Visual Abstract

Investigation of the effect of yarn waste fibers and cocamide diethanolamide chemical on the strength of hot mix asphalt

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ABSTRACT. In this study, conventional bitumen tests were performed on bituminous binder modified with Cocamide Diethanolamide chemical at different ratios. According to results of tests, the most suitable additive ratio has been determined as 5%. However, it was concluded that indirect tensile strength and resistance to moisture of samples prepared with bituminous binder modified with 5% Cocamide Diethanolamide has been adversely affected. It was desired to investigate that whether these properties could be strengthened by yarn waste fibers. Firstly, the effect of 0.1%, 0.2% and 0.3% yarn waste fibers on samples prepared with reference bituminous binder was investigated. Obtained results showed that both indirect tensile strength and resistance to moisture of samples containing 0.1% yarn waste fiber increased. Therefore, 0.1%, 0.2% and 0.3% yarn waste fibers were added to the aggregate mixture and mixing of them with bituminous binder modified with 5% Cocamide Diethanolamide was provided. According to obtained results, different ratios of yarn waste fibers added to aggregate mixture did not have a positive effect on moisture sensitivity. Tensile strength ratio values of samples containing bituminous binder modified with 5% Cocamide Diethanolamide and yarn waste fibers added to the aggregate mixture did not provide specification limit.

KEYWORDS. Cocamide diethanolamide; Yarn waste fiber; Superpave; Moisture Sensitivity.

OPEN ACCESS

Citation: Saltan, M., Kaçaroğlu, G., Karadağ, Ö, Investigation of the effect of yarn waste fibers and cocamide diethanolamide chemical on the strength of hot mix asphalt, Frattura ed Integrità Strutturale, 62 (2022) 54-63.

Received: 29.03.2022
Accepted: 11.07.2022
Online first: 25.07.2022
Published: 01.10.2022

INTRODUCTION

Although bituminous hot mixtures contain a relatively small amount of bituminous binder, this material plays an important role achieving the expected performance from pavements. Bituminous binder has a significant effect on deformation and fatigue resistance of the pavement besides load distribution ability. Loading conditions and temperature are two important parameters in terms of the deformation resistance and stiffness of bituminous binder, a material which have viscoelastic and thermoplastic properties. Bituminous binder exhibits variable behaviors depending on climate and environmental conditions because of its thermoplastic structure. For instance, this material is hard and brittle in cold weather but soft and fluid in hot weather [1]. These properties which belong to bitumen, also are transferred to hot mix asphalt when bituminous binder mixed with aggregates. Variable behaviors of bituminous binder cause decrease in the performance of pavement. These decreases in the performance are caused by deformations in the pavement. In order to prevent deformations by improving pavement performance, bituminous binder has been modified with various additives and many studies which aim to improve bituminous binder properties have been carried out [2-7]. Not only the properties of bituminous binders, but also the moisture which the mixture is exposed to can cause deformations, too. For example, loss of strength and permanent deformation in the pavement are problems which caused by moisture [8]. There are also studies in the literature which have investigated the effects of different materials on the moisture sensitivity of hot mix asphalt [9-13].

It is considered that surfactant additives are suitable for use in modification of bituminous binders as they can also meet the mentioned expectations while protecting the mechanical properties of the mixture. Due to the properties of the existing surfactants and their possible effects on the rheological properties of the bituminous binders, the usage of surfactants to modify the bituminous binder can significantly change the binder performance. Therefore, interest in researches which are conducted on the usage of surfactants with the aim of modify the bitumen is quite a lot [14-18].

