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The Effect of Demolition Concrete Waste on the Physical, Mechanical, and Durability Characteristics of Concrete

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Abstract: With the development of urbanization, more and more construction and demolition waste (CDW) is generated. To enhance the mechanical properties and durability of concrete through the incorporation of recycled aggregate, the water/cement ratio was controlled to optimize the properties of concrete. In this work, one reference concrete with a water/cement ratio of 0.5 was prepared. The demolition concrete waste from East China was used, and 50% and 100% of the natural aggregates of the reference concrete were substituted. Furthermore, the water/cement ratio of concrete with 50% and 100% CDW was reduced to 0.3, and the superplasticizer was used to justify the workability of fresh concrete. Finally, the workability of fresh concrete was determined. After curing for 28 days, the density, water absorption, and resistance to chloride penetration of concrete were realized. The compressive and flexural strength were examined at 14 and 28 days, and the electrical resistivity test was conducted at 7, 14, and 28 days. The results indicate that with increasing CDW content, the mechanical properties and durability of concrete decreased. However, when the water/cement ratio decreased to 0.3, the concrete properties were optimized, such as the compressive strength and resistance to chloride penetration of concrete with 50% CDW increased by 74.2% and 28%, respectively.

Keywords: green concrete; recycled concrete aggregates; physical properties; mechanical properties; durability properties

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1. Introduction

Concrete is the most widely used engineering material in the world today, accounting for approximately 90% of the major construction consumables. The Global Cement and Concrete Association reported [1] that 14 billion cubic meters of concrete was consumed worldwide in 2020, 40% of which was used for the residential market. China, as the most populous country globally, consumes approximately 10 billion tons of concrete annually, with a per capita consumption of approximately 700 million tons [2]. In recent years, with increasing attention to environmental issues, in September 2020, China officially introduced the concept of "low-carbon concrete technology" in the "Dual Carbon Goals" document [3]. This concept refers to concrete technologies that can directly or indirectly reduce greenhouse gas emissions during the production and use of concrete. Specifically, it includes green high-performance concrete technologies that pursue long-term durability and high durability while reducing cement consumption, as well as the application of tailings, construction and demolition waste (CDW), and other solid waste recycling resources in concrete engineering.

At the same time, with the rapid development of urbanization, the quantity of demolished buildings has increased, leading to a substantial generation of CDW. According to statistics, China produces 2.3 billion tons of CDW annually [4], which not only occupies a large amount of arable land but also negatively impacts the ecology, environment, and surrounding water sources [5–7]. Therefore, the resource utilization of CDW has become an urgent issue that needs to be addressed. Many researchers and construction industry technicians have studied the comprehensive utilization of CDW to produce coarse aggregates, recycled fine aggregates, recycled powder, recycled garden soil, and other intermediate products and have investigated the application of recycled products in recycled concrete, mortar, blocks, bricks, road backfill materials, and other construction projects [5,8–11]. The recycling and utilization value of CDW is enormous. According to the China Association of Circular Economy [12], utilizing 100 million tons of CDW can produce 24.3 billion bricks, replace 10 million natural aggregates of concrete, reduce land occupation by 60.7 million m^2, save 2.7 million tons of coal, reduce carbon dioxide emissions by 1.3 million tons, and create an additional output value of 8.46 billion Chinese yuan. In particular, the utilization rate of CDW in China is less than 5% [13]. Therefore, there is enormous economic potential in this sector.

In fact, relatively mature technology accumulation and industrial recycling have been formed in terms of recycled coarse aggregates. However, there is not much confidence in its strength and durability when applied to concrete [14]. Many researchers have published on recycled aggregates used as coarse aggregates in concrete and pointed out that recycled aggregates suffer from lower quality, mainly in old transfer zones (connecting areas of adhered mortar and aggregate) and high porosity [15–20]. Majhi et al. [17] found that recycled concrete aggregate from 10-year-old precast railway sleepers was used in concrete. The quantities of 25%, 50%, and 100% recycled concrete aggregates that replaced natural coarse aggregates were investigated, and the results showed that with an increase in the recycled concrete aggregate content, the compressive and flexural strength of the concrete decreased. The maximum reduction observed was approximately 13% in the compressive strength and 10% in the flexural strength at 28 days after curing. Simsek et al. [21] concluded that when recycled concrete aggregates replaced natural coarse aggregates in concrete, the mechanical properties of concrete decreased by 21% with the incorporation of 100% recycled concrete aggregates. This behavior was attributed to the existence of a lot of transition zones and high porosity in the recycled aggregate. Sasanipour and Aslani [22] studied recycled aggregates with mixed-in self-compacting concrete. The results indicated that as the recycled aggregate content increased, the workability and mechanical properties of the concrete decreased. However, when 25% recycled aggregate was substituted, the electrical resistivity and chloride ion resistance of the self-compacting concrete showed no significant effect. Cartuxo et al. [23] used superplasticizers in fresh concrete to achieve the purpose of increasing the durability of concrete with the incorporation of recycled aggregates. The reason was that the superplasticizer optimized the distribution of the cement particles in water, increasing their contact area and facilitating a more complete cement hydration reaction.

