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Research Article

Experimental Study on Engineering Properties of Recycled Olivine Aggregate Filled CF Reinforced Electrically Conductive Mortars

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ABSTRACT

Electrically conductive concretes produced for different purposes were introduced years ago and since then, intensive scientific research has been going on. Studies in the literature have generally been carried out on conventional concretes with electrical conductivity for floor applications. The current study investigates carbon fiber reinforced mortars filled with fine olivine aggregate. Fine aggregate filled mortars are generally produced for building facade applications. Within the scope of the study, the mechanical, electrical, dynamic and microstructural properties of cementitious mortars containing 0.5%, 0.75% and 1.0% carbon fiber and 100% recycled olivine aggregate were investigated. The purpose of performing dynamic resonance tests was to investigate the effect of carbon fiber on damping ratio. 28-Day compressive, flexural, dynamic resonance, ultrasonic pulse velocity (UPV), Leeb hardness and dry density tests of conductive mortar samples obtained from four different mixtures were performed. In addition, 2, 14, 28, 90 and 180 days electrical conductivity tests were carried out to determine their resistivity in different time intervals. The purpose of performing dynamic resonance tests was to investigate the effect of carbon fiber on damping ratio. While a significant positive effect of CF on electrical conductivity and damping ratio was observed, a negligible decrease in mechanical results was observed. Calcium silicate hydrate (C-S-H) structure formed by hydration using olivine filler in the cement mixture confirmed the binding formations.

1. Introduction

It has been known that the electrical conductivity of cement-based mortars, which are insulating in the dry state and semiconductor in the wet state, shows low performance. However, when voltage is applied to concrete, which has electrical conductivity, it resists electric current [1, 2]. Different studies have been carried out to determine the conductivity of cement mortars and concrete. It has been tried to increase the conductivity of the concrete by adding different conductive additives to the cement mortar [3]. Electrically conductive concrete could be produced by adding conductive materials such as carbon nanotubes, graphene, carbon black, and carbon fiber to cement-based mixtures. Conductive materials provide both structural and electrical use possibilities due to their excellent electrical conductivity and superior mechanical properties [4].

It was stated that the distribution of graphene and carbon fiber in the cement mortar affects the electrical and mechanical properties of the material [5]. On the other hand, it has been

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reported that carbon fiber, which is not homogeneously dispersed in the cement matrix, has a negative effect on the compressive strength and flexural strength of the material [6]. It has been stated that carbon nanotube [7] and graphene [8] as conductive additives added to concrete mix are important factors in reducing concrete material resistance.

Ma et al. [9] emphasized that the possible increase in electrical resistance due to insufficient dispersion of graphene in the cement matrix can be overcome by making carbon dispersion more effective. Bi et al. [10] used silicium dioxide (SiO_2)to improve the dispersion of carbon nanotubes in the cement mixture. However, they stated that due to the high cost of these conductive components, it limits their widespread use in construction. Also, it was stated that the distribution and size of the filling material in the cement matrix were at least as important as the conductivity of the material used to increase the conductivity of the concrete [11].

It was stated that low-cost fiber conductive components of different structures could improve the electrical conductivity of conductive concrete [12]. Among the conductive additives, carbon fiber has been preferred in the production of conductive cement mortars, which are superior in terms of both mechanical and physical properties. In addition, it was stated that the distribution of carbon fiber added to the concrete mortar in the mixture and the mixing method are important factors affecting the conductivity of the concrete mortar [13].

Wen and Chunk [12] reported that the use of 50% carbon fiber and 50% carbon black contributes to the resistance of the material in electrically conductive concrete. In addition, they stated that the use of conductive aggregates instead of sand and aggregate contributed significantly to the conductivity of concrete. He et al. [14] reported that 0.6% by volume of carbon fiber and 30% by volume of conductive aggregate should be added to Portland cement to obtain under of 3.5 Ω.cm electrical resistivity. Similarly, in the study of conductive mortar containing swcnt and steel fiber, it was stated in the literature that the electrical resistance decreased up to 500 cm.Ω [15].

Also, it could be used for heating and defrosting by putting carbon fiber in an electrically conductive cement mortar. However, as thermal stress may occur on the concrete road with this application, the structure is damaged and thermal stability decreases. Therefore, electrically conductive cement mortar application could be realized by reducing the thermal stress between layers [16]. Vilaplana et al. [17] reported that conductive concrete exhibited an electrical resistance of 97.86 Ω cm with carbon fiber reinforcement in the range of 0.29% - 0.58% by volume in the concrete mix, and this resistance was lower than that of portland concrete.

