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Research Article

Correlation of Destructive and Non-Destructive Tests with Electrical Resistance in Cementless Composites

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Abstract

In the construction industry, tests such as compressive strength, density porosity, and water absorption porosity are frequently used to determine material properties. In general, experimental studies are divided into two categories: destructive and non-destructive testing methods. According to the common consensus, destructive testing methods produce more dependable results than non-destructive testing methods. However, it is not possible to reuse the samples in destructive tests, and there are difficulties in taking samples from the building whose construction process has been completed. In addition, the experimental implementation of destructive tests creates time and cost disadvantages. Within the scope of this study, destructive and non-destructive experiments have been carried out on alkali-activated concrete composites, which have attracted interest as sustainable environmentally friendly composite building materials in recent years. Compressive strength, density, porosity, water absorption, etc. traditional test methods have been associated with electrical resistance measurements. Electrical measurements have been taken with the MEGGER equipment, and resistance values have been directly correlated with the other parameters. The positive results indicate that different structures of materials used in the construction industry can be evaluated regardless of sample size or localization.

Keywords: *Alkali-activated composite; Electrical resistance; Non-destructive test*

Çimentosuz Kompozitlerde Tahribatlı ve Tahribatsız Testlerin Elektriksel Direnç ile İlişkilendirilmesi

Öz

İnşaat sektöründe, malzeme özelliklerini belirlemek için basınç dayanımı, yoğunluk, su emme ve prozite gibi testler sıklıkla kullanılmaktadır. Genel olarak deneysel çalışmalar tahribatlı ve tahribatsız muayene yöntemleri olarak iki kategoriye ayrılır. Ortak görüşe göre, tahribatlı muayene yöntemleri tahribatsız muayene yöntemlerine göre daha güvenilir sonuçlar üretir. Ancak tahribatlı testlerde numunelerin tekrar kullanılması mümkün olmamakta ve inşaat süreci tamamlanan binadan numune alınmasında zorluklar yaşanmaktadır. Ayrıca tahribatlı testlerin deneysel olarak uygulanması zaman ve maliyet açısından dezavantajlar doğurmaktadır. Bu çalışma kapsamında, son yıllarda sürdürülebilir çevre dostu kompozit yapı malzemeleri olarak ilgi gören alkali aktivasyonlu beton kompozitler üzerinde tahribatlı ve tahribatsız deneyler yapılmıştır. Basınç dayanımı, yoğunluk, prozite, su emme vb. geleneksel test yöntemleri elektriksel direnç ölçümleriyle ilişkilendirilmiştir. MEGGER ekipmanı ile elektriksel ölçümler alınmış ve direnç değerleri diğer parametrelerle doğrudan ilişkilendirilmiştir. Elde edilen olumlu sonuçlar, inşaat sektöründe kullanılan malzemelerin numune boyutu veya lokalizasyondan bağımsız olarak önerilen yöntemle değerlendirilebileceğini göstermektedir.

Anahtar Kelimeler: *Alkali aktivasyonlu kompozit; Elektrik direnci, Tahribatsız test*

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I. INTRODUCTION

The harmful effects of global warming are increasing in parallel with the development of industry **[1, 2].** Besides, the construction sector is held directly or indirectly responsible for a significant part of global warming **[3].** Pozzolans and industrial wastes used as cement substitutes contribute to reducing cement production quantities. However, this practice is not sufficient. The need for alternative solutions for this sector, which is held responsible for 8% of CO_2 emissions, has been increasing gradually. In recent years, studies on the production of building materials from different wastes by using alkali activators have increased **[4-12].** Alkali-activated composite products may have different physical and mechanical properties compared to cementitious composites due to the variety of materials entering the mixture **[13].** The most commonly used methods for determining mechanical properties include compressive strength, flexural strength, splitting tensile strength, and so on. In addition to mechanical properties, density, water absorption, porosity, etc. physical properties are also among the most basic properties of building materials **[14].** Changes in material properties affect mechanical and physical properties as well as electrical properties **[15, 16].** Defects such as capillary spaces, microstructural cracks, pore solution etc. in the material can affect the electrical conductivity **[17, 18].** Micro cracks and defects may occur during or after the production process in composites that have a heterogeneous structure such as building material**[19].** Tests used to classify building materials are often associated with these defects.

