CARBONATION BEHAVIOUR OF CONCRETE CONSIDERING THE CONSTITUENTS OF COARSE AGGREGATE

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Abstract - This study investigates the carbonation behavior of recycled aggregate concrete (RAC) considering the constituents of coarse aggregate (CA). Coarse natural aggregate (CNA) was replaced with coarse recycled aggregate (CRA) at 0%, 20%, 40%, 60%, 80%, and 100%. The CA constituents such as Rc, Ru, Ra, Rb, and Rg were determined according to NF EN 933–11 by manual sorting before casting. Accelerated carbonation tests were performed to evaluate carbonation depth and rate. Results indicate that the variability in CA composition significantly influences RAC carbonation behavior, with strong correlations (R^2 > 0.9) observed between Rc and Rb contents and the carbonation performance of RAC.

Keywords - Recycled aggregate concrete; convolutional neural networks; carbonation depth; carbonation rate

1. Introduction

The significant emissions in the construction industry associated with construction and demolition waste (CDW) have become a primary environmental concern in recent years. In the European Union, the rate is 36% for waste in the construction industry, accounting for the most significant discharge rate of all economic activities and households [1]. CDW recycling is an issue in sustainable construction development and the main subject for converting to a green and circular economy. The recycling of CDW as aggregate in concrete has been comprehensively researched in recent years. Concerning mechanical properties, concrete consists of 100% CRA and exhibits a lower-quality performance than natural aggregate concrete (NAC) [2]. However, studies on durability have found that the percentage of substitution replacement is 30% to achieve equivalent results [3]. It should be emphasized that the performance of RAC depends on the parent concrete strength and replacement ratio of CRA.

According to Tabsh *et al.* [4], the RAC's mechanical qualities were between 10% and 25% worse than those of the NAC. To examine the mechanical properties of RAC, Etxeberria *et al.* [5] used four replacement ratios of CRA in RAC mixtures: 0%, 25%, 50%, and 100%. According to their findings, when the replacement ratio of CRA was 100%, the compressive strength of RAC was 20–25% lower than that of the NAC. According to Xiao *et al.* [6], there was a correlation between the rise in RA replacement level and the decrease in RAC's compressive strength and elastic modulus. Casuccio *et al.* [7] investigated crushing different concrete strengths using CRA-derived crushing. Comparing the RAC to the NAC, the RAC's compressive strength and elastic modulus were roughly 1–15% and 13–18% lower, respectively.

Numerous studies revealed that the carbonation depths of RAC are 1.3–3.2 times more significant than those of NAC when it comes to the durability qualities of RAC [8] - [10]. The characteristics of CRA, which raise permeability and water absorption (WA) in RAC, are connected to this discrepancy. RAC (around 30%) has been shown to function comparably when utilized in place of NAC [11]. The process is affected by many factors, including the kind of aggregate, the degree of concrete saturation, the W/C, cement content, the addition of minerals, curing time, and porosity [12]. Because RAC has a more complicated composition than NAC, carbonation behavior in RAC is tightly connected with many interfacial transition zones (ITZ) properties between old and new mortar. With a 100% replacement ratio, Silva *et al.* [13] revealed that the carbonation coefficient was two times higher than that of NAC.

The impact of CRA on mechanical and durability characteristics has been nearly wholly established through criteria like replacement ratio, CRA composition, and the use of supplemental cementitious materials (SCMs). This study offers a complementary perspective on the traits of RAC that were impacted by CRA's composition. In detail, considering the composition of CA, the suggested experimental program was used to evaluate the carbonation behavior of RAC.

2. Materials and methods

2.1. Materials

In the study, a recycling platform in France provided CRA with fractions 5-20 mm. The CNA with ingredients is diorite, blended in 5-10 mm and 10-20 mm with a mass ratio of 9:1, respectively, and is aimed at the same particle size as CRA and CNA. Fine aggregate with a fineness modulus of 2.8 and a specific gravity of 2670 kg/m^3, cement type CEM II/B 42.5 R with a specific gravity of 3150 kg/m^3 were used in the experiment. Before the experiment, manual sorting determined the constituents of CRA as input parameters; the results are depicted in Table 1. It was observed that the main composition of CRA is Rc and Ru (96% subclass is limestone), which depends on the replacement ratio. The physical properties of the materials used are given in Table 2, where it is mentioned that Rc and Rb have the highest WA in CRA.

