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Impact of Chemical Attack on Concrete Produced from Recycled Concrete Aggregate, both Fine and Coarse.

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Abstract:

While the recycled concrete aggregate (RCA) reduces the need for natural aggregate, the use of recycled concrete aggregate (RCA) in place of natural aggregate (NA) in concrete is becoming more and more popular in the building sector. Furthermore, The utilization of Recycled Concrete Aggregate (RCA) provides a viable approach to addressing the environmental issue stemming from concrete waste in Mosul city. This paper investigates the effect of acidic curing environment concerning the compressive strength, mass loss, and ultrasonic pulse velocity (UPV) at different ages cured in water containing a 5% concentration Sulphuric acid (H_2SO_4). The density, UPV, and compressive strength were negatively impacted by an acidic curing environment for all Recycled Aggregate Concrete (RAC) mixtures. On the other hand, the concrete contains calcium-based chemical compounds, namely hydroxide of calcium ($Ca(OH)_2$) and hydrates of calcium silicate (C-S-H), dissolves when sulfuric acid incorporates with them. This reduces the amount of binding materials within the concrete matrix, which, in turn, weakens the structure, and sulfuric acid in contact with calcium-containing materials in the concrete can form gypsum (calcium sulfate dehydrate, ($CaSO_4.2H_2O$). Gypsum formation can occupy a larger volume than the original calcium compounds, leading to expansion, cracking, and hence a growth in mass loss and a decrease in UPV and compressive strength.

Keywords:-Recycled aggregate; Recycled concrete; Chemical attack resistance; Acid attack resistance; Compressive strength.

1. Introduction

Since the world's population continues to rise at an exponential rate, there is an increased demand for concrete, urbanization, and infrastructure. It is resulting in an insufficient amount of raw resources and natural aggregates required for producing cement and concrete [1]. In the world, each person requires about one ton of concrete production annually [2]. In the last 20 years, the amount of cement produced worldwide has quadrupled, from 1.10 billion to 3.27 billion tons. With more buildings currently in construction, it is expected that by 2030, cement production will have reached 4.83 billion tons [3]. In addition to this, increased population causes worries about running out of resources, releases of greenhouse gases, and power consumption [1,2]. The international community is responding to these types of crises. A good example is the 2015 signing of the Paris Agreement, which attempts to lower greenhouse gas emissions. With the help of the European Green Deal, the European Union aims to achieve carbon neutrality (zero emissions of carbon dioxide) by 2050 and to different resource consumption from development in the economy. By 2060, the Chinese government hopes to achieve carbon neutrality through the execution of a similar program [3].

The largest volume of concrete is comprised of aggregates, which make up 60–75% of its volume. Aggregates are extracted, and producing 1m³ of concrete requires about 2775 MJ of energy, which is released into the atmosphere when coal is burned [4]. An estimated 10–11 billion tons of aggregate are utilized annually worldwide; roughly 8 billion tons of aggregate, which includes crushed rock, gravel, and sand, are used to make Portland cement concrete [5]. When new construction is being built, or when existing construction—such as streets, highways, bridges, buildings, utility facilities, piers, and dams—is rehabilitated or demolished, waste is usually produced, is what the US Environmental Protection Agency refers to as construction and demolition recyclables [3].

Construction and demolition waste is one of the most common and significant types of municipal waste products, which not only has a negative influence on the environment but also imposes large costs of transportation and recycling management [6]. The Iraqi environmental ministry estimates that 1,111,788 tons of construction debris are produced annually in Iraq [5]. It is possible to recycle a lot of concrete after it has been used for a building, pavement, or other structure. As a result of this, one could decrease the amount of concrete that ends up in landfills and prevent the need for natural resources when building new projects. Over two million tons of construction and demolition waste are produced annually worldwide, with an average recovery rate of over 50%. In many undeveloped nations, the recovery rate is as low as 10%, while in nations like Taiwan, Japan, Denmark, and the Netherlands, it is up to 90% [6].

The features of recycled concrete aggregate (RCA) are expected to be influenced by the original concrete materials' properties, the presence of contaminants, and the aggregate extraction process. The primary distinction between RA and NA was the old mortar that was applied to the aggregate's surface. The total amount of mortar that is adhered to the aggregate surface depends on the quantity and processing technology that are used in the manufacture of recycled aggregates. The interfacial translation zone (ITZ) microstructure in RAC differs from that in NAC, and as the RCA content rises, so do the concrete's overall porosity and average pore diameter [7]. The properties of new concrete manufactured with recycled concrete (RCA) can be influenced by the strength of the old concrete from which the RCA was made, the method was using to produce the RCA, and the amount of moisture of the RCA [6].