A change in any parameter in a matter or system causes changes in different parameters. Therefore from the changes in the physical properties of the matter, evaluations can be made about the different properties. The electrical properties of each of the natural or artificially produced materials also differ according to the other. The electrical characteristics of materials may vary depending on the effects of different stresses to be applied to the material **[20-22].** If the material undergoes permanent deterioration due to the applied stress, the change in the electrical characteristic of the material may be permanent. In this case, the change can be associated with the rating of the degradation of the material. However, the material may deteriorate during the process of applying stress and return to its former state when the stress is removed. In this case, the temporary changes in the electrical characteristics of the material allow making sense of the applied stress.

One of these methods is the electrical resistivity measurements of the structures **[23, 24].** In this method, the relationships between the mechanical properties of the building material, the porosity or void ratio in the material and/or the additive ratios can be determined **[25-27].** Resistivity is not affected by the size and geometry of the sample for a homogeneous structure. However, it is not always possible to provide absolute homogeneity for structures such as mortars, concrete with additives and alkali activated composites. Therefore, testing on a particular sample may not always describe the overall structure. Instead, it may be necessary to test on more samples. However, this time, problems arise in terms of cost increase and sustainability.

In this study, we aimed to measure the resistance of the structure directly instead of the electrical resistivity. For this purpose, we preferred the MEGGER measurement system, which is used to measure very large resistance values. In this way, the resistance values of not only samples but also larger structures can be measured directly.
Thus, the obligation to produce samples suitable for the measurement system is eliminated, and the resistance values taken from the measurement points of the structure of the desired shape and size are directly used. Therefore, more generalized results regarding the structure can be produced. Based on the preferred approach, the relationship between the electrical properties and strength properties of sustainable environmentally friendly alkali-activated composites has been investigated, in this study. Four different alkali-activated composite mixtures containing ground granulated blast furnace slag (GGBFS), zeolite, aggregate, NaOH (sodium hydroxide), and Na_2SiO_3 (sodium silicate) have been prepared. Prepared fresh alkali-activated composite mixtures have been placed in cube molds (70,7 mm) with the help of vibration. Samples with different mix properties have been subjected to activation temperatures of 90°C and 120°C for 20 hours. Compressive strength, water absorption, porosity, density,

and electrical resistance measurements have been performed on the specimens left to water cure for 28 days after the activation temperature.

II. THEORETICAL DESCRIPTION AND MEASUREMENT SYSTEM

During the preparation of alkali activated composites, it is desired to have as homogeneous a mixture as possible as shown in Fig. 1(a). In this case, since the resistivity (ρ) values in each region are equal to each other, the resistance values (R) in the equi-sectioned regions are also equal to each other, theoretically. Therefore, equations (1) and (2) can describe the model in Fig. 1(a). Where d is the length and S is the cross-sectional area of the sample, and n is the number of equi-sections. However, this is hardly possible in practice. In such structures, there are cracks and voids at micro levels, or fractures under stress can also be observed as shown in Fig. 1(b). Or the fabricated building sample may differ from one another in terms of its properties or additive material, as in Fig. 1(c). Therefore, the resistivity values at each small volume location will also be different. This will change the resistances in the equi-sections. Therefore, the total equivalent resistance value of the realistic model $R_{1\to j}$ will differ from the total equivalent resistance value obtained with the theoretically homogeneous sample $R_{1\to n}$.

