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Asphalt Concrete for Binder Courses with Different Jute Fibre Content

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Abstract. Since the beginning of modern road construction, there have been effort to make durable, long life pavements. But no one pavement can fulfil designed purpose forever. On the other hand, some natural resources are limited, so it is important to maximize use of renewable resources. In recent years, there is a visible pursuit of this trend, in road construction represented mostly by use of waste materials, such as industrial by-products or recycled asphalt pavement itself. Within the effort, fibrous additives were established on the market to prolong life of pavement layers. Some commercial ones are synthetic polymer based, so it does not go well with the renewable part of pavement life cycle if we want to secure sustainable future. This paper describes use of fibres from natural renewable resource, specifically jute plant (Corchorus). Three asphalt mix variants with jute fibres were designed and further compared. Fibre content was 0.1 %, 0.2 % and 0.3 % by weight. Several tests were conducted to examine the effect of fibres on mixture properties, with aim on stiffness modulus (IT-CY) and crack propagation (SCB). Furthermore, indirect tensile strength ratio was calculated as a parameter showing performance of the mixture under the wet conditions. Control mixtures with paving grade and polymer modified bitumen were tested for better comparison and evaluation of the results.

1. Introduction

Idea of making road pavements safe and durable goes back to the Roman empire, maybe even further. Fast and effective road network with user-friendly pavements is one of the key pillars of a developed country. Pavements must withstand in their environment for designed lifetime. In the Czech Republic, designed lifetime is set up to 25 years [1]. This period can be applied for concrete pavements, which fulfil their purpose even longer. However, real lifetime of asphalt pavements is shorter. Upper asphalt layers must be changed roughly twice as fast, depending on environmental circumstances and road importance in the network. Fortunately, asphalt pavement is a recyclable material and is used in bitumen mixtures under the name **R**eclaimed **A**sphalt **P**avement. On the other hand, a longer lifetime of asphalt pavements should be still a goal to pursuit. Generally, this can be achieved by proper mix design, bitumen properties, road maintenance, type of used binder and other admixtures, added within the mixing of asphalt mixture. This paper discusses last option, from which jute fibres have been chosen as the admixture used in the research.

Fibres can have reinforcing and/or stabilizing effect on asphalt mixture. To stabilize the mixture means to prevent a draindown of bitumen binder from aggregate in higher temperature range. Typically, this group of fibres is represented by a cellulose fibre, obtained from wastepaper. It is used in mixtures with higher bitumen content (SMA, PA). Reinforcing fibres should be featured by high tensile strength and modulus and should provide sufficient transfer of tensile stress when a crack occurs, resulting in ductile fibre reinforced asphalt [2]. Several materials were used as reinforcing fibres, beginning with asbestos, steel, carbon, basalt or glass fibres and fibres from synthetic or natural polymers [3]. Each material has some advantage and disadvantage. In commercial application, fibres made from synthetic polymers prevails, represented by polyolefin-aramid (FORTA-FI®) and e.g. PET polymer fibres (NAMFLEX®). Positive effects of synthetic polymer fibres have been reported, such as increasing toughness [4], higher stiffness moduli at high temperatures [5], significantly improved rutting resistance [6] and improved fatigue life [5] [6]. Eventually, fibres also increased fracture toughness [7] and decreased thermal induced cracking [4].

An alternative to synthetic polymers is use of natural polymers, mainly represented by cellulose. Because no pavement can fulfil designed purpose forever, use of admixtures that are obtained from growing plants and can decompose after target time may be favourable. Mixture with kenaf fibres showed better ability to retain the binder draindown, high resistance to rutting and high dynamic modulus at higher temperatures [8]. Lignin fibres provided greater effects on the flexural strength and ultimate flexural strain than the polymer fibres, although had worst indirect tensile strength ratio (ITSR) [6]. Jute fibres were used in several researches and provided higher fracture toughness than control mixture [7], high indirect tensile strength (ITS) [9] and low rut depth [10]. In previous research, some of these claims have been demonstrated with use of hemp and flax fibres [11].