Table 1. *Constituent of CA following the NF EN 933–11*

Description	CA mass proportion (% wt.) of every mix design					
	Reference	20CRA	40CRA	60CRA	80CRA	100CRA
Rc	0	13.8	28.1	40.2	54	65.5
Ru	100	84.1	67.74	53.7	37.88	24.4
Ra	0	0.1	0.12	0.24	0.35	0.4
Rb	0	1.8	4.0	5.8	7.7	9.6
Rg + X	0	0.2	0.04	0.06	0.07	0.1

Where: Rc: concrete, concrete products.

Ru: unbound aggregate, natural stone, hydraulically bound aggregate

Ra: bituminous materials

Rb: clay masonry units, calcium silicate masonry units, aerated non-floating concrete

Rg: glass + X: metals, non-floating wood, plastic, gypsum plaster

Table 2. *Physical properties of coarse aggregate*

Physical tests	CNA	CRA	Rc	Rb	Ru
Apparent particle density (kg/m^3)	2650	2354	2360	2350	2367
Water absorption (%)	0.5	7.95	10.5	8.2	1.2

2.2. Mix design

In addition to the Reference mix, mixes including CRA were created to replace 20%, 40%, 60%, 80%, and 100% of the total amount of CNA. Before casting samples, CA was prepared to a saturated state [14]. Concrete has a w/c ratio of 0.6 and a target strength of C25/30. All mixes maintain the 19 ± 1 mm slump range for improved analyses after one hour. The investigation employed a superplasticizer (SP) to regulate the mix proportion slump. Table 3 displays all of the mixed proportions.

Table 3. *Mix proportions of concrete (kg/m3)*

No.	Water	FNA	Cement	CA		SP
				CNA	CRA	
Reference	219	926	290	947	0	1.86
20CRA	219	926	290	758	170	1.87
40CRA	219	926	290	556	329	1.91
60CRA	219	926	290	371	494	1.94
80CRA	219	926	290	189	673	2.01
100CRA	219	926	290	0	842	2.05

2.3. Tests

Manual sorting tested the CA composition 3 times (1kg per test) in this experimental procedure. The physical properties of the CRA were tested based on NP EN 1097-6. Initially, the slump was performed based on EN 12350-2 (2002), and the density test was performed according to EN 12350-6 (2002). Hydrostatic weighing was used to assess the water porosity of the concrete samples according to NFP 18-459 standards. Regarding the carbonation test, this study used an accelerated carbonation test, which evaluates the possible carbonation resistance of concrete and follows the procedure of the Perfdub National Project [15]. Following a preconditioning phase (2 weeks in the oven at 45 ^{0}C and one week in the CO_2 chamber with controlled relative humidity at 65±5 %, (20±3) °C), the test is conducted with a higher concentration of carbon dioxide (3-4%) under under-regulated exposure circumstances.