$$R_1 = \frac{\rho d}{S} \;, \qquad and \quad R_1 = \cdots = R_{n-1} = R_n \tag{1}$$

$$R_{1\to n} = \frac{\rho d}{Sn} \tag{2}$$

For a realistic model;

$$R_1 \neq \cdots \neq R_{n-1} \neq R_n \;\;, \; and\; also \;\; R_{1\to j} \neq R_{1\to n} \tag{3}$$

$$If, \quad \frac{d}{S} = \delta \;\; \therefore \;\; R_{1\to j} = 1\Big/\!\left(\frac{1}{\rho_1 \delta} + \cdots + \frac{1}{\rho_n \delta}\right) \tag{4}$$

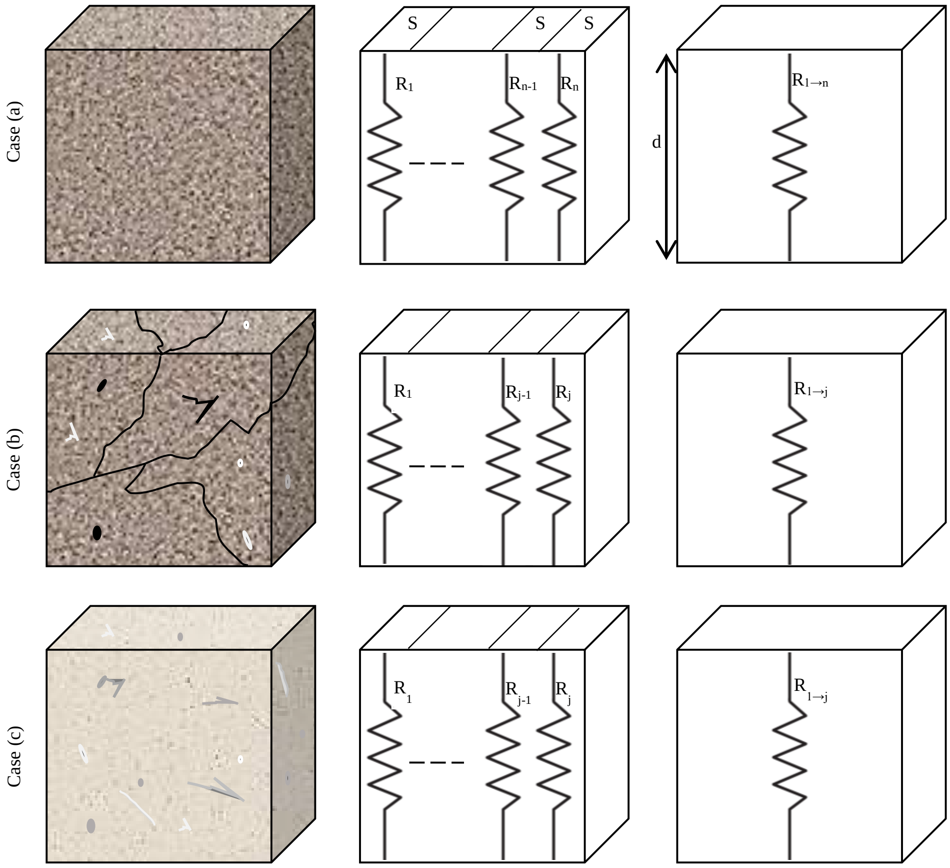

Figure 1. *Different alkali activated composites, (a) theoretically homogeneous structure; (b) cracked structure; (c) robust but different types of alkali activated composite.*

