Investigation the CF Based Conductive Asphalt Mixtures for Anti-icing

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ABSTRACT

In recent years, researchers have been working on a new type of pavement called electrically conductive asphalt to be anti-icing. In this study, hot mix asphalt (HMA) stone mastic asphalt (SMA) specimens were prepared by adding carbon fiber (CF) in three different lengths (5-10-15 mm) and five different percent (0.1-0.2-0.3-0.4 and 0.5% by weight). Volume resistivity measurement and temperature changes of the specimens under constant voltage (20 V) were determined for each of the specimens. As a result of the study, it was determined that the CF properties and aggregate gradation difference were quite effective on the electrical conductivity, and the electrical conductivity properties also changed depending on the CF length and percentage in the mixtures. According to the electrical conductivity test results, it was concluded that 5 mm long CF specimens were more suitable for use in electrically conductive asphalt concretes (CAC), one of the lowest volumetric resistivity values in the literature was obtained. In addition, it was concluded that aggregate gradation is also effective on electrical conductivity.

Keywords: Aggregate Gradation; Conductive Asphalt Concretes (CAC); Carbon Fiber (CF); Electrical Conductivity; Fiber Length.

1. INTRODUCTION

Traditional methods such as chemical and salting are commonly used for snow and de-icing on highways. However, these methods are insufficient for anti-icing, and inevitable problems are experienced. Such methods are systematically damaged asphalt pavements and decreased their service life. The use of ice-dissolving chemicals deteriorates asphalt pavements and bridge decks and has a devastating effect on the soil and ecological environment (Gürgöze, 2017). When the temperature drops to less than -3.9 ^{o}C, the traditional salt (sodium chloride) used to prevent icing will not work (Ağar and Kutluhan, 2021). Known as mechanical methods for anti-icing and anti-snow accumulating, snow removal machines require high maintenance of large amounts of the workforce and material resources. Machine vibration and misuse of the mechanical device also cause damage to the surface of the asphalt pavement during its natural service period (Gürer, 2015). Scientists and engineers have been carrying out different studies for a long time to eliminate the adverse effects caused by traditional methods and prevent surface icing and snow accumulation in the asphalt pavement. Studies in recent years were shown that electrically conductive asphalt pavements would play a key role in preventing such problems (Ding et al., 2012, Pan et al., 2014, Vo et al., 2017, Vo and Park, 2017, Gürgöze, 2017, Gürer and Elmacı, 2019 & Arabzadeh et al., 2019, Sun et al. 2019). Conductive asphalt concrete is a technology that emerged to ensure safe driving in winter. Heated pavement systems made of conductive asphalt concrete provide temperature stability and robust performance (Rew et al., 2018 & Arabzadeh et al., 2019).

Traditional asphalt mixture material includes coarse aggregate, fine aggregate, asphalt binder, and mineral filler. Due to these components' high electrical resistivity, conventional asphalt mix is an electrically insulating material with a resistivity value between 10^{8} and 10^{12} Ω.m. It can be transformed into a conductor by adding conductive materials with a resistivity of less than 10 Ω.m into such insulating materials (Pan et al., 2014). Based on particle sizes, there are three categories for conductive materials:

1. Powder materials containing graphite, carbon black, and aluminum parts,
2. CF, steel wool, carbon nanofiber, and steel fibers,
3. Solid particles such as slag instead of coarse and fine aggregate (partially or wholly) (Pan, 2014).

Considering the percolation theory, it is possible to observe that electrical resistivity decreases sharply with increasing fiber content. Notani et al. (2019) reported that CF affects the asphalt pavement's electrical conductivity and ability to generate heat. Sun et al. (2019) performed a study about the electrical characteristics of conductive ultrathin bonded wearing course (CUBWC) for active deicing and snow melting. The temperature sensitivity test and the temperature cycling test were further conducted to evaluate the temperature-sensitive property and stability of CUBWC. Researchers determined that the optimal contents of the graphite and CF as 25% and 4% respectively by considering the effective electrical conductivity and temperature stability of CUBWC. Ullah et al. (2021), investigated the CAC incorporating CF and iron tailings. Researchers reported that the addition of CF with iron tailings significantly improved the electrical and mechanical properties of the mixtures.

