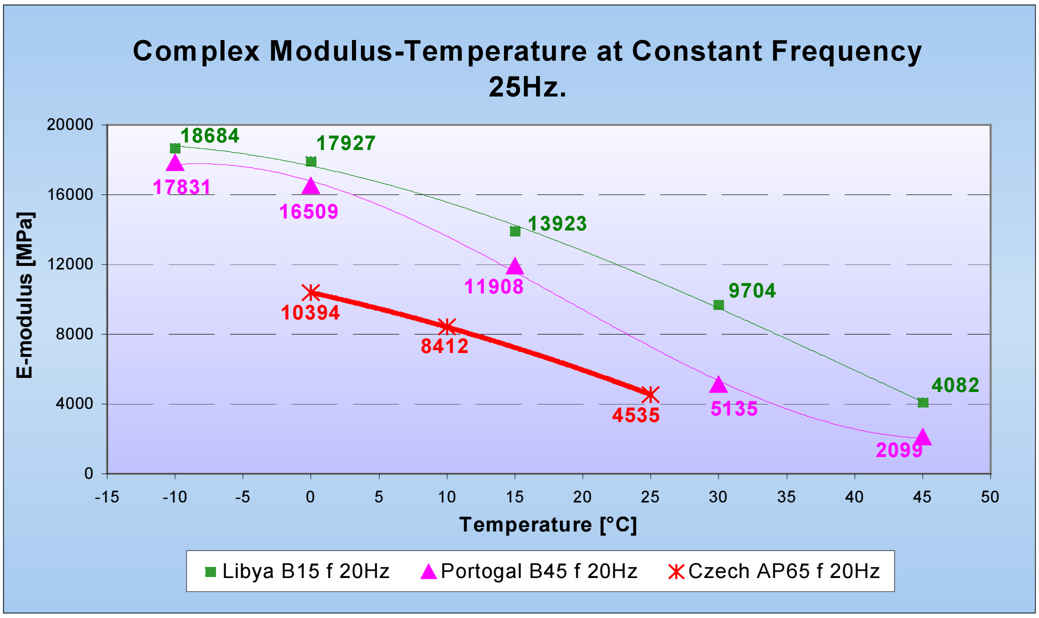


Figure 5.7 Comparison of stiffness modulus for Libya, Portugal and Czech at frequency of 20 Hz.

As a result of this comparison with referring to the values shown in Table 5.4 we may conclude that the bitumen rheological properties such as penetration, softening point, and ductility have their great impact and influence on the complex modulus of the bituminous mixture.

Table 5.4 Recovered bitumen results

Test	Units	Original Bitumen 60/70 pen	Bitumen Recovered			Recommended Value	
			Libya 15 years	Libya 6 years	Portugal 3 years	10/20 Pen	40/50 Pen
Penetration	[mm]	60/70	11.0	18.0	35	10/20	35/50
Softening Point	[^{0}C]	46/54	75.7	67.6	54.6	57/72	54/49
Ductility	[cm]	≥ 100	6.5	-	110	≥ 5	≤ 40

This result agrees with Isacson et al [27]. The high modulus of stiffness well agrees with the result obtained from the permanent deformation (rutting) test. The bituminous mixture pavement showed that the mixture is so far rigid and has good resistance to permanent deformation; the result was compared with the recommended value for heavy and slow traffic, as shown in Figure 5.8.

