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# Evaluation of mechanical properties for stone mastic asphalt containing textile waste

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## ABSTRACT

Bitumen draining in stone mastic asphalt mixtures has become a potential problem. Due to the storage and laying temperatures as well as difficulties in providing the necessary compaction, the temperatures of the asphalt mix cannot be lowered to prevent or reduce drainage. In stone mastic asphalts, generally cellulose or mineral-based fibers are preferred to reduce draining down of bitumen. Conventional fibers commonly used in stone mastic asphalt increase pavement costs because they are expensive.

The aim of this research is investigation of textile waste used to prevent bitumen drainage problem in stone mastic asphalt pavements instead of traditional fibers. Following the determination of the bitumen content, Marshall Stability tests, Schellenberg bitumen drainage test and Indirect Tensile Strength tests were conducted to evaluate the mechanical properties of the stone mastic asphalt mixtures in comparison to mixes containing textile waste. The results indicated that it is possible to produce stone mastic asphalt mixes with textile waste that exhibits similar mechanical properties mixes including cellulose fiber. Moreover, it was found that samples prepared with textile waste exhibits advantage in terms of cost compared to samples prepared with cellulose fiber.

**Keywords:** Asphalt; cellulose fiber; mechanical property; recycling; textile waste.

## 1. INTRODUCTION

All kinds of substances that we do not need and remove can be defined as waste. It is divided into three as solid, liquid and gas. With the recycling of waste; our natural resources will be protected, energy savings will be achieved, the amount of waste will be reduced, a contribution to the economy will be made and an investment will be made in the future [1].

There are three basic principles of solid waste management in the world. These are the generation of less waste, the recycling of waste and the disposal of waste without harming the environment. In our world where natural resources are limited and consumption is increasing rapidly, one of the issues that has been emphasized in recent years is recycling [2, 3]. In addition to preventing waste of resources, raising living standards. Developed countries that see this reality with their efforts are developing methods for recycling and reuse of wastes [4–6].

The Turkish textile industry consists of cotton yarn, wool yarn, silk yarn, regenerated yarn, synthetic yarn, weaving, knitting as well as nonwoven products. The most commonly used fibers in the textile industry are mainly cotton, vegetable fibers such as jute and sisal, and animal fibers such as wool and silk [7, 8].

Processes such as yarn production (carding, drawing, combing, roving, spinning etc.) fabric weaving (winding, warping, sizing, tying, weaving etc.), fabric knitting, fabric dying and printing of various textile products and cutting, sewing and embroidery on them are carried out in textile production units. In these production units; industrial solid wastes such as fabric scraps, yarn wastes, mattresses, fiber wastes, ragweed and dusts are formed. Production units sell some of these solid wastes to scrap dealers for recycling, and throw away or incinerate some of them [5, 8, 9].

In the world, highways are under the influence of heavy traffic loads. The increase in stresses cause deterioration in the pavement and decrease in road service capability [10]. It is necessary to carry out maintenance and repair operations in terms of the continuity of transportation. In such cases, there will be an additional cost to the country's economy [11–13]. Stone mastic asphalt mixtures, which show higher resistance to negative effects,

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have started to be used more widely in our country in recent years in order to reduce the deterioration and the total costs [14].

Stone Mastic Asphalt (SMA) pavements are a design used for the first time in Germany. SMA were used to prevent deformations after it was understood that they cause deformations in the wear layer of studded tires, which started to be used on snowy roads in Germany [15, 16]. SMA is a kind of bituminous pavement prepared in accordance with the plans, profiles and cross-sections specified in the design project by mixing crushed and sieved coarse aggregate, fine aggregate and mineral fibers containing at least four different grain groups with certain gradation limits and physical properties.

Although the construction cost is 20–25% more than traditional asphalt designs when the initial and final costs are considered together, SMA has significant advantages throughout its long term service life [17, 18]. The main advantages of the use of SMA are long service life, high resistance to continuous deformations and abrasion, resistance to moisture, slow aging, low noise level [17–20]. Due to these superior features, it is preferred in intersections, bus stops, parking lots, sloping lands, bridges, ports and routes where heavy traffic loads pass [21]. However, segregation of crushed SMA mixtures is the main disadvantage point. Nowadays, this problem has been solved by using expensive stabilizing additives [22, 23].

Stone mastic asphalt (SMA) has high durability due to the fact that it is an asphalt mixture with a course type of aggregate distribution by the contact of the stone with the stone and the high binder content that fills the void structure [24]. Due to its high binder content and porous structure, bitumen is drained from aggregates during production, transportation and laying. It is undesirable for the bitumen to be filtered from the aggregates [25].

