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THE USE OF FIBERS IN CEMENT-STABILIZED BASE COURSE OF PAVEMENT

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Abstract

Nowadays, various materials are being analyzed as a possible component of pavement structure with the goal of using sustainable building materials and protecting the environment. Waste and recycled materials are added to pavement layers in order to improve it. Also, the possibility of using natural, renewable materials by incorporating them into existing standard materials is been examined. Cement-stabilized base course increases load-carrying capacity of the pavement but is prone to cracking which causes reflection cracks in an asphalt surface. Reinforcement of cement-stabilized base course can be achieved by the addition of fibers. Fibers added to the cement stabilization tend to prevent or delay the crack initiation and propagation by redistributing the resulting stresses. Considering the research conducted to-date and the need to use sustainable materials in combination with cement stabilization, some attempts are being made to achieve improvements of this pavement layer. Natural fibers are locally available, economical, renewable and degradable, and can be used as reinforcement. In the Mediterranean area, a possible source of cellulose fibers is found in the wild plant named Spanish Broom (Spartium junceum L). This paper offers an overview of research studies about fiber reinforcement of cement-stabilized base course. It also presents current research on Spanish Broom fibers in cement composites, as well as possible ways of obtaining and treating fibers. Based on the results of this research, a method for obtaining the fibers can be selected which might improve the mechanical properties of cement-stabilized course.

Keywords: cement-stabilized course, fibers, Spanish Broom

1 Introduction

Cement-stabilized base (or subbase) course (CSBC) is the structural part of pavements. It is a good base for upper pavement layers due to its high strength and low sensitivity to water, as well as a good protection for underlying layers because it significantly reduces stresses caused by traffic load. The main problem of CSBC is its sensitivity to cracking, which eventually reflects through the upper bituminous layers to the surface. Over time, cracks can widen and the pavement can become damaged, which seriously reduces its structural strength, thus affecting the pavement service performance. The use of fibers may help control the problem with cracks, especially in the light of the findings of previous studies on cementitious materials. Adding fibers to the cement mixture might affect the mechanical properties and control crack initiation, propagation rate and width. Reinforcement of CSBC can be achieved by the addition of fibers to improve the toughness, ductility and cracking resistance of the cement matrix. There are different types of fibers that can be used as reinforcement, and given their origin, they can be classified into four basic groups: steel, glass, synthetic and natural fibers. The influence of fiber addition on crack resistance and mechanical properties of cement stabilization have been analyzed in numerous research studies, some of which are presented in this paper. Nowadays, more attention is paid to the possibility of using waste, recycled and natural materials with the aim of protecting the environment and using renewable materials. Natural fibers have not yet been tested as a possible reinforcement in CSBC; hence, the basic properties of cellulose fibers, with an emphasis on Spanish Broom fibers, are presented in this paper.

2 Reinforcement of the cement-stabilized base course by various fibers

CSBC contains aggregate of various sizes, small quantities of cement and water. This layer has high strength, rigidity and water stability. However, this material also presents some disadvantages, such as high shrinkage rate, poor resistance to deformation and high brittleness [1]. Because of that, and due to changes in temperature and humidity, cracks appear in this layer of pavement. Initial cracking occurs in the form of transverse cracks caused by thermal contraction and shrinkage of the layer. Secondary longitudinal cracking is created due to the traffic load. Those cracks cause most damage in the pavement and they occur owing to the tensile failure of a CSBC. They are controlled by improving the aggregate gradation, adding various additives or applying other pre-cracking techniques. These measures are less effective in preventing CSBC from cracking and do not solve the cracking problem effectively [1][2]. Fiber reinforcement in CSBC is intended to overcome the problems which result from cracking. Adding fibers to CSBC strives to prevent or delay generation and propagation of cracks by transferring the resulting stresses to adjacent sections. This can be achieved because fibers act like bridges between two cracked sides of the matrix, i.e. like micro reinforcement. The fiber reinforcement of CSBC is examined in various research studies. Shahid et al. [3] reinforce CSBC with 1 % (by volume) steel fibers. They perform tests on cube specimens (100 mm sides) and cylinder specimens (150 mm diameter and 150 or 300 mm height) and compare the results with and without fibers. They analyzed direct and indirect tensile strength, compressive strength, elastic stiffness, load versus deformation characteristics and post-cracking behavior of the mixtures. The resulting cracks in the specimens have had a very narrow width and a high load transfer. The tensile strength increased by 33 %, whereas the compressive strength did not change significantly. Coni and Pani [4] presented results of the experimental indirect tensile tests of reinforced CSBC with steel fibers. Also, they analyzed two semi-rigid pavement sections to evaluate the effects of fibers during the pavement service life. The number of load cycles prior to collapse increased by more than 60 times on the section with 3.5 % of cement and 1.5 kg/m^3 of steel fibers.
Farhan at el. [5] used recycled steel fibers extracted from old tires (0.5 % by volume of aggregate) to reinforce the CSBC matrix. Cement content varies up to 7 % by weight of aggregate and fibers. As expected, the results indicate better tensile strength in the case of reinforcement with higher cement content. Also, the use of steel fibers (extracted from waste tires) reduces the crack propagation rate at all cement contents, with the greatest reduction occurring at high cement contents. They recommended that this reinforcement should be used with a cement content not lower than 5 %. Zheng et al. [2] used basalt fibers for mixtures of CSBC with the constant length of fibers (25 mm) and their different content. The tests included the analysis of compressive and flexural strength of specimens, the analysis of anti-shrinkage properties and the analysis of cracking. The results indicated higher flexural strength without significantly affecting the compressive strength of specimens. The anti-dry shrinkage properties and cracking ability under the temperature cycle of cement-stabilized macadam are improved by basalt fibers in quantities exceeding 6 kg/m^3.

