

# Statistical Analysis of Total Replacement of Coarse Aggregate by Sustainable Recycled Aggregates

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## Abstract

Since building materials have been increasingly chosen based on their ecological attributes, contemporary development is strongly tied to preserving natural resources through avoiding environmental deterioration. Nevertheless, it was argued that concrete cannot be considered environmentally friendly because of its destructive, resource-consuming nature and the potential for severe environmental impact after its use. Concrete is among the most adaptable materials in construction and contributes significantly to expanding the infrastructural and industrial segments. Nevertheless, it will continue to be the dominant building material utilized everywhere. Even though recycled aggregates (RAs) were still less often employed in the construction sector, much effort was conducted to recycle hardened concrete, and further improvements are needed to maximize this. Some investigations on recycled aggregate's characteristics, applications, drawbacks, and behavior were also discussed. The current research aims to present a statistical analysis of coarse aggregate replacement with different water/cement ratios utilizing Single and two-way ANOVA for different mechanical features (tensile and compressive strengths) and durability features (Chloride ion penetrability) at 28 and 90 curing days. The results show no significant differences in one-way ANOVA and two-way ANOVA for compressive strength and chloride ion penetrability at 28 and 90 curing days.

## 1. Introduction

While aggregate serves as a structural filler in concrete, its function goes beyond what that straightforward description may suggest. Most of the concrete's volume is made of aggregate. It is the substance that the cement paste binds and coats. The concrete's shrinkage, weight, strength, durability, and workability are all significantly influenced by the aggregate's composition, shape, and size. Additionally, the aggregate may affect the way the surface of the casting looks, which is a crucial factor to consider when mixing concrete for countertops (Al-Khafaji & Falah, 2020; Jing et al., 2019).

Many aggregate sources, such as crushed rock and natural stones, are selected to use as filler materials in different concrete mixtures. The ordinary stones are basalt, quartz, granite, limestone, and marble. The gradation and size of aggregate are considered effective factors affecting the concrete's strength. The coarse aggregate is generally mixed with fine aggregate (sand) to fill the gaps between the large fractions and blended as one piece. The aggregate shape also influences the concrete strength and the workability of the fresh concrete (Shubbar et al., 2020).

Any contemporary development must prioritize the preservation of natural resources and the mitigation of environmental risks. Construction materials are being evaluated increasingly in terms of their ecological qualities. Nevertheless, even though concrete is not environmentally friendly because of its destructive resource-consumption nature and serious environmental effects after use, it has emerged as the most versatile material for construction work with the expansion of the infrastructure and industrial sectors. Nevertheless, it remains the dominant building material utilized globally (Awadh & Yaseen, 2019; Mussa et al., 2020; Yass, 2015).

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For the construction and maintenance of its infrastructure, almost every municipality in almost every industrialized or industrializing nation depends on aggregate resources (stone, gravel, and sand). Even rural towns rely on well-maintained transportation infrastructure to transport goods to markets. Regrettably, it is only possible to grow aggregate resources by influencing the environment to fulfill social demands (Al-Masoodi et al., 2017; Sanikhani et al., 2018).

## **2. The issues of utilizing natural aggregate (NA)**

Environmental concerns are rapidly growing as one of the most pressing challenges influencing manufacturing natural concrete aggregates. Natural aggregate (NA) concrete usage as the most significant component material is a major problem since it accounts for three-quarters of the ingredients in concrete. The enormous need for aggregate in manufacturing concretes necessitates extensive use of natural stone resources, threatening the environment's ecological equilibrium. The influence of accelerated economic growth is shown in the continuing development of land for industrialization and urbanization usage, particularly in emerging regions, including Pulau Pinang, Johor, and Selangor. Furthermore, as the population grows, communities are expected to expand.

As a result, land use rivalry will begin to emerge, necessitating additional space for development while also increasing demand for construction minerals required for infrastructure and building projects. As a consequence of the fast growth of the economy and people, numerous residential and urban districts around the quarries have developed and expanded (Soosan et al., 2005). This development will increase sensitivity to current mineral extraction operations and conflicts in certain regions. Consequently, the public will object to quarry operations, citing the dangers of noise, air, and environmental pollution caused by quarry operations.

Several investigations have also emphasized essential problems such as increasing awareness about environmental degradation and controlling and reducing the impact of pollution from quarry and mining operations (Ashraf et al., 2011; Er et al., 2011). As a result, the federal and state governments established several environmental rules and regulations to oversee and restrict quarry operations. These rules will make getting a license more difficult and limit the operations of a new quarry or mining.

Most of the environmental effects linked to mining for aggregate are minimal. Aggregate mining seldom results in acidic mine drainage or other hazardous effects often connected with mining metals or energy resources. There are a few other environmental health risks. Most anticipated effects are transient, predictable, and simple to detect. Most effects may be managed, reduced, or maintained at acceptable levels using current technology and reasonable operating procedures. They can also be kept localized to the area directly around the aggregate activity.

The switch of land use, most commonly from agricultural or undeveloped land use to a (temporary) hole in the earth, is the most evident environmental consequence of aggregate mining. Along with this significant impact are changes, sedimentation, erosion, blasting impacts, dust, noise, and habitat loss to the surrounding environment. Mining aggregate may have adverse effects on the environment. The effects of aggregate development on the environment may be made worse by societal pressures. The resources available and competing land uses severely restrict the regions where aggregate may be produced in high-density communities, which could also drive several aggregate businesses to congregate in a limited number of locations. By doing so, effects may compound, turning what may otherwise be a minor annoyance into serious repercussions (Langer & Arbogast, 2002).