1.1 Objectives

The most important aim of this study and its difference from previous studies is to investigate the effect of carbon fiber length and weight percentage on electrical conductivity and temperature rise of specimens in different types of conductive asphalt mixtures (HMA and SMA). It is to determine which fiber length is more effective on conductivity. Although the same conductive contents were used in two different asphalt mixture specimens (HMA and SMA), different results were obtained both in volume resistivity values and in temperature increases under constant voltage (20 Volt). This showed that aggregate gradations were also effective on electrically conductivity.

2. MATERIALS AND METHOD

2.1 Material

Limestone obtained from Afyonkarahisar KOLSAN Inc. Comp. and basalt originated aggregates obtained from Kütahya were used as aggregate in the study. Basalt aggregates were used in the coarse fractions of the SMA specimen. VIATOP® cellulosic fibers were used as fibers in the blends. The CF (24K A-49) used as a conductive component for the mixture specimens in the study was obtained from Dow Aksa Inc. Company Inc. in Yalova. Engineering properties of the CF and gradation of mixtures are given in Tables 1 and 2, respectively. CF was prepared by cutting into three different lengths and used in 5 different ratios by weight in the mixtures. B 50-70 penetration grade bitumen properties were shown in Table 3. Specific gravities of aggregates and the CF properties in the CAC mixtures were given in Table 4 and Table 5 respectively.

Table 1. Characteristics of CF

Fiber Characteristics	Values	Test Method
Tensile strength (MPa)	4900	ISO 10618
Tensile modulus (GPa)	250	ISO 10618
Unit deformation (%)	2.0	ISO 10618
Density (g/cm^3)	1.79	ISO 10119
Yield (g/1000 m)	1600	ISO 1889

Table 2. Gradations of HMA and SMA mixtures

	HMA Gradations Type 3 TCK 2013		SMA Gradations TCK 2013	
Sieve(mm)	% Passed	% Remaining	% Passed	% Remaining
25	100	0	100	0
19	100	0	100	0
12.5	100	0	100	0
9.5	90	10	85	15
4.75	63.5	36.5	35	65
2.0	44.5	55.5	25	75
0.425	22	78	17	83
0.180	12	88	13	87
0.075	6	94	10	90

Table 3. Bitumen properties

Properties	Values	Specification
Source	Aliağa	-
Penetration Value	50/70	-
Penetration at 25 °C	64	ASTM D5-06e1,
Specific Gravity	1.030	ASTM D70-09e1
Softening Point (°C)	47	ASTM D36/D36M-09
RTFOT (%)	2.2	ASTM D6-95
Flash Point (°C)	280	ASTM D92-05a
Ductility (5cm/dak 25 °C)	>100 cm	ASTM D113-07
Viscosity135 °C	0.400 pas	ASTM D4402-06
Viscosity 165 °C	0.101 pas	ASTM D4402-06

Table 4. Specific gravities of aggregates specimens

	Bulk Specific Gravity	Apparent Specific Gravity
Coarse aggregate (Limestone)	2.68	2.74
Coarse Aggregate (Basalt)	2.67	2.77
Fine Aggregate	2.67	2.69
Mineral Filler	-	2.56

Table 5. CF properties in the CAC mixtures

Series	Fiber lengths (mm)	Fiber % (By the Weight of the CAC Specimen)	Fiber Weight / Specimen (g)
1 / 2 / 3	**5 / 10 / 15**	0.1	1.2
		0.2	2.4
		0.3	3.6
		0.4	4.8
		0.5	6.0

2.2 Method

Within the scope of the study, CF 5-10-15 mm. cut into length, 0.1; 0.2; 0.3; 0.4; with 0.5% CF added, by weight of aggregate; and 1200 g HMA and SMA Marshall asphalt specimens were prepared. Besides, control specimens without CF were produced from HMA and SMA specimens. Volume resistivity (two-electrode method with external contact), temperature change with constant electrical voltage were performed on asphalt specimens, and the results were assessed.

The two-electrode method is seen as an essential method for measuring the volume resistivity of CAC (Pan, 2014; Ullah, 2021). Volume resistivity measurement with the two-electrode method was carried out (Figure 1). The measured volume resistance value is equal to the sum of both the specimen's contact resistance values and the used conductor and plate.