To verify the safety of its application in the construction industry, numerous studies on the structural safety and durability performance of RAC have been done [8]. Rao et al. investigated three percentages of recycled aggregates (0%, 50%, and 75%) as partial substitutes for conventional aggregates. Two distinct acids (HCL and H2SO4) were employed in this investigation, with varying amounts (3 and 5%). The results show that as RCA goes up, weight loss goes up, and mass loss from H2SO4 is greater than mass loss from HCL. Also, replacing 0–50% of RCA is more resistant to acid attack than replacing 75% of RCA [9].

According to Umale et al., the effect on the cubes' strength and mass reduction increases with an increase in the exposure period. Additionally, at lower acid concentrations (5%), the rate of decline in the cubes' mass and compressive strength is significant and gets faster as the concentration rises to 10%. It appears that depending on the kind of acid and attack strategy, the compressive strength decreases with increasing acid concentration. When compared to sulfuric acid, the effects of hydrochloric and nitric acids on concrete are noticeably greater. In order for the cubes' compressive strength to be reduced to a maximum of 47 and 45%, respectively, after 60 days of full immersion in 10% hydrochloric and nitric acid, but only 25% in sulfuric acid [10].

According to Murthi et al., concrete specimens of grades M20, M30, and M40 that were immersed in 5% H2SO4 and 5% HCl solutions for up to 32 weeks showed severe degradation. After being submerged in a 5% H2SO4 solution, the PCC mix saw the most degradation in terms of mass loss. After 28 and 90 days, respectively, the mass loss of the cured M20-grade PCC specimens was 19.6% and 16.1%. Some samples of cured M20-grade Binary Blended Concrete (BFC-20) showed the highest Strength Deterioration Factor (SDF) value of 87% in 28 days after being submerged in water for 32 weeks. Meanwhile, during the same 32-week immersion period, the minimum SDF value of 58% was noted in 90 days for cured M40-grade concrete. Fly ash (FA) is mixed with BFC-20 concrete samples [11].

The mechanical properties of concrete subjected to solutions containing varying percentages of sulfuric acid (0.5%, 1%, and 3%) are examined by Tavares et al. Two types of concrete were made: high-performance concrete (HPC) and conventional concrete. Splitting tensile and compressive tests were utilized to evaluate the remaining mechanical properties after immersion. The weight of the samples varied more as the immersion period in the sulfuric acid solutions increased. Similarly, increasing the concentration and immersion duration in the solutions resulted in a decrease in the strengths of the two types of concrete, particularly for the HPC samples [12].

2.Research Objective.

This study aims to evaluate the impact of acid attack (H_2SO_4) on recycled aggregate concrete using different substitution level for both fine and coarse recycled aggregate.

3.Research Significance.

Reusing these huge quantities of waste from demolished concrete buildings for the purpose of producing recycled aggregate concrete and studying the durability properties of the new recycling aggregate concrete, especially after the establishment of the Mosul Debris Recycling Center in the Al-Athba area of Mosul city.

4. Experimental Program

4.1. Materials

4.1.1. Cement

The Ordinary Portland Cement (OPC) produced by the Badoosh Tawsee plant, which is of local origin (Iraq), was used in this study. It passed the Iraqi Standard Specification (IQS 5:2019) [13]. The chemical analysis and physical characteristics of the used cement are shown in Tables (1,2), respectively. The chemical analysis was carried out at the Environmental Engineering Laboratory/College of Engineering/University of Mosul. The physical properties were conducted at the Construction Materials Testing Laboratory/College of Engineering/University of Mosul.

Table 1: Chemical Analysis of Cement

Chemical Compounds (%)	Cement
Cao	64.64
SiO_2	20.6
AL_2O_3	4.9
Fe_2O_3	2.6
MgO	3.32 (5.0 max)
SO_3	1.58 (2.8 max)
Free Lime	2.9
Loss on Ignition	2.61 (4.0 max)
Insoluble Residue	0.4 (1.5 max)
Solid Solution	14.71
LSF	0.97 (0.66-1.02)
C_3S	53.64
C_2S	18.59
C_3A	8.58
C_4AF	7.92

Table 2: Cement's Physical

Property	Result	Limits of Iraqi Standard (No.5, 2019)
Fineness – Sieve No.170 (%)	4.6	≤ 10
Initial Setting Time (min.)	150	≥ 45
Final Setting Time (hr.)	5.25	≤ 10
Compressive Strength (MPa): at 3 Days at 7 Days	 21.1 30.0	 ≥ 15 ≥ 23

