An overview on the experimental methods for the evaluation of properties and durability performance of RCA-containing concrete

J P L Ngenge¹, and P Akpınar¹

¹Civil Engineering Department, Near East University, Nicosia, Via Mersin 10, Turkey
²Email: johnlukongo@gmail.com

Abstract. The usage of recycled concrete aggregates (RCA) originates from buildings’ demolishing and increased demand in construction. Demolishing could be due to completion of building’s service life or its pre-mature failure as well as due to other reasons such as wars or earthquakes. In such cases, wastes of demolished buildings pose a threat to nature. RCA usage avoids the environmental degradation resulting from excessive extraction of raw materials to produce natural aggregates (NA) and storage of waste materials from devastated structures. Since RCA originates from construction waste, it becomes important to ensure the quality of new structure to be erected using RCA. From this perspective, the examination of general properties and long-term durability of RCA is vital. Hence, an understanding on the critical parameters to be inspected and experimental procedures are essential. This paper aims to provide a compact overview on the crucial parameters defining the quality, properties and the durability of RCA-containing concrete for the civil engineers and researchers aiming to work in this field. The adopted approach for this study implies a systematic literature review that copes with collecting essential information on this topic from existing respected studies from all around the world and the standard codes covering practices for related issues. The found results asserts that, performing tests on each type of waste materials irrespective of theirs sources is vital. For structural usage, the replacement of RCA with respect to the NA shall not be more than 30%. Finally, the usage of finer RCA shall be minimum for the better performance of RCA-concrete containing.

1. Introduction

Recycled concrete aggregates (RCA) are types of aggregates produced from devastated concrete structures. The existing concrete to be utilized may be the construction waste coming from demolished buildings, bridges, roads as a result of war, earthquake, explosion or demolition requested by the owner of the structure [1]. In order to obtain desirable size and shapes, several steps have to be done during crushing [2].

Motivation behind the usage of RCA originates mainly from increased demand in building construction and natural hazards that occurs. The increased demand in buildings is due to the worldwide growth in population [2, 3, 4]. This population growth as described by Ngenge and Nouban [5] was 7.6 billion in 2017 and expected to be 8.6, 9.8 and 11.2 billion in 2030, 2050 and 2100 respectively. It is a known fact that the construction of reinforced concrete buildings and other concrete facilities require huge materials’ consumption; among them, aggregates occupy around 70%
of concrete’s total volume [6]. In this regard, a huge amount of aggregates is needed for construction purpose. This scenario seems to experience some issues due to shortage in the supply of NA with respect to the demand. Another scenario is the negative impact to the environment when the NA are taken from quarry and also when the demolished materials such as concretes are filled in low level areas [2, 4]. Considering all these issues, another alternative needs to be found in order to meet the demand required and protects the environment. Thus, the considered alternative is recycled concrete aggregates [4, 7]. Usage of these aggregates is important; in one hand it permits to decrease the negative impact caused to environment as a result of extraction of rocks from quarries and to the other hand, since the waste disposal is considerably minimized, different portions of land are protected for the benefit of forthcoming development such as agriculture. However, the extent of the use of RCA in concrete manufacture can only be widely accepted if the concrete to produce exhibits satisfactory performance. Hence, experimental verification of the properties and the durability of RCA-containing concrete is critical. Additionally, some fields of concrete research in civil engineering are known to make use of alternative programming tools successfully for the verification of properties of concretes [8, 9]. Since recycled concrete aggregates may come from very different sources possessing properties varying significantly, adopting real laboratory experimental procedures to verify the performance in each case of RCA use is essential. This paper aims to provide an overview on the experimental procedures used for evaluation of RCA-containing concretes in a compact way in order to facilitate the practices of engineers as well as the studies of researchers willing to work in this field.

2. Methodology
The existing literature on the experimental studies covering different aspects of concretes made with recycled concrete aggregates have been surveyed thoroughly for the preparation of this paper. The information gathered have been organized and presented in three main sections of this work. Section 3 focuses on the quality and the performance of recycled concrete aggregates prior to their inclusion to concrete mixtures. Section 4 includes the critical information gathered for the evaluation of properties of RCA-containing concrete mixtures with experimental procedures. Finally, section 4 presents the critical information for understanding the long-term durability performance of RCA-containing concretes by using experimental methods. Relevant subsections are provided under each section in order to present the essential information in a more systematic and clear way. The methodology considered in this paper is systematic literature review. With this method, authors are able to review different types of journals and codes that specify the best ways to evaluate properties and the durability performance of RCA. Therefore, the below topics clearly discuss the methods permitting the best assessment of RCA-containing concrete.

3. Understanding the quality and the properties of RCA prior to its use in new concrete
In order to understand the quality as well as properties of RCA prior its use in new concrete, knowledge on RCA physical and mechanical properties is required. In light of this, different codes give numerous types of tests to perform in order to understand the quality and properties of aggregates in general. Tests to be carried out depend up on what is intended to be achieved. This section presents critical information on important tests such as absorption, specific gravity, bulk density, voids ratio, abrasion, toughness, size, shape and texture.

3.1. Absorption of RCA
As the name indicates, absorption test measures water quantity that may be absorbed by aggregate in its pores thereby determines pores volume in the said aggregate particles (ASTM C127). This test is of importance since it enables concrete designers to know the behaviour of RCA when coming into contact with water; absorption affects the strength of RCA-containing concrete [10]. Taffese [11] found that RCA has higher absorption rate than NA; that is 4.2 times higher. The reason is the existence of dry mortar that sticks to old coarse aggregates. Water that enters in aggregates pores allows the evolution of microstructures; thus, affects fresh as well as hardened states of concrete [11].
That’s why Amario et al. [6] specified that it is better to decrease the absorption rate of RCA by removing old mortar adhered into aggregates and clean properly aggregates before usage. To perform absorption test, specifications are given in standards such as AASHTO T 96, ASTM C127, etc. Thomas et al. [10] inform that according to Indian standard IS 383, the permissible limit for absorption rate of aggregates to be utilised shall be less than 10%. RCA shall be pre-wetted before mixing process [12]. Safa et al. [13] give the maximum limit for RCA as per ASTM C127 to be 2%.