In this study, the optimization and design of CDW-based concrete primarily involved reducing the water/cement ratio and using a superplasticizer, resulting in the enhanced performance of high-volume CDW-based concrete. Specifically, two replacement rates of 50% and 100% CDW were compared to replace the natural coarse aggregate in the concrete mixture, ultimately improving the concrete's performance through the optimized water–cement ratio design. Subsequently, the workability, density, and water absorption of the concrete specimens were evaluated. Furthermore, after curing periods of 14 days and 28 days, tests of the compressive strength, flexural strength, and electrical resistivity of the concrete were conducted. Moreover, the resistance to chloride penetration was analyzed by determining the non-steady-state migration coefficient of chlorides (D_{NSSM}). This experimental approach enabled us to assess the feasibility and performance of utilizing

CDW in concrete production while considering physical, mechanical, and durability aspects, which are crucial for sustainable construction practices.

2. Experimental Program

2.1. Materials

Ordinary Portland cement 42.5 with a density of 3140 kg/m^3 was used [24]. The superplasticizer (SP) was from China, and the density was 1040 kg/m^3 [25]. River sand and crushed stone were used, with size distributions of between 0 to 4 mm and between 4 to 10 mm, respectively. The detailed particle size distributions of the natural aggregates were examined through standard ASTM C136 [26] (see Table 1). According to standard ASTM C 128-11 [27] and ASTM C 127-11 [28], the density and water absorption of river sand and crushed stone were determined, and the results are shown in Table 1.

Table 1. Characterization of the aggregates used.

Aggregate	Size/mm	Passing Material (%) in Different Sieve Sizes (mm)										Saturated Surface Dry Density (kg/m^3)	Water Absorption (%)
		12	10	8	4	2	1	0.5	0.3	0.13	0.063		
River sand	0–4 mm	100	100.0	99.9	97.6	89.9	65.8	21.8	2.3	0.8	0.6	2642	1.23
Crushed stone	4–10 mm	100	96.4	64.5	4.5	2.6	2.0	1.7	1.3	0.9	0.6	2212	0.48
CDW	4–10 mm	100	99.7	75.9	4.7	0.6	0.4	0.3	0.2	0.2	0.2	2386	5.71

The CDW was collected from a demolished building comprised of a concrete structure that was more than 20 years old in Nanchang City, China. Then, the iron was separated, and the original CDW was cleaned. Furthermore, the CDW was crushed using a jaw crusher in the laboratory and screened to make the particle sizes of the recycled concrete aggregate the same as crushed stone (see Table 1). The density and water absorption of the CDW were determined to be 2386 kg/m^3 and 5.71%, respectively. According to the classification of the density of recycled coarse aggregates in the GB/T 25177-2010 standard [29], this type of recycled aggregate is at the class II level. Figure 1 shows one particle of CDW used. It is easily observed that the old mortar adhered to the old natural aggregates, and transition zones exist at their junction. There is also high porosity in the adhered mortar, which is responsible for the high water absorption of the recycled aggregates.

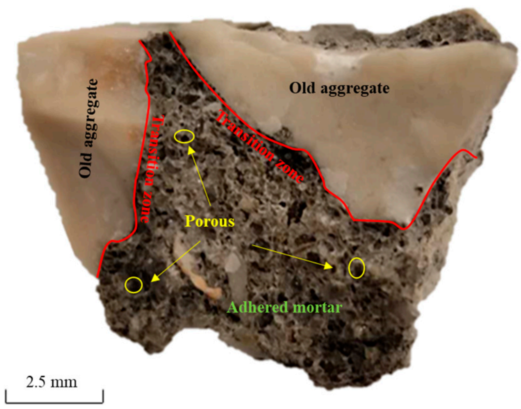

Figure 1. A particle of the recycled concrete aggregate used.

2.2. Mix Design and Curing Procedure

In this study, five concrete mixtures were prepared. Initially, a control concrete (C5) was designed with a compressive strength of 30 MPa, a cement content of 400 kg/m^3, and a water/cement ratio of 0.5. All aggregates used were in a dry state, and the water for saturating the aggregate was considered in the mixing process. Specifically, a vertical shaft mixer with a volume of 20 L was utilized for the mixing process, as depicted in Figure 2. The aggregates were added sequentially, starting from those with larger particle sizes and progressing to the smaller ones. Following a mixing period of one minute, "aggregate saturation water" was poured in and mixed for an additional 3 min. Subsequently, the mixture was allowed to stand for 10 min to ensure the thorough absorption and saturation of the aggregates. Next, cement was added, followed by stirring for 1 min, after which water (mixing water) was gradually introduced. Following the addition of water, stirring continued for 3 min to complete the production of fresh concrete. Then, the slump of the fresh control concrete was determined to be 10 cm.

Figure 2. Vertical shaft mixer at work.

Additionally, two concrete samples were prepared, replacing 50% and 100% of the crushed stone using the CDW, denoted as 50CDW5 and 100CDW5, respectively. This was based on the negative correlation between the water/cement ratio of concrete, its mechanical properties, and the purpose of optimizing the mechanical properties of concrete [30]. On the front concrete foundation, the water/cement ratio was reduced to 0.3, and the concrete slump was adjusted using a superplasticizer (1% by weight of the cement) to achieve a slump similar to the other concrete formulations. These modified mixtures were named 50CDW3 and 100CDW3. According to standard ASTM C 192 [31], all of the specimens were cured in water at a temperature of 20 ± 2 °C for 14 and 28 days. Table 2 provides the mixed proportions of all the concrete formulations.

Table 2. Concrete formulations (kg/m^3).