In addition, various fibers have been used for many years on the purpose of strengthen the pavement. It is known that the fibers increase the stability, resistance to fatigue and rutting and provide benefits in preventing the formation of cracks [19]. There are studies in which fibers of different properties and forms are used in hot mix asphalt [20-23]. In one of the studies in the literature, by emphasizing to the fact that the use of waste fibers which emerge from the textile industry abundantly will contribute to the improvement of the pavement, waste polyester fibers have been used [24]. In another study, the effects of various fibers used in mixtures on the mechanical properties of the hot mix asphalt have been examined [25]. Besides all these, it is known that the addition of fibers increases the fracture toughness of asphalt concrete [26]. Fracture toughness is a measure of the resistance to propagation of cracks observed in materials [27]. Limited availability of studies reported on the fracture properties of fiber-reinforced asphalt mixtures show that addition of fibers can positively affect the toughness resistance of asphalt mixtures depending on the type and usage rates of fibers [28-36].

In this study, Cocamide Diethanolamide (CDEA) was added to bituminous binder at the ratios of 1%, 3% and 5%. With the help of a temperature – controlled high shear mixer, CDEA and bituminous binder were homogeneously mixed for 1 hour at 2000 rpm and 165 °C. Conventional bitumen tests were carried out to determine the consistency of modified bituminous binders. According to the obtained results, the most suitable Cocamide Diethanolamide ratio was determined as 5%. Samples suitable for asphalt surface course were prepared by Superpave Volumetric Mix Design Method. Indirect Tensile Strength test was performed on the prepared samples. The resistance to moisture of the samples was determined according to AASHTO T 283 standard. Indirect tensile strength and the resistance to moisture of samples prepared with bituminous binder modified with 5% CDEA were negatively affected. To this respect, it was desired to investigate that whether these properties could be strengthened by yarn waste fibers. Primarily, the indirect tensile strength and the resistance to moisture of the samples containing 0.1%, 0.2% and 0.3% yarn waste fibers with reference bituminous binder were investigated. According to the obtained results, a positive effect was observed on the indirect tensile strength and the resistance to moisture of the samples containing 0.1% yarn waste fiber. Then, 0.1%, 0.2% and 0.3% yarn waste fibers were added to the aggregate mixture and mixing of them with bituminous binder modified with 5% CDEA were provided. However, the fibers added to the aggregate mixture did not have a positive effect on the indirect tensile strength and moisture sensitivity.

MATERIALS AND BITUMEN MODIFICATION

Aggregates

The limestone aggregates have been used in the study. Specific bulk gravity [TS EN 1097-6], water absorption, Los Angeles abrasion test [ASTM C 131-03] and micro – deval abrasion test [TS EN 1097-1] were performed on limestone aggregates used in experimental studies. The results of tests applied on coarse aggregates, fine aggregates and filler are shown in Tab. 1.

Bituminous binder

Bituminous binder which has a penetration class of 50/70 has been used in the study. Penetration [TS EN 1426], softening point [TS EN 1427], ductility [TS EN 13589] and specific gravity [TS EN 15326+A1] tests were performed on the bituminous binder used in the study. Obtained results are given in Tab. 2.

Properties	Coarse Aggregates	Fine Aggregates	Filler
Specific Gravity (g/cm^3)	2.701	2.606	2.501
Resistance (Los Angeles wear loss) (%)	18.48	-	-
Resistance (Micro-Deval wear loss) (%)	9.95	-	-

Table 1: Physical properties of coarse aggregates, fine aggregates and filler.

Test	50/70 Bituminous Binder	Standard
Penetration (25°C)	50	TS EN 1426
Softening Point	49.8	TS EN 1427
Ductility (5cm/min)	>100	TS EN 13589
Specific Gravity (g/cm^3)	1.021	TS EN 15326+A1

Table 2: Properties of bituminous binder.

Yarn waste fibers

There are a wide variety of fibers that are used to create yarns and they come from a variety of sources. Yarns are comprised of a group of fibers twisted together to form a continuous strand. The fibers used to create these yarns include animal fibers and plant fibers which are named as natural fibers, besides synthetic fibers.