4.1.2 Fine Aggregate

In this investigation, natural river sand from Kanhash region was used. The recycled fine aggregate (RFA) used in this work was produced at Al-Athba recycling plant from demolished concrete structures waste generated in Mosul city because of the war of liberation. The waste was taken to the plant for recycling, where they were treated by crushing, removing impurities and sieving. The recycling plant has a production capacity of 50 tons/h. To find out the characteristics of aggregates, the following experiments were done: sieve analysis–IQS 45:1984 [14]; relative density and water absorption according to–ASTM C128-15 [15]. Figure 1 depicts the natural and recycled fine aggregate's particle size distribution, while Table (3) lists their physical properties. The grading of recycled fine aggregate was compared with natural sand and the recycled fine aggregate behaved very much close to the normal aggregate which are shown in Figure 1. The sieve analysis and physical properties were carried out at the Construction Materials Testing Laboratory/College of Engineering/University of Mosul.

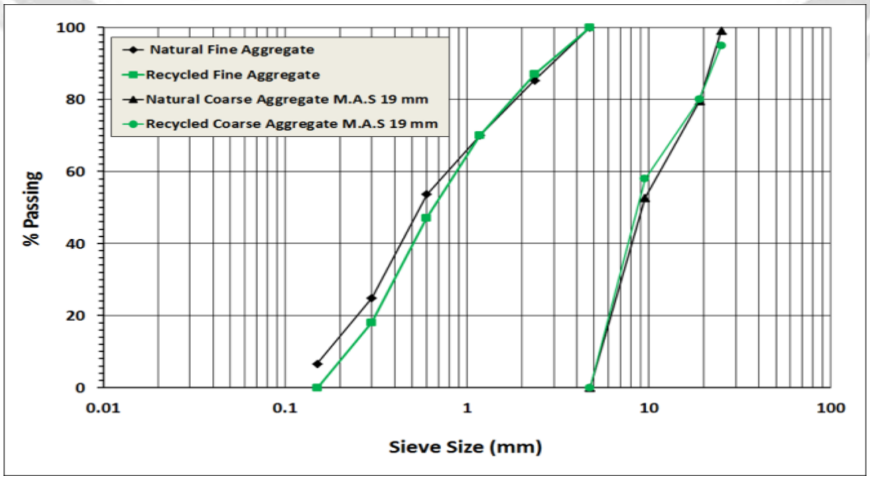

Figure 1: Gradation of Natural Aggregates and Recycled Aggregates.

Table 3: Physical Properties of the Natural and Recycled Fine Aggregates

Property	Natural Fine Aggregate	Recycled Fine Aggregate
Fineness Modulus	2.67	2.77
Specific Gravity	2.59	2.29
Unit Weight (kg/m^3)	1680	1358
Water Absorption (%)	2.45	8.2

4.1.3. Coarse Aggregate

Crushed stone was used as natural coarse aggregate in all mixes, with a maximum size of 19 mm. Al-Athba recycling plant, which recycles concrete structures that have been demolished, is another source of recycled coarse aggregate (RCA). Recycled coarse aggregate is made from the material that was kept on a 4.75-mm screen after passing through a 20-mm sieve. To ascertain the characteristics of aggregates, the following tests were carried out: IQS 45:1984 [14] consists of sieve analysis; ASTM C127-15 [16] provides relative density and water absorption. The particle size distribution of natural and recycled coarse aggregates is shown in Figure 1, and their physical characteristics are shown in Table 4. The grading of recycled coarse aggregate executed similarly to the crushed stone shown in Figure 1 when compared to natural coarse aggregate. The physical properties and sieve analysis experiments were carried out at the University of Mosul's College of Engineering and Construction Materials Testing Laboratory.

Table 4: Physical Properties of the Natural and Recycled Coarse Aggregates

Property	Natural Coarse Aggregate	Recycled Coarse Aggregate
Specific Gravity	2.8	2.43
Unit Weight (kg/m^3)	1549	1364
Abrasion Value (L.A) (%)	15.38	28.88
Water Absorption (%)	0.3	2.78

4.1.4. Water

All concrete specimens were prepared, mixed, and cured using potable tap water.

4.1.5. Superplasticizer

The high-performance superplasticizing additive Hyperplast PC200, which used to be called Flocrete PC200, is made up of polycarboxylic polymers with long chains that are designed to make the concrete's water content work better. To achieve the best concrete durability and performance, this effect can be applied to flowable and high-strength concrete mixtures. Depending on the dosage utilized, this product conforms with ASTM C494, Types A and G [17]. Table 5 lists the admixture's characteristics according to the DCP technical department [18].