Basalt fibers can help the CSBC to transfer and share the load stress, thus improving the cracking resistance capacity of CSBC.

Zhang et al. and Peng et al. [1][6][7] analyzed the effects of polypropylene fibers on the properties of CSBC. Mechanical and shrinkage properties of CSBC were improved. Polypropylene fibers can decrease the average dry shrinkage coefficient and average thermal shrinkage coefficient with the growth of fiber content (up to 0.1 % of fiber volume), so the fracture behavior is improved. With the increase of fiber volume, the compressive modulus of resilience and flexural modulus of elasticity also decrease. By reinforcing CSBC with polypropylene fibers, Ma et al. [8][9] investigated the fatigue performance and the freeze-thaw performance of specimens. They concluded that the mixing of polypropylene fibers of a certain length and volume content into the cement-stabilized aggregate can significantly improve its bending fatigue resistance. The amount of fibers they recommend is 0.7 kg/m3. The fibers improve the density of the internal micro-structure of the cement-stabilized aggregate, which helps to improve the strength and fatigue performance of the specimens. The freeze-thaw compressive strength and freeze-thaw splitting strength in reinforced specimens increased, while the freeze-thaw mass-loss rate decreased.

Liu [10] investigated the effects of CSBC reinforced by polyester fibers. His conclusion based on the conducted test is that the addition of those fibers can effectively decrease the shrinkage coefficient in CSBC, following the fiber content increase. At the optimum fiber content (approximately 0.7 ‰), the cleavage strength and the compressive strength of mixed specimens increase, by 7.6 % and 7 % respectively. Also, the effects of polyester fibers are compared with those of polypropylene fibers. According to his results, polyester reinforcement has a greater effect on the performance of CSBC specimens than polypropylene reinforcement. Cavey et al. [11] conducted a coordinated laboratory and field study to assess the feasibility of producing an economically suitable pavement base course material by reinforcing cement-stabilized recycled concrete aggregate with strips of reclaimed plastic or tire wires and tire chunks from recycled scrap tires. Based on the results, they concluded that the waste fibers not only afforded little or no improvement in material behavior, but also adversely affected both the strength and toughness of the composite material.

Nowadays, a special emphasis is placed on the use of environmentally friendly materials and in this regard, extensive research is being conducted on the possibility of using renewable natural fibers in composite materials. The use of cellulose fibers and their effect on the CSBC has not been investigated so far.

3 Reinforcement by natural fibers

Natural cellulosic fibers have several advantages, such as low cost, bio-renewability and biodegradability, low density, good toughness and strength [12]. Different properties of fibers, including their length, diameter, density, surface roughness and structure, stem from different natural sources. The quality of fibers also depends on their required processing. All of those characteristics will result in the quality of adhesion between fibers and the matrix, and further impact the properties of composite materials. The use of cellulose fibers results in reduced plastic shrinkage and better thermal and sound insulation. The reinforcement capacity of specimens with fibers also depends on the amount of fibers used, their length/thickness ratio and dispersion in the matrix [13]. Fiber-matrix bonding can be well-balanced, allowing stress transfer between the matrix and the fibers. On the other hand, if fibers are not well spread in the matrix because of proportioning limitations (they are too long or overdosed), it can cause a grouping of fibers which results in a non-existent or poor bonding quality. Fiber modification with different treatments can improve the durability of the fibers themselves and the fiber–cement matrix adhesion. Due to the need to obtain fibers from the shoots, some chemical elements of the structure need to be decomposed, which can be

achieved by soaking those shoots in appropriate solutions. This process is called maceration.
Ardanuy et al. [13] presented a review of recent research studies on cement-based composites reinforced with cellulosic fibers. The reinforcement based on cellulose fibers can be classified by the function of their form (strands, staple fibers or pulp). Some of the natural fiber sources that are used in cement-based composites are hemp, jute, sisal, agave, eucalyptus, coir, banana and pinus [13]. According to [13], the use of cellulose fibers can improve the mechanical properties of cement-based composites if the fibers are adequately dispersed in the matrix. One of the disadvantages of using natural fibers is that they have great variability in mechanical properties. The quality of natural fibers depends on geographical and climate conditions, soil quality, weathering conditions, extraction methods, time of harvesting and plant maturity [14].