On the other hand, cement has been widely used as a binder in the construction industry. However, during cement production, there is both high energy consumption and significant carbon dioxide (CO_2) emissions into the atmosphere. Instead of cement alkali activated binder materials such as kaolin, metakaolin, and fly ash are recommended [18]. The CO_2 emission value of olivine was measured as 9 Mtons of CO_2 per year-1 after approximately 25 years of use [19]. The use of recycled and reusable materials instead of aggregate and sand used in cement mortars may benefit from reducing concrete waste. It has been stated that olivine cement mortar can provide low density and less mechanical resistance by affecting both physical and mechanical properties. Thus, it will be able to contribute to building materials in terms of sustainability [20]. To ensure sustainable concrete production, it is expected that using olivine as a binder in cement mortar will be more suitable both in terms of environment and economy.

Papayıannı et al. [21] aimed to develop shotcrete mixtures with olivine aggregates that can act as a protective coating in case of high temperature exposure such as fire in a tunnel. They used olivine aggregate instead of limestone aggregate in shotcrete mixes. The results showed that replacing limestone with olivine was superior in strength at all strain temperatures of concrete; This proves that the use of olivine-based shotcrete enables the production of fire resistant shotcrete at temperatures up to 850°C. There has been limited research on the compressive strength of concrete materials based on olivine minerals.

The mechanical properties of the concrete obtained by using olivine mineral instead of aggregate and sand in cement mortar were tested. In addition, scanning electron microscopy-energy distribution spectrometry (SEM-EDS) was used to examine the effect of olivine in concrete structure on microstructure and porosity. In this study, a new type of conductive concrete was designed by using olivine as aggregate, and carbon fiber as conductive material. The engineering properties of the conductive concrete material were investigated by changing the carbon fiber ratio.

2. Material and Methods

2.1. Material properties

100% olivine aggregate was used as the filling material in all mixtures. The specific gravity of olivine aggregate used was 3.24. CEM II-42.5 R white cement, which is preferred in facade cladding, was used as binder. As a pozzolanic additive material, calcined kaolin was preferred in equal proportions in all mixtures. The particle size ranges of olivine, cement, and calcined kaolin were compared in figure 1. 12 mm long, 7.2 µm diameter, and 0.00155 electrically resistant, CF has been used as conductivity enhancing fiber. Polycarboxylate based superplasticizer was used to ensure adequate workability in all mixtures.

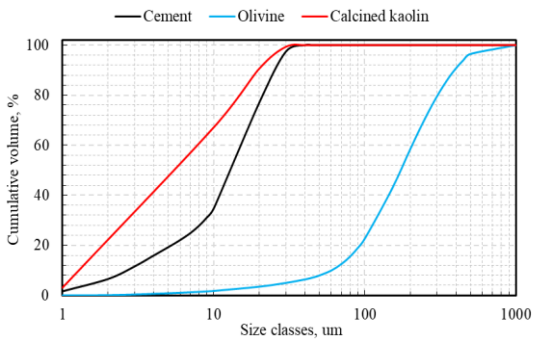

Figure 1. Grain size analysis curves of cement and filling materials

Details of materials used in electrically conductive mortars are given in Table 1. olivine filled pure mix is a normal primix mortar consisting of filler, binder, pozzolanic, water, and plasticizer, and is defined as the matrix for other mixtures. In the primix mixture, all dry ingredients are put into the mixer, mixed for 90 seconds, then plasticizer is added together with water and mixed for 90 seconds again, then placed in molds. In carbon fiber mixtures, after all the components came together and the matrix was ready, the fibers were added and mixed with a mixer for 90 seconds.

Table 1. Component ratios in electrically conductive mortars

No	**1**	**2**
Code	OLV	OLV-0.50CF
Olivine (g)	1350	1341
Cement (g)	500	500
Calcined kaolin (g)	50	50
Su (g)	220	220
CF (g)	0	9
Superplasticizer (g)	6	7.5
No	3	4
Code	OLV-0.75CF	OLV-1.0CF
Olivine (g)	1337	1333
Cement (g)	500	500
Calcined kaolin (g)	50	50
Su (g)	220	220
CF (g)	13	17
Superplasticizer (g)	8.5	10

2.2. Test methods

The electrical resistivity of the 40x40x160 mm mortar samples produced were obtained by the two-point uniaxial measurement method, which is frequently preferred in studies such as [1, 11]. The electrical resistivity of an object is a measure of its opposition to the electrical conductivity [3]. The potential difference applied in all resistivity measurements was 30 V. Longitudinal resonance frequency testing was performed for samples according to ASTM C215 standard [22] in this. The sample was fastened in the midpoint between two supports and oscillation was applied from one end of the sample with a spherical impact pull, while the impact response from the other end was measured with an accelerometer. Using the data obtained by the accelerometer, different equivalent resonance frequency diagrams are drawn for each sample. Based on the longitudinal resonance frequency, damping ratio of mortars is calculated. Schematic images of resistivity and dynamic resonance test methods are shown in Figure 2.
The method used in this study is based on the half-power bandwidth method [23, 24]. The schematic experimental setup view of resonance

and resistivity tests are shown in Figure 1. UPV tests were performed according to ASTM C597 [25]. The ASTM A956 standard [26] was used to determine the Leeb hardness of the produced samples. Flexural and compressive strength tests were carried out in accordance with the TS EN 196-1 standard [27] on three 40 x 40 x 160 mm prismatic samples obtained from each mixture.