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Table 5: Technical Properties of Superplasticizer at 25ºC

Property	Result
Color	Light yellow liquid
Freezing Point	≈ -3ºC
Specific Gravity	1.05 ± 0.02
Entrainment in Air	At standard dosages, typically less than 2% more air is entrained above the control mix.
Quantity	Cementitious materials ranging from 0.50 to 2.50 liters per 100 kilogram
Fire	Nonflammable

4.2. Mix Proportions

The concrete mix was designed according to ACI (PRC-211.1) 2022 to target 28 – days characteristic compressive strength of 34 MPa [19]. The mixture specifics of the mixes made for the study are shown in Table 6. Five mixes including reference mix and four recycled aggregate concrete mixes, were formulated with a constant water/cement (w/c) ratio of 0.53. Five different replacement of recycled fine and coarse aggregates including 0%, 25%, 50%, 75%, and 100% by volume, were used to find the optimal combination of recycled aggregate. These concretes were identified with the abbreviation RACx, where x is the volumetric percentage substitution of natural aggregate by recycled concrete aggregate. The day before mixing concrete, all of the aggregates were oven-dried. Therefore the amount of water in the mix had to be adjusted to maintain a constant level of free water and water content, depending on the quantity of both coarse and fine aggregate-absorbed water. In the beginning, the coarse and fine aggregates were uniformly mixed for 30 seconds. Afterwards the cement was added, and all dry compounds were mixed for 30 seconds too. Water was added and stirred for an additional 30 seconds, and after 3 minutes of continuous mixing, a uniform and homogenized mixture was obtained. When the superplasticizer was used, it was combined with the mixing water and added, so the mixing time is extended to 2 minutes even to make a homogeneous mix. Every concrete mix showed no signs of segregation or bleeding, and each mix's slump value varied from 100 to 140 mm. The final step involved pouring the mixture into molds that had been well-oiled and physically compacting it. The specimens were unmolded after 24 h, and kept submerged in water curing tank at 23 ± 2 ºC until testing.

Table 6: Mix Proportion for Reference Mixture

Materials	Quantities (kg/m^3)
Cement	427
Sand	734
Recycled Fine Aggregate	0
Crushed Stone	958.12
Recycled Coarse Aggregate	0
Water	225.86

4.3. Testing Procedures

Chemical attack resistance tests were examined based on several researchers, such as Umale and Joshi, Murthi and Sivakumar, Xuan et al. [10,11,20]. In the chemical attack resistance tests, the specimens were 100 mm by 100 mm by 100 mm. In these studies, a 5% concentration of sulfuric acid (H_2SO_4) was used. Every month, the acidic solution was changed out to keep the pH of the mixture at about 0.75. The concrete specimens were completely immersed in the solutions, as seen in Figure 2, putting all of their surfaces in touch with the strong solutions. In order to determine the specimens' resistance to H_2SO_4, they were cured for 28 days in water at room temperature, dried for 24 hours, and then submerged in 5% H_2SO_4 for 56 and 90 days.

Figure 2: Chemical Attack Resistance Test, A) Specimens under Full Immersion, B) Specimens after 90 Days of Immersion.

After their full immersion for 56 and 90 days, the specimens were taken out of the solution container, cleaned, and allowed to dry for a full day. After that, their compressive strength, pulse velocity, and mass loss were measured. For every kind of concrete that was made, three cube specimens were used. With an accuracy of 0.001 g, Using an electronic balance, the mass changes of the specimens during exposure situations were determined.

After the specimens were dried in the air for 24 hours at 30 to 35 degrees Celsius, the mass was measured. The following formula can be used to evaluate the mass change [21]:

$\Delta m_i = (m_i - m_0)/m_0 \times 100\%$

m_0 = The initial mass that was measured (gm)

m_i = The mass that was measured at the i^{th} times (gm)

5. Results and Discussion

5.1. Mass Loss

Figure 3 shows the results obtained for the mass loss percentage of concrete cubes for different RAC mixtures after fully immersed in 5% H_2SO_4 for 56 and 90 days.