Additives such as fiber or polymer are used to fix the mastic in the stone framed structure and to prevent these infiltrations [26]. Besides, use of fibers can contribute to the reduction of traffic noise that occurs between wheels and surface of pavements [27, 28]. Drainage of bitumen is considered as the portion of the mixture (fine materials and bitumen) that flows down the mixture, separating it from the sample as a whole [29, 30]. The amount of drainage is limited to a maximum of 0.3% of the mixture weight by General Directorate of Highways specifications [31, 32].

In recent years, researchers have been studying on obtaining new products with high performance, reducing production costs, protecting natural resources, less harmful to the environment and more efficient to replace highly cost SMA pavements. Mainly, coconut, sisal, banana fibers, waste plastics and polypropylene are used in SMA mixtures to eliminate waste and to achieve the drainage tests [26]. ARSHAD *et al.* [29] and UDAYABHANU *et al.* [30] observed that sunhemp and kenaf fibers improve the performance against to rutting in asphalt pavements. According to review work by KUMAR and RAVITHEJA [33]; mechanical properties of asphalt mixtures containing coconut fiber obtained better results compared to sisal and banana fibers. BABY *et al.* [34] proved that waste carpet fibers could be an alternative option as stabilizing additives in SMA pavements. RAHMAN *et al.* [35] and SHEKAR *et al.* [36] stated that sugar cane high density polyethylene, marble quarry waste, building demolition waste, crushed rubber, cooking oil, palm oil fuel ash, coco-nut, sisal, cellulose and polyester fiber, starch, plastic bottle, waste glass, waste brick, waste ceramics, waste volatile ash and various wastes such as cigarette butts would play an important role in reducing the costs of asphalt pavement and reducing environmental pollution by eliminating the wastes in the asphalt industry for a sustainable future.

The main aim is both to present a study at reducing the increasing waste density of the textile industry, which is one of the important sectors of Turkey due to production, and to propose a new product that can replace the highly cost cellulose fiber used in SMA pavements in asphalt industry.

## 2. MATERIALS AND METHODS

Materials which were selected in the scope of this study provide all regulations General Directorate of Highways in Turkey. Basalt was used in the coarse aggregate as well as limestone is used in the fine aggregate components. 50/70 penetration grade base bitumen supplied from İzmir Aliağa Refinery. Unmodified bitumen is to better observe the effect of fibers by eliminating the favorable effect of polymers in bitumen drainage tests. In the study, no additives were added to the bitumen in order to clearly reveal the effect of textile wastes in asphalt mixtures.

Stabilizing additives are used in Stone Mastic Asphalt (SMA) mixtures to minimize the drainage of the binder. These additives are called stabilizers or drainage inhibitors. These additives stabilize the aggregates in the mixture with high bitumen content and prevent the draining downing of bitumen from the aggregates. Stabilizers consist of bitumen absorbent additives (mineral, cellulose fibers) or viscosity increasing additives (polymers).

Among the binder absorbent stabilizers, the most effective stabilizer to date is cellulose fibers. Since these fibers have very high binder absorption, they allow the binder to be held firmly in place. Cellulose fibers consist of irregularly shaped loose fiber forms, granule forms of fibers that do not contain binders, or granules in the form of cylinders formed by a mixture of binder material (bitumen, wax, etc.) with fiber [15]. Cellulose fibers, which are used as stabilizers in SMA mixtures, are preferred because of their absorbent power. In addition to preventing the draining down of bitumen in asphalt mixtures, cellulose fibers also have advantages such as increasing the cracking resistance, reducing the formation of reflection cracks and contributing to the increase of mechanical stability. Since traditional cellulose fibers produced by various brands are expensive products, they cause an increase in pavement total costs. To overcome this problem, inexpensive and environmentally friendly fibers have been the subject of many research.