2. Materials and methods

The effect of different jute fibre content was determined on selected performance based (functional) and empirical properties of an ACL 16+ mixture for binder course, in accordance with the Czech technical standard ČSN EN 13108-1:2018 and ČSN 73 6121. Base control mixture and mixtures with fibres contained a standard paving grade bitumen 50/70. Second control mixture was made with a polymer modified bitumen (PMB) 25/55-60. Bitumen content was the same within all mixtures, 4.2 % by weight. Compaction temperature was 150 °C with the standard bitumen and 160 °C with the PMB. Specimens were compacted by a Marshall impact compactor with 2x50 (2x25 for ITS specimens) hits.

Jute fibres were supplied by JUTEKO spol. s.r.o. in a yarn form. At first, yarn was cut into 20 mm long elements and then was disintegrated into individual fibres. Fibre content in mixture was 0.1 %, 0.2 % and 0.3 % by weight. All mixtures have been manufactured and tested in accordance with the Czech national specifications given in the standard ČSN 73 6121.

Water susceptibility test was performed in accordance with the standard ČSN EN 12697-12, the tensile strength was determined according to ČSN EN 12697-23. The stiffness modulus was tested by a repetitive non-destructive indirect tensile stress method on cylindrical test specimens (IT-CY) according to the standard ČSN EN 12697-26, annex C.

The semi-circular crack propagation (SCB) test was carried out according to ČSN EN 12697-44, with a continuous recording of force and deformation, which also allowed to calculate fracture energy, separately for crack initiation and crack propagation. The standard procedure was modified based on the long-term experience at the Czech Technical University in Prague. The test specimens are compacted by a Marshall compactor and not using gyratory compactor. Their diameter is 101±1 mm instead of 150±1 mm as defined in the standard. The reason is that specimens for stiffness testing were later used for SCB test. Because of calculating not only fracture toughness but also fracture energy, the loading rate was reduced from 5.0 mm/min (as defined in the standard) to 2.5 mm/min. The lower loading rate allows to capture more single point data from which the load-displacement curve can be more precisely depicted. A total fracture energy during the test was calculated until the loading force dropped to 0.30 kN on decreasing branch of the curve. For providing better understanding of cracking potential of asphalt mixtures containing fibres or yarns the test temperatures were 0 °C and 25 °C. The first temperature is related to potential frost cracking risk, the latter then more to fatigue cracking. Both aspects are important for asphalt binder courses.

3. Results and discussion

3.1. Voids content

Optimal voids content is one of the key necessities of every asphalt mixture and determines behaviour of the mixture. The higher voids content, the higher the probability of air/water penetration into the asphalt mixture.