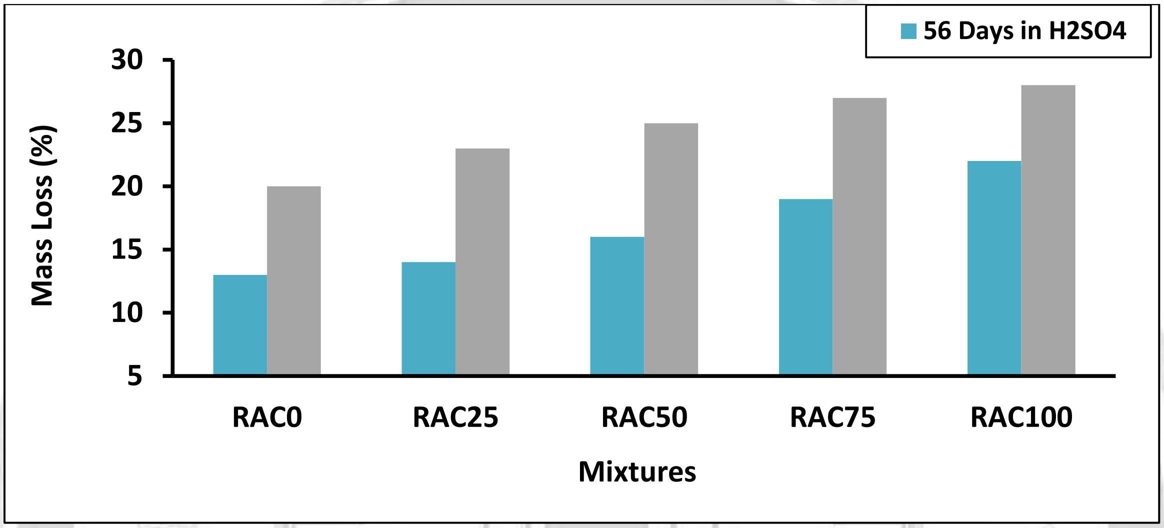

Figure 3: Mass Loss of Various RAC Mixtures at 56 and 90 Days Immersed in 5% H_2SO_4 Acid

According to Figure 3, the obtained results showed that, for both ages 56 and 90, the mass loss percentage increased with an increase in the proportion of recycled aggregate in the concrete affected by chemical attack. At 56 days of fully immersed RAC specimens in 5% H_2SO_4 acid, the mass loss of the reference mixture (RAC0) was 13%, and it was gradually increased by different ratios of (14, 17, 20, 23)% for the mixtures RAC25, RAC50, RAC75, and RAC100, respectively. The mass loss of RAC0 was augmented to 17% after 90 days of fully immersed in 5% H_2SO_4 acid, and it continued to increased due to the substitution. The mixture RAC25 and RAC50 achieved a slight reduction of 19 and 22%, compared with the mixture RAC0. In contrast, the greatest increase was in the mixture RAC100, which was around 27% relative to the reference mixture. The results shown in Figure 3 correspond to a variety of literature trends, such as, Rao et al. and Xu et al. who discovered that the rates of weight loss rises in relation to the percentage of RCA. Due to the specimens' absorption of the acid solution, there is a negative weight loss on the first day of immersion. However, weight loss gradually increases on the seventh, fifteenth, twenty-eighth, and fifty-sixth days of immersion [11,22]. This occurrence happened as a result of sulfuric acid's strong ability to react with cement's constituents, especially the calcium compounds. The acid attacks and dissolves the calcium compounds in the concrete, weakening its structure and the acid reacts with calcium hydroxide ($Ca(OH)_2$) in the concrete, converting it into calcium sulfate ($CaSO_4$) and water. Furthermore, during the deterioration process, the original mortar that was attached to the RCA was more likely to have its loose pore structure filled in by the large reaction products. As a result, the reaction products expanded and cracks formed, resulting in weight loss and surface abrasion [22]. Al-Baghdadi et al. discovered that sulfate attack-induced spalling and softening of the concrete at the surface had an effect on the mass loss in concrete specimens, which is similar to their findings. Concrete containing calcium-bearing elements reacts with sulfuric acid to produce gypsum (calcium sulfate dihydrate, $CaSO_4.2H_2O$), which can occupy a larger volume than the original calcium compounds. The expansion associated with gypsum formation can cause the concrete to crack and spall, which will cause mass loss [23]. Sulfuric acid can also attack the amorphous silica in the cement paste and aggregates, leading to the formation of soluble silicic acid (H_2SiO_3) and the loss of silica from the concrete matrix. Recycled aggregates may contain impurities or weaker bonding material on their surfaces, making them more susceptible to acid attack. This can lead to the deterioration of the aggregates themselves, causing mass loss. Because of the unstable ettringite production, the concrete matrix becomes more permeable and vulnerable to acid attack via capillary pores [11]. Additionally, Xie et al. showed that adding 30% RA to cast-in-situ recycled aggregate concrete (CRAC) won't have a significant impact on the concrete's sulfate resistance. Additionally, according to Xie et al., the quality of the recycled aggregates, the concentration of the acid, the exposure conditions, and the design of the concrete mix will all affect how much mass is lost in recycled aggregate concrete when it comes to sulfuric acid exposure. Therefore, in locations where exposure to sulfuric acid is a worry, it's vital to consider employing protective coatings or acid-resistant concrete mixes in order to alleviate this issue [24].