In this study, the experimental results were compared by using textile wastes instead of traditional cellulose fibers. The image of the conventional cellulose fiber used in the SMA mixture is given in Figure 1 as well as the image of the textile waste is given in Figure 2. The mechanical properties of the cellulose fiber and textile waste according to the regulation of the Turkish General Directorate of Highways are shown in Table 1. In the present study, textile wastes are cotton that are collected from cotton yarn spinning mill at Polat Textile

**Figure 1:** The image of the conventional cellulose fiber.

**Figure 2:** The image of the textile waste.

**Table 1:** Mechanical properties of the cellulose fiber and textile waste.

| PROPERTY | CELLULOSE FIBER | TEXTILE WASTE | SPECIFICATION |
|---|---|---|---|
| Ash content, % | 16 | 14 | %18 ± %5 |
| PH | 7.8 | 6.9 | 7.5 ± %1 |
| Oil absorption, gr | 9.5 | 6.0 | Fiber weight 5 ± 1 multiple |
| Moisture absorption, % | 6 | 5 | %5 by weight |

Company. In order to prevent agglomerations of textile wastes in SMA mixture and to prevent dusting before being added to the aggregate mixture, it was compressed and brought into pallet form.

Fibers are added to the mixture at the rate of 0.3%–0.1% of the mixture weight for the SMA wear layer, or at the rates recommended by the manufacturer. In this study, stone mastic asphalt mixtures were evaluated by adding textile waste and cellulose fiber at the rate of 0.3%. Then, the experiments were repeated by adding 0.1% textile waste and 0.2% cellulose fiber in order to reduce the proportion of the material used.

### 2.1. Stability and flow tests

Marshall design method is an experiment applied to hot bituminous mixtures in accordance with TS EN 12697-34 standard and is an experiment applied to determine stability and optimum bitumen ratio [32]. Stability is known as the specimen's maximum resistance to deformation, while yielding is the vertical deformation that occurs when the maximum load is reached. The heights of the compressed and cooled samples are measured and recorded in accordance with the standard. Marshall test steps of SMA samples are illustrated in Figure 3. Marshall stability test is performed on cylindrical compressed samples with a diameter of 100 mm and a height of approximately 63.5 mm, placed in a water bath at 60 °C for 30–40 minutes. It is an empirical experiment in which the fault is then loaded using curved steel loading plates across a diameter at a constant rate. At the compression condition of 51 mm/min, the Marshall stability value (in kN) is the maximum force recorded during compression, while yield (in mm) is the deformation recorded at the maximum force. Hence, the optimum bitumen value is evaluated by the bitumen content corresponding to the median of designed limits of percent air voids ($V_h$) in asphalt mixture specimen. According to Marshall test results, authors determined the optimum bitumen content corresponding to 4% air voids.

### 2.2. Drainage test

Bitumen ratio is higher in SMA mixtures compared to traditional hot mixtures. With the excess of bitumen ratio, problems such as the bitumen draining and moving down during transportation or bleeding after the pavement production is terminated. Drainage test steps of SMA samples are presented in Figure 4. The prepared mixture is placed in a 1000 ml glass beaker heated for 15 minutes in a 110 °C oven and weighed with an accuracy of 0.1 g.

The beakers are covered and kept in an oven at 175 °C for unmodified bituminous mixtures. At the end of this period, the mixtures are removed from the oven and the mixture is emptied without shaking the beakers. The emptied beaker is weighed with an accuracy of 0.1 g and the weight loss is calculated as a percentage. According to the specification, the Schellenberg bitumen drainage percentage should be 0.3% maximum.

### 2.3. Indirect tensile strength test

In the evaluation of the mechanical properties of asphalt pavements, indirect tensile strength (ITS) values are used instead of Marshall stability in terms of tensile strength. Indirect tensile strength (ITS) is one of the most important parameters in determining the stiffness of the pavement. As this value increases, the cohesion increases. For this reason, the cohesion property of the bitumen directly affects the ITS value. The ITS test is used also to calculate the tensile strength of hot bituminous mixtures and to characterize the tensile stresses due to temperature and fatigue.

The loading speed of the Marshall device should be adjusted according to the indirect tensile test. For this, the loading speed of the Marshall device is set as 51 mm/min. According to ASTM D6931-07, a cylindrical specimen is placed with a single or repeated compression load moving parallel to and along the vertical diameter plane at a specified rate of deformation as well as test temperature. The peak load at failure is recorded and used to calculate the IDT strength of the specimen. Diagram of an IDT strength loading fixture is illustrated in Figure 5.

**Figure 3:** Marshall test steps of SMA samples.

**Figure 4:** Preparation SMA mixture samples for the Schellenberg test.

The tensile strength using the following Equation 1 is calculated.

$$St = 2P/\pi*t*D \quad (1)$$

Where;

St = Horizontal tensile stress at center of specimen, kPa.

P = Applied load, kg.

D = Diameter of specimen, cm.

t = Thickness of specimen, cm.