Testing of the proposed approach is possible with MEGGER equipment where high resistances can be measured. It is normally used for testing grounding and/or high electrical insulations in electrical systems. Meggers have a structure that can produce DC voltage between 250V and 5000V. These voltage values are applied to the resistance value to be measured and It is possible to measure up to 5 Tohm by applying the largest value. In Fig. 2, the measuring setup is presented. Prepared alkali-activated composite samples are placed between pertinaxes, one surface of which is covered with copper. Thus, full contact with the sample surface is ensured. The surface area of the pertinaxes ($0.03m^2$) has been kept wider than the sample in order to take the measuring tip. After connecting the determined connector tips to the MEGGER device, tests have been carried out under 1000V DC voltage. Measurements have been recorded at the end of the 15th second from the moment the voltage has been applied for each sample. The materials required for the mixture have been prepared according to the values determined as a result of the trial mixtures carried out before. NaOH has been first turned into an aqueous solution during the preparation of alkaline-activated concrete mixes. More detailed information about NaOH and Na_2SiO_3 can be obtained from previous studies **[4, 7-13].** Then, coarse and fine aggregates have been placed in the mixer and mixed until a homogeneous distribution is obtained. Afterward, GGBFS and zeolite have been added to the mixer sequentially, and the mixing process has been continued. Finally, the process has been completed with the addition of alkaline activators. The fresh alkali-activated concrete mixtures obtained have been placed in molds with the help of vibration, and their upper surfaces have been covered for temperature activation and placed in the oven. . In order to examine the effect of activation temperature on physical and mechanical properties, the specimens were subjected to 2 different activation temperatures (90°C and 120°C for 20 hours). After the activation process that lasted for 20 hours under constant temperature, it has been taken out of the molds and taken into the standard curing pool. The standard curing process has been applied for 28 days. After the curing period, mechanical, physical, and electrical measurements have been carried out.