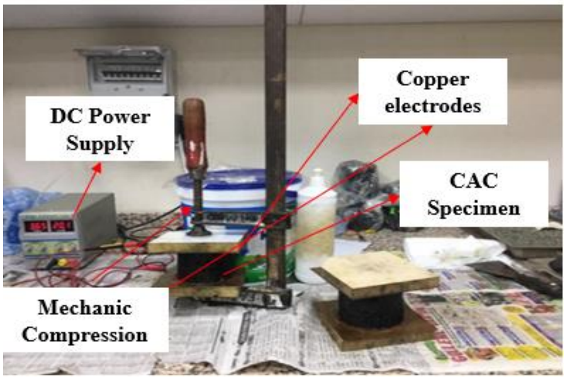

Figure 1. Two-electrode method volume resistivity measurement setups

A Digital multimeter device was used to measure the electrical properties, and copper plates completely covering the bottom, and top surfaces of cylindrical hot mix asphalt specimens were used as electrodes. Ultrasound gel material was also used to fill the air gaps between the copper plates and the asphalt specimen. The current values passing through the specimens under constant voltage (5-10-15-20-25 Volt) were measured from the device to calculate the volume resistivity of asphalt specimens. The resistance value is calculated with this measured value, and the resistivity values are computed as Ωm based on the specimen heights and cross-sectional areas. The electrical resistivity (ρ) was calculated as Eq. (1).

$$\rho = \frac{R.S}{L} \qquad (1)$$

Here R is the electrical resistance (Ω), S is the cross-section area (m^2) of the tested specimen, and L is the distance (m) between two circular copper electrodes. The conductive contact area (S) of the CAC specimen is 0.0314 m^2. If the current (I) measured at a 25 Volt electrical voltage is 3.3 A, the resistance value is calculated as 7.57 Ω from the equation (2). The specimen height was measured as L=0.065 m with a caliper.

$$V = I \times R \qquad (2)$$

Then, the measured and calculated values are substituted in equation (1) and the resistivity value is calculated as 3.65 Ωm. In the heating test, the changes in the temperature of the conductive specimens under 20 Volt constant DC voltage were determined at room temperature with the same method. Temperature measurements were performed with an infrared thermometer at three different central points in the middle of the specimen.

3. RESULTS AND DISCUSSION

3.1 Volume Resistivity Results

To compare the produced asphalt specimens' conductivity, electrical resistivity measurements were performed using the two-electrode method by external contact, and the obtained results were compared. Volume resistivity changes of CF added (5, 10, 15 mm) HMA specimens are shown in Figures 2, 3, and 4 respectively.