All materials in the form of clippings, pieces, fibers are described as textile waste. Textile wastes can be collected under three main groups. The first is wastes from artificial yarn factories, the second is textile manufacturing waste, and the third is textile waste of consumers [37]. It has been known that, a lot of textile waste comes out of the factories, houses, workshops. Disposal of these wastes into the environment causes both environmental pollution and the recyclable wastes to disappear. In the study, the effect of using of yarn waste fibers which comprise the majority of textile wastes on the strength of the pavement was evaluated. The yarn waste fibers were added to the aggregate mixture at the ratios of 0.1%, 0.2% and 0.3%, after they were cut in 2.5 cm size (Fig. 1).

Figure 1: Yarn waste fibers which cut to the size of 2.5 cm.

Cocamide diethanolamide

Cocamide Diethanolamide (CDEA) material was used in the modification of bituminous binder. CDEA is known as a surfactant material and has the chemical formula in the way that CH3(CH2)nC(=O)N(CH2CH2OH)2. CDEA is a water – soluble derivative of a mixture of fatty acids obtained from coconut oils. It is a non – ionic material that increases viscosity and provides foam stabilization in anionic based systems such as soaps, shampoos, cosmetics.

CDEA decreases the viscosity by thinning the bituminous binder because it is a smaller molecule material compared to bitumen which has a long – chain and high flow resistance. The properties of CDEA chemical are shown in Tab. 3.

Properties	50/70 Bituminous Binder
Boiling Point	169-275°C
Melting Point	23-35 °C
Specific Gravity (g/cm^3)	0.976-0.99
pH	9 (1% solution)

Table 3: Properties of CDEA chemical.

Bitumen modification

Cocamide Diethanolamide was added to bituminous binder at the ratios of 1%, 3% and 5%. Different parameters have been tried to modify the chemical material with bituminous binder. Conventional bitumen tests were carried out on modified bituminous binders and the most suitable parameter was selected. With the help of a temperature – controlled high shear mixer, CDEA and bituminous binder were homogeneously mixed for 1 hour at 2000 rpm and 165 ℃.

METHODS

Methods used in this study can be grouped as follows; aggregate tests, conventional bitumen tests and evaluation of moisture sensitivity of samples prepared by using Superpave Volumetric Mix Design Method.

Conventional bitumen tests

Penetration, softening point, ductility and specific gravity tests were performed on bituminous binders modified with CDEA.

Evaluation of moisture sensitivity of bituminous hot mixtures

Superpave Volumetric Mix Design method consists of four steps: material selection, aggregate gradation, optimum bituminous binder content and moisture sensitivity. During all these steps, the temperatures and traffic volume of Isparta province where asphalt surface course will serve have been taken into consideration. It is estimated that the number of 20 years of traffic in Isparta province where asphalt surface course will serve is more than $30*10^6$ ESALs. Within the scope of study, optimum bituminous binder content has been determined using volumetric mix design. N_{design} has been selected as 125 gyros in accordance with the 20 – year traffic load. While the optimum bituminous binder content is calculated, VMA (min 14%), VFA (65 – 75%) limit values and 4% air void criteria have been taken into consideration.

The final step of the Superpave Volumetric Mix Design method is to determine the moisture sensitivity of the prepared mixtures. In order to determine the moisture sensitivity, indirect tensile strength (ITS) test is performed on the prepared mixtures in accordance with AASHTO T-243 standard. According to the determined optimum bituminous binder content, the prepared mixtures are compacted with Superpave Gyratory Compactor. Two sets which have three samples are prepared and while one of them is conditioned, other set is unconditioned. The Indirect Tensile Strength (ITS) values of the samples are determined. For all samples, unconditioned (ITS_{dry}), conditioned (ITS_{wet}) values are recorded and the Tensile Strength Ratio (TSR) values are calculated. The limit of TSR values is 80% [38].

RESULTS AND DISCUSSION

Results of conventional bitumen tests

To determine the basic properties of samples, softening point, penetration ductility and specific gravity tests have been applied on all modified samples. Test results are given in Tab. 4.