As a result, the influence of rising environmental consciousness and, to a lesser degree, the identification of sensitive sites in recent years will contribute to decreasing production factors in new quarry areas. Concerning the protection afforded to the growing population expansion and the urbanization and industrialization processes, land areas utilized for mining or quarrying to create aggregates will no longer be accessible and will be limited in the future. Furthermore, continued usage of aggregate will deplete stockpiles quickly (Rahman et al., 2009). As a result, if aggregate demand is adequately regulated and planned, Malaysia's supply will thrive. Though importing aggregates may solve this issue, it is a short-term and inefficient solution due to the high transportation costs resulting from global fuel price unpredictability. Before a severe crisis emerges, aggregate consumption concerns must be addressed. As a result, the concrete industry must shift its focus to the reproduction and use of alternative aggregates by identifying and utilizing all available possible sources.

In some places, the haste to construct or maintain infrastructure could promote inadequate operating or environmental regulations. Aggregate operators may not adhere to ethical operating procedures under less stringent restrictions, which might have adverse environmental effects. The physical and chemical qualities, as well as the geomorphology and geometry of aggregate deposits, significantly influence the degree to which mining has an adverse effect on the environment. Pervasive mined areas and significant volumes of trash are produced when mining deposits are too thin

or include excessive amounts of inappropriate material. Additionally, specific geologic systems, such as talus slopes, active stream channels, and landslide-prone regions, are dynamic and react quickly to outside stimuli, such as aggregate mining. Rare or endangered species may find a home in certain geomorphic regions and ecosystems. Likewise, specific geomorphic landforms are exceptional instances of geologic events in and of themselves. Mining aggregate could be allowed in some of these locations, but it should only be done carefully and cautiously. Failure to do so may have detrimental, long-lasting effects on the ecosystem locally or at points far from the site. A landscape that has been damaged by mining. Minimizing the environmental effects of aggregate extraction involves utilizing the area after mining. The growth of mining offers an economic foundation and the utilization of a natural resource to enhance people's standard of living (Al-Khafaji, Al Masoodi, et al., 2018; Al-Khafaji, Al-Naely, et al., 2018).

### **3. The alternative solutions**

The usage of a large quantity of NAs and the challenge caused by a large demolition and construction waste volume are two examples of the influence of a fast-growing region on construction buildings. Demolition and construction garbage now account for much of Malaysia's solid waste (Begum & Pereira, 2007). The building industry's continued expansion creates massive construction waste, which has a negative impact on the environment and causes social difficulties in local communities (Mahayuddin et al., 2008). Construction sites now create a large quantity of garbage. A project site's total construction trash created throughout the new building construction is expected to be roughly 27,068.40 tons (Begum et al., 2006).

Close attention should be given to the environmental effects of producing the raw materials for concrete (cement, fine and coarse aggregates). To limit energy usage and the use of the natural resources that are already accessible, it is wise to investigate alternative sources of raw materials. As resources are getting scarcer and the effects of greenhouse gas emissions are becoming more apparent, reducing the environmental effect, energy usage, and Carbon dioxide intensity of concrete utilized in buildings is increasingly crucial. Therefore, applying life cycle and sustainable engineering principles makes sense when designing and utilizing concrete mixes. This calls for several factors, including maximum concrete longevity, material conservation, waste utilization, and extra cementing ingredients, including metakaolin, rice husk ash, silica fume, silica fume, and fly ash, as partial substitutes for Portland cement. These materials are less energy and Carbon dioxide-demanding than cement and may increase the durability of concrete while lowering the danger of thermal cracking in mass concrete. Utilizing aggregate made from crushed concrete is an instance of resource recycling and preservation. (Hammood et al., 2019; Tuama et al., 2020).

Aggregate typically makes between 55–80 percent of the volume of concrete. After 2010, the worldwide aggregate demand for the concrete industry, assuming sustained aggregate usage, would range from 8 to 12 billion tons annually. The usage of Demolition Waste and Construction (DW) as coarse and fine aggregate recycled aggregate (RA) has rapidly risen around the globe. Large developing nations like India, China, and Japan produce a lot of demolition waste and construction as a result of new zoning regulations, altered settlement patterns, rising populations, industrial development in urban areas, modernization of aging road bridges for the present as well as for future increases in traffic, and other factors (Awadh et al., 2020; Hooton et al., 2002; Sanikhani et al., 2018).

According to the Central Pollution Control Board, around 48 million tons of solid waste are produced in India annually, with the building sector accounting for 25% of that total. The ninth five-year plan also predicted the construction industry's need for coarse aggregates. Additionally, an expected 750 million cubic meters of coarse aggregate as sub-foundation material would be needed to meet the goal for road building up to 2010. Recycled coarse aggregate (RCA) utilization may partially close this gap. Recycling old concrete is thus advantageous, essential for protecting the environment, and helps make the best use of available resources. An efficient way to utilize demolition waste and Construction is to use recycled coarse aggregate from DW in fresh concrete. (Ashrafian et al., 2020; Dr. Abdullah Jabar Hussain, 2020; Keshtegar et al., 2019).

### **4. The types of RA and applications**

The term recycled aggregate (RA) is called crushed glass, asphalt, and concrete, and it is used again as fine and coarse aggregate within new concrete, road bases, and other infrastructure projects. Nevertheless, the increasing interest in reducing waste materials, especially construction waste materials, opens the way to an increase in the number of waste materials used as aggregate in filling the concrete mass.



