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Asphalt mix reinforced with vegetable fibers

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Abstract. The use of a larger share of renewable materials in road construction is a trend that in the long term cannot be avoided. In some cases, due to this pressure, new innovative opportunities are generated. This article attempts to outline and bring one of such opportunity. The article describes selection and the use of special natural fibers from renewable natural resources adapted for use in various types of asphalt mixtures to improve the range of properties. Experimental results showed an improvement in stiffness modulus, indirect tensile strength (ITS) and good resistance to permanent deformation of blends containing vegetable fibers. This is a new topic in the road construction. But the results have so far proven that the used type of fibers can be a perspective way, as simple and in line with the policy of sustainable development, to improve the properties (reinforce) of the asphalt mixtures.

1. Introduction

This article is devoted to analyse the use of rather new, potentially perspective type of asphalt mix reinforcement. Its main purpose is to provide an introduction to the theme of the use of natural fibers in asphalt mixtures with a focus on fibers obtained from plants, which are increasingly starting to be used also in other parts of construction industry. In this industry, natural materials are currently mainly used for example as an insulation of buildings. However, natural fibers have greater potential than just work as simple insulators. In the automotive industry, they are used as reinforcement of plastic parts to form a composite structure with greater strength and lower weight than conventional plastic parts. In construction, the natural fibers as a reinforcing material begins to enforce slowly, but can be expected to increase their usage. Currently, for example, there are experiments with natural fibers working as a reinforcing additive in concrete, with potential application in the concrete pavement. However, the situation is different for the use in asphalt mixtures. The only natural material which is commonly added to asphalt mixtures, particularly mixtures of the SMA type, is cellulose or fibres based on basalt. Though, its primary function is not a reinforcement of the asphalt mixture.

The application of natural fibers for reinforcing asphalt pavement is still just a vision for greater use of renewable natural materials in construction industry. The high volume of traffic, the requirements for increased durability, sustainable development and lower cost of asphalt mixtures are a motor of discovery and use of new, perhaps unusual solutions.

2. Background

The use of fibers in asphalt mixes dates back many decades. Or longer: Button and Epps (1981) maintain that the earliest use of fibers in asphalt was the use of straw in ancient Egyptian building specifications. In the United States, asbestos fibers were used as early as the 1920s (Serfass and Samanos 1996), and this usage continued until the 1960s, when health and environmental concerns put an end to it (Busching et al. 1970). Cotton fibers were used in the 1930s (Busching et al. 1970), but they tended to degrade over time (Freeman et al. 1989). Since then many types of fibers have been used in various applications and different parts of the world. Fibers were reportedly used in asphalt mixtures for decades to provide the following benefits (Busching et al. 1970; Peltonen 1991):

- Increased tensile strength resulting in increased resistance to cracking,
- Reduced severity of cracking when it did occur,
- Increased fatigue resistance,
- Increased rutting resistance as a result of lateral restraint within the mixture,
- Increased abrasion resistance,
- Higher asphalt contents leading to increased durability, and
- Potential lower life cycle costs arising from longer service life. [1]

Early applications were in dense-graded asphalt mixtures. Beginning in 1991, the first SMA mixtures were placed in the United States after more than 30 years of successful use in Europe (Cooley and Brown 2001). These mixes were designed in Europe mainly to resist studded tire wear but were found to be highly resistant to permanent deformation as well. Usage in the United States increased rapidly: by 1997 more than 140 SMA projects across the country were evaluated by the National Center for Asphalt Technology (NCAT) (Cooley and Brown 2001). These mixes generally used cellulose or mineral fibers to help hold the asphalt binder in the gap-graded aggregate structure; that is, to prevent draindown of the binder. [1]

Fibers are also used in open-graded friction courses (OGFCs) or porous asphalt mixes to prevent draindown. These mixes have open-graded aggregate structures and high air voids to create stone-on-stone contact to resist rutting, reduce noise (McGhee et al. 2013), reduce splash and spray, and improve friction (Watson et al. 1998). [1]

In summary, there are two main uses for fibers:

- to prevent draindown in gap- and open-graded mixes, and
- to strengthen dense-graded asphalt mixes to resist rutting and cracking. [1]

Generally, it can be said, that for the first main usage are suitable cellulose (or natural) fibers. For the second main use are, with their greater elastic modulus and tensile strength, more suitable synthetic fibers such as aramid, fiberglass, polyester or similar. Only special type of synthetic fibers with irregular cross section are suitable to prevent draindown of bituminous binder. But there are few issues with synthetic fibers. The main issues are an environmental issue and economical aspect of usage of synthetic materials in construction industry. Others are e.g. polypropylene fibers which have low melting point requiring precise control of production temperatures, fiberglass fibers are brittle and may break during mixing and compaction, aramid fibers are very expensive. To secure the sustainable development policy we should looking for optimal solutions for common problems.

3. Vegetable fibers as asphalt mix reinforcement

Main goal of the research described in this article was to find an affordable and environment friendly material, which would simultaneously cover draindown and reinforce asphalt mixtures. After few thoughts it was clear, that the only material suitable to fulfill every request will be a natural fiber. Then another question arose, which one specifically? After few months of tests with many materials obtained from natural resources, the most promising candidates appeared. The most suitable fibers for use in asphalt mix seems to be hemp and flax fibers, processed into a yarn form.

Figure 1. Samples before thermal durability test.

Figure 2. Samples after thermal durability test.

3.1. Choice of fibers

Various materials were available at the beginning of the testing process. Waste materials, such as straw or raw sheep wool, hemp, flax and cotton fibers in both raw and yarn form (cut into pieces 40 – 60 mm long) and cellulose based fibers e.g. fine chipboard particles or recycled comminuted paper. Overall number of tested samples was around 22.

The amount of samples was too high, so their amount was decreased for the final testing in asphalt mix. Therefore, a special three steps selection process was designed.

First step was to find out a thermal durability of input samples, which were exposed to temperatures 150 °C, 180 °C and 220 °C for 120, 60 and 5 minutes. Weight decrease and color change of samples were monitored. Unsatisfactory samples were excluded from next steps.

Figure 3. Tufts of raw hemp fibers mixed with gravel.

Second step was about mixing samples with gravel for verification of a workability of samples. Samples with the most even dispersion in gravel were selected for further testing.

In the third and the last step, tensile strength was measured for all assessed samples. Only yarn samples were tested in this step. This process decreased the number of samples into final three, Flax 500 tex, Hemp 100x3 tex and Hemp 120 tex yarns. These samples were excellent in every testing step except sample of Hemp 120 tex, which had the lowest tensile strength but was chosen because of comparison reasons.

Natural fibers twisted into yarns have few advantages. First, twisted fibers interact with each other. Therefore, a yarn has greater tensile strength than single fibers. Second, there’s a workability factor.

Raw, single fibers tend to make tufts more easily when they are blended into asphalt mix and are hard to be cut into single pieces with exact length. Yarns prove great thermal durability too. This is major factor in case of use of vegetable fibers in hot asphalt mixes.

3.2. Yarns made of vegetable fibers

Yarns are available in many variations. Hemp and flax yarns are basically made of bast fibers, with a variety of thicknesses or better said different fineness, as it is an established term in textile industry. Eventual tensile strength of yarn depends on many factors. From conditions under which plants are grown through process of obtaining fibers from plants and it ends with spinning method, yarn fineness and cross-section. The very type of processing (spinning) fibers into yarns is crucial.

There are basically two main spinning methods:

- Ring spinning, which is the most common spinning method
- Open-end (or rotor) spinning

Ring spinning produces uniform and high strength yarns. Rotor spun yarns are more even, somewhat weaker and have a harsher feel than ring spun yarns. They are approximately 15-20 % weaker as the yarn is coarser because of loose outer layers. A further disadvantage of the loose outer layers is their sensitivity to axial rubbing. Since these open layers are not firmly secured in the core, they tend to accumulate in small knots during passage of the yarn over edges, guide elements, etc.[2,3]

Cross-section can consist of twisted fibers which create single yarn (Figure 2, 3), or can be more complex and consist of two or more single yarns/hanks twisted together (Figure 4). Yarn fineness is measured in "tex" unit; in other words, it can be defined as a unit of measure for the linear mass density of yarns.