As can be seen from the table, the penetration values have increased according to the reference binder as the CDEA ratio increases for each sample. Also, the softening point temperatures have decreased according to the reference binder as the CDEA ratio increases. The reference bituminous binder and all modified samples have indicated elongation without breakage by exceeding the specification limit value of 100 cm at 25 °C.

Sample	Penetration (25°C)	Softening Point (°C)	Ductility (5cm/min)	Specific Gravity (g/cm³)
Reference	50	49.8	>100	1.021
1% CDEA	53	47.8	>100	1.028
3% CDEA	66	45.5	>100	1.015
5% CDEA	71	44.5	>100	1.022

Table 4: Results of conventional bitumen tests.

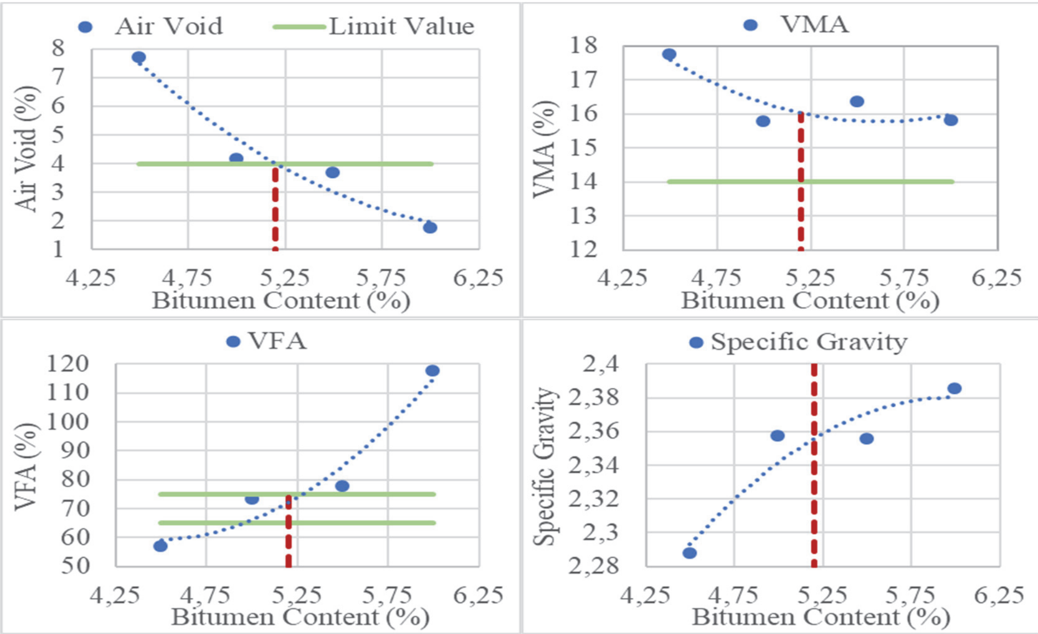

Figure 2: Graphs of reference bituminous binder.