3. Results and discussion

3.1. Compressive strength and water porosity

The compressive strength and water porosity results for each sample in the different types of concrete are displayed in Figure 1. Compressive strength decreases with an increasing replacement ratio due to higher Rc and Rb concentration in the aggregate matrix. Comparing RAC specimens to NAC samples, the compressive strength data shows a steady decline from 18% to 45%, depending on the amount of Rc and Rb. Furthermore, the findings show that the mean of the Rc and Rb content rises as the replacement ratio rises (depicted in Table 1), increasing water porosity. More precisely, RAC has a higher water porosity than NAC by 1.7%, 4.3%, %, 5.8%, 7.5%, and 9.8%, respectively, for replacement ratios of 20%, 40%, 60%, 80%, and 100%. It was explained by reduced density and increased water absorption (Table 2), which reduced RAC's porosity and density [16]. The replacement ratio is the main factor influencing these RAC features [17]. The study explains the constituents of CA that impact the qualities of RAC more precisely. However, the influence of this parameter still needs to be 100% exact because there are changes in the composition of CA in different replacements. The strong R^2 values in Figure 2 demonstrate all samples' significant association between the Rb, Rc and water porosity. In the standard of maximum percentage of replacement, CRA used in this study is type B, which has a maximum replacement ratio of 20% by mass, meaning between 20% and 40% of replacement ratio in volume. Still, in this study, when the substitution ratio is 20% by volume, compressive strength decreased by 18%. It can be explained that although the mass ratio of Rc and Ru is above 95%, the Rb content strongly affects the properties of RAC.

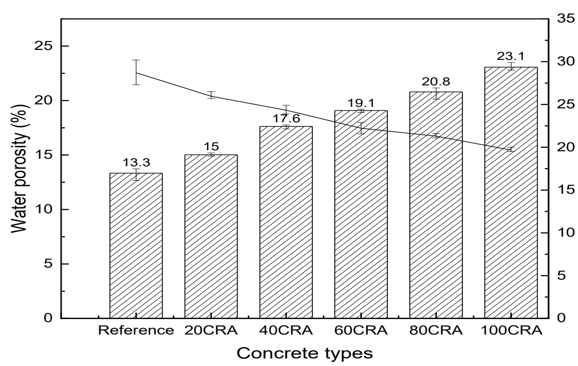

Figure 1. *Compressive strength and water porosity of all samples*

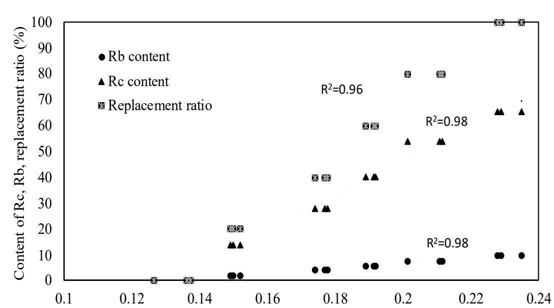

Figure 2. *Relationship between water porosity and constituents of CA (Rc and Rb)*

3.2. Accelerated carbonation

Figure 3 shows the mean carbonation depths (Xc) values of all samples at 28, 42, and 70 days, according to the pH indicator after the carbonation process. Because of high WA and CRA porosity, which is much higher than NAC's for a given w/c ratio and reduces RAC's carbonation resistance, the carbonation depths of all mix proportions rise as the substitution level increases and becomes higher over time [13]. At all ages, the carbonation depths at reference and the 20CRA mix proportion do not differ much; nevertheless, with increasing substitution ratio, discrepancies become noticeable. This can be explained by the concrete becoming more porous and CO_2 gas entering the sample more readily when the Rc and Rb content in CRA with high WA account for a significant share.

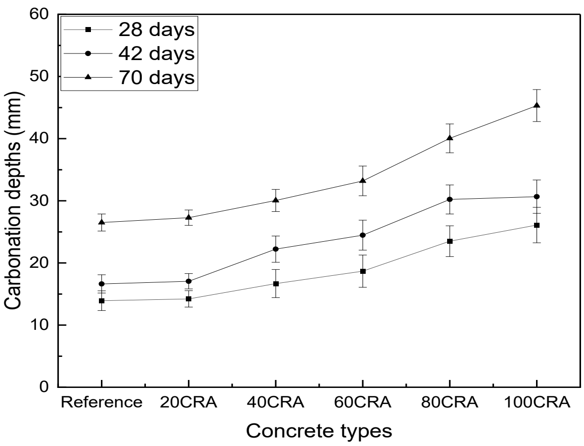

Figure 3. *Carbonation depths of all samples*

The square root of exposure duration is expressed as mean carbonation depths in Figure 4. According to the figure, the carbonation rate (K_{acc}) for reference, 20CRA, 40CRA, 60CRA, 80CRA, 100CRA mix proportion is expected to be 4.20, 4.33, 4.36, 4.72, 5.37, 6.39 (mm/day$^{1/2}$), respectively. It is evident that the constituents of CA, like Rc and Rb, impact the carbonation coefficient. Because of their high porosity, the larger the Rb and Rc content, the more the carbonation coefficient rises [18]. Figure 5, which indicates that the high correlation for all mixes used in this investigation was more significant than 80% and shows an overall excellent performance, certainly supports the tendency.

