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# Exploration of the Effect of Carbon Fiber Ratio and Dimensions on Electrical Conductivity in Mortars

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## ÖZET

This study was carried out on Class F and C fly ash reinforced, carbon fiber added mortar samples as a substitute for PÇ42,5 cement. Carbon fiber was added in different sizes at rates of 0.5%, 1%, and 3% in order to investigate the effects of the size and ratio of carbon fiber on electrical conductivity. 33 different series were formed such as obtained Class F; without fly ash 10%, 20% and Class C; without fly ash, 10%, 20% with samples without carbon fiber and with carbon fiber having dimensions 5 mm and 10 mm. The water/cement ratio was prepared to take the value of 22-23cm in the flow table test.,A viscosity regulator of 0.1% of the fine material was used in order to ensure homogeneous distribution of carbon fiber in the mortar. 3 samples were prepared for each series in order to reduce the margin of error. Electrical conductivity, compressive and tensile strength tests were applied to the oven dry and naturally moist conditions of the samples that completed their 7, 28 and 56 days curing periods. Increasing the carbon fiber size increased the tensile strengths and increasing the carbon fiber ratio increased the tensile strengths. It has been observed that carbon fiber increases the electrical conductivity, but the conductivity decreases depending on time, and as the sizes and proportions of the carbon fiber fibers increase, the compressive strength decreases due to the void effect in the mortar, while the compressive strength increases with the increase in the fly ash ratio. The microstructure and carbon fiber distribution of the samples were examined using SEM (Scanning Electron Microscopy) and it was seen that the carbon fiber distribution was in a way that supports the electrical conductivity measurement. The study allowed the size and proportion effect of carbon fiber in mortars to be compared with C and Class F reinforced mortar samples.

**Keywords:** Carbon fiber, Class F fly ash, Class C fly ash, Electrical conductivity

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## 1. Introduction

The structures of human beings constantly developed the structures, purposes of use, material types, application methods, etcfromtheir existence to the present. Many materials have been combined with the content of building elements in order to develop the elements used in buildings [1][2][3][4]. In their studies Çağlar et al. (2021),[5] state that the use of rice husk ash, which is an agricultural waste, with clay brick bricks, Çimen et al. (2020) [6] state that the use of boron waste in brick production will provide environmental and economic benefits. Although the raw materials that make up concrete are abundant in nature, the expectations from concrete are increasing day by day with the progress in construction technologies. Various researches are carried out on concrete and mortar samples in order to respond to expectations. For this purpose, researches such as reducing the cost, strengthening the weaknesses, etc. have been carried out by adding many materials into the concrete. In particular, there are studies on the use of industrial wastes in concrete mixtures. In addition to being a serious environmental pollution problem, these industrial wastes create economic and environmental problems in the disposal phase. For this reason, many wastes are tried to be eliminated regardless of their content. However, waste materials also have a value and wastes can be used to obtain products with high added value [7]. Fly ash, one of the valuable wastes, is a type of waste obtained from coal-fired thermal power plants. Fly ash obtained from thermal power plants in Turkey is generally used as raw material for cement factories [8]. In 2016, 19.5 million tons of waste was generated in thermal power plants. 87.8% of the total waste is ash and slag [9].

Various researches have been made to get benefit from fly ash as it is in every industrial waste [10][11] and it has been widely used as an additive in cement and concrete. Studies show that fly ash, which is one of the mineral mixtures, has a significant effect on the durability characteristics of concrete [12].

Energy saving with nanotechnological materials, determination of usage periods and easy recycling of structures that have completed their useful life when necessary, etc. is aimed In addition to purposes such as economy and environmental protection by using waste materials in concrete.

Although concrete, which has been used for different types of structures for many years, is resistant to compressive stresses applied to the structure, that it is not a material that is resistant to tensile stresses is one of the weaknesses of concrete. A lot of research has been done to improve this weakness. There has been a great demand to observe cracks in concrete and to prevent further progression of these cracks, and smart concrete has emerged from this demand [13]. The inventor of smart concrete, D.D.L. Chung (1993)[14] defines smart concrete as microscopic short carbon fiber reinforced concrete. When the concrete is deformed or stretched, the contact between the fiber and the cement matrix and the volumetric electrical resistivity are affected. The resulting deformations can be determined By measuring the change in electrical resistance. In other words, the structural cracks formed in the structures on the fault lines are detected by using smart concrete before they reach large dimensions. This capability can be used to monitor earthquake effects and monitor the internal conditions of the building.

