Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi
International Journal of Engineering Research and Development

UMAGD, (2023) 15(3), 82-91.

10.29137/umagd.1252097

Cilt/Volume:15 Sayı/Issue:3 Aralık/December 2023 Özel Sayı / Special Issue

Araştırma Makalesi / Research Article

Investigation of Electrical Conductivity in Cement Mortars with Waste Iron Chips

Rüstem Yılmazel[1*], Ahmet Filazi[2], Muharrem Pul[3]

[1,2,3]Kırıkkale University, Vocational School, Kırıkkale, Turkiye

***Başvuru/Received**: 17/02/2023* ***Kabul / Accepted**: 15/08/2023* ***Çevrimiçi Basım / Published Online:** 31/12/2023*

***Son Versiyon/Final Version**: 31/12/2023*

Abstract

In this study, the electrical conductivity of cement mortars formed by additive waste iron chip was investigated. Mixtures with fixed water/cement (0.5) ratios and different ratios of iron chip were prepared. Cement mortars were prepared by adding 0%, 1%, 2%, 4%, 8% and 16% by weight of cement in the mixtures and waste iron chip in the range of 0.5 mm to 4 mm in size. Firstly, the flow test was applied to the cement mortars cured in normal water for 7 and 28 days and their flexure and compressive strengths were determined. Then, the electrical conductivity test was applied to the cement mortar samples. As a result, it was observed that the flow diameter values increased as the average length increased from 0.5 mm to 2 mm in 1% and 2% additive of waste iron chip. It was determined that 1% waste iron chip was higher at 4.54% compressive strength compared to the reference sample. As the amount of added waste iron chip increased, the electrical resistivity value in the samples decreased and the electrical conductivity value increased along with it. At the same time, it was determined that the added iron chip size also increased the electrical conductivity.

Key Words

"Waste iron chip, Workability, Mechanical properties, Electrical conductivity"

***Sorumlu Yazar:** rustemyilmazel@kku.edu.tr*

1. Introduction

In recent years, composite materials with cement-binding properties such as self-sensing, heating, conditioning and electromagnetic shielding have been researched and developed (W. Li ve diğerleri, 2022). Wastes and especially heavy metal wastes constitute an important environmental problem and researchers are looking for solutions to environmental problems (Esquinas vd., 2018; Kalpana and Tayu, 2020). In particular, the reuse of these environmental wastes as materials in the construction industry was investigated and the strength and durability properties on the produced composite materials were examined (De la Colina Martínez ve diğerleri, 2019).

Some researchers used metal wastes such as iron and aluminum by replacing them with concrete aggregate (Wang et al., 2018; Fisonga, Wang, & Mutambo, 2019; Li et al., 2019), while some researchers used them as recycled fibers (Domski ve diğerleri, 2017). Especially when the recent studies were examined, it was observed that fiber reinforced composite materials improved the fragility of the material and increased the load carrying capacity (Liu et al., 2020). In addition, they improve and develop their engineering properties (Liu et al., 2020). It also advances sustainable developments in building materials, using waste to industry (Huseien et al., 2021; Yang et al., 2021). Alzaed, 2014 examined the effect of iron chips on the compressive and tensile strength of concrete. It was stated that iron chips improve both compressive and tensile strength (Alzaed, 2014)

Qasrawi et al. reinforced 0%, 15%, 30%, 50% and 100% steel slag in the sample they prepared instead of sand. For sand additive rates (up to 30%), concrete's 28-day tensile strength improved by 1.4–2.4 times and compressive strength by 1.1–1.3 times (Qasrawi, Shalabi, and Asi 2009). Binici et al. investigated the strength and durability properties of mortars and concretes with additive different percentages of iron powder instead of sand in mortar and concrete. They showed that the compressive strength of concrete is 50% higher in 20% iron powder additive (Binici, Sevinç, and Geçkil 2015).