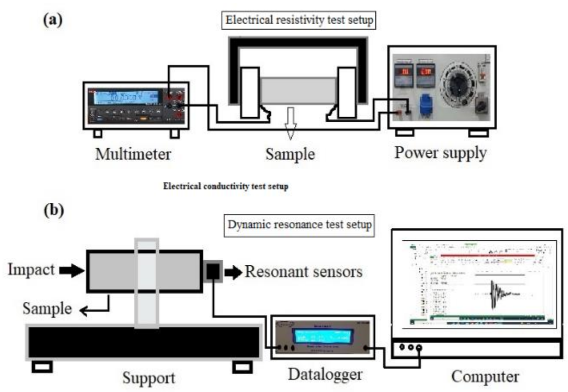

Figure 2. (a) Two-point uniaxial electrical resistivity measurement test setup, (b) Dynamic resonance test setup

Scanning Electron Microscope (SEM) (Hitachi VP-SEM SU1510) was used to examine the microstructure of powder samples and prepared conductive concrete samples and to analyze structures at the sample interface after mechanical testing. X-ray diffraction (XRD) analysis technique was used for phase identification of crystal materials. The crystal phases of the pure olivine mixture sample and the 0.75% CF added sample were determined, together with the analysis of cement powder, calcined kaolin and olivine sand added to the cement mixture. Powder samples and crystal phase characterizations of the prepared samples were performed with RIKAGU Smart Lab X-ray diffractometer. Kα Cu at a wavelength of 1.54 nm was used as the X-ray source, and scanning was performed in the range of 10° to 90°.

3. Results and Discussion

3.1. Mechanical test results

The flexural and compressive test results of the mortar samples produced within the scope of the study are compared and summarized in figure 3. When compressive and flexural strengths are compared, a harmonious parallel relationship is observed between them. The linear relationship between them is shown in figure 4. The linear relationship between compressive strength and flexural strength can prove that the mixture is homogeneous and that the fibers are evenly distributed. Campos et al. [28] proved that there is a negative relationship between the air content of normal strength concrete and its compressive and flexural strengths. According to their research, a significance test on fresh field properties revealed that air content is the most important fresh field property affecting compressive and flexural strengths. These researchers have reported its direct usability in models that relate air content, compressive strength and flexural strengths.

Considering the effect of CF on compressive strength, it was observed that the strength of the sample containing 0.5% CF increased by 2.63% compared to the strength of the pure OLV sample. However, the compressive strength of the mixtures with 0.75% and 1 CF added decreased by %3.53 and %7.40, respectively. In the flexural strength results, 0.50% and 0.75% CF had a positive effect of %13.23 and %1.61, respectively, while a negative effect of 4.84% of 1% CF was observed. This behavior of carbon fiber in cementitious materials has also been proven in the literature and it has been reported that the reason is due to the voids formed in the mixture [3].

The reason for the voids formed in the mixture is that the carbon fibers used in high doses clump in the mixture and workability problems are experienced. It has been proven that the addition of CF at higher dosages improves the flexural strength compared to the compressive strength when compared with other studies in the literature [29]. In order to prevent crack formation and propagation in bending, the optimum fiber ratio is different according to the condition of the element subjected to compressive load.

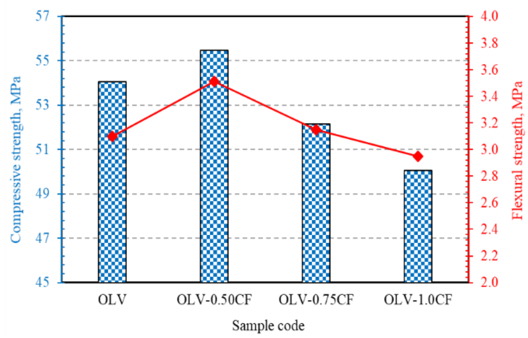

Figure 3. Compressive and flexural test results

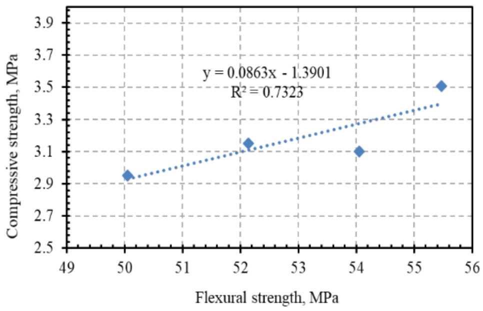

Figure 4. Relationship between compressive and flexural strengths

3.2. Non-destructive test results

In this section, the properties of the products obtained within the scope of the study were examined by applying some non-destructive testing methods. For electrical resistivity measurement, the electrical current values of 2, 14, 28, 90 and 180 days of samples produced from 4 different mixtures were read. The resistivity results obtained are summarized in figure 5 . Considering the effect of CF in the samples, it was observed that the resistivity values decreased significantly with the addition of fiber and increasing its ratio. When the age effect is examined, the resistivity values of the samples increased rapidly in the first ages, while the conductivity loss rate decreased in the later ages.