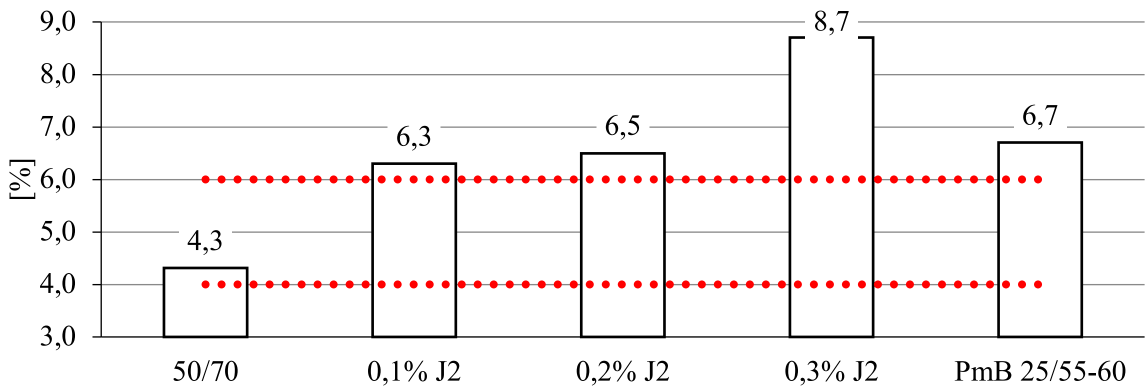

Figure 1. Voids content

Area between red dotted lines in *figure 1* defines minimum and maximum values for voids content according to ČSN EN 13108-1:2017. It shows that the defined interval of 4.0-6.0% has been fulfilled just by control mixture with 50/70 binder. Mixing temperatures or compaction energy were probably not high enough to secure better compaction of mixtures with fibres and polymer modified binder. This issue is described in other study [6]. In this paper, compaction temperature and energy are just one part of the problem. Rather low percentage of bitumen binder may be contributing to the cause. Finally, natural polymer fibres have high binder absorption, which can lead into worse compaction.

3.2. Water susceptibility

The results showed expected behaviour of mixtures with jute fibres. Dry values of ITS (*figure 2*) remained same or slightly higher than control mixture (50/70) for mixtures with 0.1 % and 0.2 % fibre content. A significant drop of ITS values for mixture with 0.3 % jute fibres is shown. This indicates limitation of fibre dosing in a mixture with low bitumen content.