Material	C5	50CDW5	100CDW5	50CDW3	100CDW3
Cement	400	400	400	400	400
Mixing water	200	200	200	120	120
River sand	413	413	413	413	413
Crushed natural stone	1062	531	0	619	0
CDW	0	544	1089	635	1269
Aggregate saturation water	10.2	38.7	67.2	44.3	77.5
Superplasticizer	0	0	0	4	4

2.3. Testing Procedures

The slump of fresh concrete was realized in accordance with standard ASTM C 143-11 [32]. The slump test was conducted on a level surface in a vibration-free environment. Initially, the slump cone and bottom plate were cleaned and moistened. Subsequently, the concrete was poured into the mold in three equal layers, each filling approximately one-third of the cone height. After pouring each layer, the concrete was compacted vertically using an iron rod, stamping it 25 times. Finally, the cone was slowly raised, and the height of the concrete slump was measured using a ruler. This method ensured the accurate and consistent measurement of the concrete's workability.

The density and water absorption via the immersion of concrete were gauged following the ASTM C 642 [33] and LNEC E394 [34] standards using three cylindrical specimens with a diameter of 100 cm and a height of 15 cm. After curing for 28 days, the specimens were weighed under saturated surface dry conditions. The samples were suspended in water and weighed, registering the mass of the specimen's immersion in water. Furthermore, the specimens were dried in an oven at 105 ± 5 °C until they reached a constant weight.

After curing for 14 and 28 days, the compressive strengths of all the concrete samples were realized in accordance with ASTM C39-11 [35] using specimens with dimensions of $15 \times 15 \times 15$ cm^3. The autotest compressive strength testing machine with a working load range of 50–3000 kN was used, with a loading speed of 13.5 kN/s. Additionally, the flexural strength of concrete with dimensions of $4 \times 4 \times 16$ cm^3 was realized following standard EN 196-1 [36]. The test used a universal press (from An Ametex company (Shanghai, China)) with a maximum load of 50 kN and a loading rate of 50 N/s.

The electrical resistivity of the concrete was measured using the Wenner four-electrode method using specimens with a diameter of 10 cm and height of 20 cm, cured for 7 days, 14 days, and 28 days prior to testing (see Figure 3).

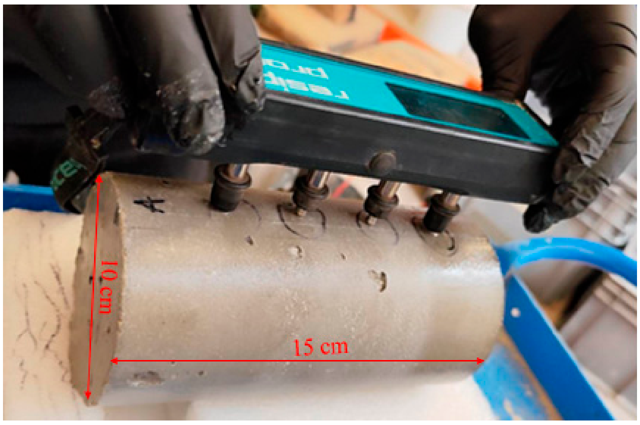

Figure 3. Electrical resistivity test.

This method constitutes a non-destructive testing approach. Factors such as the pore saturation, chloride diffusion potential, and the onset of the corrosion influence the electrical resistivity values. During the electrical resistivity testing, the concrete specimens were prepared under saturated surface dry conditions. The electrical resistivity apparatus was calibrated, positioned onto the concrete sample, and readings were obtained from a digital display in units of KΩ·cm. The augmentation of the electrical resistance contributed to the mitigation of the corrosion rate in the concrete structures. Table 3 shows the classification of concrete under the electrical resistivity value. Additionally, various parameters, including the water-binder ratio, aggregate type, cement and supplementary cementitious material composition and quantity, moisture content, soluble salt concentration, and temperature exertion, significantly impact the electrical resistivity of concrete [10,37].

Table 3. Classification of concrete.

Corrosion Risk	Electrical Resistivity (kΩ·cm)
Negligible	>20
Low	10–20
High	5–10
Very high	<5

The ingress of chloride ions into the microstructure of concrete is a well-recognized precursor to steel corrosion within reinforced concrete structures [37]. To evaluate the concrete's susceptibility to chloride penetration, the NT Build 492 standard [38] was employed. The specimen was a cylinder measuring 10 cm in diameter and 5 cm in height. To maintain uniformity in the surface treatment, a larger cylindrical specimen with a diameter of 10 cm and a height of 20 cm was initially used. The upper and lower surfaces of this larger specimen were then removed, resulting in three-cylinder specimens, each with a height of 5 cm, as illustrated in Figure 4.

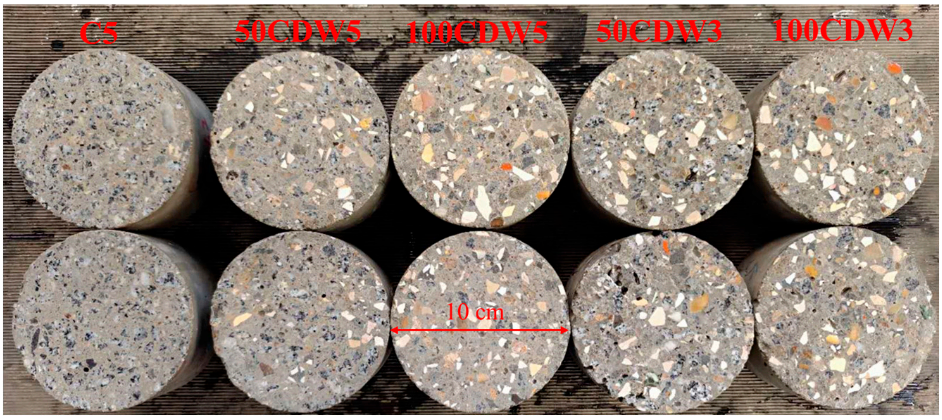

Figure 4. Specimen preparation for the chloride penetration test.