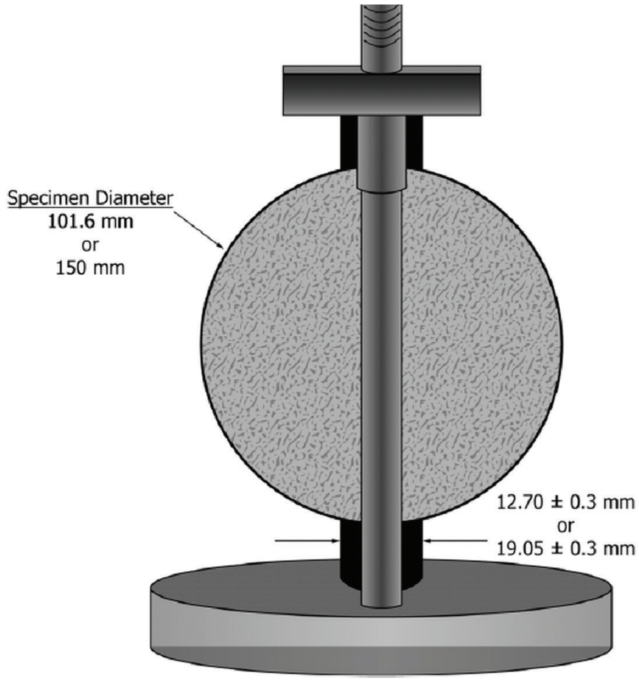


**Figure 5:** Diagram of an IDT strength loading fixture.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Stability and flow tests results

The value of optimum bitumen content that maximizes the Marshall stability value, the optimum bitumen. The optimum bitumen ratio that provides 3% voids in accordance with the specification (within the limit of 2-4 percent for the binder layer in the specification) are all determined by the Marshall stability value. After finding the optimum bitumen content, the flow value corresponding to this ratio is checked in the flow-bitumen graph and the parameters are determined.

The stability and flow values of 12 design samples were determined with the performance of Marshall Stability test device. The samples were kept in 60 °C water for 30 minutes and the sample was placed in the device within 30 seconds after being removed from the water. Consequently, the experiment was completed within 45 seconds. Volume specific gravity ($D_p$, g/cm$^3$), maximum theoretical specific gravity ($D_t$, g/cm$^3$), air void ($V_h$, %), the void ratio between mineral aggregates (VMA, %), voids filled with bitumen (VFA, %), flow (mm) and stability (kN) results related to SMA mixtures containing 0.3% cellulose fiber, 0.3% textile waste, 0.2% cellulose fiber and 0.1% textile waste were shown in Table 2.

Bitumen is a hydrocarbon material obtained from the fractional distillation of petroleum, which is used as binder in asphalt pavements. Bitumen cost varies depending on oil prices. According to air void content (3.5%), optimum bitumen ratio of asphalt mixtures including 0.3% cellulose fiber, 0.3% textile waste, 0.2% cellulose fiber and 0.1% textile waste are determined as 6.70%, 6.50%, 6.60%, 6.40% respectively. The utilization of textile waste instead of cellulose fiber in SMA mixtures reduced the optimum bitumen ratio required in asphalt mixtures. The decrease in the optimum bitumen ratio in asphalt mixtures provides economic profit.

It was evaluated from the results that the optimum bitumen ratio of the mixtures prepared with textile waste was less than the cellulose fiber mixtures. While the SMA mixture with 0.3% textile waste content gave the highest stability value, the lowest stability was obtained by 0.2% cellulose fiber mixture. SMA mixtures prepared with textile waste contributed to Marshall stability [37]. The increase in stability with the addition of different contents of textile waste indicates that the asphalt pavement is more resistant to rutting and permanent deformations.

The flow values of the mixtures prepared with textile waste increased within the specification limits compared to the mixture prepared with traditional cellulose fiber. Flow is a value that determines the behavior of the pavement under traffic loads and determines its plasticity and flexibility properties. The increase in flow value with the use of textile wastes in SMA mixtures indicates that the behavior of the pavement at the time of fracture may change positively.

When the amount of fine aggregate in the asphalt mixture is high, fine aggregates absorb bitumen. When the coarse aggregate ratio is high, it cannot be completely covered with bitumen which causes a decrease in durability. The durability of a bituminous film increases as its thickness increases. However, an appropriate void ratio between mineral aggregates (VMA) is required to provide an adequate bitumen film thickness without allowing the bituminous mixture to bleeding. The allowable VFA values for asphalt specimens are expected to be from 65% to 78% for medium traffic volume and from 70% to 80% for heavy traffic volume [15]. Also, the minimum VMA values for SMA is 16% within the specification limits. Test results revealed that all SMA mixtures prepared with cellulose fiber and textile waste specimens might meet desired values in terms of VMA and VFA.