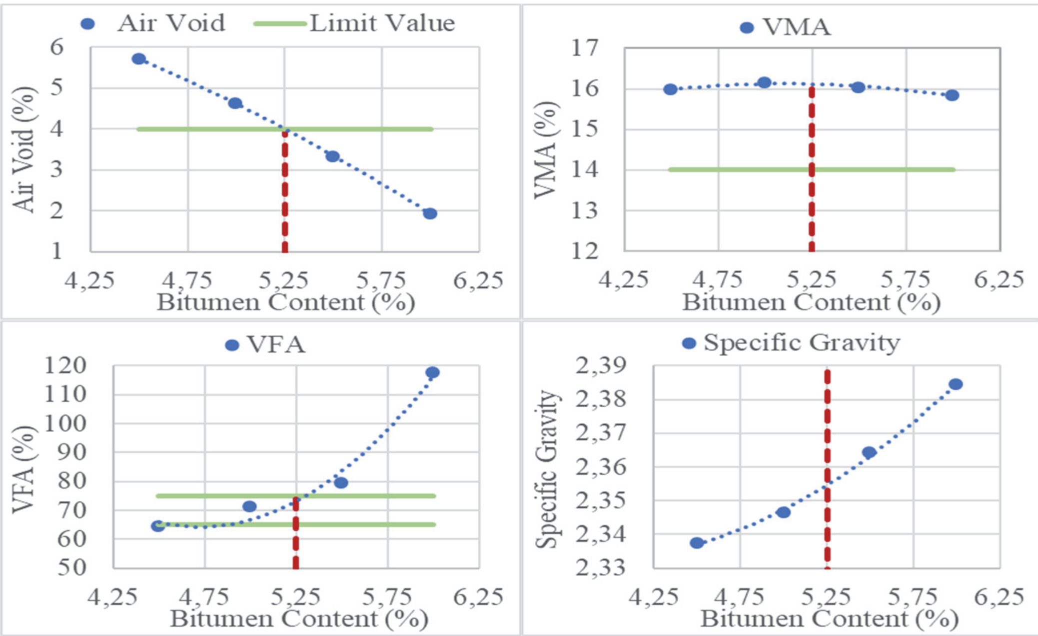

Figure 3: Graphs of reference bituminous binder modified with 5% CDEA.

Evaluation of moisture sensitivity

According to the results of conventional bitumen tests, optimum additive ratio was determined as 5%. In order to provide the 4% air void criteria of the mixtures prepared by using Superpave Volumetric Mix Design Method, bituminous binders at the rates of 4.5%, 5%, 5.5% and 6% were added to the aggregates and they were mixed until completely coated with bituminous binder. Then the mixture was compacted with gyratory compactor. Firstly, the amount of bituminous binder corresponding to 4% air void was determined from the air void graph. It was checked whether the determined amount of bituminous binder has a minimum value of 14% on the VMA graph and 65 – 75% on the VFA graph. After all these steps were carried out, the optimum bitumen content for reference bituminous binder and bituminous binder modified with 5% CDEA were determined as 5.20% and 5.25%, respectively. Graphs of obtained results are given in Fig. 2 – 3.
The final step of the Superpave Volumetric Mix Design Method is to determine the moisture sensitivity of the prepared mixtures. In order to determine the moisture sensitivity, Indirect Tensile Strength (ITS) test was performed on the prepared mixtures according to AASHTO T-283 standard. Unconditioned and conditioned tensile strengths and TSR values were found for samples. TSR value of the samples prepared with reference bituminous binder is above the specification limit, 80%. The obtained results are given in Tab. 5.

Name of sample	ITS_{dry}(kPa)	ITS_{wet}(kPa)	TSR (%)
Reference sample	798	725	91
Modified sample with 5%	464	-	-

Table 5: Indirect tensile strength of samples.

ITS_{wet} strength of samples prepared by using bituminous binder modified with 5% CDEA could not be tested. In the conditioning stage, after the samples were placed in a water bath which have 60 °C temperature, separation of the aggregates from the bituminous binder was observed (Fig. 4). When the bituminous binder modified with CDEA which is a chemical material was exposed to a water bath which have 60 °C temperature, it has been observed that the adhesion between bituminous binder and aggregates has decreased. According to the obtained results, it was concluded that the strength of samples prepared with bituminous binder modified with 5% CDEA has been adversely affected.

Figure 4: Sample prepared by using bituminous binder modified with 5% CDEA, after conditioning.