Fig. 1. The Process of producing RAs.

#### 4.1. Recycling of Concrete

Due to rising industrialization, recycling of building materials now plays a significant role in protecting natural resources. Recycling of concrete is becoming more significant to guarantee sustainable development. Following are some of the many benefits of recycling concrete:

1. Conserve the environment's resources.
2. Lessens the effect of shrinking landfill areas.
3. Lowers disposal expenses.
4. Also, it may lower the total cost of the project.

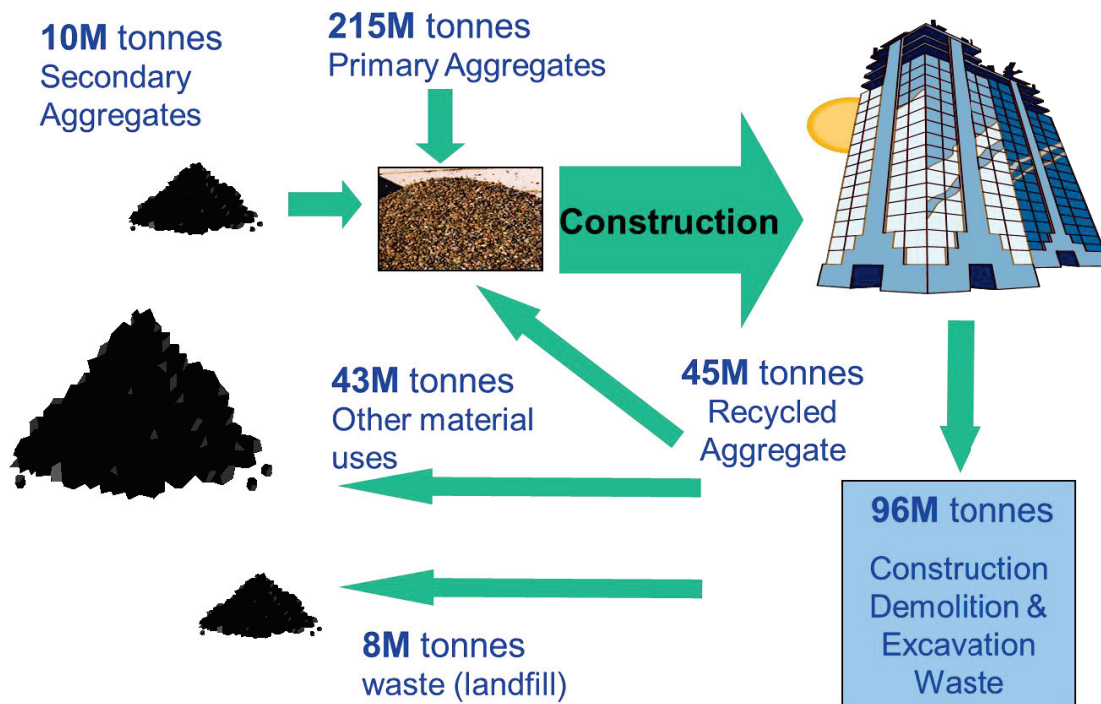
#### 4.2. Characteristics of RA

The following essential elements affect the strength parameters of RA from hardened concretes:

1. The original concrete's strength.
2. In the original concrete, the proportion of fine to coarse aggregate.
3. The proportion of RA to the original concrete's maximum aggregate size.

#### 4.3. Recycled Concrete Aggregates (RCAs)

The literature review revealed that several GCC nations have conducted in-depth studies on RCAs. (Wedding et al., 1984) conducted one of the early studies on reutilizing concrete waste as an aggregate material for buildings in Saudi Arabia. They used laboratory testing to examine the RCAs' failure mechanism, strength, and durability. Their research revealed that RA concrete seems to have a 30 percent lower strength than usual concretes with NA for low W/C proportions. Furthermore, the elasticity modulus and durability of the RA concrete were poorer.



**Fig. 2.** Construction Aggregates Lifecycle.

(Al-Mutairi, 2003) utilized saltwater to substitute 25, 50, and 100percent of the water from the tap in a typical concrete mix with a moderate goal strength and old concrete from Kuwait that had been destroyed to substitute 50percent and 100percent of the coarse aggregate. For 28 days, the recycled concrete was cured in saltwater. According to the findings, a design strength of 35 MPa was still feasible even when utilizing just RCAs 100 percent of the time. The mixing water mixture of 25 percent saltwater and 75 percent tap water resulted in the most substantial concrete.

(K. Rahal, 2007b; K. Rahal & Alrefaei, 2015; K. N. Rahal & Al-Khaleefi, 2015) examined the mechanical characteristics of concrete, including RA and having a compressive strength of 20–50 MPa, and the results were contrasted with those of concrete containing NA. The findings demonstrated that RA concrete's elasticity modulus, indirect shear strength, and compressive strength had all been within 10 percent of that of NA concrete with identical mixture proportions.

The flexural behavior of plain concrete, including crushed old concrete as a substitute for natural coarse aggregate, was studied by (AlMutairi & AlKhaleefi, 2007). Third-point loading was evaluated on simple concrete beams constructed with 0, 50, and 100 percent recycled coarse aggregate. The resulting modulus of rupture magnitudes fell within the permitted ranges once measured against the ACI standard. Additionally, statistical studies of permeability tests showed that including recycled materials in the mixture did not significantly alter the concrete.