### 3.2. Drainage test results

In the technical specifications of the General Directorate of Highways, the Schellenberg test result is required to be a maxi-mum of 0.3%. A total of 12 Schellenberg test samples were car-ried out in order to determine which fiber this condition was met with and the effect of fiber additive ratio on the test result. 6 of these tests consisted of mixtures containing cellulose fiber at the rates of 0.3% and 0.2%, and 6 of them containing textile waste at the rates of 0.3% and 0.1%.

The draining amounts of mixtures containing 0.3% cellulose fiber, 0.3% textile waste, 0.2% cellulose fiber and 0.1% textile waste are presented in Table 3.

When the Schellenberg drainage test results are examined, it is concluded that SMA mixtures prepared with cellulose fiber drain more than SMA mixtures prepared with textile waste, regardless of fiber and waste ratio. Considering the fiber and waste ratio, the draining ratio decreased as the fiber ratio increased for both fiber types. When Table 3 is examined in general, it is concluded that the use of 0.3% textile waste would be the most appropriate in order to prevent the draining down problem of bitumen in SMA pavements.

Increasing the use of stabilizers in asphalt designs increases the optimum bitumen ratio, resulting in an increase in costs. it is among the important results that using textile waste instead of cellulose fiber will both decrease the optimum bitumen ratio and prevent drainage of the bitumen from aggregate.

### 3.3. Indirect tensile strength test results

Indirect Tensile properties of SMA mixtures containing 0.3% cellulose fiber, 0.3% textile waste, 0.2% cellulose fiber and 0.1% textile waste at the optimum bitumen content are given in Table 4 and Figure 6.

**Table 2:** Marshall test results.

| MIXTURES | CELLULOSE FIBER | TEXTILE WASTE | CELLULOSE FIBER | TEXTILE WASTE |
|---|---|---|---|---|
| Stabilizer rate (%) | 0.3 | 0.3 | 0.2 | 0.1 |
| Optimum bitumen (%) | 6.70 | 6.50 | 6.60 | 6.40 |
| $D_p$ (g/cm$^3$) | 2.271 | 2.277 | 2.274 | 2.281 |
| $D_t$ (g/cm$^3$) | 2.352 | 2.358 | 2.355 | 2.361 |
| $V_h$ (%) | 3.50 | 3.50 | 3.50 | 3.50 |
| VMA (%) | 16.84 | 16.48 | 16.66 | 16.24 |
| VFA (%) | 79.0 | 78.2 | 78.5 | 77.9 |
| Flow (mm) | 4.42 | 4.48 | 4.28 | 4.31 |
| Stability (kg) | 814 | 838 | 798 | 812 |

**Table 3:** Schellenberg drainage test results.

| STABILIZER RATE (%) | OPTIMUM BITUMEN RATE (%) | DRAINAGE RATE (%) |
|---|---|---|
| 0.3 cellulose fiber | 6.70 | 0.25 |
| 0.3 textile waste | 6.50 | 0.03 |
| 0.2 cellulose fiber | 6.60 | 0.27 |
| 0.1 textile waste | 6.40 | 0.07 |

**Table 4:** Indirect Tensile properties of SMA mixtures.

| STABILIZER RATE (%) | OPTIMUM BITUMEN RATE (%) | DRAINAGE RATE (%) | ITS RESULTS (kPa) |
|---|---|---|---|
| 0.3 cellulose fiber | 6.70 | 0.25 | 1252 |
| 0.3 textile waste | 6.50 | 0.03 | 1385 |
| 0.2 cellulose fiber | 6.60 | 0.27 | 1171 |
| 0.1 textile waste | 6.40 | 0.07 | 1276 |