Extensive research has been conducted on how replacing CNA in concrete with CRA affects its carbonation behavior. The replacement ratio and the kind of recycled material used are the main factors that determine the carbonation resistance of concrete, among many other factors. As long as the cement content and the W_{eff}/C stay constant, researchers concur that small replacement ratios by mass up to 30% (mean as 30% Rc, 70% Ru) have no appreciable effect on carbonation behavior [13], [19], [20]. While in the standard, CRA in this study is type B, and maximum replacement is 20%. Conversely, the results of the study show how vital the Rb content is to the composition of CRA, as evidenced by the exact between 3% increase in carbonation rate at the 20% replacement level by volume (mean as 13.8% Rc, 84.1% Ru by mass) and 5% increase in carbonation rate at the 40% replacement level by volume (mean as 28.1% Rc, 67.74% Ru by mass) compared to the original sample. Thus, it can be seen that the Rb content of CRA can influence the maximum 20 % substitution level by mass in the standard for RAC. Additionally, with the development of AI, it is necessary to study the characteristics of CRA further and review how CRA components affect the maximum replacement rate of CRA compared to current standards.

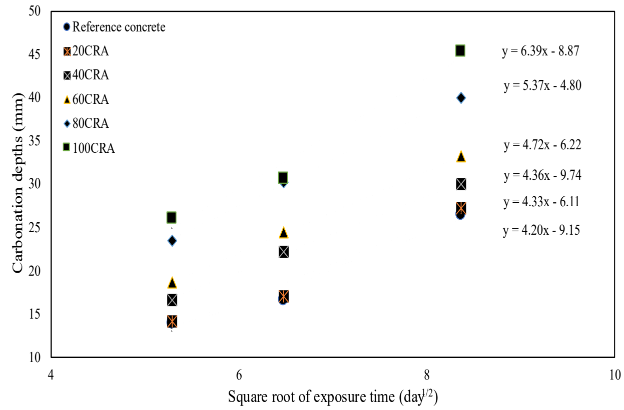

Figure 4. *Carbonation depths as a formulation of exposure time's square root*

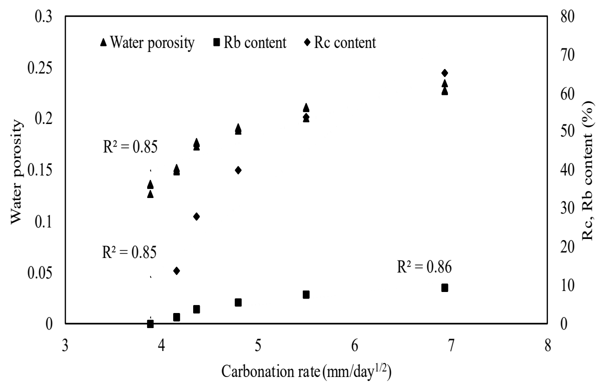

Figure 5. *Relationship between carbonation rate and water porosity, constituent of CRA*

4. Conclusions and recommendations

This work initially uses manual sorting to ascertain the constituents of CA and examines the constituents as input parameters influenced by RAC's water porosity and carbonation behavior. The conclusions are summed up in the following list:

- The mass of Rc and Rb grew as the substitution ratio increased, leading to an increase in water porosity and resulting in a decrease in RAC's carbonation resistance. RAC findings' modified porosity and carbonation behavior can be attributed to the increased water absorption of Rc and Rb.

- While it's an exciting concept, more research is required to examine different W/C and replacement ratios to understand how CA's constituent affects RAC's performance entirely.

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