After this step, the indirect tensile strength and the resistance to moisture of the samples prepared by using the reference bituminous binder and 0.1%, 0.2% and 0.3% yarn waste fibers were investigated. According to the obtained results, as 0.1% yarn waste fiber added to the aggregate mixture prepared with the reference bituminous binder increased the interlocking, the indirect tensile strength of mixtures increased (Fig. 5). The graph in Fig. 5 shows that the indirect tensile strength of the samples prepared with 0.3% yarn waste fiber added to the aggregate mixture with the reference bituminous binder decreased compared to the reference samples. It was observed that the resistance to moisture of the samples prepared with 0.1% yarn waste fibers added to the aggregate mixture and reference bituminous binder increased (Fig. 6). According to this, yarn waste fibers which were added to the aggregate mixtures and reference bituminous binder have a positive effect on the indirect tensile strength and moisture sensitivity of the mixtures. So, it has been thought that it can also have a positive effect on the aggregate mixtures containing bituminous binder modified with 5% CDEA.
As seen in Fig. 4, samples prepared with bituminous binders modified with 5% CDEA did not provide strength in conditioned conditions. To improve this situation, 0.1%, 0.2% and 0.3% yarn waste fibers in 2.5 cm size were added to the

aggregate mixture and samples were prepared with this mixture and bituminous binder modified with 5% CDEA. Samples containing bituminous binder modified with 5% CDEA and 0.1% yarn waste fibers were broken after conditioning (Fig. 7). 0.1% yarn waste fibers which were added to the aggregate mixture did not have a positive effect on the indirect tensile strength and moisture sensitivity.

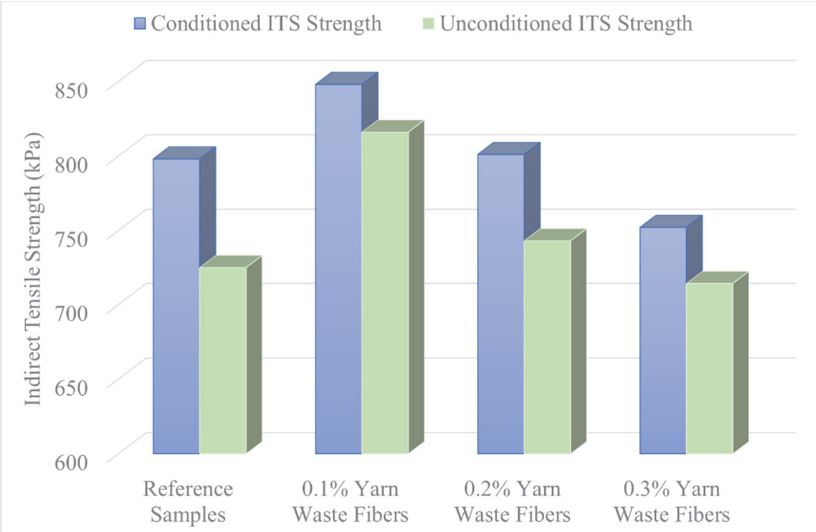

Figure 5: Indirect tensile strength values of samples prepared with yarn waste fibers added to mixtures prepared with reference bituminous binder.

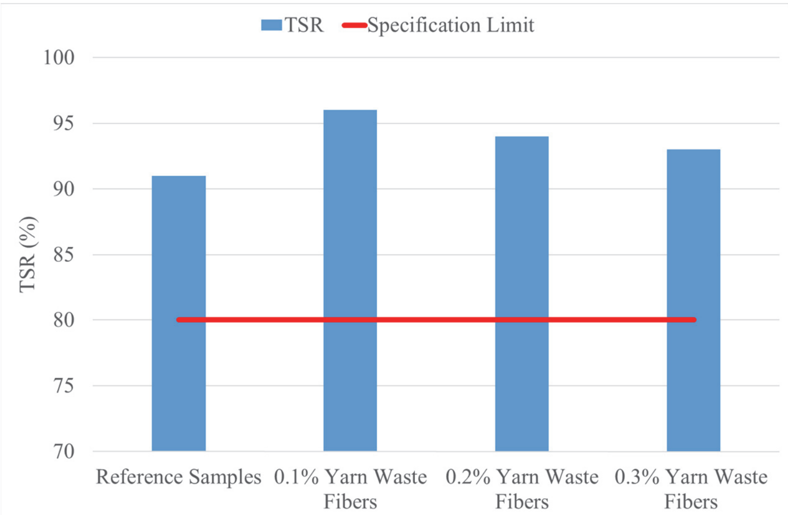

Figure 6: Tensile strength ratios of samples prepared with yarn waste fibers added to mixtures prepared with reference bituminous binder.