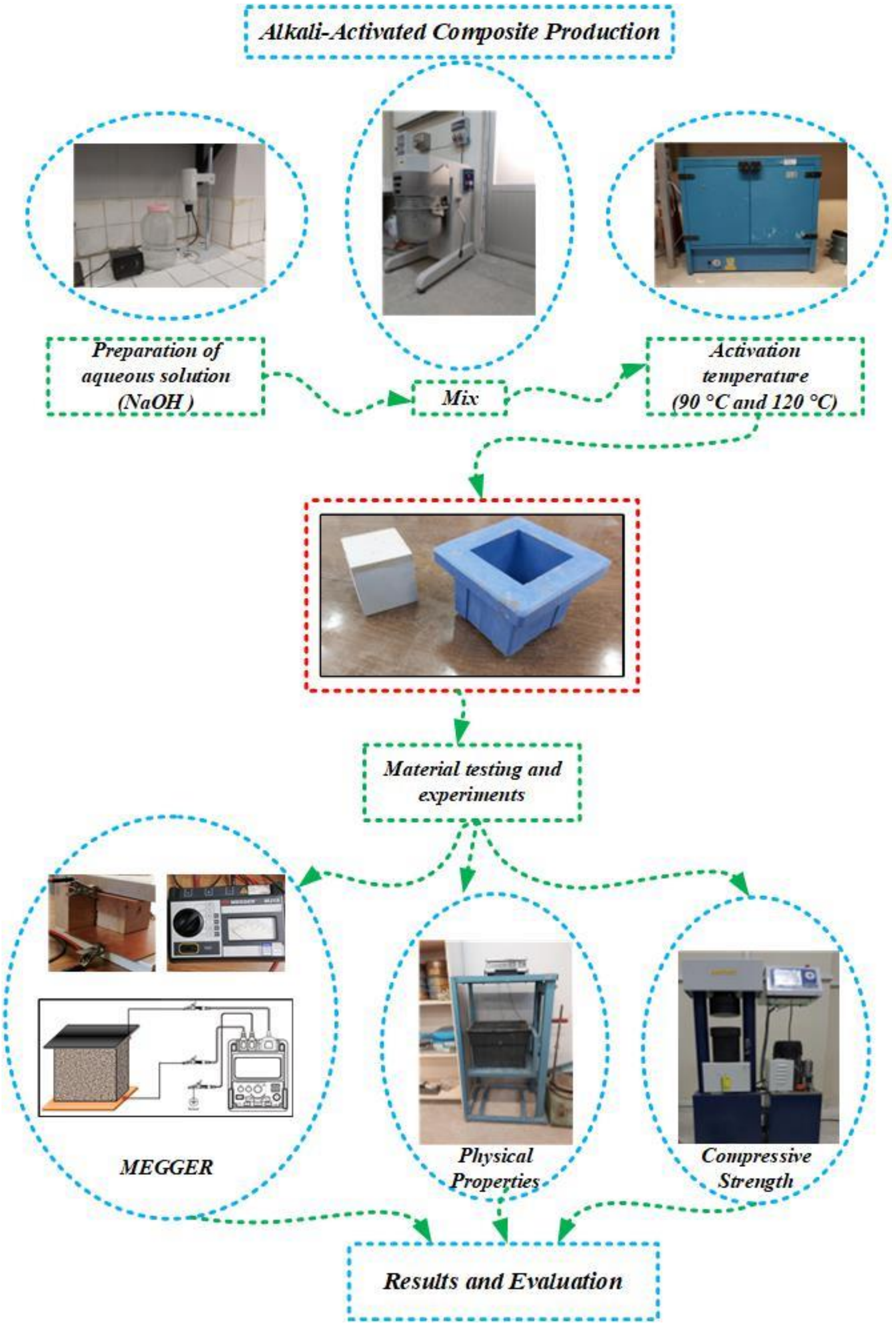

Figure 2. *Experimental study stages*

III. MEASUREMENT RESULTS AND EVALUATIONS

The resistance values obtained by the proposed method have been obtained for different alkali activated composite types. Then, the relationships between these measurement results and conventional test methods have been examined. In alkali-activated concrete mixtures, decreases in electrical resistance values have been observed with the increase of the zeolite ratio, as shown in Fig. 3. The ideal activation temperature is one of the most important parameters for strength development, depending on the properties of the materials entering the mixture in alkali-activated composite mixtures. It has been reported in previous studies that the activation temperature contributes to the polymerization process **[7, 9, 13, 28].**

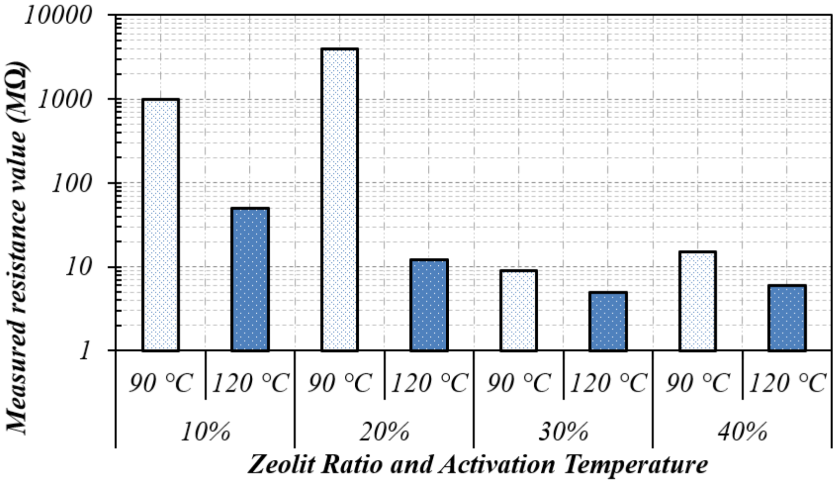

Figure 3. *Measured resistance values of different samples*

When Figure 4 is examined, it is seen that the maximum compressive strength value is obtained from mixtures with a 10% zeolite replacement rate. It can be concluded that the activation cure temperature is an important parameter for alkali activated composites **[7]** and the ideal activation temperature for this study is 90 C. The electrical resistance values of the samples with high compressive strength also reach high values. There is a substantial correlation between compressive strength and electrical resistance levels. And this correlation is shown in Fig. 5(a). This positive correlation has been obtained by considering only the data independently of the sample types. It is noticed that the positive association between the compressive strength values and the electrical resistance values is related to the water absorption values of the material and hence the pore distribution (please consider figures 5(a) and (b) together). Fig. 5(b) depicts an inverse relationship between the water absorption value and the measured resistance values.