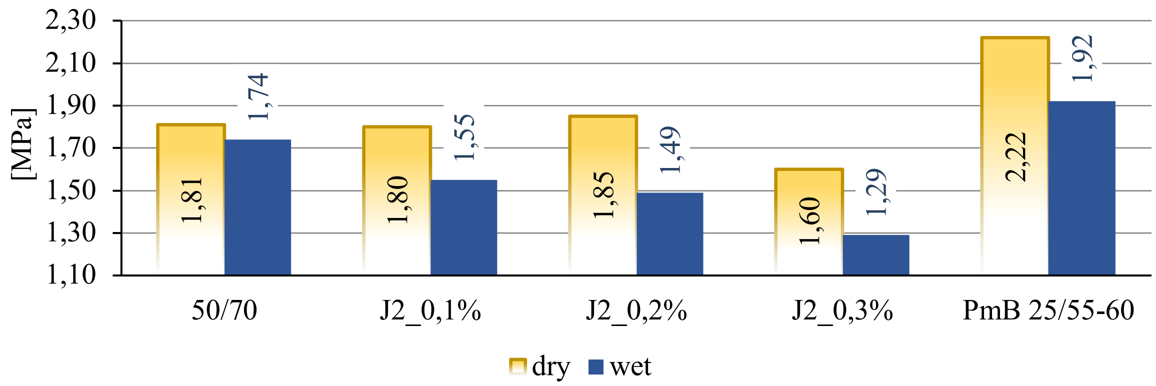

Figure 2. Indirect tensile strength

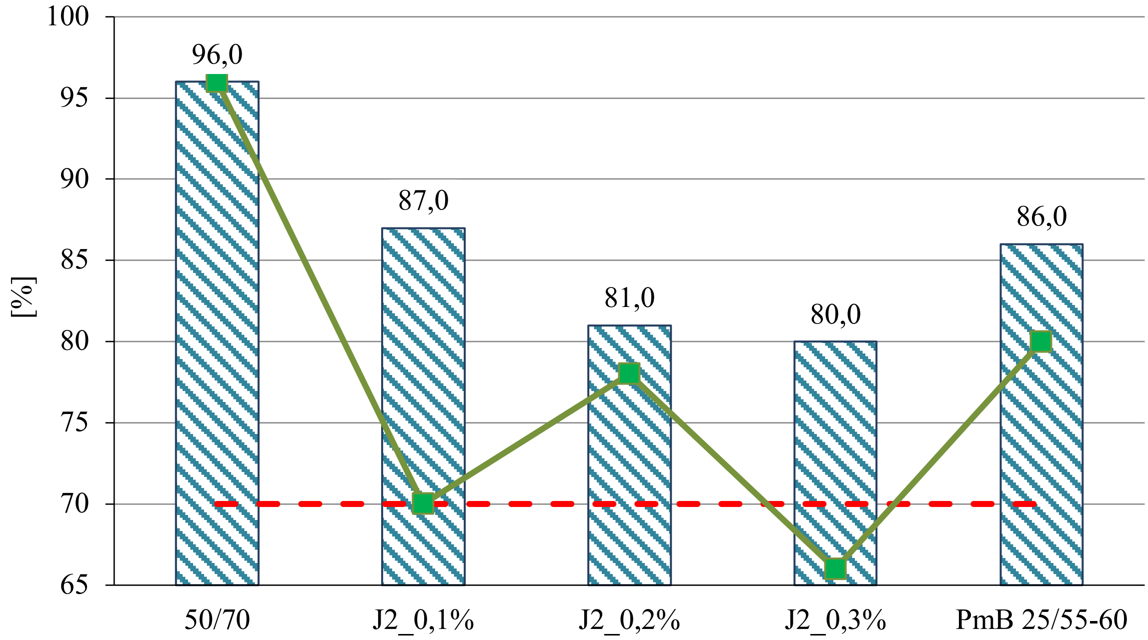

Figure 3. ITSR values (columns) with ITS modulus ratio (green line)

Difference between dry and wet conditions of ITS test is represented by ITSR (*figure 3*). The effect of water penetration is shown in mixtures with fibre content. Their indirect tensile strength ratio (ITSR) values reached lower values than in the case of the control mixture, but all mixtures fulfilled minimum requirements of 70 % given in the standard. Higher decrease in this parameter is in a direct corelation with higher fibres content. ITSR of second control mixture with polymer modified binder is also lower. Probable cause is higher voids content, which relates to the compaction temperature/energy discussed in section *3.1*. Although, values of ITS are by far the highest of all tested mixtures. Except ITSR, *figure 3* also presents values of a ratio of wet/dry modulus of elasticity. This parameter represents a functionality of stress and strain. Control mixture (50/70) showed the best performance. In other mixtures, there is a decrease in values. Worst mixture in the light of this parameter is the mixture with the highest fibre content.

3.3. Stiffness modulus

In this test, specimens were tempered and measured under four different temperatures, from 0 °C to 40 °C. Highest value at 0 °C is observed for the 50/70 control mixture (*figure 4*). Mixture with 0,3 % of fibres showed the biggest decrease in stiffness within whole temperature range. This is a confirmation of the ITS results.

We can identify two best mixtures with highest values of stiffness modulus: mixture with PMB binder and mixture with 0,2 % fibre content. They show similar performance at higher tested temperatures. At 15 °C and 0 °C, stiffness of the mixture with PMB binder is slightly higher. Hence it can be stated, all round best mixture is with 0,2 % fibre content, because it shows desirable performance of lower stiffness at 0 °C and the highest stiffness modulus values at 27 °C and 40 °C. Last sentence is represented by a parameter named thermal susceptibility, which is calculated as a ratio between stiffness at 0 °C and at 40 °C (between the lowest and the highest tested temperature). Mixture with 0,2 % fibre content has the lowest value from all, which means, it is the best also in this parameter. It can be also said that optimal fibre content will be 0,2 % of weight.