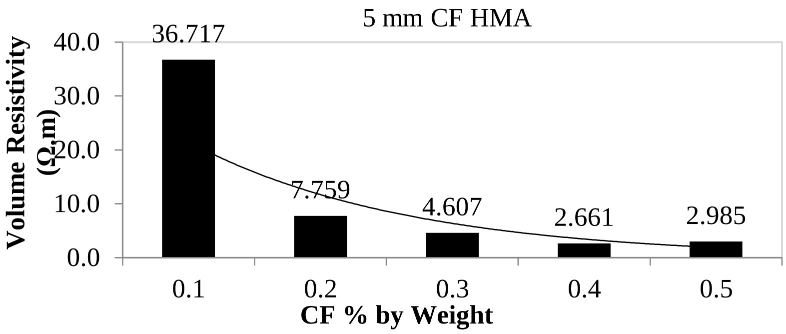

Figure 2. Volume resistivity results of 5 mm HMA specimens

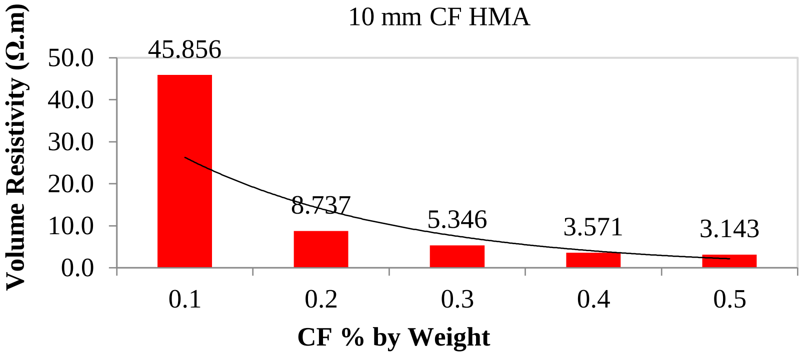

Figure 3. Volume resistivity results of 10 mm HMA specimens

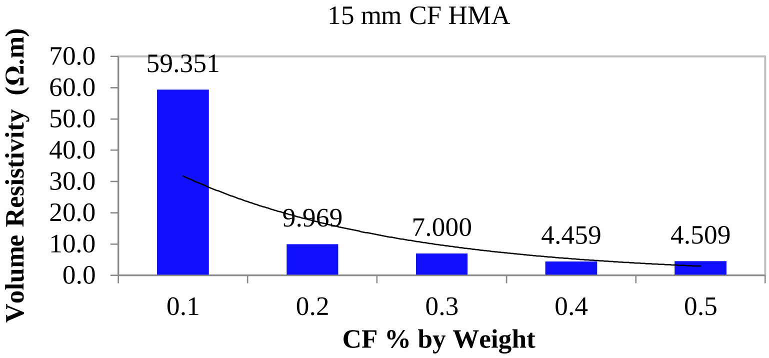

Figure 4. Volume resistivity results of 15 mm HMA specimens

In all of the specimens in all three HMA series, it was observed that the resistivity gradually decreased as the amount of CF increased. The most significant decrease in resistivity was obtained in Series-1 specimens. However, the results of the Series-1 and 2 specimens were close to each other. The series with the lowest resistivity value of the initial specimens (0.1%) was determined as 1< 2<3, respectively.

Similar measurements were repeated in SMA specimens, and resistivity changes of series 1, 2, and 3 were given in Figures 5, 6, and 7 respectively. In the specimens belonging to the SMA series (5, 10, and 15 mm), the volume resistivity values decreased with the increase of CF, as in the HMA specimens. In all three SMA series, a significant reduction of 80% in resistivity was observed at different CF contents. While a decrease of 80% resistivity was observed with 0.2% CF addition in the Series 1 specimens, it was observed that the same reduction value was obtained at 0.4% and 0.3% CF additions in the Series 2 and Series 3 specimens, respectively. The series with the lowest resistivity values in SMA specimens were obtained as 1<2<3, respectively.

The lowest volume resistivity values were obtained in 5 mm CF specimens both in HMA and SMA series. According to the test results, it is thought that when CF is used in small amounts and 5 mm in length, it is less clumped than other series. As a result of the test, it was determined that the amount of CF in the mixture and fiber length are quite effective in making the specimens conductive. The CF added specimens, volume resistivity values were obtained below 100 Ωm as stated by Pan et al. (2014).

Generally, CFs have very low resistivity compared to conductive powders due to their high aspect ratio. The results obtained from the specimens confirm this. When exponential trend lines are added to all resistivity graphs, it is seen that as the percent of the conductor component increases, the resistivity trend line becomes horizontal. As Garcı´a et al. (2009) stated, after the amount of conductive material added to the conductive materials reaches a certain value, no matter how much the conductor amount is increased, no significant change in the conductivity of the material will be observed. The test results are also consistent with the results reported by Garcia et al. (2009).