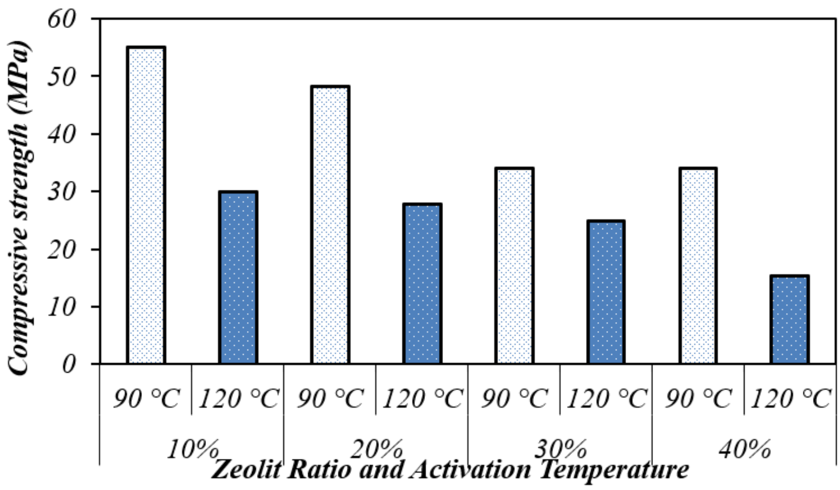

Figure 4. *Compressive strength values of different samples*

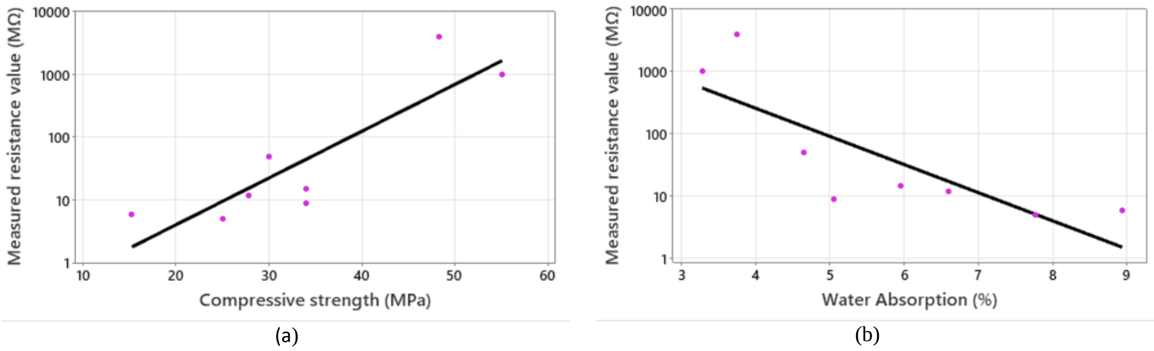

Figure 5. *Correlations for different samples: (a) between measured resistance value and compressive strength values; (b) measured resistance value and water absorption values*

Surface graphs have been drawn to better define the relationship of the measured parameters with the samples, in Fig. 6. Fig. 6(a) proves that the resistance value and the porosity are negatively correlated. This graph clearly shows that as porosity increases, compressive strength falls. In Fig. 6(b), the water absorption rate, compressive strength, and porosity parameters have been compared on the surface plot. As expected, the water absorption rate changes in a positive relationship with porosity. In addition, a very similar situation is observed between the values of water absorption and compressive strength.

