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Comparative Study On Corrosion Rates In Concrete Made Of Recycled-Concrete And Recylced-Brick Aggregate

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Abstract:
Recycling waste materials play a crucial role in minimizing the environmental impact caused by the concrete industry. However, uncertainties exist regarding the durability of recycled aggregate concretes when exposed to harsh conditions. This study conducted comparative research on the long-lasting properties of concrete containing recycled aggregates (RA). To produce RA on a global scale, discarded concrete from construction sites was crushed. Various types of concrete mixes were examined, including a control group with only natural aggregates (NA), and others that incorporated NFA and RCA (substituting 20%, 40%, 60%, 80%, and 100% RCA). The investigation focused on measuring the electrical resistivity (ER) in chloride-contaminated environments, which indirectly assesses concrete corrosion rates. The results revealed a decrease in ER with higher levels of RCA incorporation. In terms of corrosion testing, the ER of 100% RCA concrete ranged from 60% to 90% of the ER observed in the control sample. However, the decrease in ER for RFA concrete was significantly greater compared to the RCA concrete. Specifically, one study demonstrated that replacing 20% of the FA with recycled materials reduced the ER by 25%, while utilizing 100% RFA resulted in a reduction of over 60% in ER.

Keywords: *Recycled Coarse Aggregate; Electrical Resistivity; Corrosion Rate.*

1. Introduction and Previous Studies

As the demand for sustainability continues to increase, the importance of reusing waste materials in the construction industry has grown. Reusing demolished concrete has numerous benefits, including pollution reduction, landfill space conservation, and preservation of natural aggregate resources. The electrical resistivity and tensile strength of concrete depend on its composition, specifically the coarse and fine particles that make up the preponderance of the material. The durability and strength of concrete are determined by the characteristics of the cement paste and the physical and chemical properties of the aggregates. Environmentally favorable materials are now favored in the interest of sustainability, long-term viability, and minimizing the use of natural resources.

The electrochemical process of reinforcement corrosion occurs when a metal connected to an electrical source comes into contact with a fluid containing mobile particles. It is believed that the metal and its surrounding environment maintain the electrode potential [1]. Regardless of the mix design or exposure conditions, the concrete's electrical resistivity can indicate the likelihood of reinforcement corrosion. Sub-10k cm concrete resistivity is regarded as indicative of prospective steel reinforcement corrosion [2]. Cement's electrical resistance is intricately linked to its matrix, porosity, and pore size. It is believed that recycled concrete has a distinct microstructure and porosity compared to traditional concrete [3]. In a saline environment, no significant alterations were observed when 50% of the cement was replaced with byproducts and natural coarse aggregates were replaced with recycled coarse aggregates [4]. Two distinct varieties of cement were employed, and concrete containing 67% recycled coarse aggregates demonstrated superior corrosion resistance compared to conventional concrete [5]. Cement hydration decreases as coarse aggregate content increases. Nevertheless, the use of recycled coarse aggregates increases the resistivity. Water absorption and electrical resistivity are proportional to the quantity of recycled coarse aggregates, respectively. On the other hand, the opposite trend can be observed for fine aggregates. Therefore, the combination of recycled coarse and fine aggregates effectively reduces concrete's water absorption in comparison to commonly used materials [6]. Therefore, it is preferable to produce concrete from recycled materials. In addition, the efficacy of the recycled concrete and superplasticizer combination was improved [7]. This study examined comparative research on the electrical resistivity of recycled aggregate concrete, taking into account both the authors' local research and pertinent international research. Additionally, recycled brick aggregate concrete (RBA) is compared.

Table 1: List of Abbreviations.