According to Demirel (2006), the carbon fiber in the concrete increases the tensile and bending strength of the concrete, and also controls the cracking so that the cracks do not spread quickly. Chung, D.D.L. and Chen, P. (1993) [15] reported that no response was obtained from fiber-free concretes in such strains. Particularly, developments in microscope imaging techniques have provided a better understanding of the internal structure and damage mechanisms of concrete, and the distribution of reinforcement materials, thus enabling the development of effective materials and improving the properties of existing materials.

Unlike other studies, carbon fiber, whose many properties were investigated as a result of the literature review made with this study was mixed with Class F and C fly ash reinforcement on the mortar samples, and single and combination mixtures were created. It is desired to determine the 'electrical conductivity of the effect of size and ratio' of carbon fiber in the samples obtained and to create interaction tables regarding the electrical conductivity values of all samples and their compressive and tensile strengths. The distribution of carbon fiber was examined with SEM images to see a distribution compatible with electrical conductivity.

## 2. Material and Method

### 2.1 Material
#### 2.1.1 Cement

In the study, CEM I 42.5 R Portland cement, which complies with TS EN 197-1, has a particle density of 3.15 g/cm and a specific surface of 3740 cm/g, was obtained from the Ankara branch of a private cement company

[16]. The physical and chemical properties of the cement used in the study are given in Table 1.

Table 1 Physical and Chemical Properties of The Cement

| Chemical Properties | | | Physical Properties | | |
|---|---|---|---|---|---|
| **Constituents** | **CEM I 42.5R** | **TS EN 197-1** | **Properties** | **Value** | **TS EN 197-1** |
| CaO | 63,93 | | Set start | 141 | ≥60 |
| $SiO_3$ | 19,49 | C+S≥%50 | Set end | 202 | - |
| $Al_2O_3$ | 4,36 | - | density (g/ $cm^3$) | 3,15 | - |
| $Fe_2O_3$ | 3,40 | - | Blaine fineness ($cm^3$/g) | 3866 | - |
| MgO | 1,67 | Lim. ≤ %5 | Remaining at 32μ sieve | 7.7 | - |
| $Na_2O$ | 0,27 | - | Remaining at 90μ sieve | 0.1 | - |
| $K_2O$ | 0,67 | - | Total volume expansion | 1 | ≤ 10 mm |
| Ignition loss | 2,91 | ≤ % 5 | expansion | - | - |
| Insoluble residue | 0,32 | ≤ % 5 | 2 days strength | 28.1 | ≥ 20,0 Mpa |
| Sulfur Trioxide | 28.1 | ≥ 20,0 Mpa | 7 days strength | 45.7 | - |
| Chloride (Cl- ) | 0,0089 | ≤ % 0,1 | Daily strength | 56.8 | ≥ 42,5 Mpa ≤62,5 MPa |

### 2.1.2 Aggregate

Cen Standard Sand in accordance with TS EN 196-1 was used in the preparation of the mortar samples [17]. The relative density is 2.60-2.65 g/cm3. Cen Standard Sand was procured from the Trakya branch of a private concrete batching plant.

### 2.1.3 CarbonFiber

A technology product, carbon fiber, also known as carbon fibre, is a filamentous and lightweight material. The fact that it consists of tar, nylon and orlon increases its usage areas. The carbon fiber used in this study, the image of which is given in Figure 1 and the technical specifications in Table 2, was obtained from a private company belonging to the province of Yalova.

Fig. 1 Carbon fibers

Table 2 Technical properties of carbon fiber

| Property | Other |
|---|---|
| Density | 0 |
| Filament Diameter | 7 ± 5 |
| Elasticity module | 33 ± 5 |
| Electrical resistance | 67 ± 5 |
| Elongation at break | 87 ± 5 |
| Tensile strength | 99 ± 1 |
| Thermal conductivity | 0 |
| Fiber length | 5mm- 10mm |

### 2.1.4 Class C Fly Ash

Class C fly ashes are ashes produced from lignite or semi-bituminous coal with a total SiO2+Al2O3+Fe2O3 content of more than 50% and they have binding properties as well as pozzolanic properties. They are also named as high calcaraceous fly ash sinceCaO is > %10 . Soma Thermal Power Plant fly ash was used as class C in the mortar samples. Its specific gravity is 2.41g/cm3, 90µm sieve residue (%) is 33.7 .45 µm sieve residue (%) is 52.6 [18].