Özyurt and Sancak investigated whether the recycling of iron chips, an industrial waste that will no longer be used and thrown into the nature, can be achieved in concrete cantilever beams. For this purpose, it was investigated how the behavior of the cantilever beam would change by adding 20% of the iron shavings material to the cantilever beams. It was observed that the ductility coefficients increased by 1.53% and the maximum loads they carried decreased by 9.30%, if the above-balance reinforced Cantilever beams, with over-balance reinforcement whose stirrups have a hook angle of 90 degrees, with 20% iron chips added. It has been observed that if the cantilever beams, with over-balance reinforcement, whose hoops have a hook angle of 135 degrees, with 20% iron chips, the ductility coefficients increase by 0.30%, and the maximum loads they carry decrease by 11.95% (Özyurt and Sancak 2020).

Dong et al. investigated the mechanical and electrical properties of concrete containing iron particles and nanographite by-products. They found that the composite nano-graphite content with an iron particle of 1% by weight led to an almost 20% reduction in compressive strength compared to plain concrete, which was larger than nano-graphite. However, they showed that the mechanical behavior of nano-graphite concrete containing iron particles was better than that of nano-graphite concrete at 3 wt% and 5 wt%. They stated that while it caused a 70.3% reduction in electrical resistance at 1% by weight, only 11.3% was observed for nano graphite at the same concentration (Dong et al. 2021).

Li et al. investigated the conductive and mechanical properties of graphite, steel slag (SS) and slag three-phase conductive filler on conductive cementitious composites. Studies have shown that electrical conductivity increases with the addition of graphite. However, it was observed that there was a decrease in the strength part. This study revealed that both the electrical conductivity will increase and the decreased strength can be improved with steel slag and slag (J. Li *et al.*, 2022).

The purpose of this study is to increase the electrical conductivity of materials obtained by reinforcing cement mortars with waste iron chips and thereby improve their electrical properties. The reason for increasing electrical conductivity is to make such materials valuable for various applications and contribute to advanced technology. Cement mortars with high electrical conductivity enable the construction of durable structures for smart buildings, electrical heating systems, electromagnetic shields, and sensitive sensor networks. This study aims to highlight the potential benefits of sustainable use of waste iron chips and contribute to the development of more efficient and environmentally friendly solutions in the industry and technology field.

2. Material And Method

2.1. Materials

In this study; CEM I 42.5 R Portland cement (PC) corresponding to ASTM Type I cement in accordance with TS EN 197-1 was used. The physical and chemical properties of the cement used are given in Table 1.

Table 1. Physical and chemical properties of CEM I 42.5 R Cement

Chemical Properties (%)		Physical Properties	
SiO_2	21.14		
Al_2O_3	5.58	Specific gravit (g/cm^3)	3.10
Fe_2O_3	3.18		
CaO	61.96	Blaine's thinness (cm²/g)	3351
MgO	2.65		

Table 1.(cont) Physical and chemical properties of CEM I 42.5 R Cement

Chemical Properties (%)		Physical Properties	
Na_2O	0.22	Loss of ignition (%)	2.36
K_2O	0.62		
SO_3	3.10		
S+A+F	29,90		

The standard sand used in the study is the CEN reference sand specified in the TS EN 196-1 produced at the Limak Trakya Cement factory. The mixing ratios of the mortars prepared for the experiments are given in Table 2.

Table 2. Mixing ratios of the samples prepared for the experiment

Sample Name	Iron Chips Rate (%)	Waste Iron Chip Size (mm)	Standard Sand (g)	Water (g)	Cement (g)
S0	-	-	1350	225	450
S1-1	1	0,5-1,0	1350	225	450
S1-2	1	1,0-2,0	1350	225	450
S2-1	2	0,5-1,0	1350	225	450
S2-2	2	1,0-2,0	1350	225	450
S4-1	4	0,5-1,0	1350	225	450
S4-2	4	1,0-2,0	1350	225	450
S8-1	8	0,5-1,0	1350	225	450
S8-2	8	1,0-2,0	1350	225	450
S16-1	16	0,5-1,0	1350	225	450
S16-2	16	1,0-2,0	1350	225	450

Iron chip mixed into cement mortars were subjected to dimensional classification by passing through screen openings of different sizes. The chip are wastes from various iron materials processed in machining benches. Waste iron chip additive into cement mortar are shown in Figure 1. The representation of the prepared test samples is given in Figure 2.