5.2. Ultrasonic Pulse Velocity (UPV)

Figure 4 shows the results obtained of ultrasonic pulse velocity(UPV) for different RAC mixtures after fully immersed in 5% H_2SO_4 for 56 and 90 days.

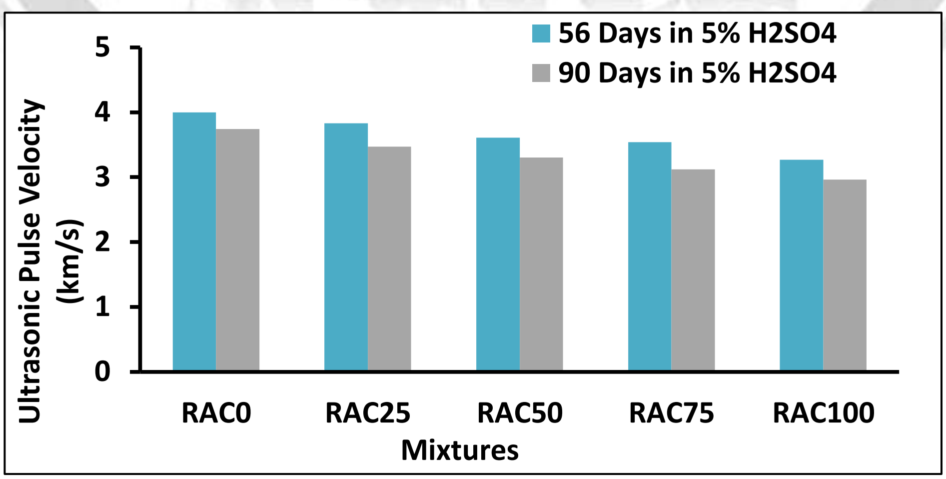

Figure 4: Ultrasonic Pulse Velocity of Various RAC Mixtures at 56 and 90 Days Immersed in 5% H_2SO_4 Acid

According to Figure 4, the obtained results indicated that the ultrasonic pulse velocity decreased with a rise in terms of recycled aggregate percent in the concrete exposed to chemical attack for both ages of 56 and 90 days. After 56 days of fully immersed RAC specimens in 5% H_2SO_4 acid, the UPV of the reference mixture (RAC0) was 4 km/s, and it was gradually decreased by different ratios of (4.2, 9.7, 11.5, and 18.2)% for the mixtures RAC25, RAC50, RAC75, and RAC100, respectively. The last had a pulse velocity of 3.7 km/s after 90 days of fully immersed in 5% H_2SO_4 acid, and it was reduced by 7.2 and 11.8% when the replacement level was 25 and 50%, i.e., RAC25 and RAC50, respectively. The greatest reduction was reached 20.9% when the substitution level was 100%, i.e., RAC100. However, the results indicated that all concrete mixtures were of poor to good quality for different replacement level [25]. While the acid can chemically react with the minerals present in the recycled aggregates. This can cause mineralogical changes and alterations in the physical properties of the aggregates, which subsequently affect the overall performance of the concrete and UPV. The aggregate, paste interface, and the existence of any voids or discontinuities at the interface all have an impact on the ultrasonic pulses passing through concrete [26]. The pore structures within the recycled aggregate concrete may have an impact on its strength and UPV values. The attached mortars would lower the UPV because they are made of porous materials. On the other hand, acid exposure can cause significant microstructural changes in the concrete, such as the transformation of the calcium-based compounds into less dense and weaker products. These changes affect the transmission of ultrasonic waves, resulting in a lower UPV [25]. Furthermore, the UPV was lower for concrete mixtures incorporating recycled aggregate due to the weak relationship between the recycled material and mortar matrix, indicating an increase in microcrack presence. The link between the recycled aggregates and the cement paste may be weakened by the acid attack. Lower UPV values are the consequence of this weakening, which lowers the load transfer capacity between the paste and the aggregates [26].

5.3. Compressive Strength

The compressive strength values for various RAC mixes after a full 90 days of immersion in 5% H2SO4 are displayed in Figure 5.