A chloride solution (10% NaCl), comprised of 100 g of NaCl in 900 g of water, and a sodium hydroxide solution (NaOH), comprised of 12 g of NaOH in 1 L water, were used as the catholyte and anolyte, respectively. This standardized test methodology aimed to expedite the assessment of the concrete's resistance to chloride ingress by quantifying the non-steady-state migration coefficient of chloride ions (D_{NSSM}) in accordance with Equation (1). The parameters for this experimental test are shown in Table 4.

$$D_{NSSM} = \frac{0.0239(273+T)\cdot L}{(U-2)\cdot t}\cdot x_d - 0.0238\cdot\sqrt{\frac{(273+T)\cdot L\cdot x_d}{U-2}} \quad (1)$$

where

D_{NSSM}: non-steady-state migration coefficient, $\times10^{-12}$ m^2/s;
U: absolute value of the applied voltage, V;
T: average value of the initial and final temperatures in the anolyte solution, °C;
L: thickness of the penetration depths, mm;
X_d: average value of the penetration depth, mm;
t: test duration, hour.

Table 4. Parameters used in this experiment and the chloride penetration depth.

Mixture	Diameter (mm)	Thickness (mm)		Voltage (V)	Temperature (°C)	Time (h)	Chloride Penetration Depth (mm)	
		Average	σ (%)				Average	σ (%)
C5	100	49.11	1.35	20	17.7	24	24.71	0.78
50CDW5	100	48.88	0.43	20	17.7	24	27.84	1.12
100CDW5	100	49.44	0.29	20	17.7	24	31.11	1.86
50CDW3	100	49.99	0.44	23	17.7	24	23.05	0.19
100CDW3	100	49.80	0.66	23	17.7	24	25.73	1.05

3. Results and Discussion

3.1. Slump of Fresh Concrete

Figure 5 shows the variation of the slump of concrete with the incorporation of CDW. It is easily seen that the slump values of the concrete with the incorporation of 0%, 50%, and 100% CDW water/cement ratios were 0.5 and 0.3, respectively. When the concrete mixture had a water/cement ratio of 0.5, the slump values of the concrete increased with an increased CDW content. The slump value of fresh concrete increased by 33% and 23%

as the CDW content increased from 0 to 50% and 50% to 100%. According to the ASTM C 192 standard [31], all aggregates with the surface saturated dry condition were used. So, the water for saturating the dry aggregates (aggregate saturation water) was calculated, considering the water absorption capacity and free surface moisture (see Table 2). However, the initial free water of fresh concrete increased when the aggregate saturation water was added. Furthermore, the higher initial free water was mainly responsible for the increase in the slump value of the concrete with CDW. Kou et al. [39] and Behera et al. [40] also observed the same phenomenon of workability in their works and noted that the dry aggregates absorbed the saturation water. Therefore, water was not available for the further reaction of cement hydration.

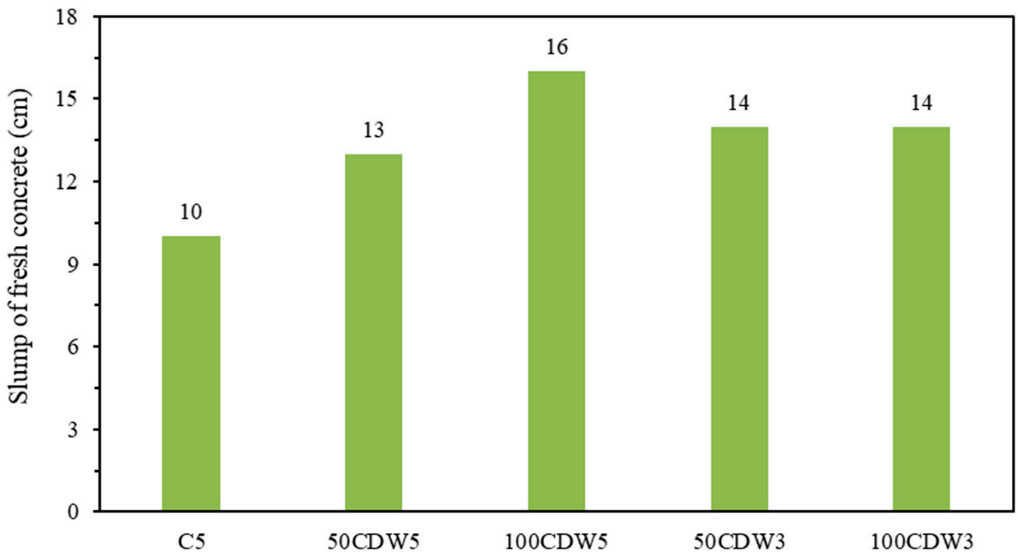

Figure 5. Slumps of fresh concrete.

When the water/cement ratio decreased to 0.3, the superplasticizer was used to justify the slump in the concrete. The 1% superplasticizer achieved a slump of concrete between 13 and 16 cm. At this time, comparing the concrete with a water/cement of 0.5, the slump of concrete with 50% and 100% CDW increased by 7.7% and decreased by 12.5%, respectively.