Abbreviation	**Definition**
ER	Electrical Resistivity
FA	Fine Aggregate
NA	Natural Aggregate
NFA	Natural Fine Aggregate
RA	Recycled Aggregate
RFA	Recycled Fine Aggregate
RCA	Recycled Coarse Aggregate

Table 2: Guidelines for corrosion resistance (after [9])

Concrete resistivity and risk of corrosion of steel reinforcement		
Resistivity value (kΩ.cm)		
Corrosion risk	Polder	Commercial wenner probe instrument manuals
High	<10	≤10
Moderate	10-50	10-50
Low	50-100	50-100
Negligible	>100	≥100

2. Electrical Resistivity

Electrical resistivity has two definitions: "the resistance of materials to the passage of electric current" and " the ratio between the applied voltage and the sample's electric current flow."[7]. The indicator of electrical resistivity can be used to assess both the corrosion of steel rods within concrete and the load-bearing capacity of concrete. The electrical resistance device consists of numerous components, including cells, connecting cables, a bulk sample container, two D100 contact sponges, a concrete probe, a controller, and several rods. This instrument executes a non-destructive evaluation of the electrical resistance of concrete to determine its wear rate. The device calculates the attrition rate by measuring the internal electrical forces' resistance (Fig. 1). This on-site test yields an abrasion rate that conforms to ASTM Standard C1760-12. [8]. Using bulk resistance technology (the uniaxial method), electrodes are set on the surface of the concrete with a sponge in between. The rate of corrosion has a major impact on the durability of reinforced concrete structures. The corrosion rate is significantly influenced by relative humidity (RH), the ratio of anodic to cathodic areas, oxygen availability, and the electrical resistivity of concrete. By utilizing electrical resistance, the rate of deterioration can be slowed because the cathodic current cannot be controlled when subjected to an anodic current in the presence of sufficient oxygen. The scientific community has reached a consensus that electrical resistance and the deterioration of reinforced concrete are inversely related. As a result, as electrical resistance rises, the reinforcement's corrosion rate decreases. Through meticulous examination of electrical resistance, the corrosion potential of reinforcing steel can be determined. Through commercial guides [post [9]], corrosion potential specialists have provided guidance on Wenner probe devices (such as Proceq and Giatec Scientific Inc.). Table 2 illustrates the four categories of standard concrete resistivity values identified by these experts, indicating the levels of reinforcement corrosion risk as high, moderate, low, or insignificant.

Figure 1: Electrical Resistivity Apparatus

3. Electrochemical Measurement on Recycled Aggregate Concrete-RCA

The resistance to the flow of an electric current per unit area and length is known as resistivity. When determining the corrosion risk of the buried steel, the strength of the concrete cover is helpful. This approach is connected to the wear performance of reinforced concrete due to its great repeatability. The danger of reinforcement corrosion is divided into four groups based on the typical concrete resistance: high, medium, low, and not significantly significant [Table 1]. Concrete's porosity and pore fluid conductivity has an inverse relationship with the material's saturation strength. It is conceivable that adding additional porous aggregates, like RA, would linearly lower concrete's resistivity because the usage of RA has little effect on the concrete's porous fluid conductivity[3]. There is evidence from several studies that adding RAs lowers resistance. (Figure 2). The pore connectivity in the concrete is affected by the reduction in electrical resistivity caused by the addition of RAs.

When comparing NAC and RAC (same w/b), the electrical resistance differences often increase with age up to 28 days [10], [11], and subsequently decrease with age [6]. The pore structure weakens with age as a result of the formation of hydration products, and the impact of porosity resistivity of total recycled concrete tends to be lower in comparison to natural aggregate concrete, which may be the cause of the reduction in the effect of RA at later ages. The findings of a Spanish study[3] show that when the RA of the concrete mixture rises, the rate of steel corrosion also increases. Concrete becomes more porous and has more different sorts of contact as a result of the presence of RA, which makes it easier for dangerous compounds like chloride to seep through. As a result, the rate of corrosion of steel rises along with the ratio of RA replacement in recycled concrete aggregate. In addition, the corrosion rate of steel is not greatly impacted by the addition of a tiny quantity of RA (about 30% RCA or 20% RFA).