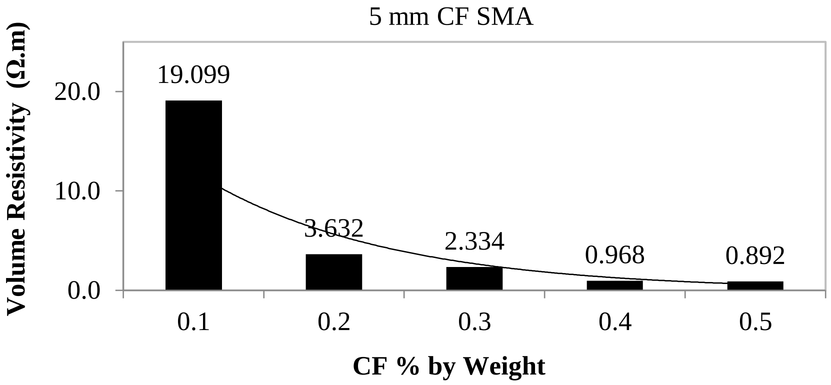

Figure 5. Volume resistivity results of SMA specimens with 5 mm CF

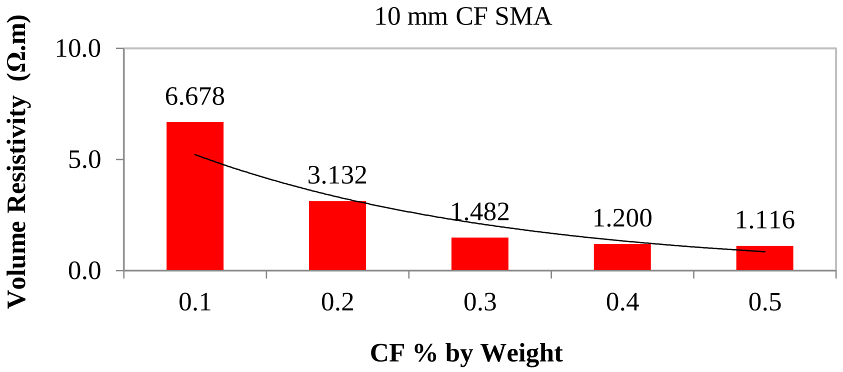

Figure 6. Volume resistivity results of SMA specimens with 10 mm CF

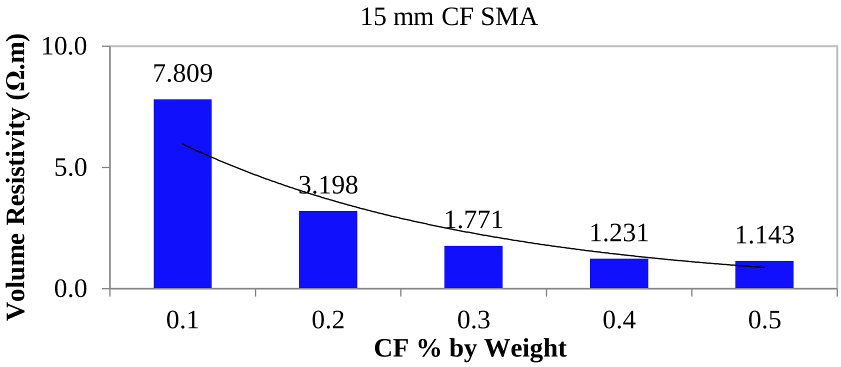

Figure 7. Volume resistivity results of SMA specimens with 15 mm CF

When compared according to specimen types, it was observed that the resistivity values for all three series were lower in the SMA specimen. Pan et al. (2014) stated that there is no detailed study showing the effect of gradation on conductivity. The test results show that the SMA specimens using the same CF series are more conductive. It is thought that gap graded aggregate gradation of SMA is effective on these results. Because the homogeneous distribution of aggregates in different diameters in closed gradation could make the formation of conductive bridges partially difficult, however, it is thought that the formation of conductive bridges in open-graded SMA specimens is easier than in HMA specimens. However, the reason why there is no significant difference between the resistivity results is thought to be directly related to the high amount of optimum bitumen of SMA specimens. Akbulut and Gürer (2017) stated that the conductivity values would decrease with the increase in bitumen. The obtained findings confirm this situation.

3.2 Determination of Temperature Changes in Specimens under Constant Voltage

Within the scope of this test, the specimens were heated with DC electric current under constant voltage (20 Volt), and changes in their temperature were determined. Changes in the HMA specimens' temperatures under constant voltage within 10 minutes with 2 minutes intervals are shown in Figures 8, 9, and 10 respectively.