3.2. Density

Figure 6 presents the density of all the concrete. The density of the concrete had no significant difference since the density of the CDW and natural coarse aggregates used were similar. Based on Table 1, it can be seen that the density of CDW was 7.9% higher than that of the natural coarse aggregate. Therefore, the density of concrete with a water/cement ratio of 0.5 increased by 0.7% and 1.7% as the CDW content increased from 0 to 50% and 50% to 100%, respectively. When the water/cement ratio changed to 0.3, the density further increased since the coarse aggregate content increased (see Table 2). That is, the density of the concrete with 50% and 100% CDW increased by 6.0% and 6.7%, respectively. Additionally, it can be noted that the possibility of errors was greater when the CDW was incorporated into the concrete compared to the control concrete. This is due to the fact that the CDW still had insufficient homogeneity during the actual operation. Therefore, in future work, the mixing procedure of coarse aggregates such as CDW needs to be optimized.

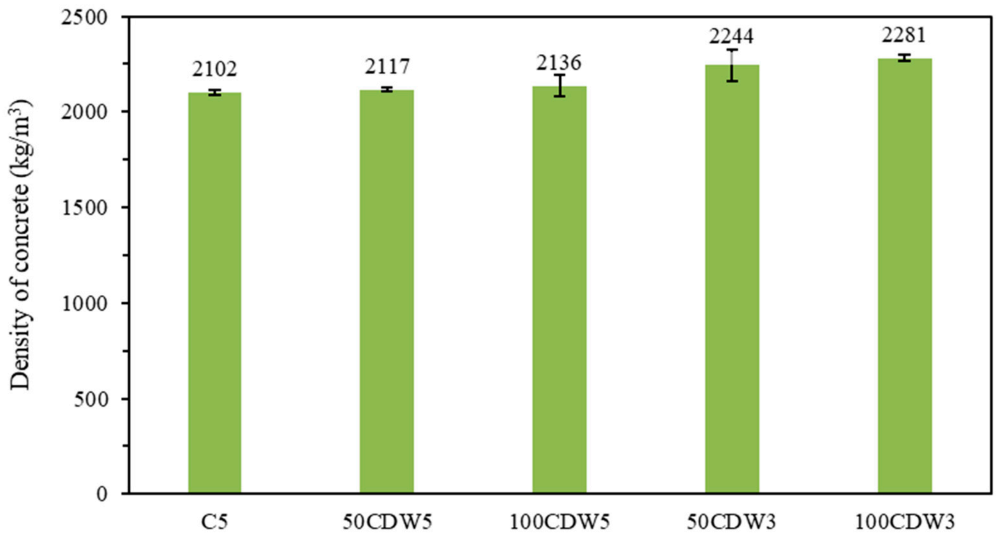

Figure 6. Density of concrete.

3.3. Water Absorption by Immersion

Figure 7 illustrates the water absorption by immersing the concretes. Consistently across varying water/cement ratios, the water absorption of the concrete increased with the incorporation of CDW. Specifically, when employing a water/cement ratio of 0.5, the water absorption by immersion increased by 33% with the introduction of 100% CDW into the concrete. Similarly, a 20% increase in water absorption by immersion was observed as the CDW content transitioned from 50% to 100% with a water/cement ratio of 0.3. This trend could be attributed to the inherently higher water absorption capacity of CDW aggregates.

Figure 7. Water absorption by immersing the concrete.

Notably, a decrease in the water/cement ratio to 0.3 resulted in a reduction in the water absorption by immersion. For instance, the water absorption by immersion decreased by 32% for the 50% CDW mixture and by 25% for the 100% CDW mixture. This phenomenon is explicable by the densification of the internal concrete structure as the water/cement ratio diminished and the aggregate content rose. This densification restricts the ingress of water into the concrete matrix, consequently reducing its water absorption capacity.

3.4. Compressive Strength

Compressive strength is an important mechanical property of concrete. There are numerous studies that have presented that with an increasing CDW content, the compressive strength of concrete decreases [16–20,41]. Figure 8 shows the compressive strength of concrete after curing periods of 14 and 28 days. It can be seen that the compressive strength of concrete decreased as the CDW content increased under the same water/cement ratio condition. This phenomenon finds justification in the presence of numerous transition zones and porosity within the CDW aggregates, which inherently compromise the mechanical integrity of the concrete matrix.