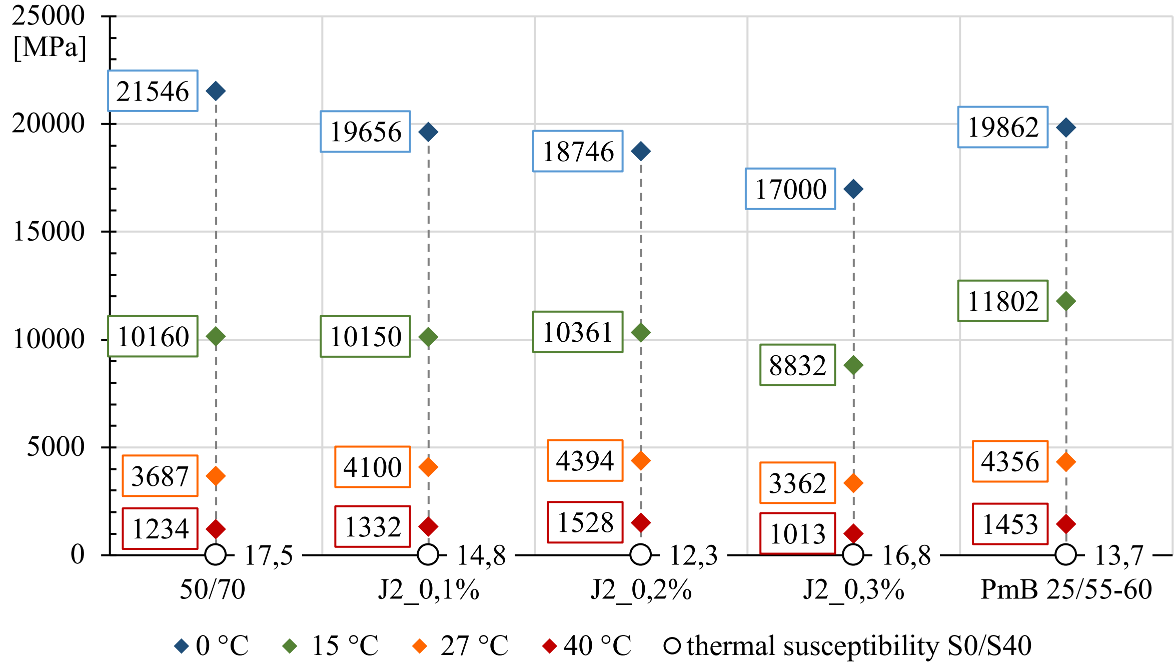

Figure 4. Stiffness modulus values with thermal susceptibility S0°C/S40°C

3.4. Resistance to crack propagation

Test was evaluated by two parameters: fracture toughness and cumulated increment of energy. Values of fracture toughness are similar for all mixtures at 0 °C, except mixture with 0,3 % of fibres. Higher fracture toughness was reached by mixture with only 0,1 % of fibres. Situation slightly changes with higher temperature. Mix variant 0,1% J2 still showed high value, but the best was asphalt mixture containing PMB. Control mixture with 50/70 bitumen showed second worst results.