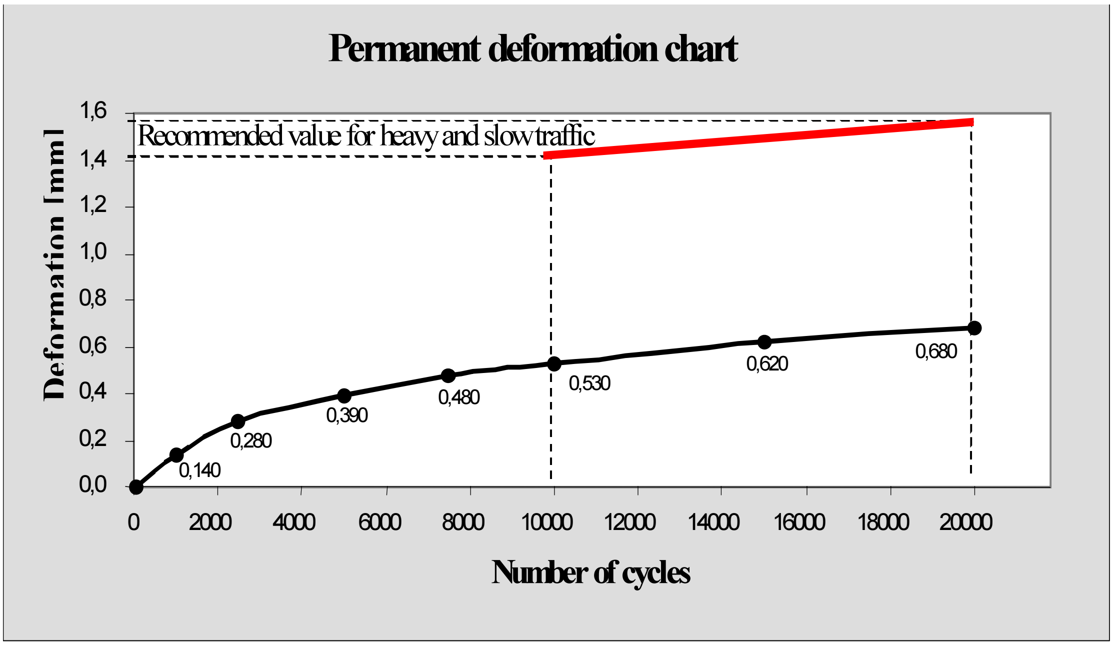


Figure 5.8 Comparison of sandstone mixture permanent deformation with technical recommendation values.

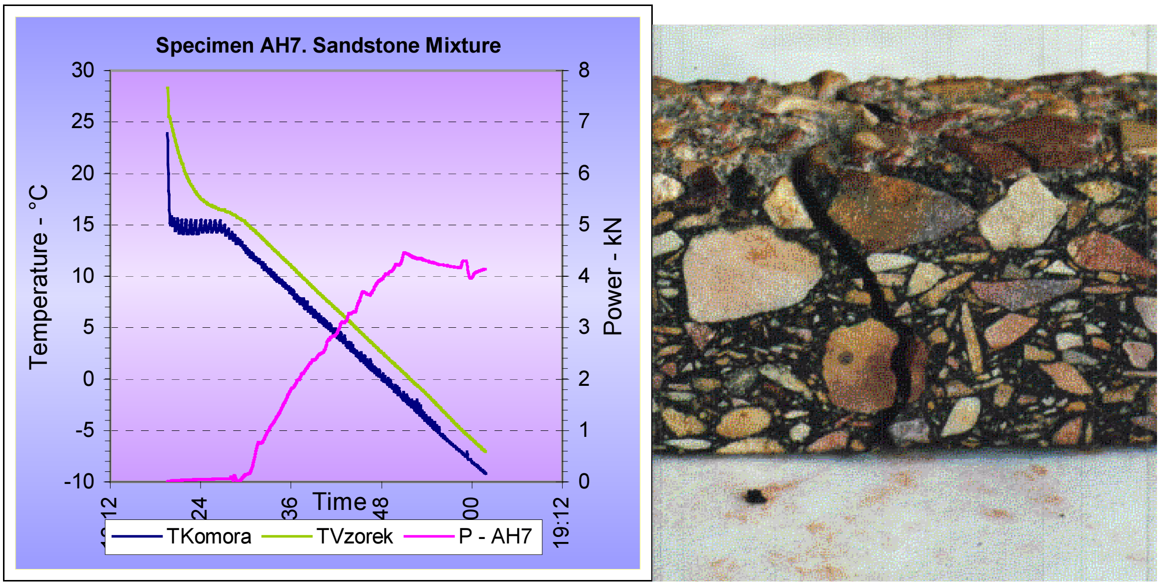


Figure 5.9 Presence of aggregate particles along the crack path.

On the other hand this high modulus due to aging showed its influence on the temperature cracking characteristics where the sandstone specimens have been cracked just few degrees below the freezing point. From Table 5.4 it was observed that the value of cracking stress has direct relation with the bitumen penetration grade and its hardening, this observation agreed with Monenaar [38]. During the testing it was recorded that the presence of the aggregate particles along the crack path prolonging the fracture travel time, as stated by Wang and El Hussien [72]. Figure 5.9 documented the above-mentioned condition.

5.4 Pavement evaluation

The pavement layers are assumed to be homogeneous, linear and isotropic. The interfaces are assumed fully adhered (no slip is allowed). The pavement construction was evaluated from the point of view of the pavement layers fatigue and the sub-grade permanent deformation under the repeated traffic loading. The values of the moduli of stiffness and fatigue properties were used in the pavement design model LAYEPS [32], as the layered half-space according to the Czech Technical Recommendation TP 77 [65].