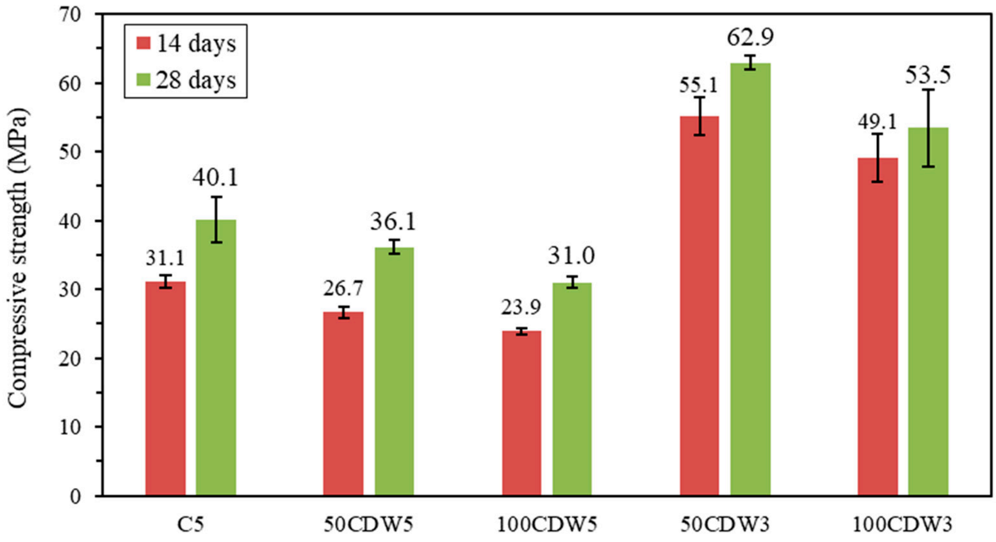

Figure 8. Compressive strength of concrete.

Furthermore, it is observed that the compressive strength of concrete increases with a prolonged curing time. This augmentation can be attributed to the progressive hydration of cement over time, leading to the attainment of optimal strength characteristics within the concrete matrix upon reaching the curing period of 28 days. Moreover, the strength gain rate of concrete was 29%, 35%, 30%, 14%, and 9% for the C5, 50CDW5, 100CDW5, 50CDW3, and 100CDW3 concrete samples during the curing period from 14 days to 28 days. Compared to the control concrete, the strength gain rate of the CDW-based concrete exceeded that of C5 when the concrete had a water/cement ratio of 0.5. Conversely, when the water/cement ratio was 0.3, the strength gain rate of the CDW-based concrete was lower than that of the control concrete. This indicates that within the standard 28-day curing period, concrete with a higher water/cement ratio exhibits slower strength development during the initial 14 days, whereas the opposite holds true for concrete with a lower water/cement ratio. This insight helps to elucidate the rate of strength gain and the ultimate strength potential of the concrete mixture.

When comparing the concrete specimens prepared with water/cement ratios of 0.5 and 0.3, those with a lower ratio exhibited higher compressive strength. Specifically, a remarkable increase in compressive strength was noted: 106% and 105% for mixtures containing 50% and 100% CDW, respectively, after 14 days of curing, and 74% and 73% for mixtures containing 100% CDW after 28 days of curing. That can be justified by a reduced amount of water, which decreases the pores within the cement slurry of concrete. Furthermore, this can enhance the compactness and impermeability of the concrete [42,43]. Additionally, the use of a superplasticizer optimizes the distribution of the cement particles in water, increasing their contact area and facilitating a more complete cement hydration reaction. This finding corroborates the observations made by Bekir Topcu and Sengel [44] and Zhao et al. [45].

3.5. Flexural Strength

Figure 9 presents the results of the flexural strength of concrete after curing for 14 and 28 days. The results reflect the same trend as the results of compressive strength; the flexural strength of concrete with a water/cement ratio of 0.3 was larger than the mixture with a water/cement ratio of 0.5. After curing for 28 days, there was an increase of 43.6% and 37.8% for the mixtures of 50% and 100% CDW, respectively. It can be seen from Figure 7 that concrete with a water/cement ratio of 0.3 was denser, therefore the mechanical behavior improved. Similarly, Korouzhdeh et al. [42] and Zivica [43] observed that a reduction in the water/cement ratio of concrete led to a decrease in the pores within the cement slurry. This results in the enhanced compactness of the cement slurry, consequently bolstering the strength of the concrete transition zone and further enhancing the mechanical properties of the concrete.

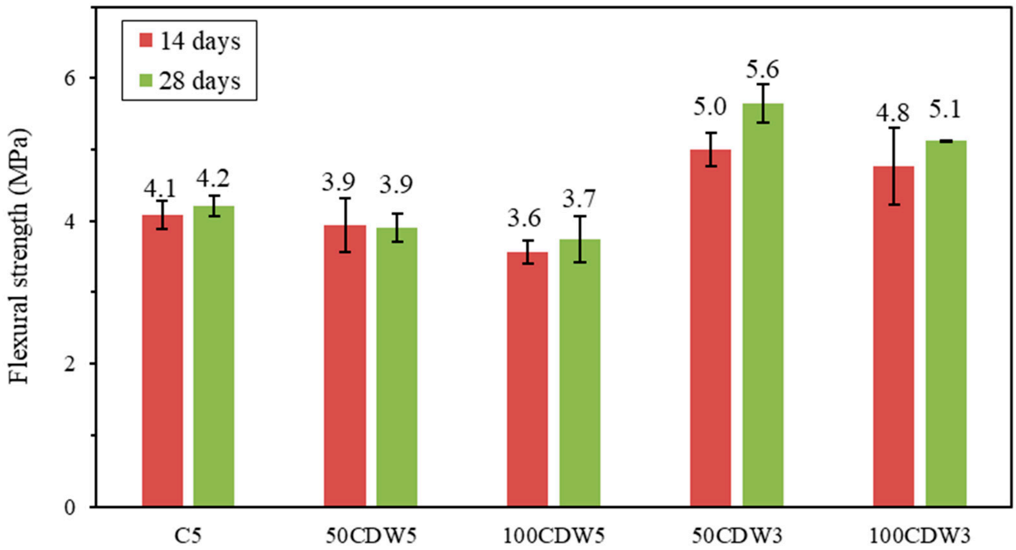

Figure 9. Flexural strength of concrete.