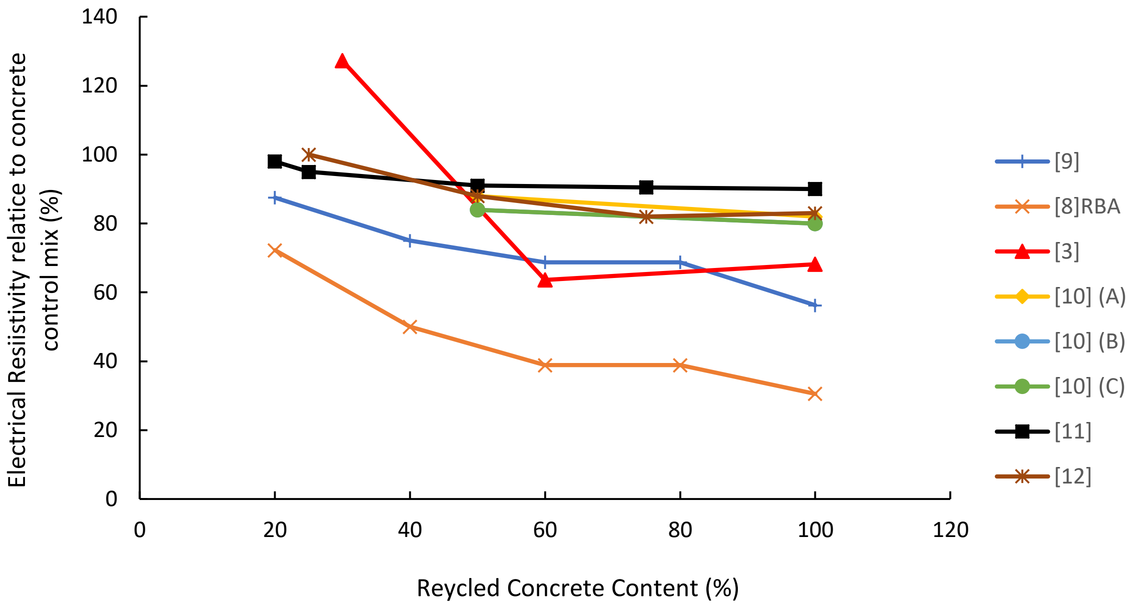

Figure 2:Electrical resistivity of various recycled aggregate concretes.

Kurda et al. [6] conducted a study and found that utilizing fine recycled aggregate (RA) significantly decreases electrical resistivity in comparison to standard concrete, especially when compared to coarse RA. Both Kurda et al. [6] and Sasanipour et al. [12] [fig. 3] demonstrated electrical resistance similar to that achieved by solely using fine RA. The superior effect of fine RA may be attributed to its higher porosity when compared to coarse RA.

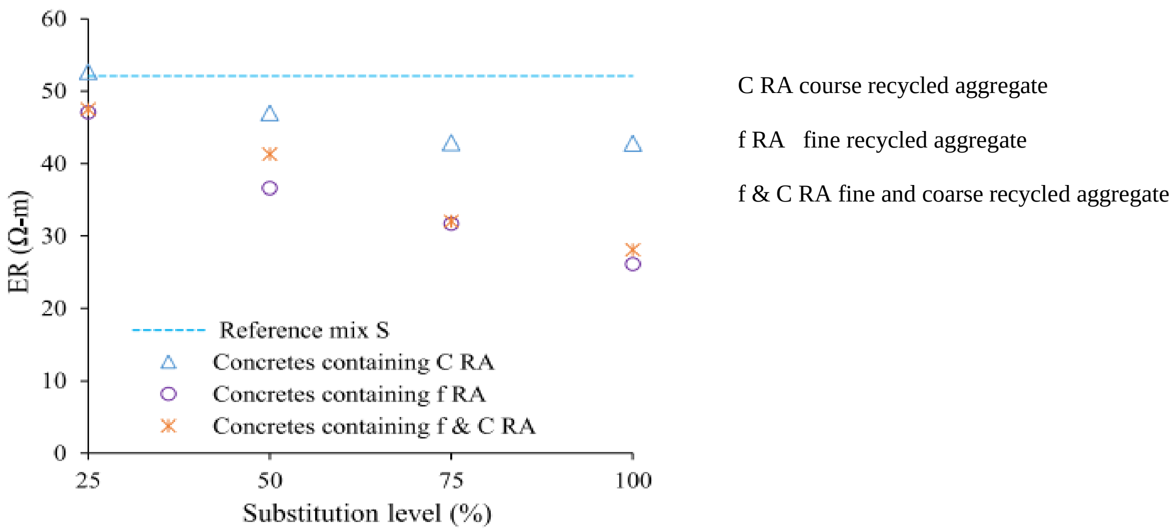

Figure 3:The effect of aggregates substitution level on Electric Resistivity. (Sasanipour et al.) [13]