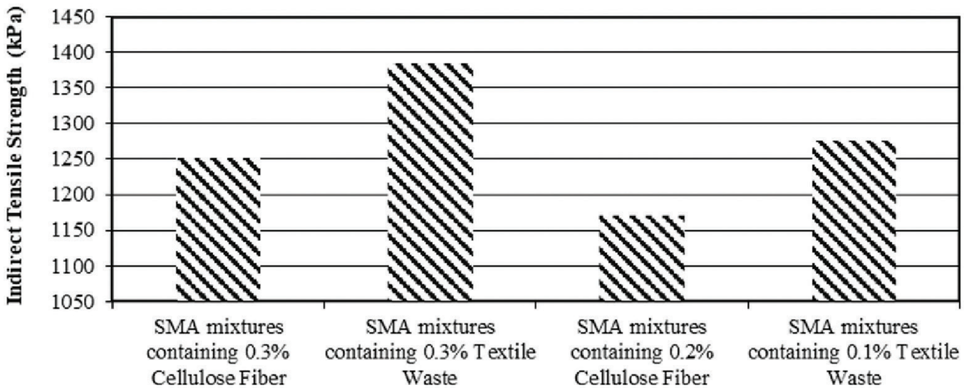


**Figure 6:** Graphical presentation of Indirect Tensile properties of SMA mixtures.

The ITS test is also used to determine the cohesive strength of bituminous mixtures and to characterize the tensile stresses caused by fatigue. In the scope of this study, the indirect strengths of SMA mixtures containing 0.3% and 0.1% textile waste are higher than mixtures containing cellulose fiber at optimum bitumen contents.

It is also among the results that the tensile strengths of SMA mixtures prepared using the least amount of textile waste are higher than the commercially produced and expensive SMA samples produced with the highest percentage of cellulose fibers. This indicates that the mixtures containing textile waste have higher values of tensile strength at failure indirect tensile strength under static loading.

SMA samples prepared using 0.3% textile waste showed the highest ITS value in all of the test samples. This would further imply that SMA mixtures with textile waste appear to be capable of withstanding larger tensile strains prior to cracking. Based on the ITS ratio, SMA mixture containing 0.3% textile waste has the most increase in tensile strength over the all asphalt mixtures.

## 4. CONCLUSIONS

A wide variety of wastes occur in the textile industry, which has an important place in our country. Reutilization of textile wastes and bringing them into the economy will be a great advantage for our country. The legal regulations implemented in the evaluation of these wastes allow to be used in the construction industry. By using textile wastes as additives in asphalt pavements, both higher performance and a healthy environment will be evaluated.

The increase in traffic loads causes an increase in the deformations of the road pavements. Researchers aim to reduce road construction costs, increase performance and increase road life cycle. Considerations such as the cost of material, efficient use of energy and resources lead engineers to find new road construction techniques and alternative materials.

The aim of this research is investigation of textile waste used to prevent bitumen drainage problem in stone mastic asphalt pavements instead of traditional fibers. It has been evaluated that SMA mixtures prepared with textile waste contribute to indirect tensile strength. The addition of textile waste instead of cellulose fiber in SMA mixtures reduced the optimum bitumen ratio required in asphalt mixtures. With the decrease in the optimum bitumen ratio, the cost of asphalt pavements also decreases. The increase in stability and flow values with the addition of different contents of textile waste indicates that the asphalt pavement is more resistant to rutting and the behavior of the pavement at the time of fracture will be improved.

The Schellenberg drainage test was carried out at the optimum bitumen ratio of the SMA samples containing cellulosic fiber and textile waste additives. As a result of test, the addition of 0.3% textile waste to the samples provided the least drainage with a value of 0.03%. According to the specifications of the General Directorate of Highways, the Schellenberg test should be a maximum of 0.3% and the test results comply with the specification limits.

Indirect tensile strength (ITS) is a very common performance test used in pavement industry. ITS testing offers a reliable indication of the crack potential for a mixture. ITS was tested on the SMA mixtures containing 0.3% cellulose fiber, 0.3% textile waste, 0.2% cellulose fiber and 0.1% textile waste order to compare effects of textile waste and cellulose fiber. It can be concluded that SMA mixtures prepared with the addition of textile waste have sufficient adhesion and cohesion, and also resistant to moisture damage at least as commercially produced and expensive cellulose fiber. SMA mixtures containing textile waste have an appreciable increase in tensile strength over mixtures including cellulose fiber, which may be due to synthetic fiber content of textile waste. As it is known, the strength of synthetic fibers is generally higher than cellulosic fibers.

The conclusion of the study covers the using of textile waste in stone mastic asphalt instead of traditional cellulose fiber. It is believed that the results and discussions obtained in this study will contribute to the textile and construction industries. With the use of textile waste, instead of cellulose fiber additive, a high benefit can be achieved in the production of 1 km of SMA, with a cost of approximately 15.000 $.

More research may be performed to investigate the rutting and fatigue behavior of the stone mastic asphalt mixtures containing textile waste under different temperatures and various loading rates.

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