### 2.1.5 Class C Fly Ash

Class F fly ash is produced from bituminous coal and has a total SiO2+Al2O3+Fe2O3 percentage of more than 70% and has pozzolanic properties. It is also known as low calcareous because its CaO percentage is below 10%. Çayırhan fly ash was used as class F in the mortar samples. Its specific gravity is 2.36g/cm3, 90µm sieve residue (%) 6,7.45µm sieve residue (%) is 24.5% [18].

### 2.1.6 Water

The water/cement ratio in all mixtures was determined to remain in the range of 220mm-230mm in the Flow Table Test according to TS EN 12350-5 [19]. Yenimahalle/Ankara city mains water was used in the experiments.

### 2.1.7 Additive Degaset Visco L

Based on the knowledge that carbon fiber decomposes from blending materials due to its low density, viscosity regulator additive was used. Degaset Visco L additive used in the study was obtained from a private company operating in Ankara. It provides the right balance between fluidity, transition property and segregation resistance in concrete and adjusts the viscosity level in the mix. Also, it is an aqueous solution based on cellulose.

## 2.2 Method

### 2.2.1 Sample Production

In this study, CEM I 42.5 R Portland cement was used as binder, Cen Standard Sand was used as aggregate, 10% and 20% C and Class F fly ash was used as a mineral additive as a substitute for cement, 0.5%, 1, 3% carbon fiber was used for electrical conductivity. The dosage of the additive was used to remain between 0.1% and 1.0% by weight of the cement, and the water/cement ratio was determined to remain in the range of 220 mm-230 mm in the flow table test.

The first control sample was prepared without carbon fiber additive and fly ash, 0.5% by weight of cement with 1.3 carbon fiber additive. On the other hand the second control samples were formed as Class F and C fly ash separately at rates of 10% and 20% by weight as a substitute for cement. In the third control samples, it was prepared separately for all series with Class F and C es with 10%, 20% fly ash, 0.5%, 1%, 3% by weight of cement, carbon fiber and cement with additives at the rate of 0.1-1.0% by weight. The mixing amounts of the samples are given in Table 3.

Table 3 Mortar mixing amounts (kg/m$^3$)

| Sample | Cement | Sand | Fly Ash | Carbon fiber | Water | Additive |
|---|---|---|---|---|---|---|
| KNT 0 | 450 | 1350 | 0 | 0 | 225 | 0 |
| KNT+CF%0,5 | 450 | 1350 | 0 | 2,25 | 225 | 0,45 |
| KNT+CF% 1 | 450 | 1350 | 0 | 4,5 | 225 | 0,45 |
| KNT +CF%3 | 450 | 1350 | 0 | 13,5 | 225 | 0,45 |
| C-F%10 | 405 | 1350 | 45 | 0 | 235 | 0 |
| C-F%10+CF%0,5 | 405 | 1330 | 45 | 2,25 | 235 | 0,45 |
| C-F%10+CF%1 | 405 | 1330 | 45 | 4,5 | 235 | 0,45 |
| C-F%10+CF%3 | 405 | 1330 | 45 | 13,5 | 235 | 0,45 |

| | | | | | | |
|---|---|---|---|---|---|---|
| C-F%20 | 360 | 1330 | 90 | 0 | 245 | 0 |
| C-F%20+CF%0,5 | 360 | 1310 | 90 | 2,25 | 245 | 0,45 |
| C-F%20+CF%1 | 360 | 1310 | 90 | 4,5 | 245 | 0,45 |
| C-F%20+CF%3 | 360 | 1310 | 90 | 13,5 | 245 | 0,45 |

The materials were prepared in dry form for 1 minute with a mortar mixer and mixed for 3 minutes after adding the mixing water (Figure 2). Prepared mixtures were filled in 40x40x160mm prismatic molds lubricated with mold oil in three stages to ensure compression. 33 different series were prepared, each series being 3 pieces. The samples were taken from the mold after 24 hours and kept in the curing pool for 7, 28, 56 days (Figure 3).

Fig. 2 Preparing the Mixture

Fig. 3 Samples taken from curing pool

The samples, which have completed their curing periods, were weighed with humidity and kept in an oven at 100 ± 5 °C for 24 hours after the electrical resistivity was measured.
The samples taken from the oven, were weighed after they came to room temperature and electrical resistivity was measured independent of humidity conditions. Samples whose resistivity measurements were completed were subjected to tensile and compressive strength tests. and SEM analyzes were made for samples of which Electrical resistivity, tensile and compressive strength tests and electrical resistance values are close to peak values.