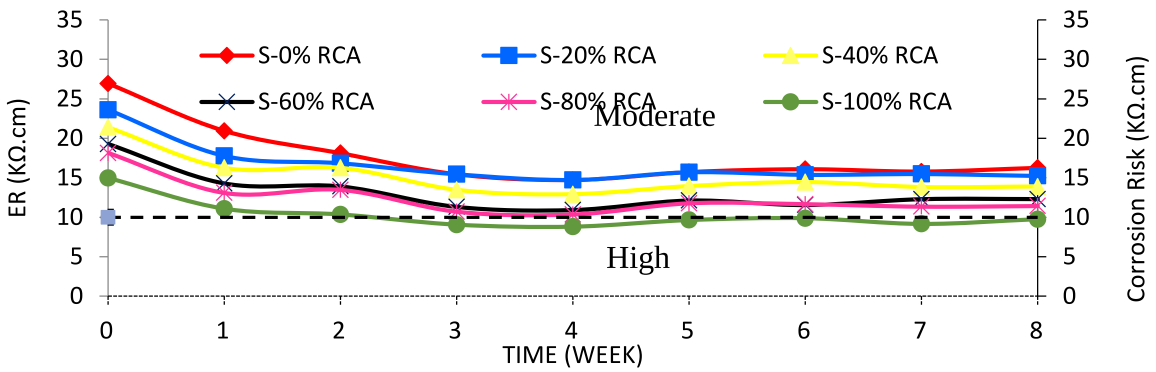

Figure 4:Corrosion risk for saline solution

The use of extra cementitious materials has been effective [6], [12] in mitigating the loss in electrical resistivity caused by the use of RA. The pore refinement induced by the pozzolanic process enhances the electrical resistivity and overall durability performance of recycled aggregate concretes.

In a subsequent, close-by study [10],the authors examined the ER of recycled concrete over a nine-week period in both pure water and brine. the Figures 4 and 5. The electrical resistance falls as the RCA ratio and exposure duration increase, as predicted. With a 64% reduction in resistance, this suggests that the wear rate will rise as the RCA ratio rises. As a result, the control sample's corrosion risks may be categorized as moderate to non-significant, and the RCA is medium or low for 100% of the time, as shown in Figure 5. (Table 1) Resistance reduced by 70% after eight weeks of exposure to clean water with a depth range of (25946-12478) cm. The control sample saw a 10% decline, while the 100% RCA experienced a 17% decrease, as seen in Figure 5. There have been no reported increases in corrosion risk after exposure. (Figure 5).

Table 6 displays the results for the 3.5% saline solution. Corrosion hazards increase after being exposed to a salty environment. At the conclusion of curing, 100% RCA concrete has an ER value that is, on average, 70% lower than regular concrete when exposed for the same amount of time. RCA concrete may be better than control concrete and have reduced corrosion hazards. A 50% drop was seen for the control sample nd a 42% reduction in the 100% RCA after eight weeks of exposure to the saline solution. However, the results of Arredondo et al. [3] are supported by this research. According to (Fig. 4), the RCA concrete used in this investigation has a "moderate to high" corrosion risk. The danger is substantial, as shown in (Fig. 6) from a research by Azba et al. [9] which substituted recycled brick aggregate for NCA. (R-100) Curve, among various research results of RCA concrete ERs.