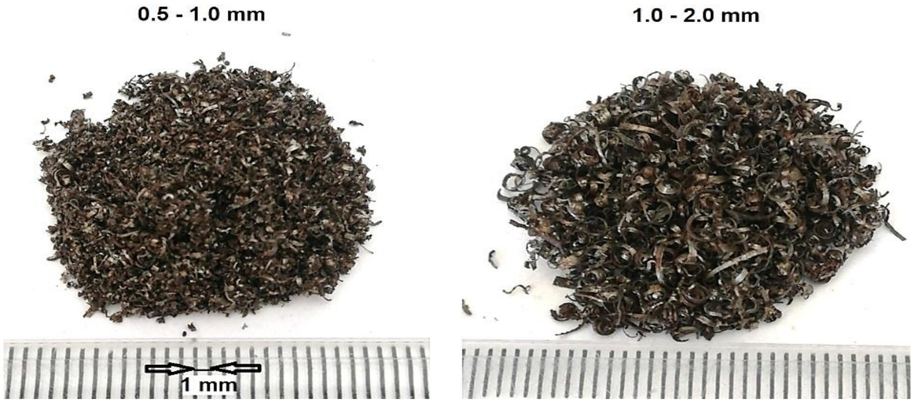

Figure 1. Waste iron chip.

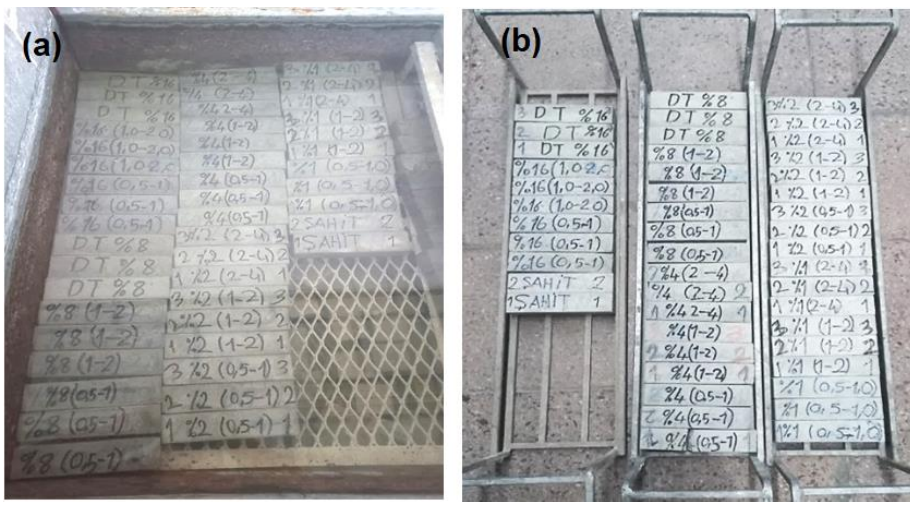

Figure 2. View of the test samples.

2.2. Flow test

In this part, workability measurements of mortar mixtures were made by mini slump test. During the experiment, the mortar mixtures prepared in accordance with TS EN 196-1 were filled into the truncated cone on the flow table. The filling process was carried out in 2 layers, and tamping was applied 25 times on each layer. After the truncated conical mold was lifted slowly, 25 strokes were made in 15 seconds in accordance with TS EN 1015-3 by rotating the agitating device. Finally, the flow diameter in both directions of the flow mortar on the table was measured and the average of these values was calculated. Samples from the images taken during the flow test are given in Figure 3. The images of the mortars with an average chip size of 1-2 mm from the mortars with 0%, 1%, 2%, 4%, 8% and 16% iron chips were selected.