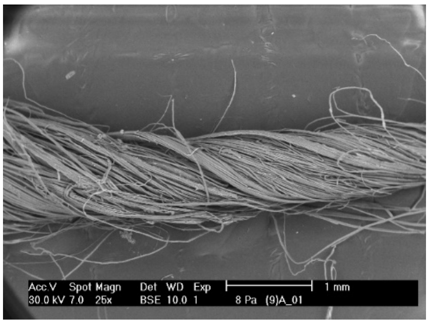

Figure 4. Ring spun flax yarn, 500 tex.

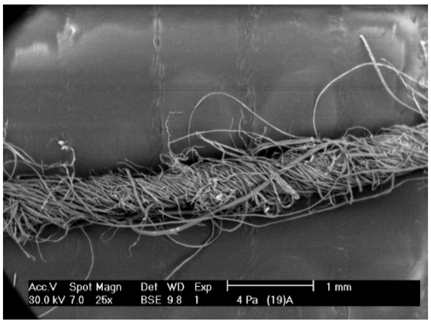

Figure 5. Rotor spun hemp yarn, 120 tex.

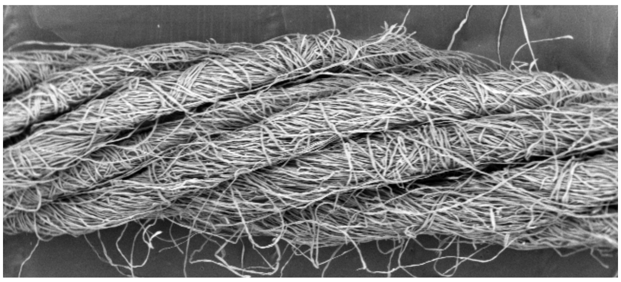

Figure 6. Plied cotton yarn made of ten single hanks, 50x10 tex.

4. Results from application of hemp and flax yarns in asphalt mixtures

For complex research of yarn addition influence on asphalt mixture mechanical properties two types of asphalt mixtures – AC_{bin} and SMA – were chose. Though, results from SMA mixture are not included in this article. Before mixing into a mixture, yarns were cut into 40-60 mm long elements. Yarn content in the mixture depends on the mixture type. Asphalt mixtures with yarns were compared with a reference mixture with identical mix design as well as with another reference where polymer modified bitumen was used. Binder in the asphalt mixtures with yarns and in the control mixture had a penetration grade 50/70. All tests and samples were designed and mixed in accordance with Czech standards, ČSN EN 13108-1 or ČSN EN 13108-5 depending on the assessed type of asphalt mixture.

4.1. Results of testing AC_{bin} 16 S mixtures

In this type of asphalt mixture 3 types of yarns – hemp 120 tex, hemp 100x3 tex and flax 500 tex – were tested. Yarn content in the mixture was 0.2 M%.

Table 1. Results of AC_{bin} 16 S tested mixtures – densities and voids content.

Asphalt mixture	Aspahlt content (%)	Bulk density ($g.cm^{-3}$)	Max. bulk density ($g.cm^{-3}$)	Voids content (%)
ACL 16 S 50/70 ref.	4.4	2.404	2.486	3.29
ACL 16 S 50/70 + Hemp 120	4.5	2.401	2.544	5.61
ACL 16 S 50/70 + Hemp 100x3	4.4	2.399	2.512	4.51
ACL 16 S 50/70 + Flax 500	4.4	2.424	2.522	3.90
ACL 16 S PmB 25/55-55	4.1	2.433	2.519	3.41