Laboratory studies were performed by (Hooton et al., 2002) to evaluate the durability and strength of RA concrete. According to the findings, RA content of up to 30 percent of the substitution of regular aggregates increases concrete strength. Nevertheless, if the RA percentage is increased further, concrete strength declines. Nevertheless, it was discovered that utilizing RA instead of NA reduced the workability of the concrete because of the RA's high absorption qualities.

The strength of concrete constructed from recycled concrete coarse aggregate was investigated by (Tabsh & Abdelfatah, 2009). The recycled coarse aggregate tested in the laboratory for toughness and soundness revealed more percentage loss than the original aggregate, although it remained within reasonable parameters. The mix proportions identify the splitting tensile and compressive strengths of concrete built utilizing recycled coarse aggregate. Because

more water was needed to maintain the slump, recycled concrete often needed more strength than ordinary concrete prepared with NA. In a follow-up research, (Abdelfatah et al., 2010) used admixtures to make up for the lack of natural coarse particles in concrete mixes that included destroyed concrete and more water to make them more workable. The findings demonstrated that by using superplasticizers rather than extra water, RA concrete's compressive strength could be raised to a level comparable to that of the control mix made with NA. This conclusion does not match the outcomes of Gull's testing of low-strength concrete utilizing RCAs (Gull, 2011).

(Mirza & Saif, 2010) investigated how silica fume affected the features of RA concrete. By weight, the replacement rates for NA with RA have been 0, 50, and 100 percent, while the replacement rates for cement with silica fume were 5, 10, and 15 percent. The findings demonstrated that as RA and silica fume levels grew, so did the magnitudes of the tensile and compressive strengths of the RCAs. The research also revealed that 5 percent silica fume must be added to the mixture for structural concrete to accept 50 percent RA.

(Elchalakani, 2010) has studied the resilience and toughness of recycled concrete manufactured in the Emirates utilizing wastewater and recycled material. Standard cylinders and cubes were used in experimental experiments to measure the compressive strength, while tiny beams were used to measure the flexural strength. The research discovered that recycled water and aggregate had a minor influence on bending and axial strength but a considerable impact on durability. For any future building development in the Gulf, the author advised utilizing ground granulated blast furnace slag and fly ash to increase the durability of recycled concrete.

In particular research, RCAs were considered rather than used to make fresh concrete for various building uses. For instance, (Al-Ali et al., 2002) looked at whether RCAs may be used as the subbase for paving projects. A test model was constructed in the lab to evaluate the recycled material pavement performance under different loads and to compare its behavior to the NA layers. The experimental program considered various layer thicknesses, compositions, material gradations, and pavement loads. The findings show that utilizing RCA typically resulted in less pavement distortion under load than utilizing NA. As a result, there is a significant chance that RCA will be used as a subbase layer in the building of roadway pavement.

The manufacture of sand lime brick in Kuwait, taken into consideration by (Al-Otaibi, 2007; Al-Otaibi & El-Hawary, 2005), is another usage for RCA. The brick's absorption, compressive strength, and specific gravity features were all assessed in the research. It shows that the qualities of the brick formed from RCA meet the requirements.

## **5. Other civil engineering applications**

### **5.1. Concrete pavement**

Nassar and Soroushian examined the field performance of RA concrete in asphalt pavements exposed to high traffic loads and harsh weather conditions (Nassar & Soroushian, 2016). The performance of RAC is on par with or even greater than that of the matching control concrete, according to test findings from cores extracted from pavement sections after 270 days of concrete age. RAC concrete's durability and strength characteristics have increased with age, suggesting that it is appropriate for concrete-based infrastructure, including pavement building.

### **5.2. Hardcore filling**

Given that the RA grading was examined to meet the state of the soil, RAs were used as hardcore infill in building construction.

### **5.3. Molded concrete bricks and blocks**

According to research by (Poon et al., 2002), the brick and block sample compressive strength was not significantly affected by the substitution of fine and coarse recycled and NAs at levels of 25 and 50 PERCENT, while the compressive strength was decreased at higher levels of substitution. Concrete paving blocks with a 28-day compressive strength of less than 49 MPa may be made with RA at up to 100% substitution levels. The blocks' and bricks' performance in shrinking and skid resistance tests were also deemed adequate.

### 5.4. Oyster beds

Virginia State has developed a fresh method for utilizing RAs in the United States of America. Utilizing RCA, an oyster bed covers the artificial reef with crushed oyster shells. Concrete, especially concretes with a high chloride concentration, is appropriate because it will be used in a maritime environment.

## 6. Comparative results between original and recycled aggregates

The research analyzed the effects of various RAs on the durability and mechanical qualities of RA concrete while comparing the characteristics of used aggregates (RAs) with diverse proportions of old attached mortar from various sources of RA concrete. Utilizing each RA to replace NA, four concrete mixtures are created entirely, one with NA and the other three with RAs, with 28-day target compressive strengths ranging from 30 MPa to 80 MPa (Duan & Poon, 2014). The experimental findings reveal a significant variation in the performance of RAs from various sources. High-strength concrete with hardened qualities like the equivalent NA concrete may be made with RA of well grade (NAC).

