Fatigue properties of asphalt rubber concrete

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Abstract

The paper presents the fatigue results of asphalt concrete with modified bitumen by crumb rubber from whole tires.

The old rubber from used tires is waste material with problems, including protection of environmental conditions. One of the way how to remove the waste - rubber is his utilizing in the road building materials, in particular, in bituminous mixtures.

Results of the laboratory tests indicate improved modified asphalt concrete properties as compared to the standard asphalt concrete. It was proved that scrap rubber binder modification increases 10 -15 times asphalt concrete fatigue life.

Keywords

Rubberized asphalt binder. fatigue, asphalt rubber concrete, fatigue

Introduction

There is considerable interest in Poland regarding the use of the waste rubber to improve the performance of asphalt concrete [4]. Each year Poland disposes a lot of passanger and truck tires. Tire disposal presents a series problems. The most important of them there are potential helth and environmental problems.

Waste rubber generally in the form of crumbed tyres can be added to bitumen and is a cheap source of elastomer [2, 3, 4]. There are two types of crumb rubber, which can be used as an additive in modified asphalt concrete:

1) rubber from tire buffings,
2) rubber from whole tires.

Rubber from tire buffings is from tread of the used tire, obtained by peeling its from the used suitable for recapping. This material after gringing to suitable mesh sizes, is free of steel and fabric and more uniform product then rubber processed from the whole used tires.

Crumb rubber from the whole tires is produced from the whole used tires with mechanical granulation equipment at ambient or at very low temperatures. The steel is removed by magnetic separation and the free fabric removed by an air vacuum system [6].

In this project crumb rubber from whole tires was used for modification of the bitumen D-70. There were applyed two types of the crumb rubber, fine - grained and coarse - grained rubbers. The paper presents a comparative analysis of the fatigue characteristics of the conventional asphalt and rubber modified concrete.

Experimentation

Crumb rubber from whole tires was used and blended with bitumen D-70, produced in the Gdańsk Rafinery in Poland. Optimum of blending times and temperatures were reached when the desired blend properties of softening point, penetration and viscosity became constant due to good additive dispersion. Homogenity was monitored visually, too. The dispersion of the blend was chacked by using a microscope to examine thin films. The rubberized bitumens used in this project were the blend of :

- 15 percent, by weight, fine-grained rubber (recycled tire rubber) and 85 percent bitumen D-70,
- 17 percent, by weight, coarse-grained rubber, 3 percent oil and 80 percent bitumen D-70. The procedures used for preparing the rubberized bitumens are given in Table1 and Table 2.

Table 1. Production procedures of the rubberized bitumens with fine - grained rubber

Blending time [houre]	Material	Blending temperature [^{0}C]	Softening point [^{0}C]	Penetration [dmm]	Penetration index
	Pure bitumen D-70	160	49.2	66.3	- 0.72
High shear-0.3	Bitumen+rubber	203	62.8	42.7	1.19
Low shear- 1.0-3.0	Bitumen+rubber				
4.0	Bitumen+rubber	203	57.5	61.3	1.05

Table 2. Production procedures of the rubberized bitumens with coarse - grained rubber

Blending time [houre]	Material	Blending temperature [^{0}C]	Softening point [^{0}C]	Penetration [dmm]	Penetration index
	Pure bitumen D-70	160	49.2	66.3	- 0.72
High shear - 0.3	Bitumen+rubber	205	63.4	47.3	1.55
Low shear - 1 ÷ 3	Bitumen+rubber				
4	Bitumen+rubber	203	61.0	71.7	2.23
5 ÷ 7	Bitumen+rubber				
8	Bitumen+rubber	204	57.4	79.3	1.78

The mineral gradiation shown in the Table 3 was used for all specimens of the modified and conventional mixes. This gradiation is suitable the standard specification for dense - graded hot mix asphalt concrete for heavy traffic. All crushed granite and gravel materials were sived to consistenlly achived the design gradation.

Table 3. Mineral aggregate of the asphalt concrete used in the research work

Sort of aggregate	Material content [%]
Limeston filler	15.9
Crushed granite 11/16	26.4
Crushed granite 6/11	15.2
Crushed granite 2/6	27.9
Crushed sand	9.3
Natural river sand	5.3
Sive size [mm]	**Percent passing by mass**
16	100
11	84.50
6	58.60
2	39.76
0.500	22.02
0.180	11.03
0.063	6.87

Specimen preparation

The modified bitumens with aggregate were mixed using the same equipment and methods used for conventional mixtures at the appropriate mixing temperatures.