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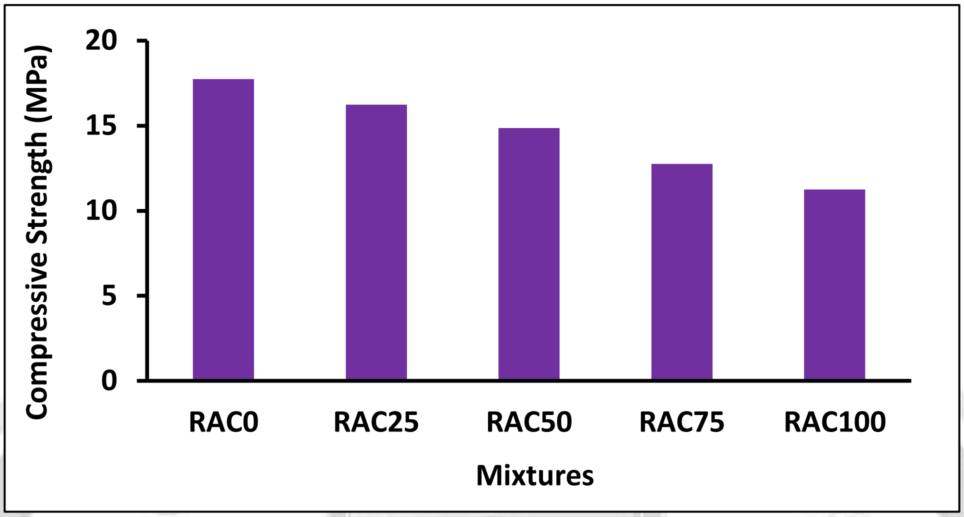

Figure 5: Compressive Strength of Various RAC Mixtures at 90 Days Immersed in 5% H_2SO_4 Acid

As the percentage of recycled aggregate in the concrete exposed to chemical attack increases, as shown in Figure 5, the compressive strength decreases. The compressive strength of the reference mixture (RAC0) was 17.73 MPa after the specimens were totally submerged in 5% H_2SO_4 acid for 90 days. The mixtures RAC25, RAC50, RAC75, and RAC100, respectively, gradually reduced it by various ratios of 14.7, 24.4, 28.7, and 36.6%. When the replacement level was 100%, i.e. RAC100, the largest decrease was 36.6%. The greatest decrease was reached 36.6% when the substitution level was 100%, i.e., RAC100. The results shown in Figure 5 correspond to a variety of literature trends, such as, Rao et al. discovered that the percentage strength loss increased somewhat as the amount of RCA in the mix increased. It was discovered that when the proportion of RCA in the mixture raised, there was a slight rise in the percentage strength loss. It was discovered that the percentage loss in compressive strength was higher in specimens subjected to H_2SO_4 than in those exposed to HCL. It has been noted that when the amount of RCA content in the mix increases, the compressive strength drops (by 50% or more) and that the acid exposure-related compressive strength loss also increases with the percentage of RCA, thus decreasing the strength of RAC [11].

Sulfuric acid reacts with calcium-based compounds in the concrete, particularly calcium hydroxide (Ca(OH)2) and calcium silicate hydrates (C-S-H), leading to their dissolution. This reduces the amount of binding materials within the concrete matrix, which, in turn, weakens the structure and sulfuric acid in contact with calcium-containing materials in the concrete can form gypsum (calcium sulfate dihydrate, CaSO4.2H2O). Gypsum formation can occupy a larger volume than the original calcium compounds, leading to expansion, cracking, and a reduction in the strength of compression. While acid attacks make the concrete more permeable, additional acid can seep deeper into the structure. The concrete may become even weaker and lose some of its compressive strength as a result of this increased permeability. Additionally, the acid attack may cause the bonding agent that keeps concrete together to dissolve, therefore decreasing the material's compressive strength [20]. Because there are more initial voids in the RCA, the RAC's compressive strength is lowered, and the number of internal voids rises. In addition, the formation of ettringite is a common consequence of sulfate attack on concrete and contributes to the degradation of its microstructure and mechanical properties, including compressive strength [27].

Bulatovic´ et al. observed that the expansion and compressive strength decreased simultaneously with the microstructural fluctuations that resulted from exposure to sulfate solutions. After 90 days of exposure to sulfate solutions, the majority of mixtures showed a noticeable decrease in compressive strength. This decrease is thought to be related to hydration effects, ettringite precipitation in coarse pores, and hydrotalcite-like precipitation. Both of these processes increase volume and tend to reduce porosity. Later on, the expansion brought on by chemical-physical reactions that occurred during the sulfate attack may prove to be related to the decrease in compressive strength [28].