Figure 7: Samples prepared by using bituminous binder modified with 5% CDEA and 0.1% yarn waste fibers, after conditioning.

Samples prepared with bituminous binder modified with 5% CDEA and 0.2%, 0.3% yarn waste fibers gave wet strength after conditioning. However, these samples did not meet the TSR specification limit (Tab. 6). According to the obtained results, the indirect tensile strength and moisture sensitivity of the samples prepared with bituminous binder modified with 5% CDEA could not be increased by using different ratios of yarn waste fibers. Since samples containing bituminous binder modified with 5% CDEA and 0.1%, 0.2% and 0.3% yarn waste fibers do not meet the specification limits, they are not suitable for use in pavement.

Name of sample	ITS_{dry} (kPa)	ITS_{wet} (kPa)	TSR (%)
Reference sample	798	725	91
Sample modified with 5% CDEA	464	-	-
Sample modified with 5% CDEA+0.1% yarn waste fibers	339	34	-
Sample modified with 5% CDEA+0.2% yarn waste fibers	376	41	-
Sample modified with 5% CDEA+0.3% yarn waste fibers	356	49	-

Table 6: Indirect tensile strength and TSR values of samples.

CONCLUSIONS

The obtained results after the tests were interpreted as follows:
According to the consistency tests, when compared to the reference binder, bituminous binders modified with CDEA chemical at the ratios of 1%, 3% and 5% are more fluid and softer. The results of softening point and penetration tests are consistent with each other. It is known that, bituminous binders which have low softening point and high penetration values can be used for pavement construction in cold regions. So, it can be said that, bituminous binders modified with CDEA are suitable for cold climatic regions.
The strength of samples prepared with bituminous binder modified with 5% CDEA could not be calculated. Asphalt mixtures prepared with bituminous binder modified with 5% Cocamide Diethanolamide decreased resistance to moisture sensitivity. It is concluded that the samples prepared with bituminous binder modified with 5% CDEA are not suitable for use in the asphalt surface course solitary.
In order to reduce the negative effect on the indirect tensile strength and moisture sensitivity of the samples prepared by using bituminous binder modified with 5% CDEA, it was considered to add yarn waste fibers to the aggregate mixtures. Therefore, in order to examine the effect of yarn waste fiber added to the aggregate mixture, 0.1%, 0.2% and 0.3% yarn waste fibers were added to the aggregate mixtures and samples were prepared by using the reference bituminous binder. According to the obtained results, the indirect tensile strength and the resistance to moisture of the samples prepared by using 0.1% yarn waste fiber added to the aggregate mixture and the reference bituminous binder increased.
Therefore, 0.1%, 0.2% and 0.3% yarn waste fibers were added to increase the indirect tensile strength and to decrease the resistance to moisture of the samples prepared with bituminous binder modified with 5% CDEA. Although the strength values of the samples prepared with 0.1%, 0.2% and 0.3% yarn waste fibers added to aggregate mixture and the bituminous binder modified with 5% CDEA were measured after conditioning, the TSR values did not meet the specification limit. According to obtained results, even if usage of different ratios of yarn waste fibers alone are suitable for hot mix asphalt, it has been seen that the usage of different ratios of yarn waste fibers together with bituminous binder modified with 5% Cocamide Diethanolamide does not provide an additional benefit.
Based on the observed positive effects of the usage of different fibers on the fracture toughness of asphalt concrete, it is considered to investigate the effect of yarn waste fiber on toughness resistance of asphalt mixtures in future studies. Fracture toughness can be improved by using different ratios of yarn waste fibers in hot mix asphalt. However, it is considered that CDEA additive will have no positive effect on fracture toughness of material, since the usage of it does not have a positive effect on strength of asphalt mixtures.

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