**Table 1.** Mixing ratios (Duan & Poon, 2014; K. Rahal, 2007a)

Groups	Mixing ID	Replacing	Proportion (kg/m <sup>3</sup> )				
			Water	Cement	Sand	10 mm CA	20 mm CA
1 (w/c=0.68)	NA1	0				376	752
	RA1		205	300	697	366	709
	RA2	100				340	687
	RA3					343	684
2 (w/c=0.51)	NA2	0				381	762
	RA 4		180	350	706	371	718
	RA5	100				345	696
	RA6					348	693
3 (w/c=0.44)	NA3	0				359	718
	RA7		185	425	696	350	678
	RA8	100				325	657
	RA9					328	654
4 (w/c=0.34)	NA4	0				726	363
	RA10		165	485	685	700	339
	RA11	100				650	329
	RA12					655	327
(K. Rahal, 2007a)							
Groups	Mixing ID	Replacing	Water	Cement	Sand	CA>10 mm	10<CA< 20 mm
9 (w/c=0.65)	NA9	0	234	360	705	500	600
	RA17	100					
10 (w/c=0.50)	NA10	0	190	380	705	500	600
	RA18	100					
11 (w/c=0.48)	NA11	0	192	400	705	500	600
	RA19	100					
12 (w/c=0.43)	NA12	0	181	420	705	500	600
	RA20	100					
13 (w/c=0.40)	NA13	0	184	460	705	500	600
	RA21	100					

The experimental program for groups 1, 2, 3, and 4, which examined the characteristics of concrete formed from RAs received from various sources, is shown in Figure 3. This report presents the findings of the first phase of this extensive investigation.



Fig. 3. The working procedure (Duan & Poon, 2014).

## 7. Results and Discussion

### 7.1. Tensile splitting strength

Figure 4 demonstrates the tensile strength for the four groups with w/c ranges (0.68-0.34) % for NA and RAs. The correlation coefficient of tensile strength and water/ cement ratio is higher in NA than in RA. Table 2 shows a one-and two-way ANOVA analysis for tensile strength for samples with NAs and samples entirely replaced with RAs at 28 curing days. In one-way ANOVA, there is a significant difference based on the P-magnitude (0.397143<0.05), but there was no significant difference in two-way ANOVA for both rows and columns.

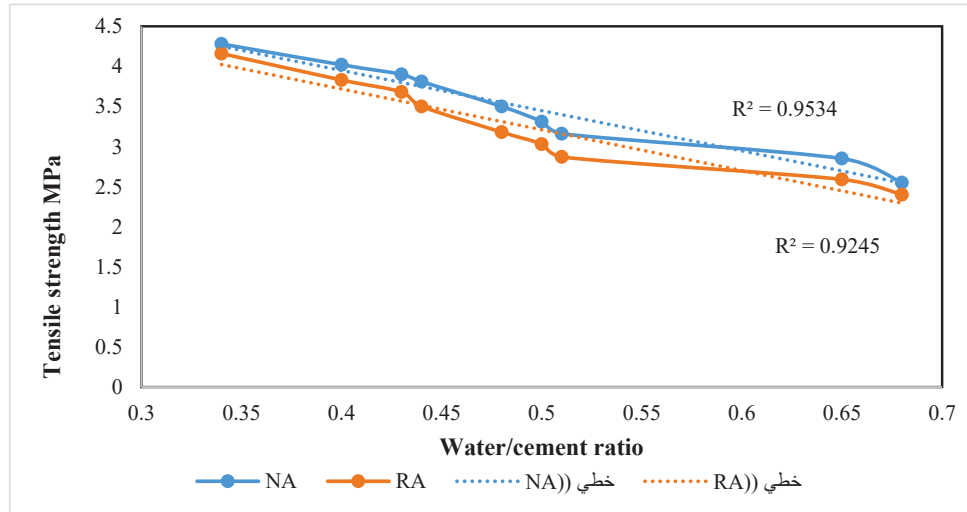


Fig. 4. Tensile strength at 28 curing ages.

Table 2. Statistical analysis of Tensile strength at 28 curing ages

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Mean	Variance		
Column 1	9	31.38	3.486667	0.32625		
Column 2	9	29.24	3.248889	0.345961		
ANOVA						
Source of Variation	SS	df	MS	F	P-magnitude	F crit
Between Groups	0.254422222	1	0.254422	0.756971	0.397143	4.493998
Within Groups	5.377688889	16	0.336106			
Total	5.632111111	17				
Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Mean	Variance		
Row 1	3	5.63	1.876667	1.079633		
Row 2	3	6.09	2.03	1.4452		
Row 3	3	6.54	2.18	2.1127		
Row 4	3	6.84	2.28	2.3959		
Row 5	3	7.16	2.386667	2.752133		
Row 6	3	7.75	2.583333	3.469433		
Row 7	3	8.01	2.67	3.7753		

Row 8	3	8.25	2.75	4.1509		
Row 9	3	8.78	2.926667	5.021733		
Column 1	9	4.43	0.492222	0.012369		
Column 2	9	31.38	3.486667	0.32625		
Column 3	9	29.24	3.248889	0.345961		
ANOVA						
					<i>P-</i>	
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>magnitude</i>	<i>F crit</i>
Rows	2.938118519	8	0.367265	2.314823	0.072834	2.591096
Columns	49.86734074	2	24.93367	157.1537	3.03E-11	3.633723
Error	2.538525926	16	0.158658			
Total	55.34398519	26				

## 7.2. Compressive strength

Figures 5 and 6 demonstrate the compressive strength for the four selected groups with w/c ranges (0.68-0.34) % at 28 and 90 curing days for both NA and RAs. The correlation coefficient of compressive strength and water/ cement ratio is higher in NA than in RA at 28 and 90 curing days. Tables 3 and 4 show a one-and two-way ANOVA analysis for compressive strength for samples with NAs and samples entirely replaced with RAs at 28 curing days. There are no significant differences in one-way ANOVA and two-way ANOVA for compressive strength at 28 and 90 curing days.