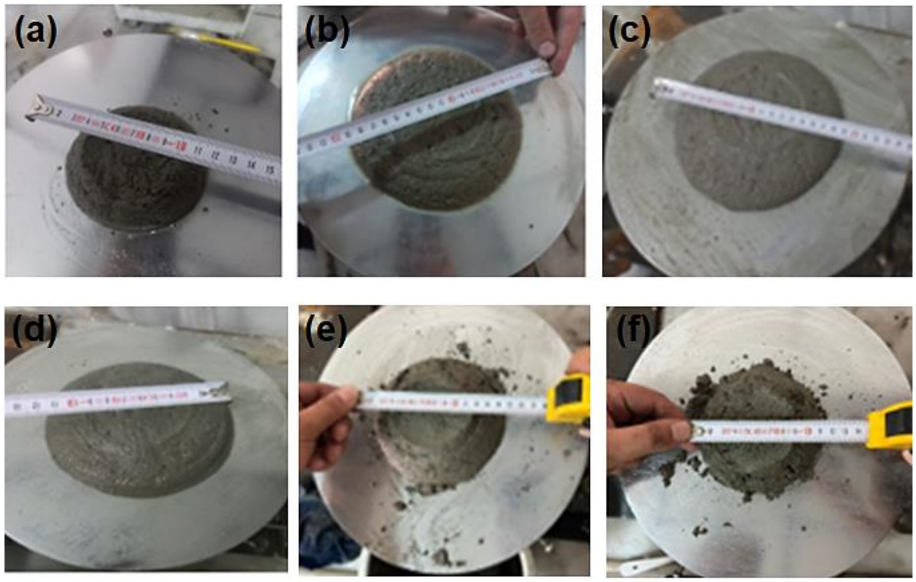

Figure 3. (a) Standard cement mortar; **(b)** 1% Iron chips reinforced; **(c)** 2% Iron chips reinforced; **(d)** 4% Iron chips reinforced; **(e)** 8% Iron chips reinforced; **(f)** 16% iron chips reinforced.

2.3. Determination of flexural and compressive strength

Flexural and compressive strengths of cement mortars reinforced with waste iron chips have been prepared in accordance with TS EN 196-1. 40×40×160 cm3 cement mortars, which were kept in normal (Figure 2a) water for 7 and 28 days for flexural strength, were removed from the curing pool (Figure 2b) and subjected to flexural test with a flexural press at (50±10) N/s loading speed. Compressive strengths were obtained from six 40×40 samples, which were formed as a result of flexural strength. Compressive strength was made with a device with a suitable capacity for the test and adjusted to a loading speed of (2400±200) N/s in accordance with TS 196-1(Standard, 2006).

2.4. Electrical conductivity test

A power supply was used to give the voltage to the material, and a digital multimeter was used to measure the current flowing through the material in the electrical conductivity test. Voltage is applied to any two points of the samples by placing the positive and negative poles of the power supply. In order to measure the current passing through the material more precisely, the power supply has been adjusted to 30V. This voltage value was set to 30V for all samples. The current flowing through each sample was measured with a digital multimeter. Since the sample is not completely homogeneous, the calculation was made by taking at least 5 different measurements for each sample. If there were excessive deviations in the measurements, they were subtracted and the average of the remaining measurement values was taken. The results obtained from the measurement values were evaluated according to Ohm's law and the resistance value of the sample was found. Since the voltage is constant, the resistance and resistivity values of the sample were calculated from the current values obtained from each averaged measurement. In the last stage, electrical conductivity was determined according to the electrical resistivity.

3. Experimental results

3.1. Flow test results

Flow results of mortar samples reinforced with iron chips at 0% (Reference), 1%, 2%, 4%, 8%, 16% by weight of cement and in sizes 0 0.5, 0.5-1 and 1-2 mm are shown in Figure 4.