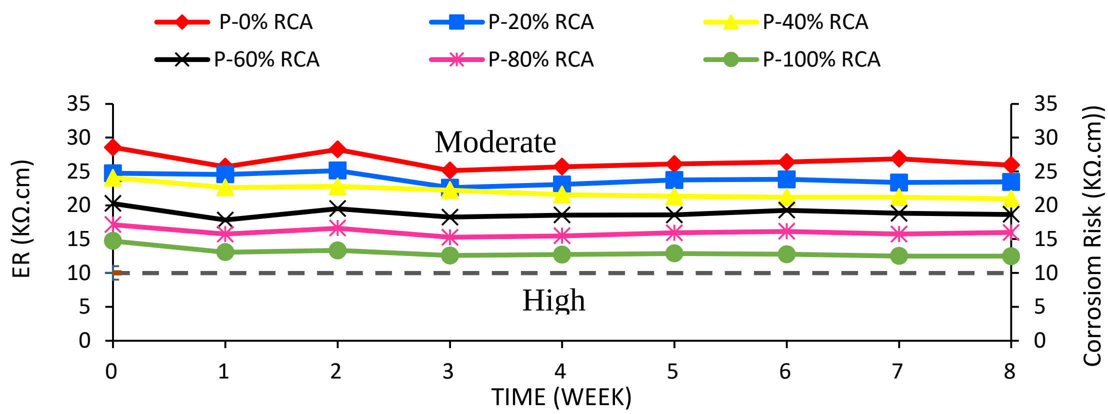

Figure 5: Corrosion risk for pure solution

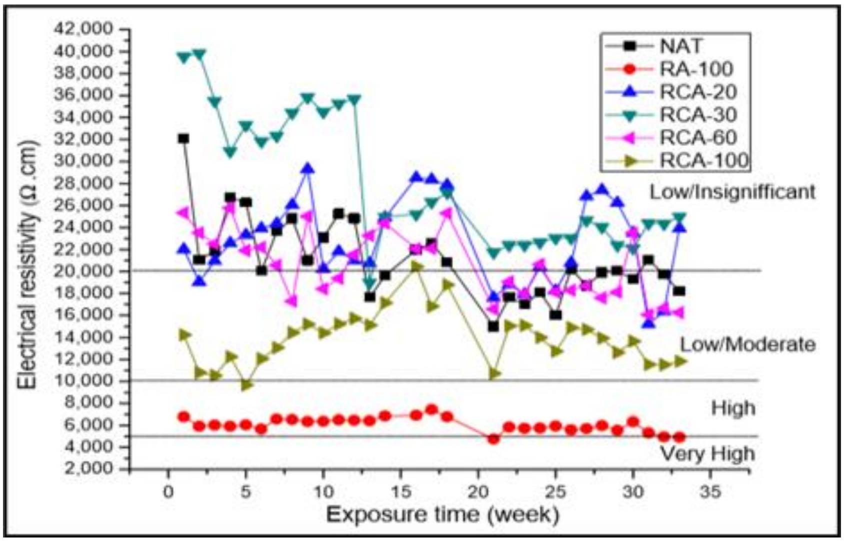

Figure 6: Evolution of ER with RCA (Arredondo-Rea et al)

4. Recycled Brick Aggregate

When Recycled Brick Aggregate RBA is incorporated into concrete, ER is significantly reduced. According to Azba and Al-Numan [9], the replacement of 20% RBA with natural aggregate reduces ER by 25% compared to the control specimen. At 100 percent RBA replacement, the reduction exceeds 60 percent. This can be attributed to the weaker, lighter, and more porous RBA concrete in comparison to the RCA and control concrete.

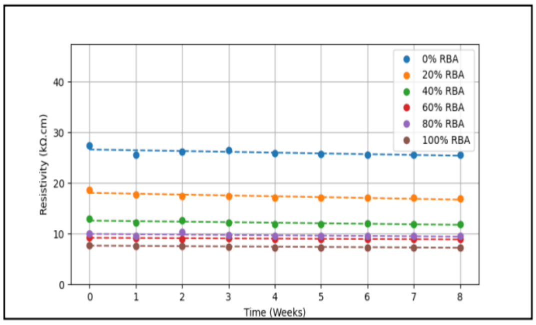

Figure 7:ER of recycled brick aggregates RBA in pure water.