One of the reasons for the decrease in the conductivity value depending on time is the drying of the water in the mixture in any way. Some of this water can be consumed for the formation of CSH products and some by evaporation. Another reason for the decrease in conductivity over time is the development of CSH products and the obstruction of the electrical current path by wrapping around the conductive fibers. This behavior may appear less in conventional concretes because the fine minerals content is not as high as in the current study, so there is less chance of passive layer formation around the fibers over time.

Resistivity values of OLV, OLV-CF0.5, OLV-CF0.75 and OLV-CF1.0 samples increased by 13, 3.7, 2.1 and 1.9, respectively, in the 2-180 day range. Here, the increase in the carbon fiber ratio seems to decrease the age effect on the resistivity. However, the 180-day resistivity values of these samples were obtained as 39921.29, 391.40, 205.33 and 101.43 Ω.cm, respectively. These values were confirmed by comparison with the literature [3, 30].

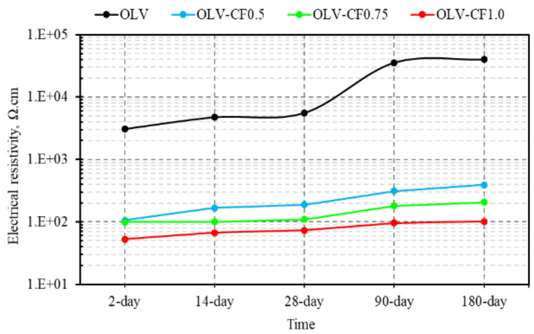

Figure 5. Resistivity results of specimens

The frequency-amplitude curves of the 28-day prismatic samples obtained from 4 different mixtures were drawn after the resonance test and compared in figure 6. Building elements produced from cementitious materials are exposed not only to mechanical but also to dynamic loads throughout their service life [31]. Therefore, it is important to examine the dynamic properties, especially the damping ratio, of these materials containing different additives and fibers. The damping ratio is one of the main parameters representing the vibration dampening property of materials [32]. According to the resonance test information in the literature, it is known that narrow and steep Frequency-Amplitude curves have less damping property of the relevant material, and wide and low curves have higher damping properties [33].

When the test results in this study are compared and the damping ratio values in figure 7 are compared, similar behavior in the literature can be achieved. Considering the damping ratio values, it was observed that the values of all three CF added mixtures increased compared to the pure OLV mixture. The damping ratio values of 0.5%, 0.75% and 0.1% CF added mixtures increased by 15.61%, 26.16% and 14.27%, respectively, compared to the pure mixture. However, the damping rate of the mixture with 1.0% CF added decreased by 9.42% compared to the 0.75% CF added. In the literature, it has been reported that the damping ratio increases when the amount and length of synthetic fibers increase up to a certain interval [32, 34]. The [15] study proves that the use of fiber above its optimum ratio can result in a reduction in damping ratio.

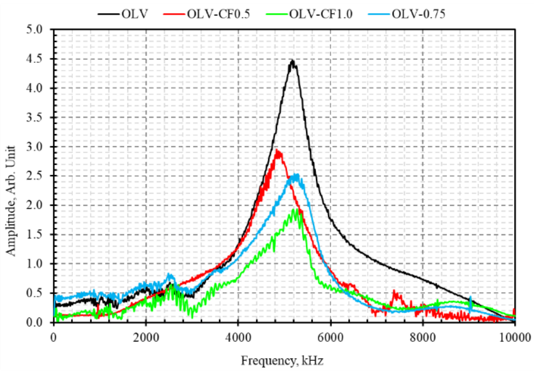

Figure 6. Amplitude-frequency curves of conductive mortar specimens

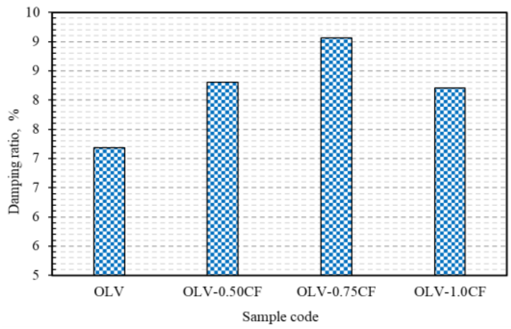

Figure 7. Damping ratios of specimens

UPV and density test results of electrically conductive mortar samples obtained from four different mixtures are shown in figure 8. When the results were compared, it was observed that there was a very strong linear relationship between them. The UPV values of 0.5%, 0.75% and 0.1% CF added mixtures decreased by 11.17%, 17.08% and 26.46%, respectively, compared to the pure mixture. Considering the density test results, the values of the same mixtures decreased by 4.60%, 6.69% and 11.30%, respectively. UPV test is a method that gives information about the internal structure defects of materials.