### 2.2.2 Tests which are applied for samples

#### Electrical Resistivity

Electrical resistance measurement provides a non-destructive approach to testing concrete materials, making it suitable for a variety of quality control projects, condition assessment purposes and research programs [20]. The measuring device used in the experiment and the sample that was measured are given in figure 4. The electrical properties were made in accordance with ASTM C 1760 (2012) [21] standard in three series for each 7, 28 and 56-day moist and oven-dry samples. The arithmetic average of the results obtained on three samples was taken for each experiment. R given in the equation represents Resistivity (ohm), Resistivity (ro), L; represents Length of sample (cm), A; represents the surface area of the sample (cm).


Fig. 4 Sample of which resistance measurement was carried out

$R = \frac{\rho L}{A}$ equation was used in electrical resistivity calculations

**Tensile Strength Test**

Tensile strength test is a method used to have information about the strength of the material, to determine the mechanical properties of the material against bending and to examine the design data. The test data taken from the samples were determined as 7, 28 and 56 days and three series for each sample, according to the TS EN 12390-5 standard, by loading the sample from the middle and tensile strength in bending was determined. The average of the obtained data was considered [22].

**Compressive Strength Test**

Compressive Strength Test is carried out to control whether the concrete class and strength prescribed during the design phase of the concrete are maintained.

**Examination of Microstructure**

The strength of concrete mostly depends on the properties of its microstructure, such as pore mesh size and interconnections., The microstructure was examined by SEM in order to see the microstructure of the mortar samples and the distribution of the carbon fiber in the sample. SEM or scanning electron microscope is a type of electron microscope that obtains images by scanning the sample surface with a focused beam of electrons.

**Water Absorbtion**

The water absorption rate is defined as the ratio of the weight of water absorbed by the material to the dry weight of the material. The electrical resistivity of concrete is closely related to its water absorption. The samples were weighed in naturally moist and oven-dry state for 7, 28 and 56 days and in three series for each sample.

The ratio of the difference between the water-saturated weight (G2) and the dry weight (G1) of the material, expressed as a percentage, to the dry weight gives the weight water absorption percentage (Sa) of the material.

$S_a(\%) = \frac{G_2 - G_1}{G_1}$ equation was used in calculations.

## 3. Research Results and Evaluation

### 3.1 Electrical resistance

Figure 5 shows the electrical resistance measurement results of the 5mm carbon fiber added and fly ash series in 7, 28, and 56 days oven-dry state. When we look at the control sample, it is seen that the conductivity decreases depending on time, and the conductivity increases in the 56-day readings with the addition of fly ash to the control sample. In carbon fiber and fly ash combinations, the series with 20% fly ash were found to be more conductive than the 10% fly ash and control series. The best conductivity value was recorded in the series with 3% carbon fiber and 10% -20% fly ash. 10% Class F fly ash series with carbon fiber combination are more conductive when it is compared with 10% Class C fly ash series.

Daily dry electrical resistance comparisons of series with CF5mm fly ash

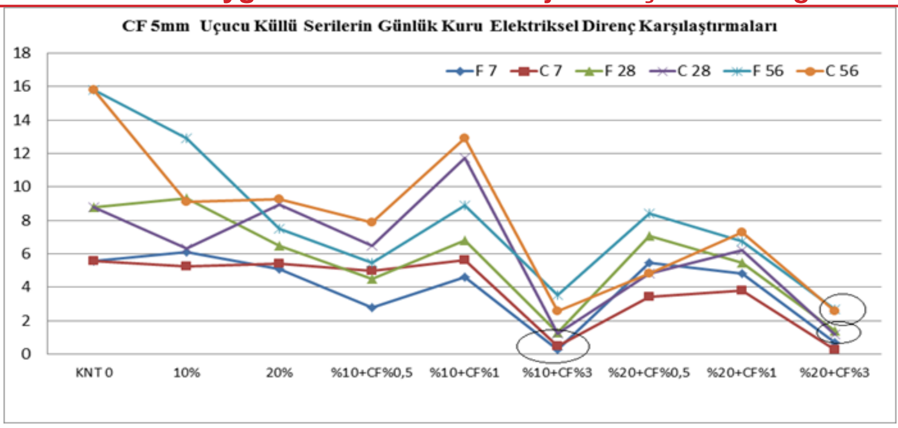


Fig. 5 Dry Electrical Resistance Values oClass F F and C 5mm CF + fly ash samples

Figure 6 shows the electrical resistance measurement results of 7, 28,56 days of naturally moist state of 5mm carbon fiber and fly ash series. No significant differences were observed in the 7, 28 and 56 day results of the carbon fiber-free fly ash combinations. In combinations with fly ash and carbon fiber, Class C series were found to be more conductive than control and Class F series. The best values were recorded in C10+CF3% and C20+CF 3% samples.