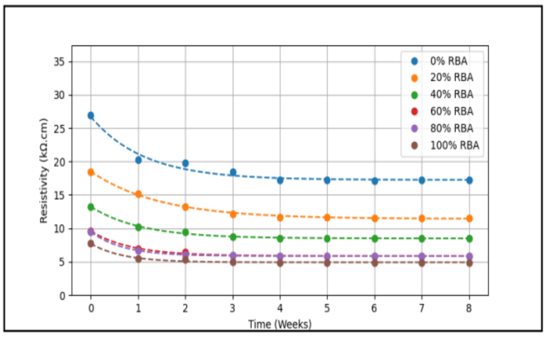

Figure 8:ER of recycled brick aggregates RBA in saline water.

As shown in Figures 7 and 8, a local investigation by (Ezbet A and Al-Numan B) revealed variation in the normal sample in the ER as the samples were subjected to a 3.5% NaCl solution. Prior to exposure to a 3.5% NaCl solution, the results indicate that higher inclusion levels of RBA will reduce the concrete's electrical resistance. The initial electrical resistance of a mixture containing 0% RBA is 27.5 k.Ohm.cm, whereas the initial electrical resistance of a mixture containing 100% RBA is 7.7 k.Ohm.cm, a decrease of 72%. However, this reduction was approximately 50%, whereas the RBA replacement rate was 40%. This decrease in ER in RBA concrete is primarily attributable to the material's high porosity, which captures water containing dissolved ions and thereby creates a path with low electrical resistance. Upon exposure to a NaCl solution, the electrical resistance decreases rapidly over the course of the first two weeks, before stabilising over the course of the remaining eight weeks of testing.

The ER of the control sample decreased by 36% after exposure to NaCl for 4 to 8 weeks. ER contraction was 31% and 37% for the 40% and 100% RBA substitutions, respectively. Comparable long-term ER decreases of 36–37% were observed for both control concrete and RBA when exposed to NaCl solution compared to the same samples during normal exposure. Figure 6 demonstrates that RBA concrete has lower ER values than RCA concrete. It is situated in a location with a significant erosion risk.

5. Conclusion

This paper sheds light on the electrical resistivity (ER) of reused concrete, a crucial factor in evaluating concrete's durability, and examines ER variations in durability experiments conducted worldwide. This inquiry yields the subsequent findings. The susceptibility to corrosion in the reference sample is moderate to insignificant, whereas it is moderate to minimal in the 100 percent reused concrete sample. The exposure to a saline environment increases the risk of corrosion to moderate to high levels. Environmental salinity can thus be demonstrated as detrimental to both new and reused concrete by accelerating the corrosion rate. In comparison to standard concrete compositions, the ER of reused concrete with 20% recycled concrete aggregate (RCA) is 97%, while it is 81% for reused concrete with 100% RCA content. When comparing reused concrete with 20% recycled brick aggregate (RBA) to standard formulations, the ER ratio is 72%, whereas it drops to 30% for reused concrete with 100% RBA.

This evident difference between ER concrete, RCA concrete, and RBA concrete, which can also be observed in figures 2 and 8, suggests a number of aspects, including the reduced porosity of RCA concrete, a better mixing structure, and stronger strength. Therefore, RBA concrete should only be utilized in "internal exposure" building situations or should be well protected when used in exterior exposure situations.

Regarding the impact of water-to-carbon ratio w/c. For water ratios of 0.35, 0.45, and 0.55, a decrease was recorded for coarse aggregate replacements of 0%, 50%, and 100%. The findings are comparable to; 31% and 36%, respectively, for 50% and 100% recycled coarse aggregate replacement with a water ratio of 0.45 prior to exposure.

After exposure, 24% and 32% for 50% and 100% recycled coarse aggregate replacement, respectively, with a water cement ratio of 0.45. For water ratio 0.55, the decreases were 39% and 44% before to exposure, and 44% and 47% after exposure.

6. Conflict of Interest

The authors declare that there is no conflict of interest for this paper.

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