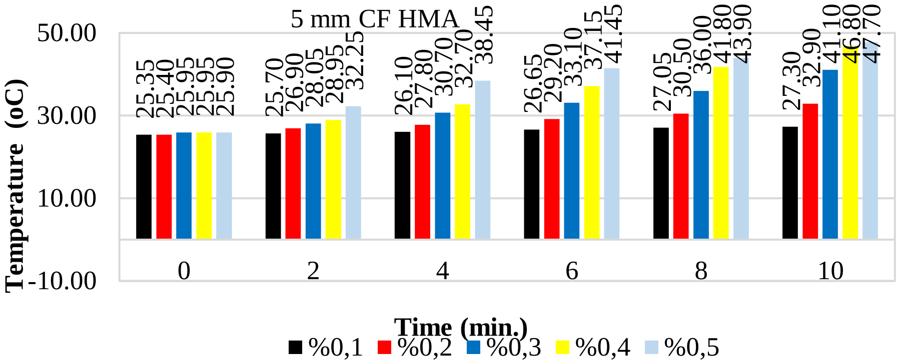

Figure 8. Temperature changes of HMA specimens with 5 mm CF

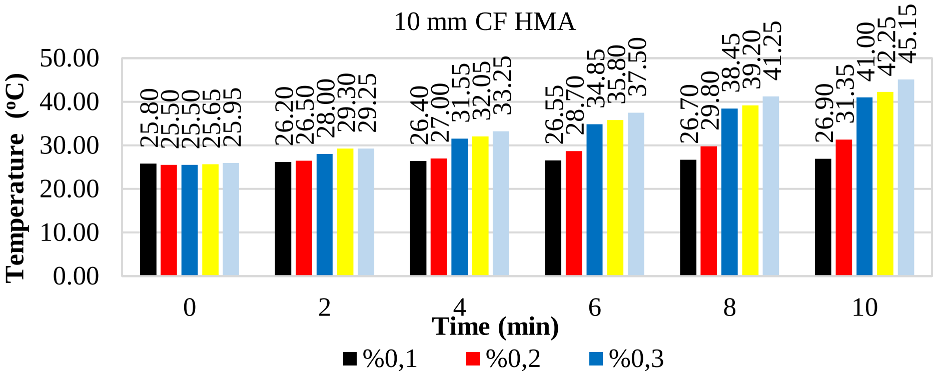

Figure 9. Temperature changes of HMA specimens with 10 mm CF

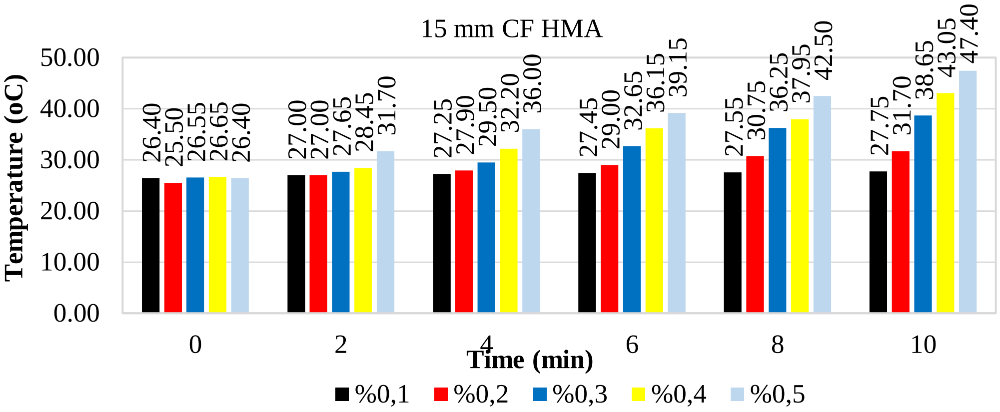

Figure 10. Temperature changes of HMA Specimens with 15 mm CF

As the HMA specimens' exposure time increased, the temperature of the specimens belonging to all series also increased. As the amount of CF in the HMA specimens increased, the specimens' temperature was also increased. The highest temperature rise was obtained in series 1 specimens with 0.5% CF addition, as in resistivity changes. Series 3 and series 2 followed, respectively. While it was observed that the temperature increase was not significant in the specimens with the addition of 0.1% CF in HMA series 1, 2, and 3, the increasing trend became evident after the addition of 0.2% fiber in all series. Similarly, the decrease in resistivity value in all series became evident after 0.2% CF addition.

As the exposure time to constant voltage increased in SMA specimens, temperature values increased in all series. It was determined that the amount of CF was also quite effective in increasing temperature values. The highest temperature increase was obtained at a 0.5% CF in all series of both HMA and SMA specimens (Figure 11, 12, and 13).

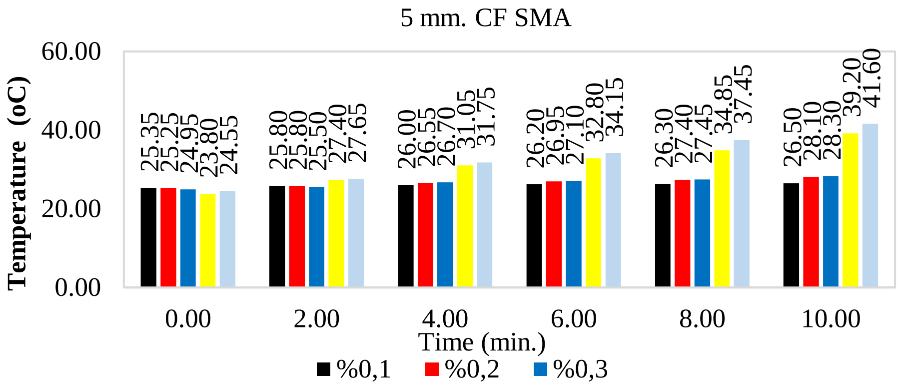

Figure 11. Temperature changes of SMA specimens with 5 mm CF.