Daily humid electrical resistance comparisons of series with CF5mm fly ash

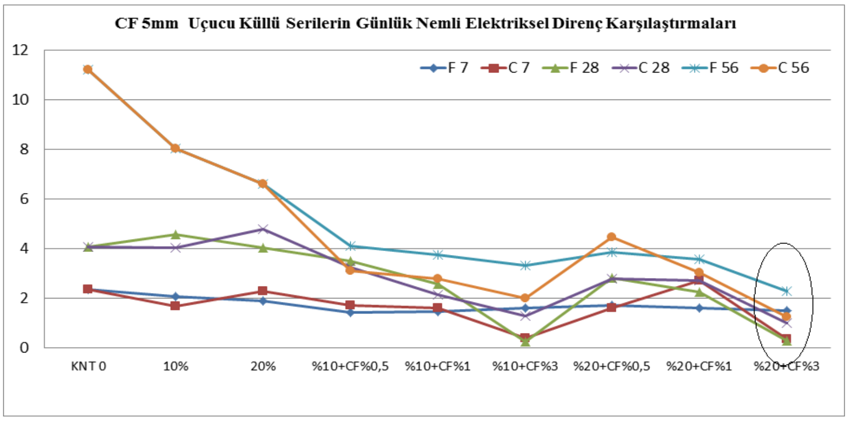


Fig. 6 Humid Electrical Resistance Values oClass F F and C 5mm CF + fly ash samples

Figure 7 shows the electrical resistance measurement results of the 10mm carbon fiber and fly ash series in 7, 28, and 56 days oven-dry state. It has been noted that in combinations with 10% fly ash without carbon fiber, the Class C series is more conductive than the F series, and the conductivity increases as the carbon fiber ratio increases to the 10% fly ash series. The series with 3% carbon fiber combination showed the best conductivity In samples with 20% fly ash and carbon fiber, however, samples with 10% fly ash and carbon fiber were more conductive than those with 20%. The best findings were obtained from C10+CF 3% and F10+CF 3% samples. Daily electrical resistance comparisons of series with CF10 mm fly ash

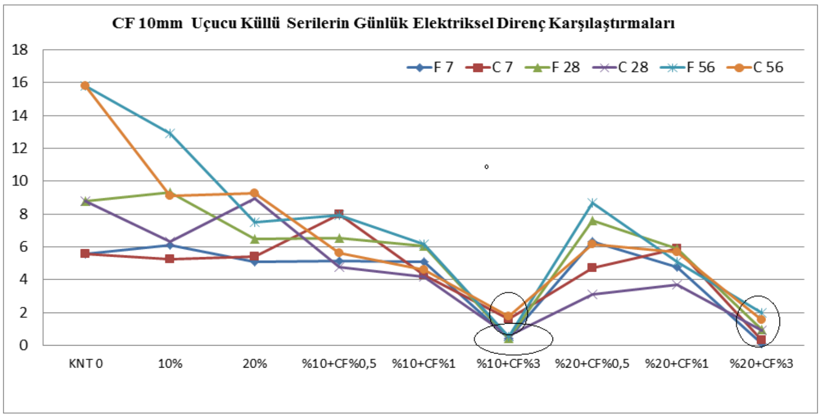


Fig. 7 Dry Electrical Resistance Values oClass F F and C 10mm CF + fly ash samples

Figure 8 shows the electrical resistance measurement results of the 10mm carbon fiber and fly ash series at 7, 28, and 56 days of naturally moist state. While the conductivity values were close in the series with 10% fly ash and 0.5%, 3% carbon fiber combinations, it was noted that the Class C was more conductive in the 56-day reading in the series with 1% carbon fiber. While C10+CF 3% and F10+CF 3% samples showed very close and good conductivity values, the best conductivity value was determined in C20+CF 3% sample.
Daily humid electrical resistance comparisons of series with CF 10 mm fly ash