From the BTDC (BitumenTest Data Chart) plot of the viscosity - temperature relation for each bitumen used in this project, the mixing and compaction temperature were selected. The used temperatures in the specimen preparation are shown in the Table 4.

Table 4. Mixing and compaction temperatures of the asphalt concretes

Bitumen	Mixing temperature [^{0}C]	Compaction temperature [^{0}C]
Conventional asphalt concrete (bitumen D-70)	145	125
Rubber modified asphalt concrete with coarse - grained rubber	180	150
Rubber modified asphalt concrete with fine - grained rubber	180	150

Immediately after each batch was mixed, it was placed in a 135 ^{0}C oven for four hours for short term aging. Then asphalt mixture were taken from the short term aging oven to the compaction oven, and were left at the compaction temperature for 60 minutes before compaction.The compaction of this mixes went in two stages:

- First compaction with a vibrating compactor consisting of a 10x15 cm vibrating steel-plate;
- Secondly rolling wheel compaction with a single steel wheel roller (weight 165 kg) with a diameter of 0.5 meter and a width of 0.6 meter.

The total mix weight was placed in the mould in one charge and then compacted with the vibratory compactor. The steel-platen of the compactor was moved along and transversely of the slab. After this vibratory compaction the steel wheel compactor was used and repeatedly passed over the mould until the mix was compacted to the level at the top of the mould.

All samples were sawn from slabs to the dimension of 450x50x50 mm.

Equipment and procedures

The flexural beam fatigue test was performed using the machine for the controlled strain testing. The mechanical scheme of the four-point dynamic bending test is given in Fig.1. The beam was placed in the loading system and was supported in four places by rollers which fit into the grooves of the clamps. The clamps were glued with bitumen. These rollers were situated above and below the beam which allowed for free rotation and translation at all loading and reaction points due to bending of the beam. The spacing of the loading and reaction points is depicated in Fig. 1. The lower centre-bearing rollers form the bending bed. This bending bed is connected to another plate located above the two top rollers. The hydraulic jack under the bending bed allowed for the vertical movement of the centre-bearing with the result of bending the beam.

All data have been acquired electronically and all the calculations have been performed by the computer.

The used test circumstance were:

- temperature $T = 10\ ^0C$,
- frequency $f = 9.8$ Hz,
- type of signal - haversine.

The fatigue test results

Fatigue has been defined as: the phenomenon of fructure under repeted or fluctuating stress having a maximum value less then the tensile strength of the material [1,5].

Under traffic loading the layers of flexible pavement structure are subjected to continous flexing with the tensile strains of the order of $30\text{-}200 * 10^{-6}$ for a standard wheel load. The fatigue failure is associated with material changes that lead to formation of macroscopic craks and subsequent structural instability. The occurence of fatigue failure is a result of two processes: damage initiation and damage growth.

For each speciment the following magnitudes have been calculated:

- ξ_0 - initial strain [μm/m],
- N_0 - namber of load cycles at E_0,
- E_0 - dynamic stiffness for calculation of N_f [MPa],
- N_f - number of load cycles at $E_f = 1/2 * E_0$ (fatigue life),

- E_f - half of the dynamic stiffness E_0 [MPa],
- E_{dyn} - complex dynamic stiffness [MPa],
- W_f - sum of energy dissipated by the sample until N_f.calculated by the formula:
  $W_{dis} = \pi * \xi^2 * E_{dyn} * \sin\varphi$ [MJ/m^3] (1)
  where:
  ξ - tensile strain [μm/m],
  φ - material phase angle.

The results from the experiment were used to calculate the fatigue relations. The majority of fatigue investigations to date suggest the response of asphalt concrete to repetitive loading can be defined by relationship of the form [5]:

$$N_f = a * \left(\frac{1}{\xi}\right)^b \qquad (2)$$

where:

ξ - magnitude of tensile strain repeatedly applied,
a,b - material coefficients,
N_f - number of applications to failure.

So that, the following fatigue relations have been composed:

N_f - ξ_0 relations,
N_f - W_f relations.

For each mix an N_f - ξ_0 relation of the following form was derived by linear regression:

$\log N_f = a_1 + b_1 * \log \xi_0$ (3).