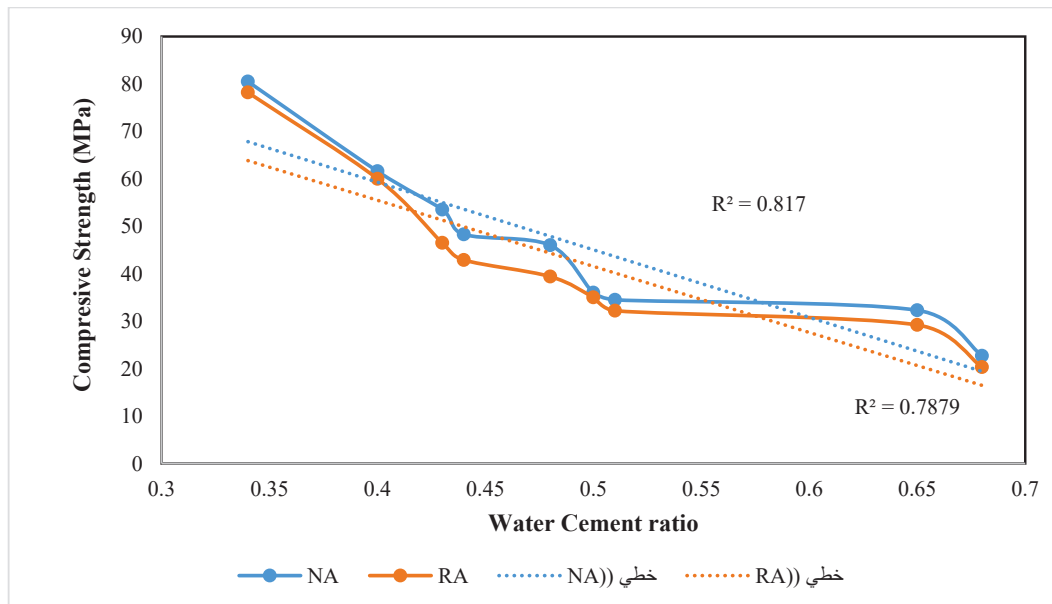


Fig. 5. Compressive strength at 28 curing days.

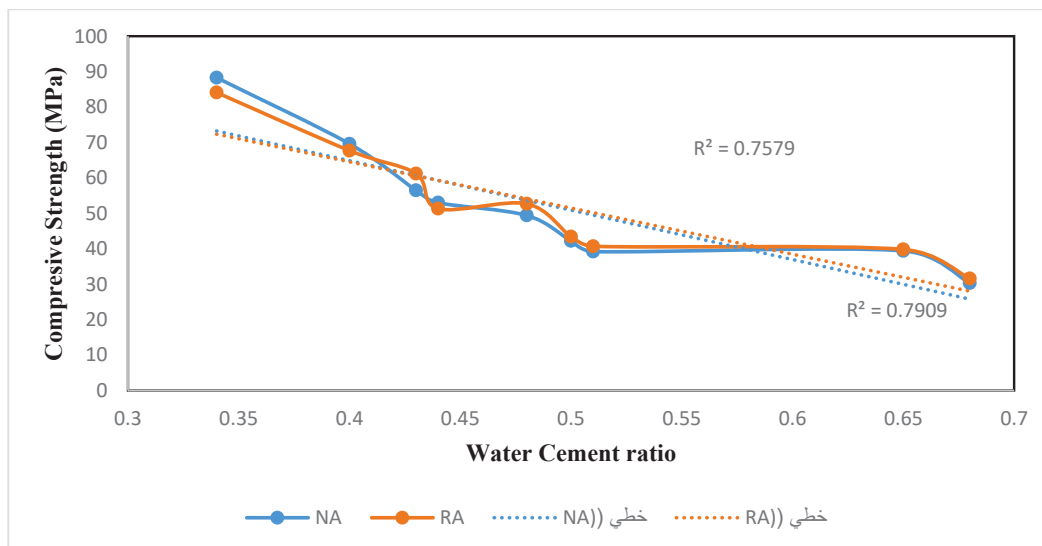


Fig. 6. Compressive strength at 90 curing ages.

Table 3. Statistical analysis of compressive strength at 28 curing days.

ANOVA: Single						
Factor						
SUMMARY						
Groups	Count	Sum	Mean	Variance		
Column 1	9	4.43	0.492222	0.012369		
Column 2	9	415.4	46.15556	307.2203		
Column 3	9	383.7	42.63333	304.8025		
ANOVA						
Source of Variation	SS	df	MS	F	P-magnitude	F crit
Between Groups	11620.26	2	5810.129	28.47939	4.61E-07	3.402826
Within Groups	4896.281	24	204.0117			
Total	16516.54	26				
Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Mean	Variance		
Row 1	3	43.68	14.56	145.9308		
Row 2	3	62.15	20.71667	304.4058		
Row 3	3	67.21	22.40333	360.811		
Row 4	3	71.5	23.83333	408.5833		
Row 5	3	85.88	28.62667	605.0661		