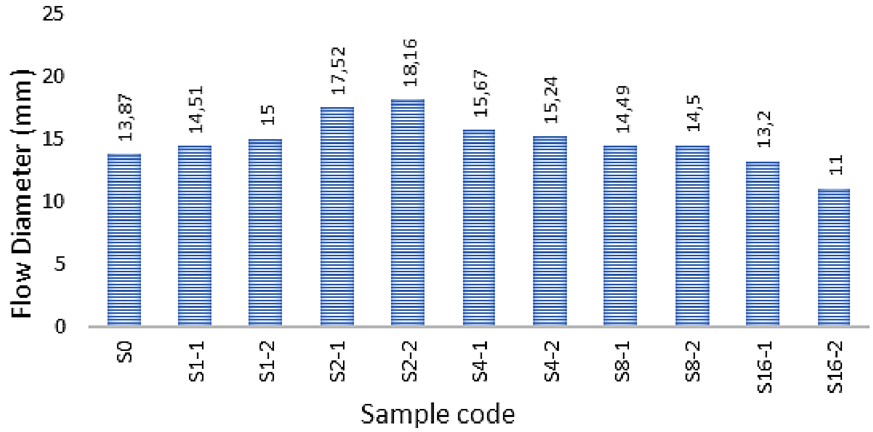

Figure 4. Flow diameters of waste iron chip mortars.

The flow diameter values increase as the average length increases from 0.5 mm to 2 mm in 1% and 2% reinforced of the waste iron chip used in Figure 4. After the 2% additive rate, the flow diameter values decrease. According to a study, they stated that as a partial replacement of fine aggregate, the addition of iron chip in different proportions to the mixtures causes a decrease in the slump and compression factor and reduces the consistency in all mixtures. They stated that while the slump decreased in the range (10–16%), the compression factor decreased in the range (4–16%) (Mohammed Breesem *et al.*, 2022). In a study of iron residues, it was stated that the slump value of the concrete decreased with the increase in the amount of iron ore residue in the concrete. They explained that the reason for this is that more cement mortar is needed to maintain the slump in the concrete and the iron residues have an angular and rough texture, which reduces the workability of the concrete (Shettima *et al.*, 2016). The reason for the reduction can be expressed in the roughness of the surfaces of the waste iron chip, resulting in an increase in surface area which increases the moisture demand. This roughness causes increased friction between the iron waste particles. As a result, it has been shown in the study that waste iron chip affects the workability of new mixes.

3.2. Compressive and flexural test results

The results obtained from the 7- and 28-day compressive and flexural strength tests of waste iron chip-reinforced cement mortars are shown in Figure 5 and Figure 6.

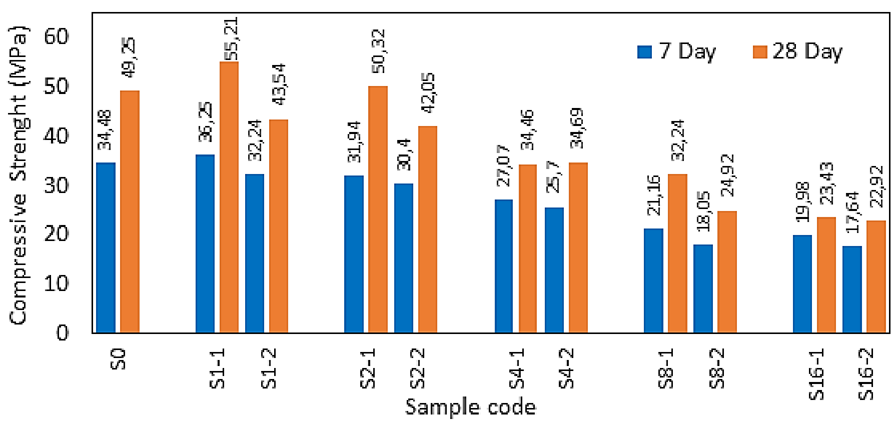

Figure 5. Results of compressive strength test.

The compressive strength of waste iron chip, 0.5-1 mm in size and 1% of the weight of cement reinforced, was compared with the reference sample in Figure 5 . There was an increase of 2.72% in the 7-day compressive strength and 3.48% in the 28-day compressive strength. As the waste iron chip reinforced ratio and the size increased, the compressive strength decreased.