The applicable models are as follows:

conventional asphalt concrete $N_f = 8.128*10^{16}*\xi_0^{-5.00}$ $R^2 = 0.98$ (4)
fine - grained rubber modified asphalt concrete $N_f = 5.370*10^{19}*\xi_0^{-5.66}$ $R^2 = 0.84$ (5)
coarse - grained rubber modified asphalt concrete $N_f = 1.445*10^{18}*\xi^{-5.00}$ $R^2 = 0.99$ (6)

To give better overview of the mixes the regression lines have been drawn in figure together . The derived N_f - ξ_0 relations are drawn in Fig 2.

Inspection of this figure indicate what appears to be relatively consistent linear relationships between log initial applied strains and log repetitions ($R^2 = 0.84 - 0.99$), as expected. From Fig. 2 it appears that the lines of the fatigue lives for the conventional asphalt concrete and coarse - grained rubber modified asphalt concretes are approximately paralel. There is diference in the slope of the fine - grined rubber asphalt concrete strain - life line.

Generally, it can be said that modified mixes obtain better fatigue properties compared to the standard mix. A comperison of the average test results for each section of the modification (ξ_0 = 300 μm/m) would indicate the following ranking for resistance to fatigue:

- conventional asphalt concrete - 1.0
- fine - grained rubber modified asphalt concrete - 15.3,
- coarse - grained rubber modified asphalt concrete - 17.8

As well,use was made of the formula:
$\log W_f = a_2 + b_2 * \log \xi_0$ (7).

A reggresion models fitted to the research mix fatigue data are as follows:

conventional asphalt concrete $N_f = 0.055*W_f^{0.60}$ $R^2 = 0.99$ (8)
fine - grained rubber modified asphalt concrete $N_f = 0.031*W_f^{0.71}$ $R^2 = 0.98$ (9)

coarse - grained rubber modified asphalt concrete $N_f = 0.031*W_f^{0.71}$ $R^2 = 0.98$ (10)

For all asphalt - aggregate mixes, laboratory fatigue life versus tensile strain and cumulative dissipated energy to failure regresion model of the following form was detrmined:

$$N_f = 320*10^4*W^{1.09}*\xi^{1.43} \qquad R^2 = 0.98 \qquad (11)$$

Regression results indicate that the fatigue life, tensile strain and cumulative dissipated energy to failure have a strong relationship (high coefficient of determination).

The effects of modifiers on cumulative dissipated energy are similar to those observed for fatigue life. It seems important to indicate that the energy approach is relatively simplistic but appears to have a significant promise, and is conceptually appealing from a fundamental material behavior standpoint.

Conclusions

From the laboratory and analitycal stady of the fatigue properties of the modified asphalt concrete , following conclusion can be made:

- For conventional and modified mixes fatigue life increased with decreasing stiffness in the controlled strain mode of loading used in this study.
- Incorporation of modifiers to the bitumen D-70 give asphalt concrete pevement better fatigue properties compared to the standard mix pavement. The modified mixes are more resistant to fatigue cracking. The results show much greater increase in fatigue life of coarse grained crumb rubber modified asphalt concrete.
- The energy approach to fatigue study has a significant promise from a material behaviour standpoint view.

References

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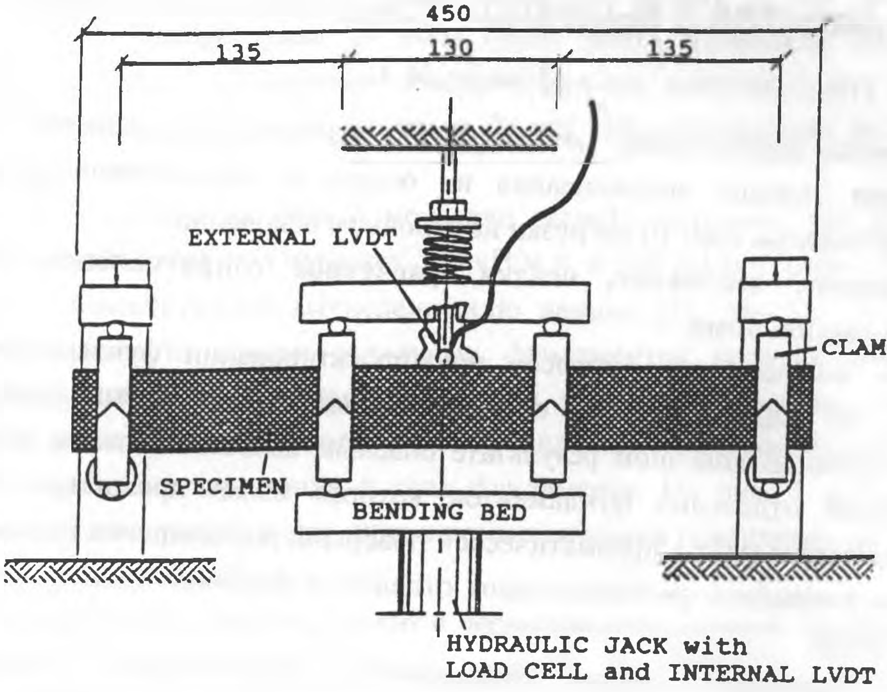