6. Conclusions and Recommendations

6.1. Conclusions

The results of this experiment led to the following conclusions:

1. Acidic curing environments had a negative impact on the RAC mixtures' density, UPV, and compressive strength for all RAC mixtures.
2. As the amount of recycled aggregate in the concrete that was impacted by the chemical attack increased, the mass loss percentage also increased. The mass loss of the reference mixture (RAC0) was 13% after 56 days of totally submerged RAC specimens in 5% H2SO4 acid. This mass loss was then progressively enhanced by various ratios of (14, 17, 20, 23)% for the mixtures RAC25, RAC50, RAC75, and RAC100, respectively. After being totally submerged in 5% H2SO4 acid for 90 days, the mass loss of RAC0 increased to 17%, and the mixture RAC100 experienced the biggest rise, rising by about 27% in comparison to the reference mixture.
3. In concrete exposed to chemical attack for both 56 and 90 days, the ultrasonic pulse velocity dropped as the percentage of recycled aggregate increased. After 56 days of completely submerged RAC specimens in 5% H2SO4 acid, the reference mixture's (RAC0) UPV was 4 km/s. Varying ratios of (4.2, 9.7, 11.5, and 18.2)% progressively reduced this value for the mixtures RAC25, RAC50, RAC75, and RAC100, respectively. After 90 days of complete immersion in 5% H2SO4 acid, the pulse velocity of the last specimen was 3.7 km/s, and it achieved a maximum reduction of 20.9% at a 100% substitution level.
4. Compressive strength drops as the proportion of recycled aggregate in the concrete that is subject to chemical attack rises. After the specimens were completely immersed in 5% H2SO4 acid for ninety days, the reference mixture's (RAC0) compressive strength was 17.73

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MPa. It was progressively lowered by different ratios of 14.7, 24.4, 28.7, and 36.6% by the mixtures RAC25, RAC50, RAC75, and RAC100, respectively.

6.2. Recommendations

1. Investigate the microstructure of the recycled aggregate concrete that had been attacked chemically using techniques like thermogravimetric analysis (TGA), scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP).

2. Future studies should look at how additional cementitious materials—like fly ash, silica fume, slag, and natural pozzolan—affect the mechanical and durability properties of recycled aggregate concrete that is exposed to chemical degradation.

3. It is advised that future studies examine the effects of other acid concentrations, such as hydrochloric (HCL) acid, on the mass loss and compressive strength of recycled aggregate concrete.

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تأثير الهجوم الكيميائي على الخرسانه المنتجة من ركام الخرسانة الناعم والخشن المعاد تدويرة

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الخلاصة :-

من المعلوم أن ركام الخرسانة المعاد تدويرها يقلل من الحاجة إلى استهلاك الركام الطبيعي، فإن استخدام ركام الخرسانة المعاد تدويرها بدلاً من الركام الطبيعي في الخرسانة أصبح أكثر شيوعًا في قطاع البناء. علاوة على ذلك، يوفر استخدام ركام الخرسانة المعاد تدويرها نهجًا قابلاً للتطبيق لمعالجة القضايا البيئية الناجمة عن مخلفات الخرسانة في مدينة الموصل. يبحث هذا البحث في تأثير بيئة المعالجة الحمضية فيما يتعلق بمقاومة الانضغاط وفقدان الكتلة وسرعة الموجات فوق الصوتية (UPV) لنماذج خرسانية بأعمار مختلفة، معالجة في ماء يحتوي على تركيز 5٪ من حمض الكبريتيك (H_2SO_4). تأثرت الكثافة و UPV ومقاومة الانضغاط سلبًا ببيئة المعالجة الحمضية لجميع الخلطات الخرسانية المعاد تدويرها (RAC). من ناحية أخرى، تحتوي الخرسانة على مركبات كيميائية أساسها الكالسيوم، وهي هيدروكسيد الكالسيوم ($Ca(OH)_2$) وهيدرات سيليكات الكالسيوم (C–S–H)، والتي تذوب عندما يتحد معها حامض الكبريتيك. وهذا يقلل من كمية المواد الرابطة داخل الخرسانة، مما يؤدي بدوره إلى إضعاف البنية المايكروية، كما يمكن لحامض الكبريتيك عند ملامسته للمواد المحتوية على الكالسيوم في الخرسانة أن يشكل الجبس (كبريتات الكالسيوم ديهيدرات . إذ يمكن أن يشغل تكوين الجبس حجمًا أكبر من مركبات الكالسيوم الأصلية، مما يؤدي إلى التمدد والتشقق، وبالتالي زيادة في فقدان الكتلة وانخفاض في UPV و مقاومة الانضغاط.

الكلمات الدالة:- الركام المعاد تدويره؛ الخرسانة المعاد تدويرها؛ مقاومة الهجوم الكيميائي؛ مقاومة الهجوم الحمضي؛ مقاومة الانضغاط.