Additionally, with the same water/cement ratio, the flexural strength of concrete decreased with the incorporation of higher CDW content. For the water/cement ratio of 0.5, the flexural strength of the concrete was reduced by 7.1% and 5.1%, with a CDW content of 0 to 50% and 50% to 100%, respectively. For the water/cement ratio of 0.3, the flexural strength of the concrete was reduced by 8.9% as the CDW content increased from 50% to 100%. This can also be explained by the transition zones and pores in the CDW aggregates, which result in the degradation of the mechanical properties.

3.6. Electrical Resistivity

From Figure 10, it is evident that the electrical resistivity of concrete decreases with increasing CDW content with an identical curing time and water/cement ratios. For instance, the concrete containing 100% CDW exhibited a reduction in the electrical resistivity by 9.6% and 13.7% with water/cement ratios of 0.5 and 0.3, respectively. This trend can be attributed to the presence of numerous cracks and pores inherent in the CDW aggregates, as illustrated in Figure 1. Consistent with these findings, Gagan and Singh [10] observed a similar trend, wherein increasing proportions of recycled aggregates led to decreased electrical resistivity values relative to the control concrete.

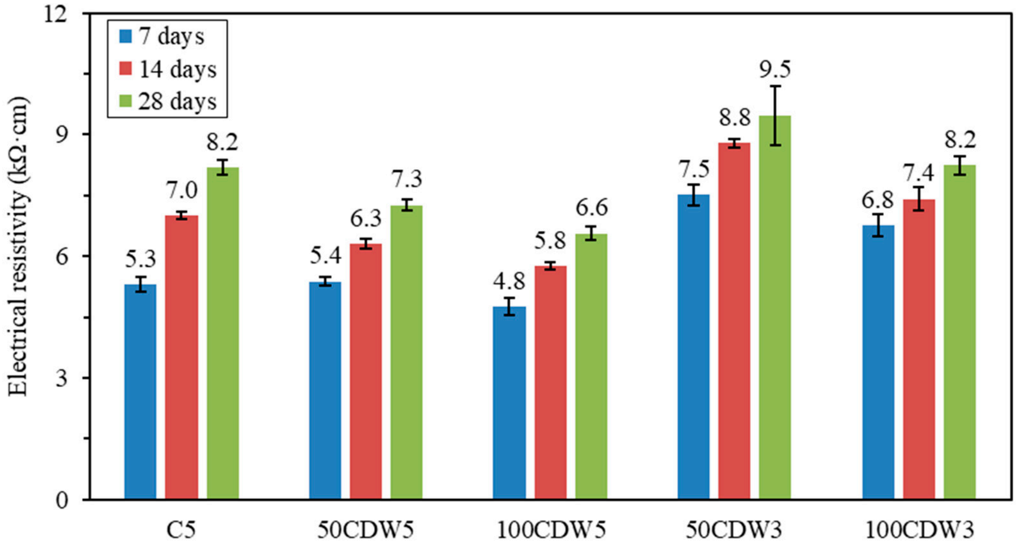

Figure 10. Electrical resistivity of concrete.

Moreover, the electrical resistivity value of the concrete prepared with a water/cement ratio of 0.3 surpassed that of mixtures with a ratio of 0.5. For instance, there was a notable increase of 30% and 24% in the electrical resistivity value for concrete containing 50% and 100% CDW, respectively, after curing for 28 days. This observation is corroborated by Figure 7, which illustrates that concrete with a water/cement ratio of 0.5 tends to exhibit higher porosity.

Furthermore, according to Table 3, after 28 days of curing, concrete containing 50% CDW and prepared with a water/cement ratio of 0.3 achieved a level indicative of a low corrosion risk. In contrast, other mixtures were classified as having a high corrosion risk. These findings underscore the critical role of CDW content and curing conditions in influencing both the electrical resistivity and corrosion resistance of concrete, thus providing valuable insights for the development of durable and sustainable infrastructure.

3.7. Chloride Penetration Test

The results of the non-steady-state migration coefficient (D_{NSSM}) of concrete are shown in Figure 11. A increase in the D_{NSSM} means that the resistance to chloride ion penetration by the concrete is reduced. When the water/cement ratio of concrete was 0.5, the D_{NSSM} increased by 13.3% and 29% as the CDW content increased from 0 to 50% and to 100%, respectively. The D_{NSSM} of the 100CDW3 mixture was 12.1% higher than 50CDW3. It can be explained by the significant amount of porosity in the CDW, causing the high porosity of concrete. That can be proven by the results in Figure 7.

Additionally, comparing the mixtures with a water/cement ratio of 0.5, the D_{NSSM} of concrete with a water/cement ratio of 0.3 was lower. The D_{NSSM} of the 50CDW3 and 100CDW3 mixtures was 27.8% and 28.8% lower than the 50CDW5 and 100CDW5 mixtures, respectively. This occurred because the water/cement ratio decreased and the aggregate content increased during the concrete design process, resulting in a more dense cement slurry of the concrete (see Table 2 and Figure 6). The pores of the cement slurry were reduced, which largely hindered the chloride ion migration into the deep aggregate. The above results show that when the concrete water/cement ratio reduces, CDW-based concrete has improved resistance to chloride penetration, which can reduce the entry of chloride into the concrete matrix, thereby minimizing the risk of corrosion-induced damage. At this time, CDW-based concrete is more conducive to use in environments close to the ocean or environments with high chloride ion concentrations.