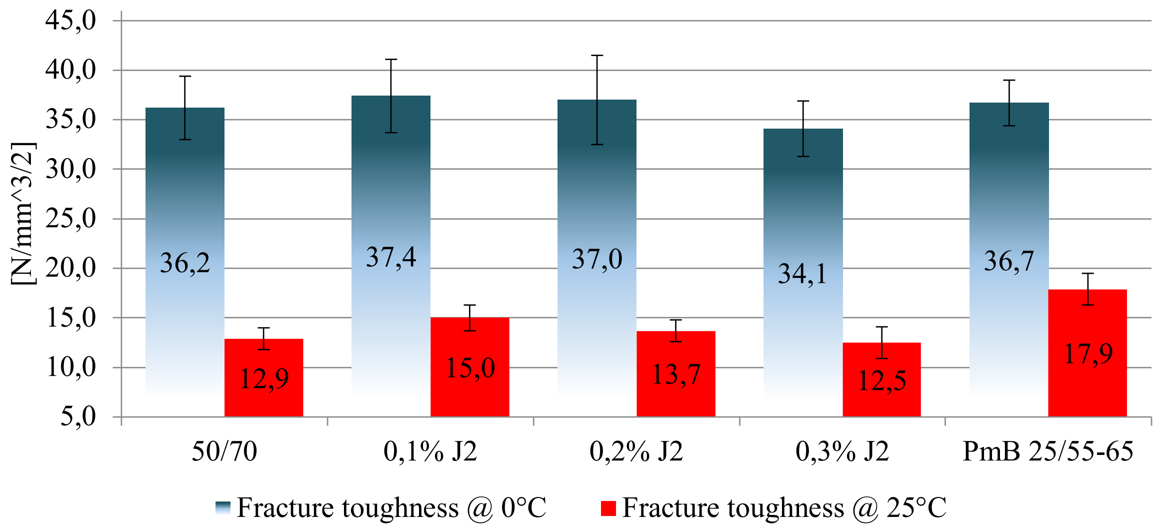

Figure 5. Fracture toughness results for assessed mixture variants

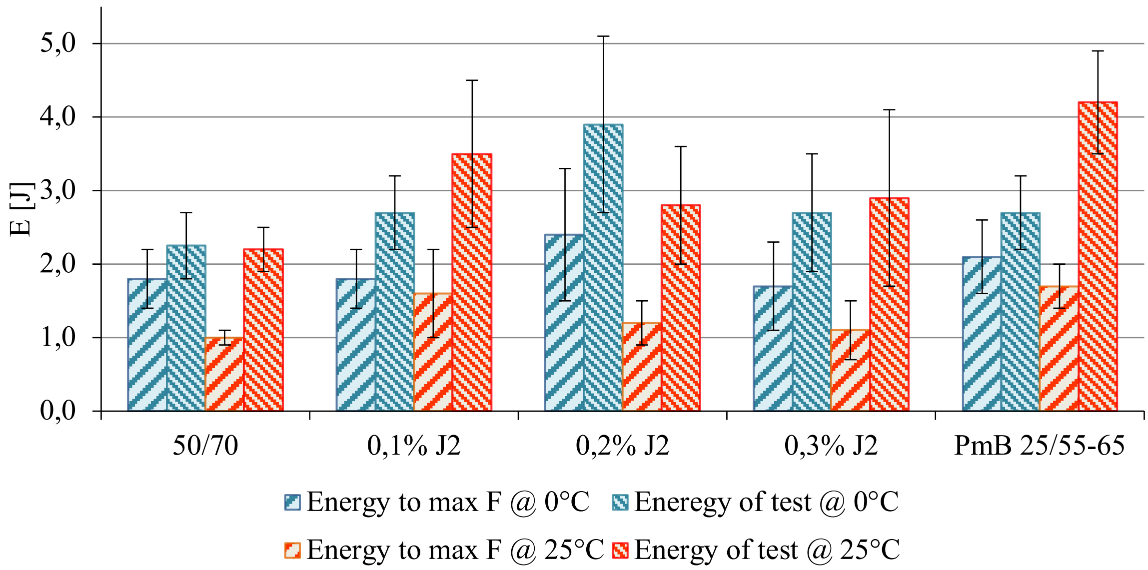

Figure 6. Fracture energy results for assessed mixture variants

Evaluation of the test via fracture energy showed clear difference between mixtures with and without fibres. At test temperature of 0 °C, energies to the maximum force are quite the same. Mixture 0,2 % J2 showed the highest energy needed for crack propagation. This mixture also showed the highest value of total energy of test. We can observe a larger gap between energy to maximum force and total energy of the test for all mixtures with fibres. That means, fibres are providing force transfer longer after crack propagation (point of maximum force).

At test temperature of 25 °C, this gap occurs for all mixtures, due to viscose behaviour of the bituminous binder at higher temperatures. However, mixtures with fibres have larger gap, than the 50/70 control mixture. Mix variant 0,1 % J2 showed best performance amongst them. Nevertheless, showed the best performance overall at the higher cracking temperature was shown for asphalt mixture containing PMB binder.

4. Conclusions

This paper presents an effort to find new admixtures for longer lifetime of asphalt pavements, which are meant to fit perfectly in line with sustainable development. Results of conducted tests showed:

- Higher voids content of asphalt mixtures with jute fibres, probably caused by lower compaction temperature or energy and by lower bitumen content of mixture.
- Lower values of ITSR - typical behaviour of asphalt mixtures with natural polymer (cellulose) fibres.
- Best results in stiffness modulus test from all – asphalt mixture with 0,2 % fibre content.
- Higher gap between crack propagation point (max F) and total energy of test in jute fibre reinforced asphalt mixtures. Fibres help to resist the crack propagation and are reducing the brittle failure of test specimens.
- Optimal jute fibre content with length 20 mm and low bitumen content (4,2 %) is found to be 0,2 % by weight.

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