Also, UPV method, known as a non-destructive method, is a technique used to determine the estimated compressive strength of building materials. UPV refers to the time it takes for the ultrasonic pulse to travel a certain distance through a material, usually in concrete and mortar specimens. As the rate of defects such as voids increases in cementitious materials, the ultrasonic sound velocity decreases, and on the contrary, the sound velocity increases with a decrease in the void ratio [35, 36]. This situation is also understood in figure 8 as the density values are parallel to the UPV values. In figure 9, the correlation coefficient of the linear relationship was calculated as 0.9965. However, this correlation is valid between 0-1% CF ratio, different relationships can be observed at different rates. UPV results also had a direct parallel relationship with compressive, flexural, resistivity and Leeb hardness test results. However, like all these test results, the UPV values also had an inverse relationship with the damping ratio.

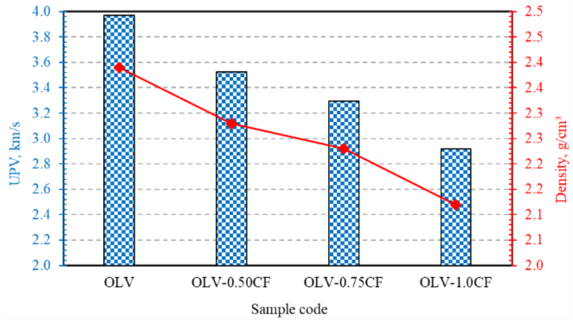

Figure 8. UPV and density values

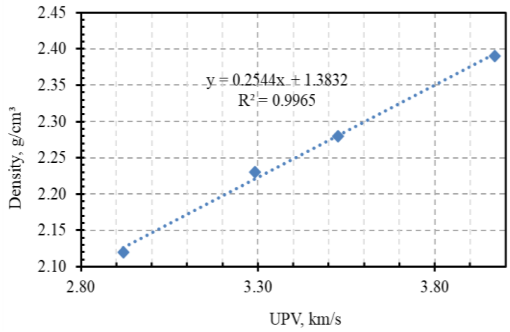

Figure 9. Relationships between UPV and density test results

Schmidt hammer test is generally applied to obtain information about the surface hardness of cementitious materials. In addition, as a more practical method, the application of the Leeb hardness test has been seen in a few studies. The Leeb hardness test method is a method developed for metal materials, but some researchers have also used it in the measurement of cementitious materials. In a study in the literature, the Leeb hardness value for a conventional concrete was obtained between 362-405 HL. Lebb hardness values measured for mortar samples vary between 560 and 542 HL. Gomez-Heras et al. [37] stated that the finer the grain size, the higher the Leeb hardness. This situation is directly related to the filling of fine-grained minerals into micro and macro pores [38]. Therefore, in this study, it can be proven to be true that the Leeb hardness is higher compared to conventional concretes, since the aggregate particle size is less than 1 mm. Since there has been no hardness research about olivine filed mortars, it is impossible to compare the obtained hardness values with the literature.

Considering the Lebb hardness results summarized in figure 10, it was observed that the hardness values decreased with the addition of CF and increasing its ratio. The negative effect of CF on hardness may be related to the resulting porosity. The low diameter of the CF may reduce the workability of the mixtures and settling problems may occur. This leads to a decrease in some physical and mechanical properties of the composite material. A similar behavior is observed when the hardness results are compared with the compressive and flexural strength results. Comparing OLV-CF0.5, OLV-CF0.75 and OLV-CF1.0 mixtures with pure OLV mixture, Leeb hardness was observed to decrease by -1.25%, -1.61% and -3.21%, respectively.

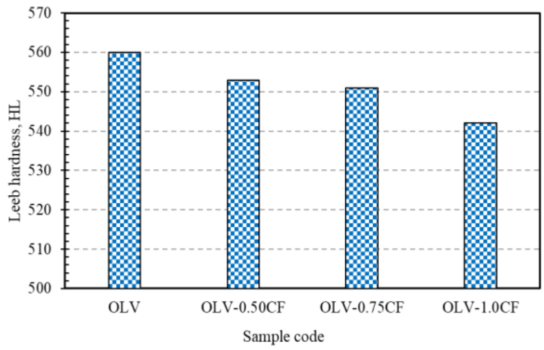

Figure 10. Leeb hardness test results

3.3. Microstructure analysis results

SEM images of cement powder, calcined kaolin powder, olivine sand, and CF are shown in figure 11. Calcined kaolin produces dehydroxylation and does not cause any change in the nested particle structure [39]. On the other hand, it is seen that the gap between the calcined kaolin particles in the cement matrix increases. This could be attributed to the increase in the surface area of the particles. In the micrograph of olivine sand, an irregular shape was seen in figure 11 (c). It could be observed that replacing the normal silica sand material with olivine sand will affect the chemical composition of the fractions in the concrete mix. The surface morphology of CF analyzed by SEM is shown in figure 11 (d). CFs with a highly smooth surface have an average diameter of about 7.2 µm and an average length of 12 mm.

