Influence of Aramid-Polyolefin Fibers on the Properties of Bituminous Mixtures

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Abstract. The use of additives in bituminous mixtures such as fibers has been the subject of various studies. Different fibres including cellulose fibres, steel fibres, basalt fibres, glass fibres and aramid fibres can be used to improve the properties of bituminous mixtures. Depending on the type of fibres used, different characteristics can be changed. The paper contains results of comparative tests of bituminous mixtures with aramid-polyolefin fibres. Asphalt concrete used for wearing course with maximum aggregate size of 11 mm was evaluated in the study. Reference mix with an average penetration grade of 50/70 was chosen as a base for modifications. Due to difficulty in preparing mixtures with fibers in a laboratory mixer, test specimens were obtained from a stationary plant. The fibers and aggregate mix was prepared before adding the asphalt. The fibers were added at a rate of 0.5 kg per 1000 kg of finished bituminous mixture. This allowed to obtain an even distribution of fibers in the mixture resulting in a homogeneity necessary for planned tests. This allowed to omit the scale effect, that could occur due to differences between laboratory and stationary mixing. Stiffness modulus tests were performed using the IT-CY (Indirect Tension to Cylindrical Specimens) method for a wide temperature range of 0-30°C. The specimen resistance to permanent deformation was evaluated. Obtained results has shown a clear increase in the resistance to permanent deformation of mixtures with aramid-polyolefin fibers, which is especially important for mixtures used for wearing course. The results has also shown a significant increase in the stiffness modulus regardless of temperature range. Results of conducted experiments has shown that it is possible to reduce the thickness of bituminous overlay in case of reinforcement of the existing pavement structure. The analysis of results has shown that the application of aramid-polyolefin fibres in bituminous mixtures can improve the functional features of the pavement and be beneficial to the investors.

1. Introduction
Reinforcing bituminous mixtures with fibers has been a subject of many studies [1]. Fibers can be divided into two groups: synthetic fibers (steel, glass, carbon, polyester [2–4]) and natural fibers (cellulose, basalt, hemp, sisal and coir [2,5–7]). Depending on the type and their content in the mix, fibers can influence various properties such as resistance to permanent deformation, fatigue strength or low temperature cracking. Fibers are also used as stabilizers in the stone mastic asphalts (SMA) [8].

Another group of fibers used in bituminous mixes are the aramid and aramid-polyolefin fibers. Experimental studies has shown considerable influence of those fibers on the properties of bituminous mixes. The fibers influence the resistance to permanent deformation [9–12], fatigue resistance [10,11]
and increase the Marshall stability [12]. Aramid fibers can have different length and be mixed with other types of fibers. One of the products of such a connection are the aramid-polyolefin fibers. Properties of aramid-polyolefin fibers are presented in Table 1. Optimal volume of fibers is 0.05% of the total mass of bituminous mix [10].

Table 1. Characteristics of Aramid- Polyolefin (manufacturers data)

| Specification            | Aramid         | Polyolefin       |
|--------------------------|----------------|------------------|
| Specific Gravity         | 1.44 Mg/m³     | 0.91 Mg/m³       |
| Tensile Strength         | 2.76 GPa       | N/A*             |
| Operating Temperature    | -73 – 427°C    | N/A*             |
| Length                   | 19 mm          | 19 mm            |
| Form                     | Monofilament** | Serrated         |
| Color                    | Yellow         | Yellow           |
| Acid/Alkali Resistance   | Inert          | Inert            |

* Fibers will melt or become plastically deformed during asphalt mix production
** Strands become fibrillated during asphalt mix production

2. Materials and methods

2.1. Materials
The study was conducted on two bituminous mixes (asphalt concrete with grading of 11 mm) of which one was modified with aramid-polyolefin fibers. Mixes were prepared in a stationary plant to achieve proper fiber distribution. Study conducted by Pszczoła [13] has proven that it is impossible to achieve proper fiber distribution using only laboratory mixer. Total of 1000 kg of each mix was prepared, sampling around 250 kg of each for further test. The fibers were added before adding the asphalt. This allowed to distribute the fibers evenly in the mix. Total of 0.5 kg per 1000 kg of fibers was added. Dosing of fibers is presented in Figure 1.

Study has been conducted on a bituminous mix intended for a wearing course. The grading of the mix is presented in Figure 2. Basic characteristics of the mix are presented in Table 2. Road asphalt 50/70 was used to prepare the mixes.