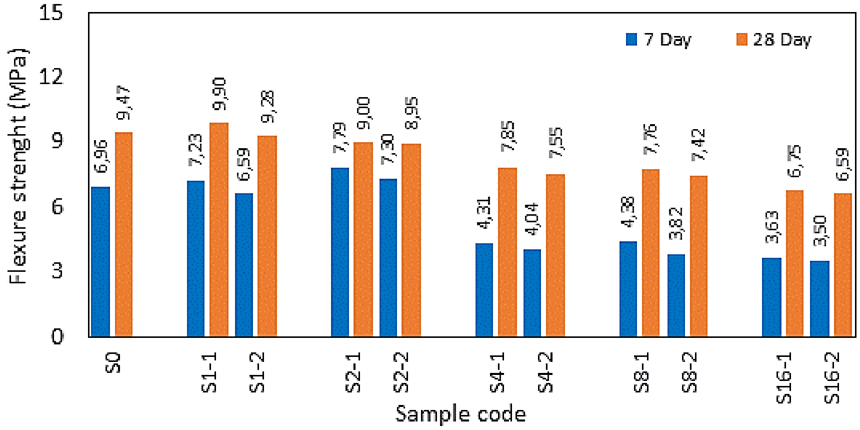

Figure 6. Results of flexural strength test.

The flexural strength of waste iron chips, 0.5-1 mm in size and reinforced by 1% of the cement weight, is compared with the reference sample in Figure 6. There was an increase of 3.95% in the 7-day flexural strength and 4.54% in the 28-day flexural strength. After 1% addition, the flexural strength decreased because the waste iron chips reinforced ratio and the size increased.

As a result, when the flexural and compressive strength values were examined, the iron chips reinforced and the increase in the amount of size had a negative effect on the strength of the material. The reason is that the iron chips reinforced mortar added to the samples reduces the consistency. In addition, it caused a negative effect as it caused gaps in the cement mortar. Li et al. conducted experiments by adding iron ore deposits to cement. They stated that the decrease in 28-day compressive strength was approximately 9.79%. They explained that there is a decrease in strength because iron ore deposits are not activated by cement and less hydration products are produced (Xiao-, Li and Fan, 2013).

3.3. Electrical conductivity test results

Electrical conductivity and resistivity values of waste iron chips reinforced cement mortars by changing different additive ratios and sizes are given in Table 3. The graphs created according to the values in the Table 4 are given in Figure 7.

Table 3. Resistivity and conductivity values according to additive ratios

Sample No	Waste iron chips ratio (%)	Waste iron chips size (mm)	Resistance (mΩ)	Resistivity (KΩm)	Conductivity (µS/m)
S1-1	1	0,5 - 1	16,393	163,93	6,1
S1-2	1	1,0 - 2	8,1632	81,6	12,255
S2-1	2	0,5 - 1	13,186	131,86	7,58
S2-2	2	1,0 - 2	6,29	62,9	15,898
S4-1	4	0,5 - 1	4,36	43,6	22,93
S4-2	4	1,0 - 2	3,614	36,14	27,67
S8-1	8	0,5 - 1	2,95	29,5	33,898
S8-2	8	1,0 - 2	2,557	25,57	39,108
S16-1	16	0,5 - 1	0,306	3,06	326,79
S16-2	16	0,5 - 1	2,557	4,89	204,49