The traffic load was determined according to the pavement design as 2,5 millions passes of equivalent axle loading 82 kN. The vehicles in Libya are usually in over-loaded condition, therefore, the Czech model of axle load of 100 kN was used, supposing the same distribution of axle loading. The mean axle load 72 kN characterizes Czech distribution of axle load and only 11% of axles have more than 100 kN load.

The effect on pavement failure is expressed by coefficient C3 = 0,7. The half of vehicles goes in one traffic lane (C1 = 0,5), the axle load is concentrated in one path (C2 = 1,0) and the mean vehicles velocity is over 60 km/h (C4 = 1,0) The temperatures of 10 °C in winter period, 25 °C under medium conditions and 40 °C under summer conditions characterize the climatic conditions in Libya were applied in the model.

The frost effect of the sub-grade soil is not taken into consideration (hot arid climatic region). The values of the sub-grade and base stiffness moduli as the input into the LAYEPS programme were determined according to the results of CBR bearing capacity. The values of the moduli and fatigue properties of asphalt courses were taken according to the measurements shown in Figures 5.1 and 5.4. The calculated strains are used in Miner's hypothesis of cumulating relative damages. The probability of failure in design level D1 is supposed 5 %. The results of pavement evaluation are shown below in Table 5.5.

The value of the relative failure of the asphalt courses is very small (0,0076). The asphalt mixtures are so rigid that their relative strain at the bottom of the courses is small and the number of the repetitions of the loading does not cause any significant manifestation of fatigue. On the contrary, this evaluation showed that; the relative failure of the sub-grade is higher than 1,00. According to the obtained value (1.5603), the sub-grade is more stressed as the base thickness do not correspond to traffic loading. Therefore, it is possible that the repeated loading can cause the accumulation of irreversible deformations in the sub-grade with the possible development of depressions in the wheel path, or even the longitudinal cracks out of the wheel path can be caused by this phenomenon.

Table 5.5 Evaluation results of Waddan – Sebha Highway
Location: Waddan - Sebha Highway – Libya

Design level of failure: D1			Number of tyres	2
Design period : 20 years				
delta z:1.00	C1 = 0.50		Loading radius	120.3
delta k:1.00	C2 = 1.00		Loading intensity	0.55
AADT 457	C3 = 0.70		Distance of tyres	344.0
Number of EAL	C4 = 1.00			
Layer: no:	Courses	Thickness	Contact	Relative failure
1.	Asphalt concrete	110.	Ideal	**0.0076**
2	Granular base	200.	Ideal	**0.0000**
Total thickness:		310.	Min. Thickness.	**-**
Sub-grade: mean modulus		100	Relative failure	**1.5603**
Spring modulus		100.		
Frost index		15.		
Regime diffuse				
Non-frost susceptible				

6 CONCLUSION

The dominant failures of the highways going through the Libyan Desert are longitudinal and transverse cracks. The laboratory full-scale measurements of asphalt courses were done.

Functional tests confirmed good pavement resistance to effect of vehicle loading from the point of permanent deformation and fatigue of asphalt courses.

The low temperature test found that the transverse cracks are caused by asphalt degradation. The reason could be the lower quality of the sandstone aggregate characterized with the value of water absorption, Los Angeles, Impact and crushing tests. The aggregate asks more bitumen as was used during the construction. The bitumen film was very thin and bitumen aged very rapidly. The stress relaxation did not occur from the temperature of +25 °C. In low temperature tester the tensile strength was reached at average temperature of –2.3 °C and this temperature occurs several times during the year. The similar bitumen with basalt aggregate having better characteristics and with the same bitumen and similar bitumen content has low temperature characteristics suitable to cold region and the pavement in the same region was without cracks.

The computer -programme LAYEPS might be helpful tool for the evaluation of pavement damage that caused by traffic loading. The calculation determined that some of longitudinal cracks could be caused by permanent deformation of sub-grade due to repeated loading.