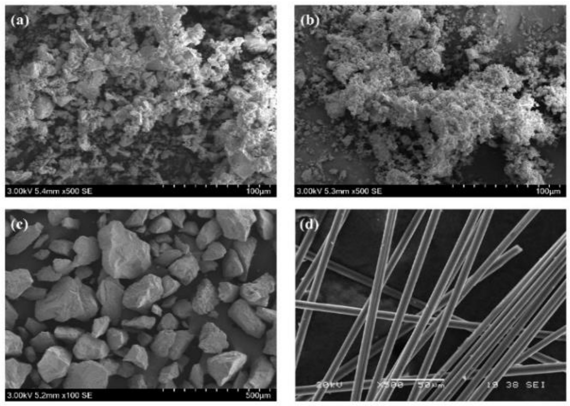

Figure 11. SEM images of cement powder (a), calcined kaolin powder (b), carbon fiber (c) and olivine sand (d) used in mixtures

Figure 12 shows XRD patterns of cement powder, calcined kaolin, and olivine sand. The peak intensities in the powder samples allow the determination of specific phase groups in the compositions. In addition, the peak intensities provide information about the residue mixtures. Crystalline phases at low peak densities contain phases that are difficult to identify. Calcite, C2S, and C3S phases were detected in the cement powder material. The cement mortar produced using fine and natural sea sand was allowed to absorb water completely. The intense peaks in the X-ray diffractogram are C2S and C3S. As stated by Jaya et al. [40], C2S (Ca_2SiO_4) and C3S (Ca_3SiO_5) crystal phases, which show the hydraulic properties of cement, participate in the hydration reaction that strengthens the cement structure.

On the other hand, quartz, kaolinite, olivine, forsterite, and portlandite (calcium hydroxide) phases detected in XRD diffractograms of powder samples indicate hydration reaction products. Behnamfard et al. [41] associated the presence of quartz in the composition of kaolin powder with an increase in SiO_2 content. A large amount of olivine was observed in the XRD crystal phase analysis of olivine sand. Thus, it is expected that olivine sand, which is used instead of aggregate in the cement mixture, will form a dense structure in the matrix.

SEM images of pure olivine-filled cement mortar at 500, 2000, and 5000 magnifications, respectively, after 28 days of curing are given in figure 13 The microstructure of the olivine-filled cementitious mortar generally shows homogeneously dispersed hydration products. In figure 13 (a), C-S-H structures were formed. It is seen that the olivine-filled cement mortar has a dense crystalline structure at the micro level (figure 13 (b)). It could be noted that magnesium hydrated silicates form crystal structures. In the high magnification SEM image of the olivine filled cement mortar, needle-like structure of ettringite was observed in the olivine filled mortar mixture.

Also, it could be emphasized that the olivine filler contributes to the strength performance of the concrete sample by affecting the microstructure. Moreover, partial agglomerations are seen in the microstructure of olivine sand, which is used instead of aggregate in the cement mixture by growing small particles. It could be defined as particles that have not completed their chemical reaction in the cement matrix [42]. The size of the scattered agglomerated particles seen in figure 13 (b) ranges. It is seen that micro-scale particles are formed by the transformation of small-sized particles into large particles with Ostwald repining [43].

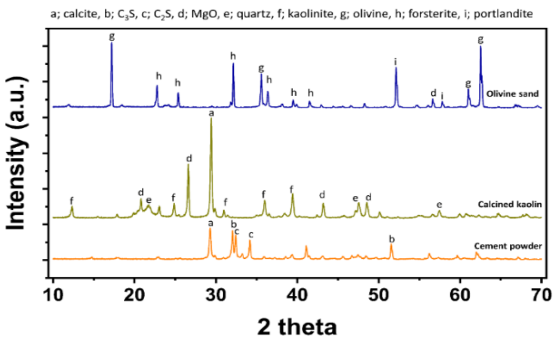

Figure 12. XRD results of cement powder (a), calcined kaolin powder (b) and olivine sand (c) used in mixes

In contrast, the olivine filler in the cement matrix appears to reduce the level of voids in the microstructure. Thus, it could be concluded that the formation of air bubbles in the hardened cement mixture is prevented and the voids decreases. Reduced voids in the matrix structure contribute to the increase in strength and are compatible with the above-mentioned compressive strength and flexural strength results. As a result, the use of olivine sand as aggregate instead of silica sand in the cement mixture could be associated with the binding property of olivine. In addition, considering the UPV test results of the conductive concrete samples, the higher UPV value of the OLV sample compared to the other samples could be attributed to the compact structure in the microstructure. The presence of only cement mortar components and the absence of conductive additive particles in the micrographic structure seen in figure 13 (c) could be explained by the low electrical resistance of the OLV sample mentioned above. The absence of conductive particles in the mixture increased the insulation of the cement mortar and aggregate in the structure and caused a decrease in the electrical resistance.