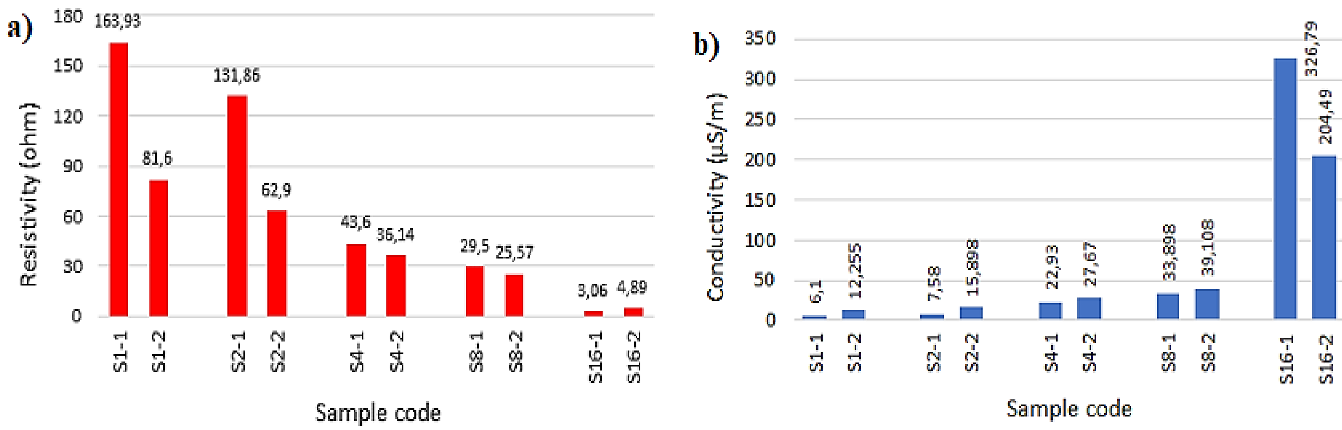

Figure 7. a) The effect of waste iron chipps reinforced in different sizes on electrical resistivity; b) The effect of waste iron chips reinforced in different sizes on electrical conductivity.

The effect of cement mortars formed by adding different waste iron chips sizes on electrical conductivity is shown in Figure 7-b. It was observed that as the size of the waste iron chips increased, its electrical conductivity also increased. When 1% of waste iron chips is added; the electrical conductivity of the waste iron chips added by passing through a 1-2 mm screen increased by 100.9% compared to the electrical conductivity of the waste iron chips added by passing through a 0.5-1 mm screen. When 2 % of waste iron chips is added; the electrical conductivity of the waste iron chipps added by passing through a 1-2 mm screen increased by 109.7% compared to the electrical conductivity of the waste iron chips added by passing through a 0.5-1 mm screen. When 4% of waste iron chips is added; the electrical conductivity of the waste iron chips added by passing through a 1-2 mm screen increased by 20.67% compared to the electrical conductivity of the waste iron chippings added by passing through a 0.5-1 mm screen. When 8% of waste iron chips is added; The electrical conductivity of the waste iron chips added by passing through a 1-2 mm screen increased 15.37% compared to the electrical conductivity of the waste iron chips added by passing through a 0.5-1 mm screen. When 16% of waste iron chips is added; the electrical conductivity of the waste iron chips added by passing through a 1-2 mm screen decreased by 37.4% compared to the electrical conductivity of the waste iron chips added by passing through a 0.5-1 mm screen. According to the results; as the size of the waste iron chips added in small additive ratios increases, the electrical conductivity also increases greatly. But; when the additive ratio increased, it was observed that there was not much gap in the material for conductivity. In this case, there was no significant increase in the level of electrical conductivity. Figure 8 shows how the electrical conductivity changes with the addition of waste iron chips to the cement at different rates.

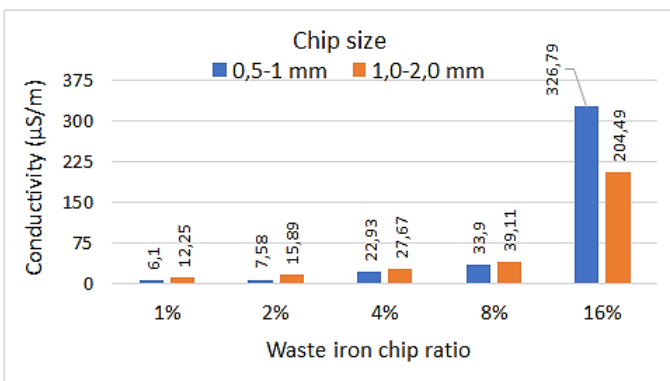

Figure 8. The effect of waste iron chips reinforced at different additive ratios on the electrical conductivity.

In the measurements with reference to 0.5-1 mm waste iron chips; The electrical conductivity of the waste iron chips added at the rate of 8% increased by 455.7% compared to the electrical conductivity of the waste iron chips added at the rate of 1%. However, when the additive rate was 16%, it was observed that the electrical conductivity increased by 861.7% compared to 8%. In measurements with reference to waste iron chips of 1-2 mm; the electrical conductivity of the waste iron chips added at 8% additive rate increased by 219.11% compared to the electrical conductivity of the 1% waste iron chips added. However, when the additive rate was 16%, it was observed that the electrical conductivity increased by 422.88% compared to 8%. This shows that the electrical conductivity increases as the proportion of waste iron chips is added to the cement too much. With the increase in the amount of waste iron chips added, the gaps between the cement started to close. Thus, since the current flows through the material more easily, the electrical conductivity value has also increased. As the size of the added iron chips increases, the gaps in the material are more easily closed. As these gaps are closed, a path is formed in the material that will facilitate the electric current. Since the added iron filings are conductive, the increase in size facilitates the movement of electrons passing on the material. As both the additive ratio and the size increase, a conductive path is formed in the material. Electron flow is also facilitated on this conductive path.