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8 CURRICULUM VITAE

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8.3 Publications

1 - OTHMAN, A. A. and MIJAILOVIC, R.: Technical report, Testing and Examination of Wadi Al Galta, Waddan-Bu Grain Highway, Prepared for General Roads Department, Libya, 25- 08-1982
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5 - OTHMAN A. A.: The Evaluation of Pavement in Desert Region in Libya, 2nd Euroashalt& Eurobitume Congress 2000, 20-22 September 2000 Barcelona, Spain

8.4 Participation in Conferences, Workshop and Seminar

- Symposium for the technology of the housing unit, Engineering Scientific Association, 1-2 April 1987, Gadames, Libya
- The conference of housing and building materials in Libya, 1987, Tripoli, Libya.
- The Conference of Building Technology and Building Materials, 2-5 October 1989, Tripoli, Libya.
- Seminar s medzinárodnou účastou, Poznatky z XXI. SVETOVĒHO CESTNÉHO KONGRESU, 17-18. 2. 1999, Žilina, Slovak Republic.
- Asfaltové vozovky, 99, 23-24 Listopadu 1999, České Budějovice, Czech Republic.
- The 11th International Scientific Conference, University of Technology Brno, Brno, 18-20 October 1999, Brno, Czech Republic.
- Euroasphalt &Eurobitume Congress, 2000, 20-22 September 2000, Barcelona, Spain
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8.5 Extra Curriculum Activities

1981-1982: Site Engineer Executive Organization of Brega and Ras Lanouf New Township, Libya.

1983-1985: Manager of Roads Department in Al Jufra, Ministry of Communications and Transport, Libya.

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9 SOUHRN

Jízdní dráhy z bitumenových směsí jsou náchylné ke zhoršování kvality a trpí působením zátěže dopravního provozu a klimatickými faktory. Jedním z hlavních způsobů, jak se projevuje poničení jízdní dráhy, je praskání. Hodnocení bitumenových směsí určených k výrobě jízdních drah je velmi obtížná, komplikovaná a namáhavá práce. Hodnocení struktury jízdních drah ovlivňuje velký počet proměnných, které jsou zahrnuty do hodnocení složení směsí určených pro jízdní dráhy (bitumen, hrubé kamenivo, drobné kamenivo a výplň), přičemž je nutno mít na mysli kromě klimatických faktorů jejich různé vlastnosti (mechanické, fyzikální a chemické) i heterogenní zatížení.

Bitumenové jízdní dráhy pokrývají velkou část libyjského systému pozemní přepravy. Za minulých 20 let se ze strany dopravních úřadů uskutečnily velké investice do této oblasti. Za účelem dosažení maximální nákladové výhodnosti tohoto obrovského přepravního systému a velkých investic by měly být před zahájením údržbových a modernizačních prací provedeny studie a hodnocení efektivnosti. Praskliny jízdních drah z bitumenových směsí se staly běžným způsobem, jak se ničí v Libyi dálnice, a to zejména dálnice, které se nacházejí na jihu oblasti. Převažujícím způsobem, jak se dálnice v Libyi ničí a čím strádají, je praskání. Dálnice Waddan – Sebha je příkladem libyjské silnice, která formou praskání vážně utrpěla.

Během opravy dálnice Waddan – Sebha byla položena nová obrusná vrstva, ale praskliny se velmi brzy objevily znovu. Během této práce díky velkému počtu zúčastněných proměnných, které znesnadňují stimulování všech skutečných faktorů, kterým je jízdní dráha vystavena a které ji ovlivňují během doby její životnosti, proto výzkumníci zjednodušili zatížení, kterému je jízdní dráha vystavena, aby charakterizovali vlastnosti materiálu, ze kterého je jízdní dráha vyrobena, a upřesnili hlavní důvod poničení jízdní dráhy. V terénu byly z povrchu dálnice Waddan – Sebha vyřezány náhodné vzorky, a to v blízkosti oblasti rozsáhlého popraskání. V laboratoři zabývající se výzkumem silnic Technické univerzity Brno, byly změřeny fyzikální, mechanické a zejména funkční vlastnosti asfaltových vozovek. Výsledky testů byly vyhodnoceny českou metodou návrhu jízdních drah upravenou pro libyjské klima a podmínky. Toto zhodnocení zjistilo hlavní důvod, proč se jízdní dráhy ničí. Bylo provedeno laboratorní podrobné měření asfaltových vozovek. Funkční testy potvrdily dobrou odolnost jízdní dráhy vůči účinkům zatížení vozidly z hlediska plastické deformace a únavy asfaltové vozovky. Nízkoteplotní test zjistil, že příčné praskliny jsou způsobeny rozkladem asfaltu. Důvodem by mohla být nižší kvalita pískovcového kameniva charakterizovaného hodnotou absorpce vody, rázovou a mělnící zkouškou (Los Angeles). K uvolnění napětí nedošlo od teploty +25 °C. V nízkoteplotním zkoušecím zařízení bylo dosaženo pevnosti v tahu při průměrné teplotě –2,3 °C a tato teplota se vyskytuje během roku několikrát.

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