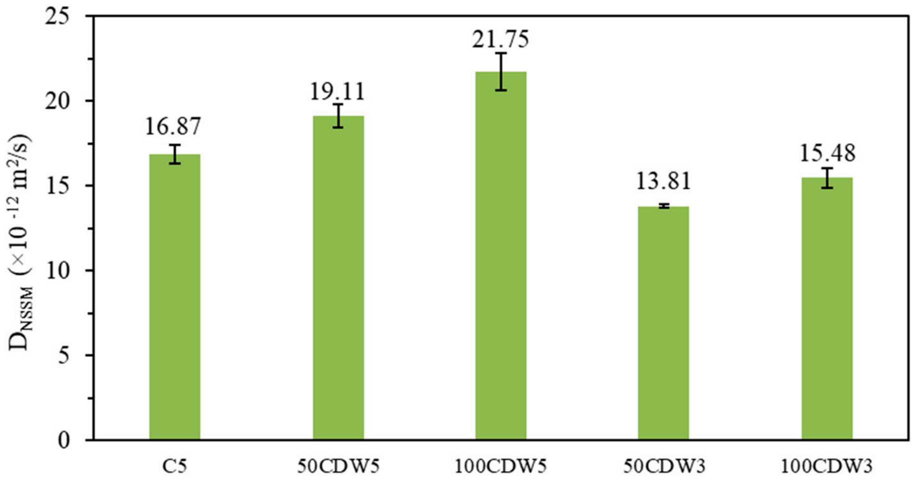

Figure 11. Non-steady-state migration coefficient of concrete.

4. Conclusions

4.1. Conclusions in This Work

The application of CDW in the construction sector faces multiple challenges, including contamination, inconsistency in performance, strength reduction, durability concerns, structural compatibility, regulatory compliance, transportation and logistics, quality control, market acceptance, and education and awareness. Despite the potential sustainability benefits of CDW utilization, overcoming these challenges is necessary to realize its effective use and propel the construction industry towards greater sustainability. In this study, the impacts of incorporating demolition concrete waste on the physical, mechanical, and durability properties of concrete were systematically investigated. Through the controlled manipulation of the water/cement ratio and the utilization of superplasticizers, this work aimed to optimize the mechanical properties and durability of concrete while incorporating varying proportions of CDW aggregates. The key findings and conclusions drawn from this investigation are summarized below:

The added aggregate saturation water led to a higher initial free water content. Furthermore, the workability of fresh concrete with the incorporation of CDW increased as the CDW content increased. Since the density of CDW is larger than the natural coarse aggregates, the density of the concrete increased with the CDW content with the same water/cement ratio. Additionally, water absorption by immersion was observed, with increasing CDW content generally leading to increased water absorption by immersion. This is because CDW aggregates have a large number of pores. When the water/cement ratio decreased, the water absorption of the concrete was reduced. Therefore, the physical properties of the CDW itself are the main factors affecting the performance of concrete. In the future, the physical properties of concrete could be optimized through the pre-treatment and performance improvement of CDW.

The addition of CDW significantly impacts the mechanical properties of concrete. The compressive and flexural strength tests conducted on days 14 and 28 of curing revealed a decrease in strength with increasing CDW content at the same water/cement ratio. This trend highlights the influence of CDW porosity and the presence of old transition zones, which increase the overall porosity and transition zones within the concrete. Addressing CDW porosity through pre-treatment or technical means emerges as a potential solution to enhance the quality of CDW applications. Moreover, this study optimized the mechanical properties of CDW-based concrete by reducing the water/cement ratio from 0.5 to 0.3. This reduction in water consumption resulted in decreased pores within the concrete and ultimately improved its strength. By comparing the strength gain rates of CDW-based concrete with different water/cement ratios during the curing period of 14 days to 28 days, it can be found that a lower water/cement ratio can enable the concrete to obtain stronger early strength. This is because there is relatively little moisture in the concrete, so after the concrete solidifies, the water evaporates relatively quickly, which is beneficial for improving the early strength of the concrete.

The durability of concrete, as assessed through the electricity resistance and resistance to chloride penetration, was adversely impacted by the incorporation of CDW. Higher CDW content correlated with decreased electricity resistance and resistance to chloride penetration, indicating heightened susceptibility to corrosion over time. Nevertheless, concrete with 50% CDW exhibited good electricity resistance and resistance to chloride penetration when the water-to-cement ratio was reduced, underscoring the importance of optimizing mixture proportions to enhance durability.

Overall, the findings of this study underscore the complex interplay between the CDW content, water/cement ratio, and the physical, mechanical, and durability properties of concrete. By carefully controlling these factors, it is possible to mitigate the adverse effects of CDW incorporation and optimize the performance of recycled aggregate concrete. The experimental assessments of concrete with varying CDW content demonstrated that a water/cement ratio of 0.3 yields CDW-based concrete capable of meeting structural component standards. These insights are invaluable for informing sustainable practices in construction and waste management, paving the way for the development of a more resilient and eco-friendly infrastructure system.

4.2. Future Work

Future research endeavors could explore innovative approaches for pre-treating or modifying CDW for applications in building materials. Additionally, investigations into the long-term performance and environmental impact of CDW-based concrete, considering CDW's inherent porosity, are warranted. Moreover, efforts to develop comprehensive waste management strategies and technologies aligning with circular economy principles to mitigate construction-related environmental impacts are essential.

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