The 500, 2000, and 5000 magnification SEM images of the 0.75% CF reinforced OLV-0.75CF sample, which provided the optimum conditions among the test samples containing three different ratios of CF to the cement mixture, were shown in figure 14. As it is known, micro cracks damage the structure of the concrete, negatively affect the strength of the material, and reduce the durability of the structures [44]. It has been seen that the CFs in the cement matrix are effective in the porous structure of the concrete and there is a partially regular distribution. Since the non-homogeneous distribution of CFs in the cement matrix could not contribute to the crack resistance, it caused a decrease in the strength of the concrete sample. Guo et al. [45] reported that the mechanical behavior of concrete with a CF content of 1.4% decreased.

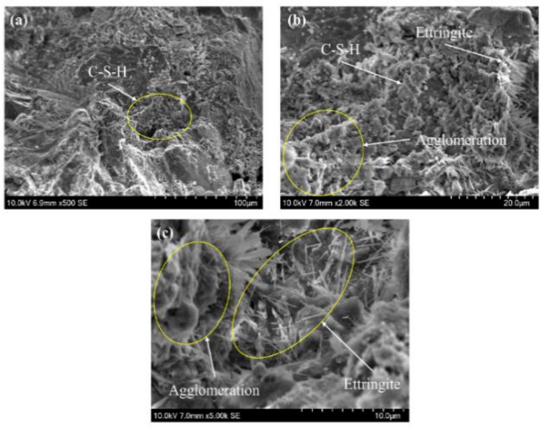

Figure 13. SEM images of 28-day pure olivine filled mixture; (a) 500 magnification, (b) 2000 magnification and (c) 5000 magnification

Figure 14 (a) shows CFs, it could be concluded that the increased CF content in the cement matrix significantly affects the voids [46]. The CFs seen in figure 14 (a) and (b) have prevented the formation of large-scale cracks in the concrete. Thus, it could be said that CFs resist the stresses caused by high pressure, prevent crack propagation, and contribute to the mechanical strength of concrete. Also, In figure 14 (a) and (b), the hydration products adhering to the CF show that the CFs in the matrix are bonded with the cement mortar. CFs forming a bond between the aggregate and the cement matrix prevented crack propagation, which caused a decrease in mechanical strength based on the applied stresses. On the other hand, figure 14 (c) shows the cracked region between the aggregate and the cement matrix.

During the mechanical test applied to the concrete, it is understood that the concrete could not show enough resistance to the loaded pressure and ruptures started. This cracked structure is indicated as the weak zone and is associated with a decrease in material strength (Mehta, P.K., Monteiro, P.J.M., 2014. Concrete: Microstructure, Properties, and Materials, 4 ed. McGraw-Hill, Nova York). It could be concluded that CFs randomly distributed in the cement matrix contribute partially to the concrete strength, and the Leeb hardness value decreases with the formation of brittle structures. In addition, it is seen that CFs adhere strongly to the cement matrix and generally do not break, resisting the pressure applied to the sample. It could be concluded that the CFs remain intact within the matrix, even if the concrete is physically fractured by the applied pressure.

Figure 14 (c) shows ettringite structures concentrated in C-S-H formed by hydration. It has been reported that needle-like ettringite structures affect the porosity. In addition, it is stated that C-S-H formations in the structure support the increase in strength in concrete [47]. The high rate of ettringite in the structure affects the formation of cracks in the matrix. Thus, low crack formation at the OLV-0.75CF sample interface may be associated with increased resistance to compressive stress.

Moreover, the content of conductive CFs in the cement matrix allows current to flow between the particles in the mixture. This could be attributed to the increase in the electrical resistance of the OLV-0.75CF sample compared to the above-mentioned electrical resistance test results. Also, it can be stated that the conductive network structure formed by CFs in the cement matrix is stable. Furthermore, the short distance between the unevenly distributed CFs in the matrix contributed to the conductivity of the cement mortar by forming a network between the aggregate and the cement. As stated by Chen et al. [48], a conductive network can be created by reducing the distance between conductive fiber particles.

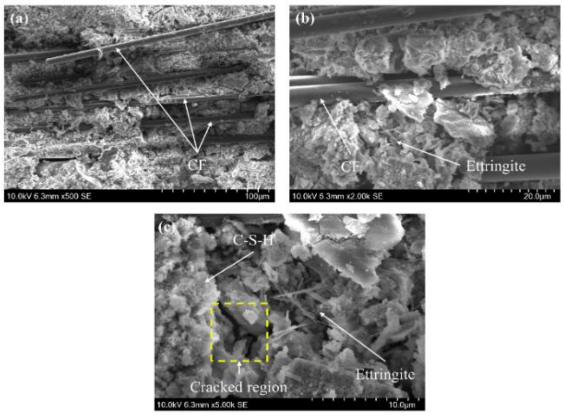

Figure 14. SEM images of 28-day olivine filled,0.75% CF reinforced mixture; (a) 500 magnification, (b) 2000 magnification and (c) 5000 magnification

The contribution of CFs dispersed in the matrix to the desired electrical conductivity is related to controlling the CF content in the mixture. Thus, a balance is established between both the mechanical properties and the electrical conductivity properties of CF. On the other hand, it can be stated that the effect of the olivine filler used as aggregate in the mixture on the conductivity of CF is low.