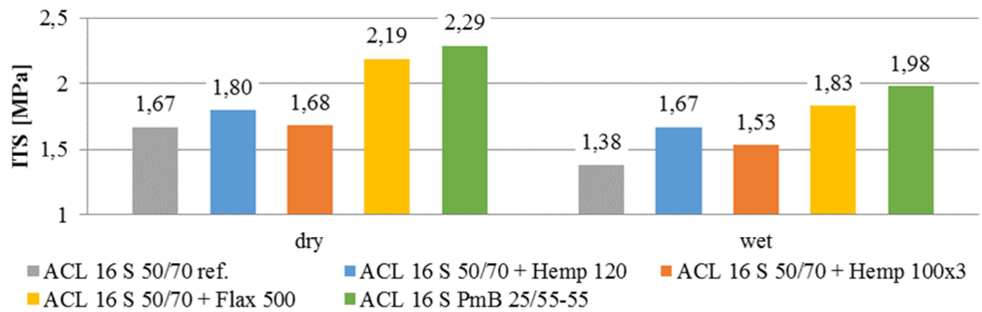

Figure 7. ITS results of asphalt mixtures AC_{bin} 16S with natural fibres.

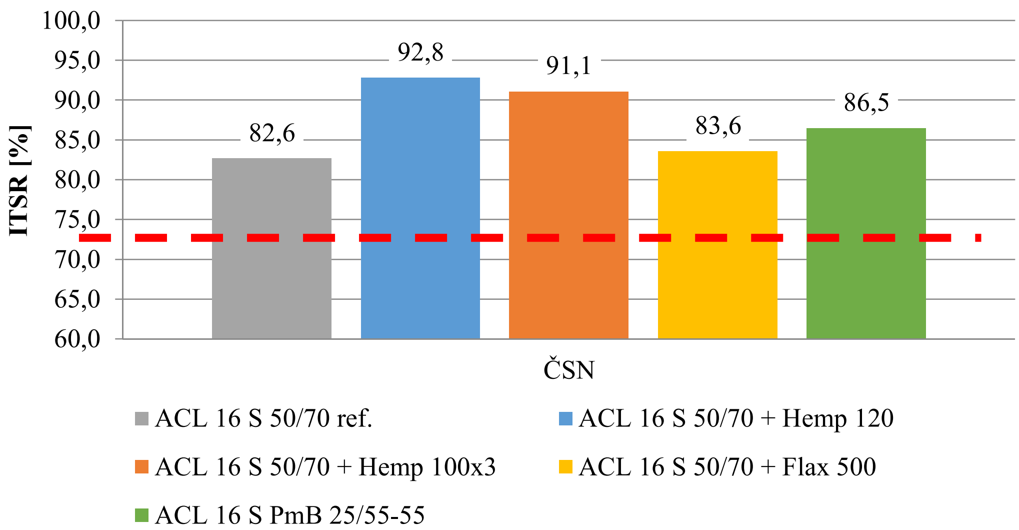

Figure 8. ITSR results of asphalt mixtures AC_{bin} 16S with natural fibres.