Row 6	3	91.64	30.54667	687.0985		
Row 7	3	100.43	33.47667	831.3116		
Row 8	3	122	40.66667	1216.693		
Row 9	3	159.04	53.01333	2082.183		
Column 1	9	4.43	0.492222	0.012369		
Column 2	9	415.4	46.15556	307.2203		
Column 3	9	383.7	42.63333	304.8025		
ANOVA						
					<i>P-</i>	
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>magnitude</i>	<i>F crit</i>
Rows	3232.373	8	404.0466	3.885277	0.010049	2.591096
Columns	11620.26	2	5810.129	55.8697	6.06E-08	3.633723
Error	1663.908	16	103.9943			
Total	16516.54	26				

**Table 4.** Statistical analysis of compressive strength at 90 curing ages.

Anova: Single Factor						
SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Mean</i>	<i>Variance</i>		
Column 1	9	4.43	0.492222	0.012369		
Column 2	9	467.9	51.98889	318.1236		
Column 3	9	472.5	52.5	265.865		
ANOVA						
					<i>P-</i>	
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>magnitude</i>	<i>F crit</i>
Between Groups	16070.93	2	8035.465	41.27801	1.7E-08	3.402826
Within Groups	4672.008	24	194.667			
Total	20742.94	26				
Anova: Two-Factor Without Replication						
<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Mean</i>	<i>Variance</i>		
Row 1	3	43.68	14.56	145.9308		
Row 2	3	62.15	20.71667	304.4058		
Row 3	3	67.21	22.40333	360.811		
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Row 5	3	85.88	28.62667	605.0661		
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Row 8	3	122	40.66667	1216.693		
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Column 1	9	4.43	0.492222	0.012369		
Column 2	9	415.4	46.15556	307.2203		
Column 3	9	383.7	42.63333	304.8025		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-magnitude</i>	<i>F crit</i>
Rows	3232.373	8	404.0466	3.885277	0.010049	2.591096
Columns	11620.26	2	5810.129	55.8697	6.06E-08	3.633723
Error	1663.908	16	103.9943			
Total	16516.54	26				

### 7.3. Chloride ion penetrability

Figures 7 and 8 demonstrate the total charge passed (Coulombs) for the four selected groups with w/c ranges (0.68-0.34) % at 28 and 90 curing days for NA and RAs. The correlation coefficient of total charge passed (Coulombs), and water/ cement ratio is higher in aggregate comparison with RA at 90 curing days, while the correlation coefficient of total charge passed (Coulombs) and water/ cement ratio is higher in RA comparison with nature aggregate at 28 curing days. Tables 5 and 6 show a one-and two-way ANOVA analysis for total charge passed (Coulombs) for samples with NAs and samples with entire replacement with RAs at 28 curing days. There are no significant differences in one-way ANOVA and two-way ANOVA for total charge passed (Coulombs) at 28 and 90 curing days.

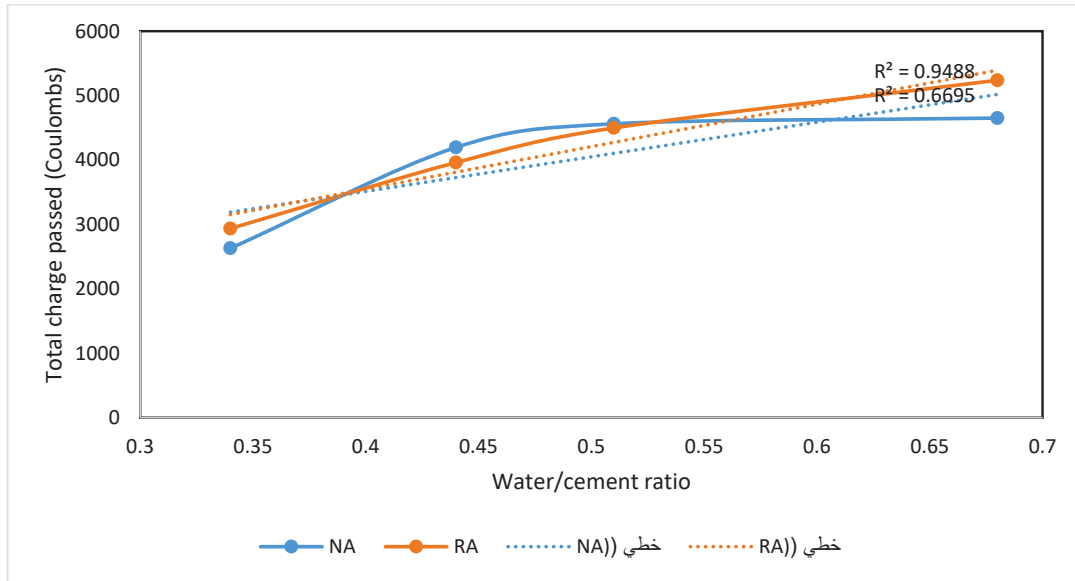


Fig. 7. Total charge passed (Coulombs) at 28 curing ages.