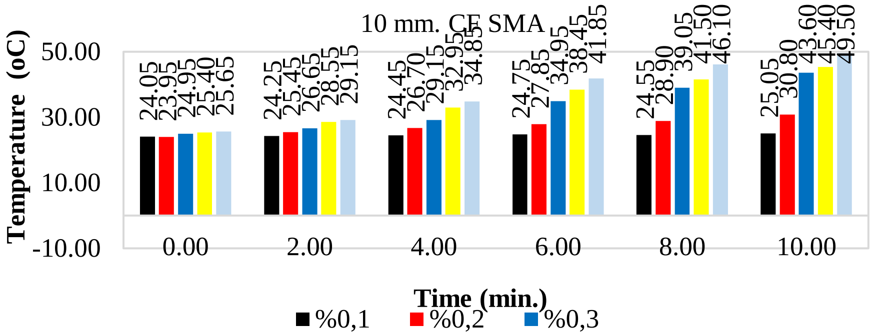

Figure 12. Temperature changes of SMA specimens with 10 mm CF.

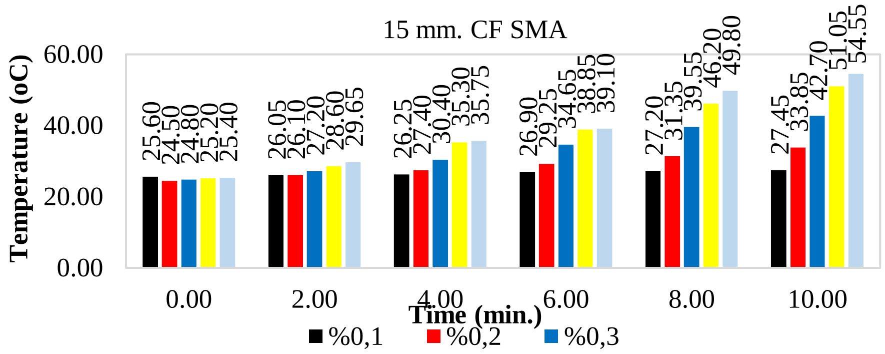

Figure 13. Temperature changes of SMA specimens with 15 mm CF

4. CONCLUSION

How the use of CF in HMA and SMA specimens affects the conductivity of asphalt mixtures was investigated by laboratory tests. As a result of the experimental investigations, the following results were concluded:

- Due to the use of CFs in the form of hair strands, the lowest resistivity values in the literature were achieved with very low percent use of CF.
- The amount of increase in temperatures under constant voltage in all specimens was determined. It was concluded that the specimen's temperatures gradually increased depending on the CF content and length. The most significant increase in HMA specimens was found to be 21.8 ^{o}C in 10 minutes in specimens with 5 mm 0.5% CF content. In SMA specimens, it was determined as 29.2 ^{o}C for 10 minutes in specimens with 0,5% content of 15mm length. It is thought that in both specimen types, CF-containing HMA and SMAs can be used as active methods in anti-icing.
- It was observed that the volume resistivity was significantly decreased at 0.2% CF content of the HMA and SMA specimens, regardless of the CF length.
- In both HMA and SMA specimens, as stated by Garcı´a et al. (2009), after a particular value, no matter how many conductive components CF are added to the mixture, the resistivity will not show a significant change; in other words, the decrease in resistivity trend gradually becomes linear. Similarly, depending on CF percent and length, the difference in temperature increase changes gradually decreases.
- Test results show that aggregate gradation is also effective on conductivity. Because when the resistivity values and temperature increase of the HMA and SMA specimens are compared, it was seen that the SMA specimens are more conductive. The gap-graded gradation of the SMA specimens was facilitated the conductive bridge effect of the CFs by contacting each other. Thus, the volume resistivity of the mixtures is obtained as lower. Considering that conductive SMA can be used extensively in bridge and tunnel pavements that are risky in terms of icing, this result also important.

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LIST OF ABBREVIATIONS

CF: Carbon fiber

CAC: Conductive asphalt concrete

CUBWC: Conductive ultrathin bonded wearing course

DC: Direct current

HMA: Hot mix asphalt

RTFOT: Rolling thin film oven test

SMA: Stone mastic asphalt

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