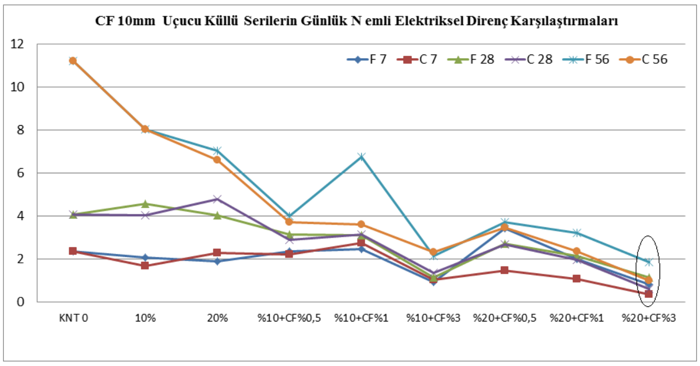


Fig. 8 Humid Electrical Resistance Values oClass F F and C 10mm CF + fly ash samples

### 3.2 Comparisons of Tensile Strength

7, 28, 56 days tensile strength measurement values of 5mm size carbon fiber and fly ash series are shown in Figure 9. When we look at the carbon fiber series without fly ash, there was no significant change in the 0.5% carbon fiber series compared to the control sample, but an increase was observed in the 56-day readings compared to the control sample. Decreases were observed in tensile strength at 7-day readings in combinations with fly ash and carbon fiber,, while significant increases were observed at 56-day readings, except for the 20% fly ash and 0.5% carbon fiber series. C10+CF3% sample showed the best value in tensile strength.
Tensile strength comparisons of series with CF5mm fly ash

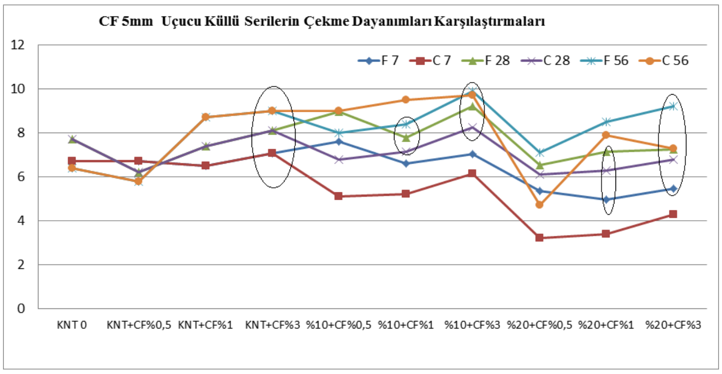


Fig. 9 Tensile Strength Values oClass F F and C 5mm CF + fly ash samples

7, 28, 56 days tensile strength measurement values of 10mm size carbon fiber and fly ash series are shown in Figure 10. It is seen that the series with Class C fly ash and carbon fiber show higher tensile strength compared to the control sample and Class F fly ash and carbon fiber series. The highest tensile count values were observed in the CNT+CF 1% sample. The series with 20% fly ash showed values close to the control sample., It was determined that there was an increase in the tensile strength values at the 56-day readings While no significant differences were observed in the seven-day readings compared to the control sample.
Tensile Strength comparisons of series with CF10 mm fly ash

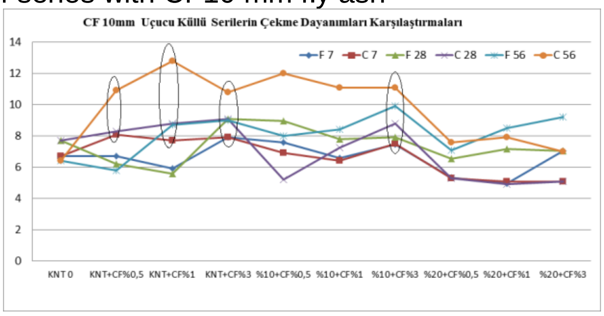


Fig. 10 Tensile Strength Values oClass F F and C 10mm CF + fly ash samples

According to the findings, the increase in carbon fiber size and ratio affects the tensile strength positively. The use of fly ash increases the strength in the long term, but as the face ratio increases, it affects the tensile strength negatively. Class C fly ash combinations show higher tensile strength than Class F fly ash combination compared to the control sample.

### 3.3 Values of Compressive Strength

Figure 11 shows the 7,28,56-day compressive strength measurement values of 5mm-sized carbon fiber and fly ash series. It was observed that the compressive strength of the samples decreased as the carbon fiber ratio increases. highest compressive strength values were observed in the F10+CF1% and F20+CF1% samples compared to the control sample and other combination series . The Class F fly ash series compressive resistance was higher than the Class C fly ash series.. This data is compatible with the pozzolanic feature of the Class F.