4 Properties of Spanish Broom fibers

In the Mediterranean area, a possible source of cellulose fibers is found in the wild plant named Spanish Broom (Spartium junceum L). Spanish Broom usually grows as a bush varying from 1 to 1.5 m in height and it is widely known for its yellow flowers characterized by a rather intense scent. Branches are very tough and constitute the most important part of the plant. The fibers can be found inside the shoots and the process of obtaining fibers includes harvesting and maceration of shoots. Spanish Broom bushes and fibers obtained after the maceration of shoots are presented in Figure 1. The chemical composition of Spanish Broom fibers (SBF) is 91,7 % cellulose, 3,2 % lignin, 4,1 % pentosane and some ashes [14]. SBFs have the lowest specific weight and similar tensile strength compared to other natural fibers. Angelini et al. [15] established that the elastic modulus for Spanish broom is approximately 21.5 GPa, which is in the range of other fibers such as cotton, jute and sisal [16].

Figure 1 Spanish Broom bush and fibers

Several studies have been conducted on the possibility of using SBF as a reinforcement for composite materials. Nekkaa et al. [17][18] used SBF and polypropylene matrix. The tests indicated that the quantity of absorbed water increased with an increase of SBF in the composite. Good adhesion between the fibers and the matrix can be improved if the fibers are treated with silane. The surface treatments give better tensile and impact strength as well as fiber dispersion. Kovačević et al. [19] reinforced polylactic acid matrix with SBF. Avella at al. [20] used SBF as reinforcement for the polypropylene matrix. In both studies, better mechanical properties were obtained compared to non-reinforced specimens.
Juradin et al. [14][16] examined the possibility of cement mortar reinforcement with SBF. They treated the shoots in the solution of 5 % NaOH, in seawater and a combination of alkali (5 %

NaOH) and seawater. After obtaining the fibers, they cut them into three lengths: 10, 20 and 30 mm. The quantities of fibers in cement mortar were 0.5 % and 1 % of the total volume. Fibers with 10 and 30 mm in length have achieved better results than fibers of 20 mm in length. The samples with 30 mm-long fibers showed the highest flexural strength values, but also a slight decrease in compressive strength. Furthermore, the authors compared referent mortar specimens (label E – specimens without fibers) with those whose fibers were obtained by a 28-day maceration with seawater, followed by 7 days in 5 % NaOH solution (label MN). They concluded that SBF specimens can take over the load, while the etalon specimens are currently fractured, which is ultimately the purpose of micro-reinforcement (Fig. 2a). Fig. 2b shows fiber reinforcement of Spanish Broom in cement mortar specimens.

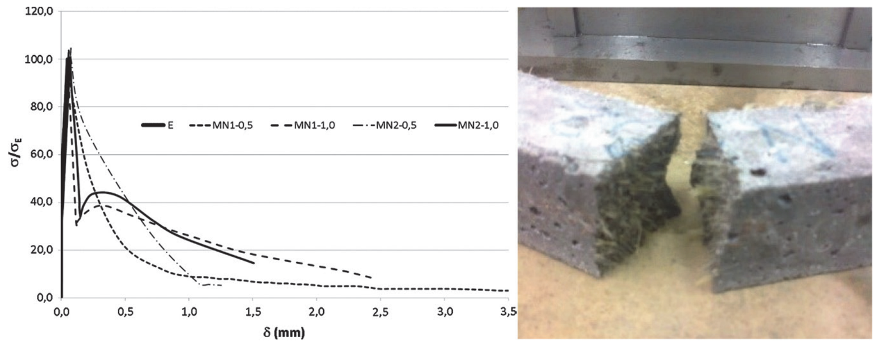

Figure 2 a) σ / σE – δ diagram [23] and b) SBF reinforcement of cement mortar

In [21] the authors compared the results obtained for Spanish Broom and hemp fiber-reinforced mortars and concluded that natural fibers do significantly increase mortar ductility. Treatment of Spanish Broom and hemp fibers in different solutions (2.5, 5, 6, 8, 10 and 15 % NaOH solution, 2.5 % NaOH + 2 % Na_2SO_3 and 5 % NaOH + 2 % Na_2SO_3 mixed solution, seawater, and a combination of 5 % NaOH and seawater) showed that pH values of the treatment medium influence the crystallinity of fibers. It was observed that the Spanish Broom fibers showed potential for reinforcing cement-based composites.

5 Conclusion

Cement-stabilized base course increases load-carrying capacity of the pavement and serves as a good protection of underlying layers because it redistributes stresses over a wide area. The main disadvantage of this layer is its sensitivity to cracking which causes reflective cracking in the asphalt surface. Results of the presented studies indicate that reinforcement of CSBC with steel or synthetic fibers can improve certain mechanical characteristics of the material. The improvements depend on type, characteristics and amount of fibers, amount of cement and the quality of bonding between fibers and the cement matrix. With regard to using sustainable materials, natural fibers are renewable, biodegradable and environmentally friendly. Research conducted with Spanish Broom fibers has indicated the potential for reinforcing cement-based composites with these fibers. Due to the fact that the Spanish Broom plant is locally available and its fibers contribute to the reinforcement of different materials, the aim of the future study is to use SBF in the CSBC matrix. Therefore, future research will be based on examining the possibility of CSBC reinforcement with differently treated (NaOH and seawater), different lengths and different amounts of SBF.

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