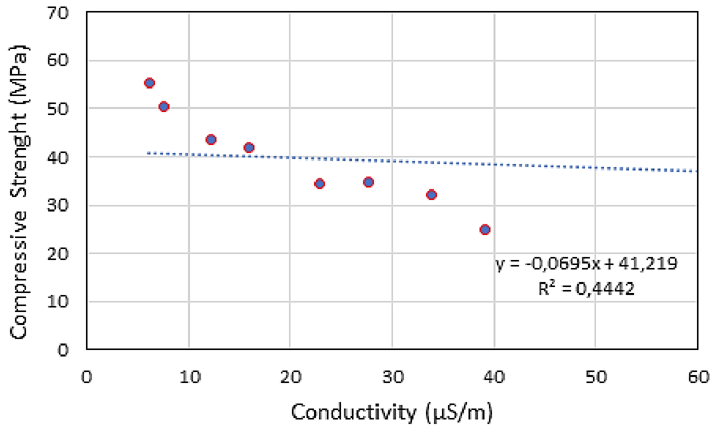

Figure 9. Correlation graph between compressive strength and electrical conductivity

Equations 1 is used to express the correlation between compressive strength and electrical conductivity. In Equation 1, y is the compressive strength and x is the conductivity. This equation is a linear regression model that connects the compressive strength to the electrical conductivity value.

$$y = -0{,}0695x + 41{,}219 \tag{1}$$

R^2 refers to the coefficient of determination value. R^2 is a statistical measure that expresses the fit of the model and shows the percentage of the change in the dependent variable being explained by the independent variables. The R^2 value takes a value between 0 and 1. R^2 value is calculated as 0.4442. The R^2 value indicates that 44.42% of the variation in model dependent variables can be explained by independent variables. Therefore, it can be said that the relationship between Conductivity (x) and Compressive Strength (y) is quite low and weak.

4. Conclusion

The results for cement mortars with waste iron chips can be summarized as follows.Due to the decrease in consistency, the workability was adversely affected with the addition of waste iron by weight of cement and the increase in the size ratio. It has been observed that 0.5-1 mm waste iron chips have a positive effect on flexural and compressive strength at 1% replacement rate. However, as the iron waste chips reinforced rate increased, flexural and compressive were adversely affected. The reason is that the material has reduced its compactness. It is seen that the results are close to the reference sample at 4%. He revealed that this sample could be used for special purposes.

It was concluded that the electrical conductivity value increased as the amount of waste iron chips added to the cement mortars increased. It was observed that the increase in the size of the waste iron chips positively affected the electrical conductivity. The reason is that it sticks in the gaps in the cement mortars. Thus, the electrical conductivity value has increased as the current flows through it more easily.

As a result, adopting cement mortars with high electrical conductivity and incorporating waste iron filings into cement mixtures not only embraces an environmentally friendly and sustainable approach but also contributes to the development of innovative solutions in the industrial and technology sectors. This enhances the durability and energy efficiency of structures while optimizing waste management processes and promoting more efficient use of natural resources. This innovative approach paves the way for more interconnected and sustainable structures, thus playing a crucial role in creating an environmentally conscious future. Additionally, it will inspire similar eco-friendly and innovative solutions in other industries. In conclusion, embracing these high-tech and eco-friendly cement mixtures represents a significant step towards a more connected, energy-efficient, and sustainable future. It fosters a revolution in the way we construct and interact with structures, and simultaneously supports sustainable waste management practices. By collaborating and investing in such environmentally friendly materials and technologies, we can contribute to building a safer, more sustainable, and eco-friendly world for generations to come.

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