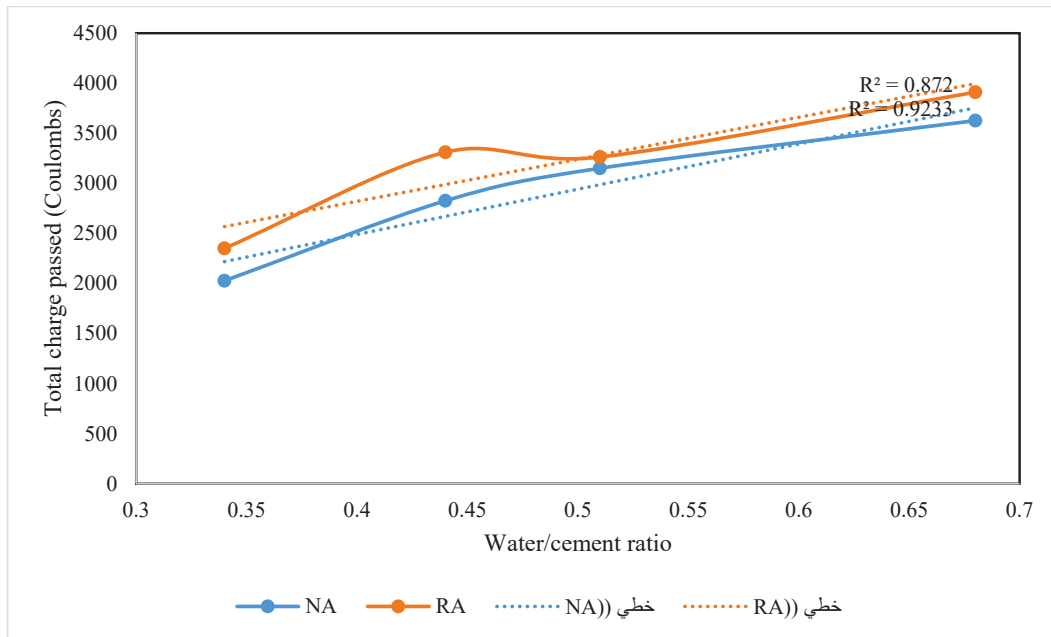


Fig. 8. Total charge passed (Coulombs) at 90 curing ages.

Table 5. Statistical analysis of total charge passed (Coulombs) at 90 curing ages.

ANOVA: Single Factor				
SUMMARY				
Groups	Count	Sum	Mean	Variance
Column 1	4	1.97	0.4925	0.020492

Column 2	4	16039	4009.75	884860.3		
Column 3	4	16633	4158.25	938030.9		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-magnitude</i>	<i>F crit</i>
Between Groups	44510861	2	22255430	36.62659	4.74E-05	4.256495
Within Groups	5468674	9	607630.4			
Total	49979534	11				
Anova: Two-Factor Without Replication						
<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Mean</i>	<i>Variance</i>		
Row 1	3	9889.68	3296.56	8233261		
Row 2	3	9060.51	3020.17	6839784		
Row 3	3	8157.44	2719.147	5557331		
Row 4	3	5566.34	1855.447	2604475		
Column 1	4	1.97	0.4925	0.020492		
Column 2	4	16039	4009.75	884860.3		
Column 3	4	16633	4158.25	938030.9		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-magnitude</i>	<i>F crit</i>
Rows	3509834	3	1169945	3.583584	0.08588	4.757063
Columns	44510861	2	22255430	68.16922	7.49E-05	5.143253
Error	1958840	6	326473.3			
Total	49979534	11				

**Table 6.** Statistical analysis of total charge passed (Coulombs) at 90 curing ages.

Anova: Single Factor				
SUMMARY				
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Mean</i>	<i>Variance</i>
Column 1	4	1.97	0.4925	0.020492
Column 2	4	11631	2907.75	452964.9
Column 3	4	12836	3209	414096
ANOVA				

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-magnitude</i>	<i>F crit</i>
Between Groups	25116557	2	12558279	43.4512	2.38E-05	4.256495
Within Groups	2601183	9	289020.3			
Total	27717740	11				

ANOVA: Two-Factor Without Replication				
<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Mean</i>	<i>Variance</i>
Row 1	3	7538.68	2512.893	4753576
Row 2	3	6414.51	2138.17	3430329
Row 3	3	6137.44	2045.813	3196470
Row 4	3	4378.34	1459.447	1622988
Column 1	4	1.97	0.4925	0.020492
Column 2	4	11631	2907.75	452964.9
Column 3	4	12836	3209	414096

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-magnitude</i>	<i>F crit</i>
Rows	1711014	3	570338	3.844247	0.075514	4.757063
Columns	25116557	2	12558279	84.64651	4.01E-05	5.143253
Error	890168.7	6	148361.4			
Total	27717740	11				

## 8. Conclusion

The issue of managing C&D waste may be addressed by utilizing RAs in concrete. RAC may be utilized in lower-end concrete applications based on a study of the production and usage of RA in RAC and the features of RA and RAC mentioned in this research. The current research aims to present statistical analysis by one and two-way ANOVA for the mechanical and durability of concrete before and after the total replacement of coarse aggregate by RAs, and the following conclusions are drawn down:

- The high water-cement ratio sample with NAs records the highest tensile strength, while the medium and low cement ratio sample with RAs records the highest strength.
- The compressive strength of the selected mixture increased after 90 curing days, and mixtures with natural concrete had the highest magnitudes.
- The correlation coefficient of tensile and compressive strength with natural coarse aggregate is higher than that of RA at 28 and 90 curing days.
- The chloride ion penetrability correlation coefficient at 28 records a high magnitude when utilizing RAs, while at 90 curing days, the chloride ion penetrability correlation coefficient records a higher magnitude when utilizing NA.
- There are no significant differences between one-way ANOVA and two-way ANOVA for compressive strength and chloride ion penetrability at 28 and 90 curing days.

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