Compressive Strength Comparisons of Series with CF 5m Fly Ash

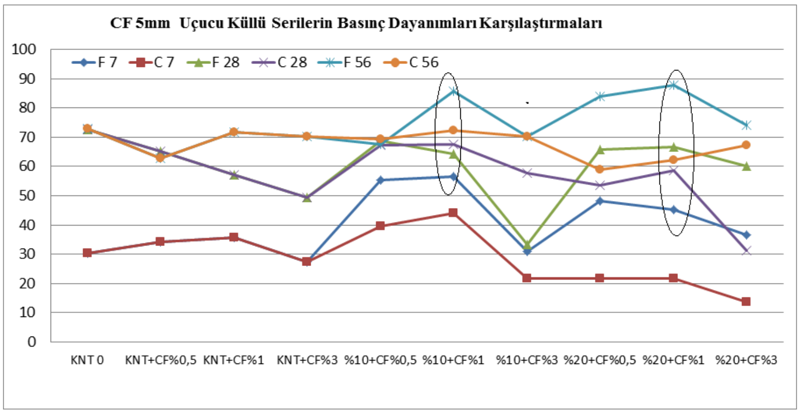


Fig. 11 Compressive strength values of Class F and C 5mm CF + fly ash samples

7, 28, 56 days of compressive strength measurement values of 10mm size carbon fiber and fly ash series are shown in Figure 12. Class F and carbon fiber combination series showed higher compressive strength compared to C class carbon fiber series. The highest compressive strength was determined in F10+CF 0.5% VE F20+CF 1% samples. When carbon fiber ratio is used more than 1%, there is a decrease in compressive strength.

Compressive Strength Comparisons of Series with CF 10 mm Fly Ash

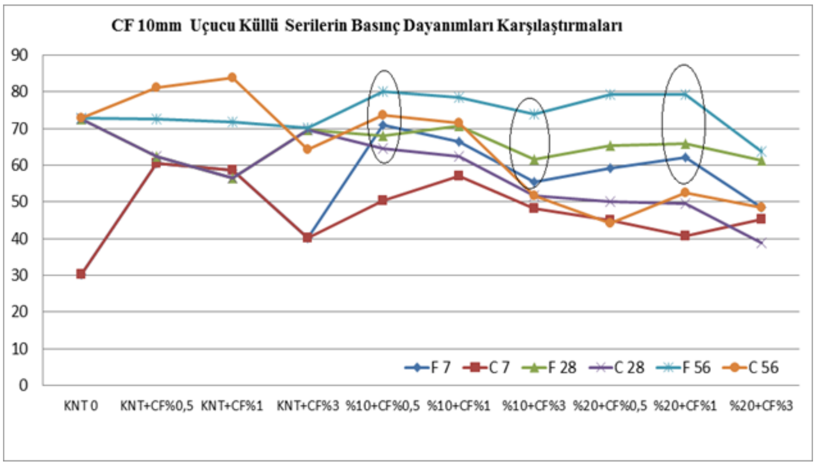


Fig. 12 Compressive Strength values of Class C and F 10mm CF + fly ash samples

According to the findings, the increase in carbon fiber size affects the compressive strength positively, while the increase in carbon fiber ratio affects the compressive strength negatively. When the percent water absorption data and compressive strength are compared, carbon fiber causes spaces in the mortar and these spaces negatively affect the compressive strength in the same direction. Fly ash combinations affect the compressive strength positively depending on time. Class F class fly ash combinations show higher compressive strength than Class C c fly ash combinations compared to control sample.

### 3.4 Water Absorption Values

The water absorption percentage values of the carbon fiber-free fly ash series are higher compared to the control sample. According to Figure 13, all series of the C class fly ash mixtures have a high water absorption rate, except for the C10+CF 0.5% sample, compared to the control sample. Among the carbon fiber-free samples, the percentage water absorption rates of the C class fly ash series are higher than the F class series. A percentage water absorption rate increase was detected in parallel with the increase in the carbon fiber ratio compared to the control sample.

The data show that as the carbon fiber ratio increases in the samples, the percent water absorption value also increases. The series containing 10mm carbon fiber at the same rate has a higher percent water absorption value compared to the series containing 5mm size carbon fiber.