Figure 15 shows the XRD models of the olivine-sand-filled mortar sample (OLV) and olivine-filled (OLV-0.75CF) sample containing 0.75% CF, used instead of aggregate in the cement mixture. Olivine sand in the cement mixture resulted in the formation of forsterite crystal phase because of the hydration reaction with magnesium. The C-S-H phase in the phase analysis of the OLV sample shows the crystalline phase product formed by the hydration reaction. Thus, it is confirmed that mixtures with binding properties are formed with a hydration period of 28 days. On the other hand, ettringite peaks were formed depending on the CF content in the XRD model of the OLV-0.75CF sample. Also, C-S-H (calcium silicate hydrate) hydration products were detected. In addition to these, a carbon peak was detected, proving that CF added as a reinforcement component in the cement mixture is in the cement matrix. All the XRD phases appear to be in crystalline form. Ramkumar et al. [49] attributed the presence of hydration products to the effect of secondary hydration and filler material in cements containing carbon. It can be associated with the olivine filling in the conductive concrete mix.

In addition, it could be stated that CFs with high surface area accelerate the hydration process with other particles in the matrix, and as a result, contribute to the strength of the concrete [50]. Nambiar and Ramamurthy reported that the compressive strength increased with the decrease of the spaces between cells in the cement matrix. Thus, the ineffectiveness of CFs added to the cement matrix in filling the micropores can be explained by the relatively low compressive strength value mentioned above. In addition, although the strength of the cement matrix was increased with CFs, it was understood that the effect on the compressive strength of the concrete material was limited. The very weak calcite peak can be explained by the formation of a layer on the surface of the CFs by the cement particles during the hydration reaction.

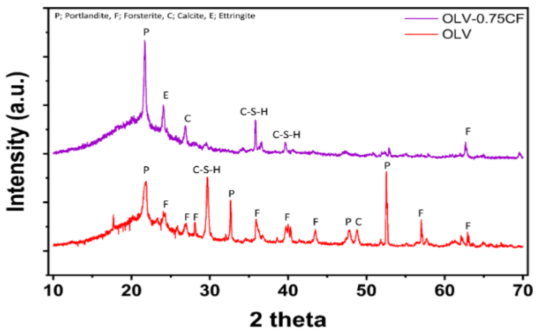

Figure 15. XRD results of 28-day pure and 0.75% CF reinforced mixture

4. Conclusion

In this study, the effects of olivine sand, which is used instead of aggregate, and CFs, which are used as additive components, on the strength properties and electrical resistance of the concrete sample are explained by experimental studies. According to the electrical resistivity results, while the wet effect was more pronounced in the insulator sample, the resistivity values of the conductive mortars containing CF changed less over time. The lowest resistivity value was measured for the mixture containing 1% CF. Carbon fiber also had a significant positive effect on the damping ratio. The sample showing the highest damping rate was 0.75%.

It has been understood that 28 days of hydration provides an increase in compressive strength and flexural strength. When the CF content was 0.75%, the compressive and flexural strength effects of CF on conductive concrete increased significantly. However, 0.75% CF content increased fiber agglomeration and caused a decrease in the strength of the concrete sample. CFs in the cement mixture prevented crack growth and improved the mechanical properties of the conductive concrete. It was observed that the compressive strength and flexural strength of the cement mixture decreased relatively with the increase in CF content. Thus, it is concluded that the effect of CF on compressive strength, flexural strength, and Leeb hardness is limited.

SEM analysis results of OLV-0.75CF sample show that CFs contribute to the mechanical properties of cement mortar by preventing crack formation. In addition, the low distance between the CFs observed in the SEM images contributed to the reduction of the electrical resistance of the concrete.

It was observed that CFs strengthened the bond between the cement matrix/CF by filling the voids in the voids structures of the cement matrix. However, OLV-0.75CF sample with optimum content in electrical resistance test results obtained higher conductivity compared to other samples. C-S-H structure formed by hydration using olivine filler in the cement mixture confirmed the binding formations. It is understood that olivine filler and CF additive can be compatible with conductive concrete. It could be said that the ettringite peak seen in the XRD analysis results reduces the contribution of CF, which increases the strength of the cement matrix. As a result, the increase in the mechanical properties of the olivine-filled cement mortar was more pronounced compared to the CF-added conductive concrete. The contribution of 0.75% CF content in the cement mortar to the mechanical properties of the concrete was lower than the electrical resistance effect of the sample. On the other hand, CFs form a stable conductive network structure between the cement mortar and the aggregate, significantly reducing the electrical resistance. It could be said that the CF content in the conductive concrete mixture contributes to both the mechanical and electrical properties of the concrete.

Article Information Form

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Authors' Contribution

The authors contributed equally to the study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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