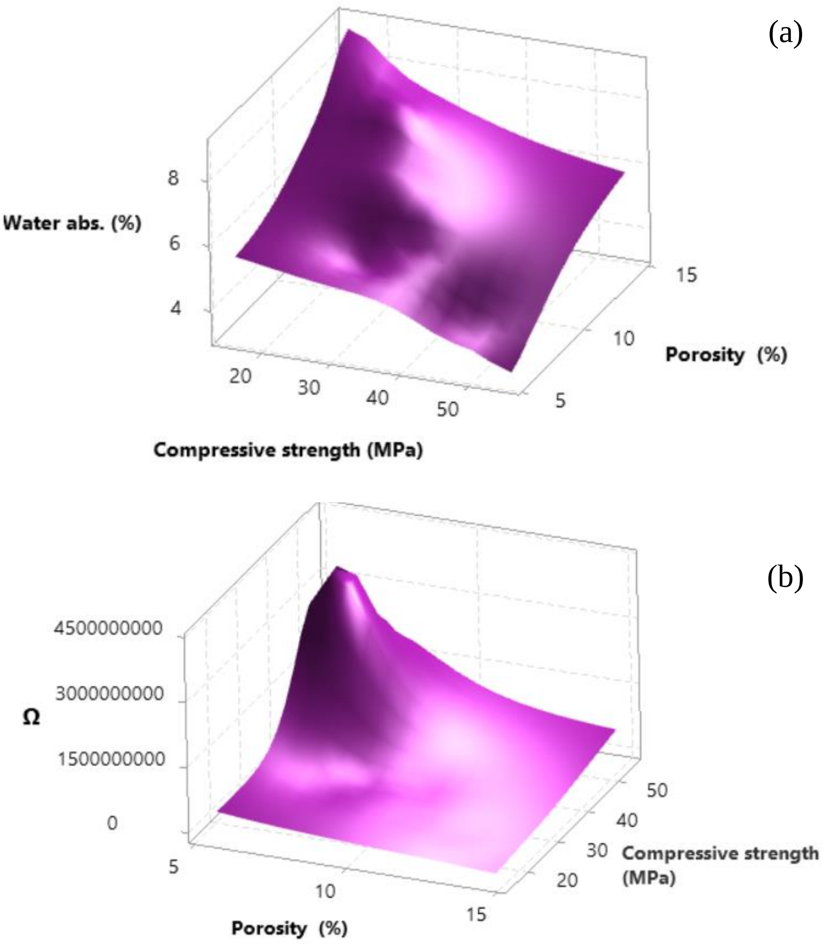

Figure 6. *Surface plots, (a) measured resistance – compressive strength – porosity; (b) water absorption – compressive strength – porosity*

IV. CONCLUSION

Within the scope of this study, sustainable environmentally friendly alkali-activated concrete composite mixture designs have been carried out. Additionally, the relationships between electrical resistance values and physical and mechanical properties of cementless composites produced from hybrid wastes were examined. Mechanical and physical tests have been carried out on alkali activation concrete composites prepared with 4 different mixing ratios of zeolite, with GGBFS which is an important waste of the iron and steel industry. Compressive strength, density, porosity, water absorption, and electrical resistance measurements have been correlated with each other. MEGGER device has been used for electrical resistance measurement. The results obtained as a result of the experimental study are summarized below.

* It has been concluded that there is a strong relationship between the compressive strength test results, which is one of the destructive testing methods, and the electrical resistance values.
* Moreover, the strength values in alkali-activated concrete have been shown to decline as the zeolite replacement ratio increases.
* It has been concluded that the proportions and chemical compositions of the materials entering the mixture for cementless composites with alkali activation hybrid binders have a significant effect on the physical and mechanical properties.
* It has been observed that maximum pressure and electrical resistivity values can be obtained at low porosity values.
* It has been concluded that the activation temperature has a significant effect on the physical and mechanical properties of alkali-activated composites.
* It has been inferred that determining the optimum activation temperature is an important parameter for strength development, especially in cement-free composites, due to the difference in the physical and chemical properties of the hybrid materials entering the mixture.

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