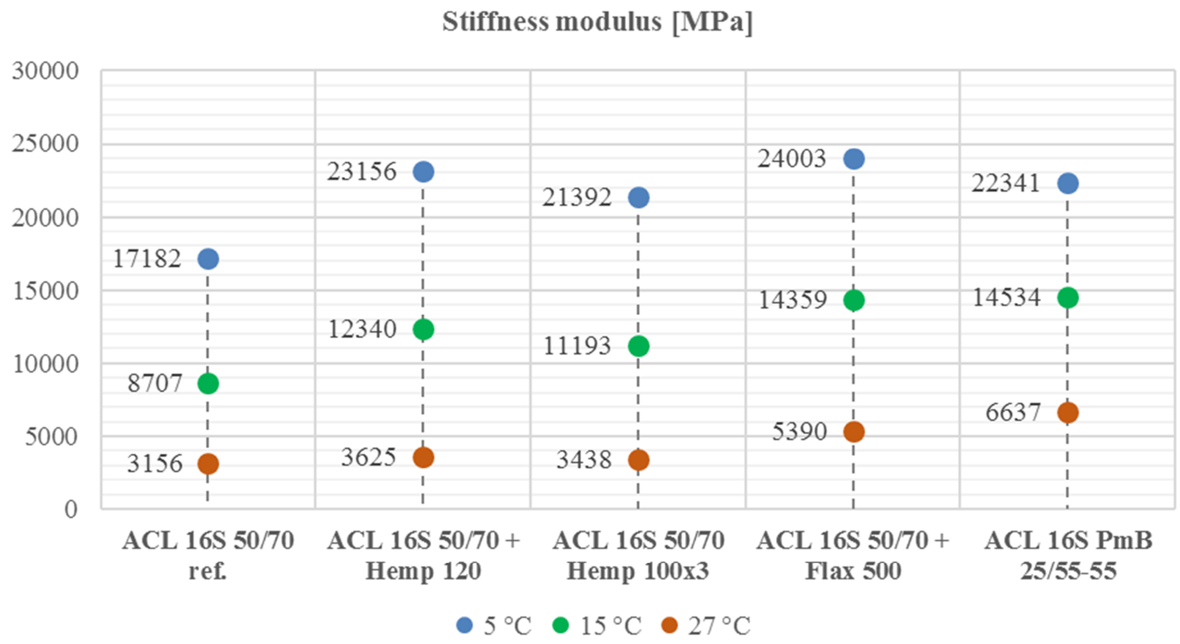

Figure 9. Stiffness modulus results of reinforced AC_{bin} 16S mixtures.

Results of performed tests show some potential of use of vegetable yarns as asphalt mix reinforcement. Asphalt mixtures with vegetable yarns show better tensile strength and rigidity than the reference mixture (Figure 7 and Figure 9). Especially the asphalt mixture with flax yarn reached promising values and results were close to the mixture with polymer modified bitumen. All mixtures fulfilled ITSR test requirement according to the Czech standards, which is at least 80 %. That is a proof of good water resistance of blends with vegetable fibers, although are water absorbent. However, when mixed in asphalt mixture, vegetable fibers soak up with bitumen binder, which protects them against water. That is also a key element in SMA type mixtures, when vegetable fibers hold bitumen binder and decrease binder pourability. Blends with yarns also shown good resistance to permanent deformation (Table 2.). Asphalt mixture laboratory slabs with 6 cm thickness were used for resistance to permanent deformation test. Test was conducted in air-bath at 50 °C in a small testing device according to EN 12697-22. Key material parameters were the proportional rut depth (PRD_{AIR}) and wheel tracking slope (WTS_{AIR}).

Table 2. AC_{bin} tested mixtures – densities and resistance to permanent deformation.

Asphalt mixture	Thickness (mm)	Bulk density (g.cm^{-3})	Degree of compaction (%)	Rut after 10 000 cycles (mm)	WTS_{AIR} [mm/10^{3}cycles]	PRD_{AIR} [%]
ACL 16 S 50/70 ref.	60.31	2.354	98.2	2.26	0.101	2.9
ACL 16 S 50/70 + Hemp 100x3	60.29	2.365	98.6	1.54	0.038	2.2
ACL 16 S 50/70 + Flax 500	60.13	2.386	98.4	2.01	0.039	3.0
ACL 16 S 50/70 + Hemp 120	60.22	2.372	98.5	1.52	0.033	2.1

5. Conclusion

A great potential of use of materials from renewable energy sources in asphalt pavements has been shown in this article. Except cellulose fibers, these materials are not common in road construction. Perhaps this is due to prejudice, distrust or underestimation of natural materials. It is understandable, that using vegetable fibers in an environment of relatively high temperatures, which undoubtedly hot asphalt mixtures are, may create some concerns. Only empirical concerns are not sufficient justification for ignoring any attempt to research this field. And the results of this article only confirm that. Asphalt mixtures with vegetable fibers achieved better results than the reference mixture; showing better tensile strength, stiffness and resistance to permanent deformation.

Issue of using the natural materials in construction industry is therefore a challenge for the future and the possibility of such simple, relatively inexpensive and significantly improve serviceability and the real life of asphalt pavements.

Acknowledgements

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