![Figure 1. Dosing of fibers](image-url)
Table 2. Basic characteristics of the asphalt mix used in the study

| Characteristic                        | Method                  | Unit       | Value  |
|---------------------------------------|-------------------------|------------|--------|
| Soluble binder content B              |                         | %          | 6.8    |
| Density MMA pmh                       | PN-EN 12697-5           | Mg/m³      | 2.632  |
| Bulk density MMA ρb (2x50 strokes)    | PN-EN 12697-6           | Mg/m³      | 2.581  |
| Void volume V (2x50 strokes)          | PN-EN 12697-8           | %          | 2.0    |

2.2. Methods

The aim of this study was to determine if reinforcing the bituminous mixes with aramid-polyolefin fibers can be an alternative to other reinforcing methods such as geosynthetics. Two key tests were conducted: resistance to permanent deformation in accordance to EN 12697-24:2018 (small wheel tracker, procedure B in 60°C) and stiffness modulus IT-CY (Indirect Tension to Cylindrical Specimens) in accordance to EN 12697-26:2018. The stiffness modulus was determined for 4 samples at temperatures of 0, 10, 20, 30°C. To determine if the changes in results were caused by the characteristics of binder, the binder was extracted (in accordance with EN 12697-3:2013+A1:2018) and its characteristics were determined. Specimen for the permanent deformation resistance test were prepared using cylindrical compactor in accordance to EN 12697-33:2019 in a 30.5x30.5x4.0 steel molds. Specimen for the stiffness modulus tests were prepared using Marshall compactor.

To compare the theoretical thickness of the asphalt layers, the formulas for determination of overlay thickness coefficient that can be found in the deflection design method was applied [14]:

\[ h_1 = h_2 \sqrt[3]{\frac{E_1}{E_2}} \]  

where: \( E_1 \), \( E_2 \) – stiffness modulus of each mix in 20°C

The ratio of layer thickness was determined (2):

\[ h_{ratio} = \frac{h_1}{h_2} \]  

Using equation (1) in equation (2) we have acquired:

\[ h_{ratio} = \frac{3}{\sqrt[3]{E_1/E_2}} \]
3. Results and discussions

Results of the resistance to permanent deformation has been presented in Table 3 and Figure 3. Results has shown an increase of the resistance on permanent deformation of the mix reinforced with fibers. Average PRD\textsubscript{AIR} decreased by 10.5% compared to reference mix. It was also observe that the slope of the rutting curve shown as the value of WTS\textsubscript{AIR} coefficient decreased from 0.26 (reference mix) to 0.13 in case of the mix reinforced with fibers.

![Figure 3. Results of the resistance to permanent deformation tests](image)

| Temperature [°C] | Reference mix | Mix with fibers |
|------------------|---------------|-----------------|
| PRD\textsubscript{AIR} | 15.2, 0.81 | 10.5, 0.90 |
| WTS\textsubscript{AIR} | 0.26, 0.04 | 0.13, 0.03 |

Table 3. Results of the resistance to permanent deformation tests

Results of the stiffness modulus tests has shown an increase of the stiffness for mixes with fibers at all studied temperatures (Table 4, Figure 4). Increase in the stiffness modulus was from 21.5% (T=0°C) to 34% (T=30°C). This results can explain the increase in the resistance to permanent deformation. Results of stiffness modulus in relation to temperature has been presented in Figure 4. The correlation is an exponential function with a strong correlation (R\textsuperscript{2}≥0.98). Using equation 3 and obtained values of stiffness modulus at T=20°C (4093 MPa and 5283 MPa) the obtained h\textsubscript{ratio} was 1.09. Use of aramid-polyolefin fibers allows to decrease the thickness of the overlay asphalt by 10% comparing to the reference mix, with simultaneous improvement of the resistance to permanent deformation.

![Figure 4. Results of the stiffness modulus test (IT-CY method)](image)

| Temperature [°C] | Reference mix | Mix with fibers | Increase of the stiffness modulus |
|------------------|---------------|-----------------|----------------------------------|
| Mean stiffness [MPa] | 17605, 1743 | 21396, 1461 | 21.5% |
| Std [MP] | 9894, 326 | 12637, 1310 | 27.8% |
| Mean stiffness [MPa] | 4093, 394 | 5283, 544 | 29.1% |
| Std [MP] | 1828, 162 | 2452, 299 | 34.1% |

Table 4. Results of the stiffness modulus test (IT-CY method)
Figure 4. Results of the stiffness modulus test (IT-CY method)

Results of the basic characteristics of the binder extracted from the mix (Table 5) do not indicate any changes for the penetration test (T=25°C) and softening point (R&B). Obtained results are within the test errors. In case of elastic recovery the results indicate slight increase in ductility of the asphalt. Asphalt specimen extracted from the reference mix taken for the elastic ductility test exhibited failure at 164 mm.

| Characteristic                  | Method                  | Unit   | Result Reference | Result Mix with fibers |
|--------------------------------|-------------------------|--------|-----------------|------------------------|
| Penetration, 25°C              | EN 12697-24:2018        | 0.1 mm | 38              | 36                     |
| Softening point R&B           | EN 1427:2015            | °C     | 59.2            | 58.8                   |
| elastic recovery, 25°C        | EN 13398:2017           | %      | -.*             | 16                     |

* The sample ruptured at 164 mm

4. Conclusions
The article presents the determination of the characteristics of bituminous mix reinforced with aramid-polyolefin fibers. Based on the results and analysis of the results following conclusions were drawn:
- Addition of the aramid-polyolefin fibers significantly increases the resistance to permanent deformation of bituminous mixes, which concurs with other studies;
- Fibers increased the stiffness modulus of the mixes at all studied temperatures;
- Use of mixes with aramid-polyolefin fibers can decrease the overall thickness of overlays. Calculated thickness of overlays made of reinforced mixes was 10% lower than for reference mix.

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