Fig. 1. Four point bending test set-up

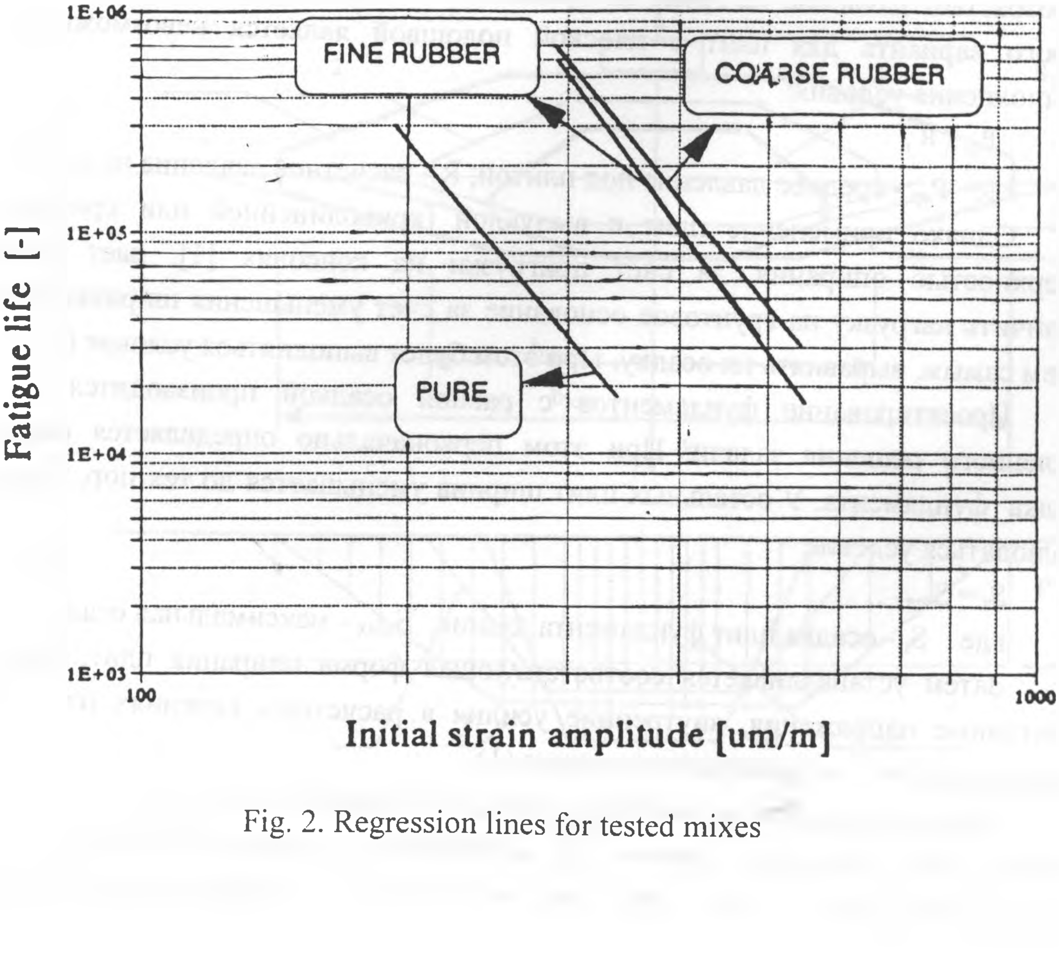

Fig. 2. Regression lines for tested mixes