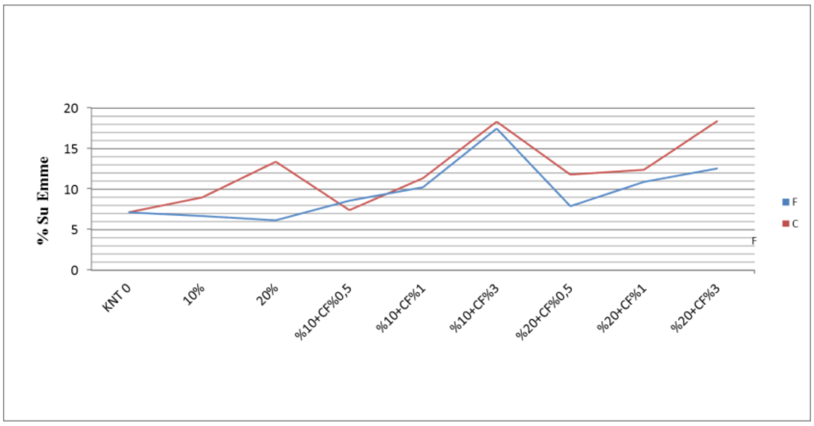


Fig. 13 F Water absorption values of Class F and C fly ash

### 3.5 SEM Imaging Analysis

In Figure 14, the SEM image of a part of the C10+CF3% 5mm carbon fiber sample obtained by the fracture in the compressive strength test is seen. The stripping that occurs in the fracture and the rupture of the fibers are clearly seen at the ends. In their study, Chen and Chung (1993) state that the contact resistance between the fiber surface and the matrix is parallel to the cleanliness on the surface [14]. It has been determined with this image that there is a parallel distribution and interlocking with the electrical resistivity value and strength tests.

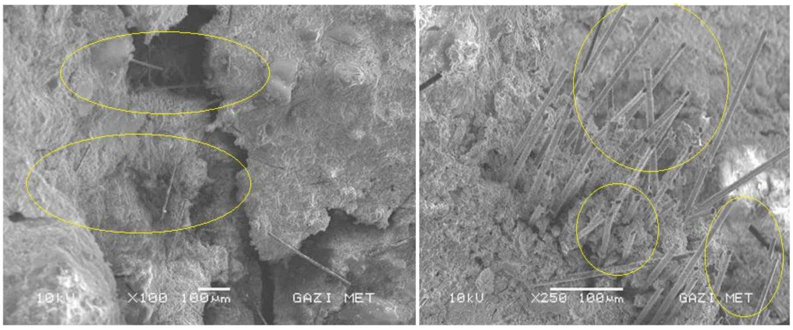


Fig. 14 SEM Image of C10+CF%3 5mm sample

## 4. Results and Recommendations

The effects of carbon fiber ratio and size on electrical conductivity and strength in mortars were examined in this study. The findings obtained during the studies are given below:

1. The conductivity increases as the carbon fiber ratio increases in the fly ashless series compared to the control sample according to the electrical resistivity measurement in Class C and F 5mm carbon fiber doped and naturally moist samples,.
2. It is seen that the electrical conductivity decreases with time in all series compared to the control sample,. In all series, the electrical conductivity values in the naturally moist state are higher than the electrical conductivity values in the oven-dry state.
3. It was observed in the series without fly ash that the tensile strength increased as the carbon fiber ratio increased. Carbon fiber series without fly ash showed higher tensile strength compared to series with fly ash and carbon fiber. When examined in terms of size, 10mm size series showed higher tensile strength than 5mm carbon fiber series. Generally, C class fly ash and carbon fiber combination series showed higher tensile strength data compared to the  Class Ffly ash and carbon fiber combination series.  The highest tensile strength in carbon fiber blended series was determined in the series with a ratio of 3%.

4. All series with fly ash and carbon fiber mixtures showed higher compressive strength compared to the control sample. F class fly ash series with 5 and 10 mm size carbon fiber provided higher compressive strength compared to C class fly ash series.
5. The percent water absorption rate of the C class fly ash series, which is one of the carbon fiber-free samples, is higher than the F class series. There was no significant change in the percent water absorption rate in the F class series in the control samples, while an increase in the percent water absorption rate was found in the C class fly ash series.
6. This study showed that carbon powder increases electrical conductivity in fly ash reinforced mortars used as mineral additives. It has been determined that carbon fiber can be beneficial in structures targeted for conductivity. The use of fly ash and carbon powder together has been found to be more economical than other carbon containing materials. In addition, it is thought that the widespread use of carbon fiber used with mineral additives will reduce the rate of environmental pollution.

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