3.2. Specific gravity (SG)
SG is the ratio between aggregate density and distilled water density. It is important because it permits to calculate the volume that aggregate occupies in a concrete mix. Lower SG may mean more porosity level in aggregate and reveals less strength and durability of aggregates. Several studies that have been investigated [12-17] show that the SG of RCA is lower than that of NA, the reason is due to more porosity inside RCA. Taffese [11] and Vinod et al. [16] said that most of NA has a SG ranging from 2.0 to 3.0 and the average is around 2.68. The specific gravity shall be done in accordance with standards such as ASTM C127.

3.3. Unit weight (UW) and void ratio
Unit weight is also known as bulk density, is just a measure of mass over unit volume; it is used to determine the value of bulk density in order to permit a good selection for concrete mixtures’ proportions (ASTM C29/C29M). These two tests are used to determine the physical property of RCA. As said in specific gravity, the UW of RCA is lesser than that of NA. NBR NM 52, ASTM C29/C29M and other similar standards, give specifications for test procedures of bulk density as well as void ratio. Taffe [11] says that when bulk density is high, voids are less. He also said that the typical range for unit weight of aggregates varies from 1280 kg/m3 to 1920 kg/m3.

3.4. Size, shape and texture
These are important since they lead concrete performance. Aggregate gradation is checked through sieve analysis so as to obtain a good particle size distribution, thereby increase the workability and obtain low segregation of concrete. It is known that RCA has rough surface; this situation is responsible in generating more voids among particles; to deal with it, more cement paste is needed during concrete mix [11]. Flakiness and elongation tests are also important to be determined because aggregates having these shapes are undesirable in construction due to their weakness. The following standards give their specifications BN EN 932-6 as well as ASTM C136.

3.5. Abrasion and toughness
This test is of importance since it measures the strength of aggregates. Abrasion test is done in Los Angeles machine and measures the toughness of materials; it checks aggregates wear. RCA is known to have more abrasion loss than NA [11-14, 16, 17]. Steps to conduct this test are given in ASTM C131/C131M. BS EN 12620 gives 30% as permissible value when using on the top of a road surface and 45% for general concrete works. ASTM C131/C131M specifies 50% for general concrete work.

4. Evaluation of the properties of concrete made with RCA inclusion
The properties’ assessment of RCA-containing concrete is done taking into consideration its fresh as well as hardened properties.

4.1. Fresh properties of RCA-containing concrete
The main property to be checked in concrete during its fresh state is workability; this workability is then checked through consistency as a result of slump test [12]. Workability is the ease with which a concrete may be mixed, transported and casted. Thomas et al. [10] found that the increase in RCA leads to decrease in workability; they also found that the workability is affected due to the internal friction created by old mortar that is also part of RCA. The workability of concrete may be affected
due to the ability of RCA to consume more water, so super plasticizer is the answer to this problem as well as pre-wetting the RCA before mix process [18]. Slump test is specified in many standards such as ASTM C143/C143M, AASHTO T119/T119M, IS 1199:1959, EN 12350-2. The ideal value for slump may be 150 to 175mm measured vertically and for self-compacting concrete it is measured horizontally; 65cm is already a good value in this case.

4.2. Hardened properties of concrete containing RCA

One of the most important tests to check the hardened or mechanical property of concrete is compressive strength (CS). Many studies show that the CS of concrete containing RCA is lower than that made with NA [10, 17]. However, this issue depends up on the source of RCA [17]. It was seen that RCA consumes more water and has less SG; these factors affect the CS of concrete [17]. Pepe [18] discovered that, when the replacement percentage of RCA with respect to NA goes behind 30%, CS of concrete goes on decreasing; thereby, it is not suitable for structural works. The reason is the excessive presence of interface zones as a consequence of old mortar. These zones are widely known to be weak and when the percentage of RCA increases in a mix design, number of interface zones increases. In addition to those factors affecting the CS namely, cement type, w/c ratio, properties of aggregates, admixtures as well as curing, aggregate replacement ratio is also considered. Consequently, when all given parameters are not respected properly, the CS of concrete will be affected [18]. Furthermore, the CS may vary between 30 MPa to 60 MPa depending up on the source of RCA. Specifications of this test are given in ASTM C39/C39M. Apart from CS, which is widely known as the key parameter to check the mechanical property of concrete, there are other parameters such as elastic modulus, flexural strength and split tensile tests. Pepe [18] found that “the elastic modulus is inversely proportional to the increase in RCA content, decrease in water-cement ratio and increase in curing. Also, flexural strength and split tensile strength of concrete was found to be good up to 50% replacement of RCA. Behind this percentage, the strength decreases considerably. The interface zone is the main point that affects the split tensile strength of concrete containing RCA. Another parameter is the dry shrinkage that affects considerably the concrete beyond 50% replacement”.

5. Evaluation of the long term durability performance of concrete made with RCA inclusion

The durability performance of concrete containing RCA is so important because all the future of the structure lies on it. There exist many tests to check the durability performance of concrete containing RCA; they are sorptivity, chloride penetration, test related to carbonation problem; water absorption by capillary and immersion, freezing and thawing (F-T), drying shrinkage and test related to creep. Among them, the first 3 tests are explained below.

5.1. Sorptivity

The test is performed with respect to ASTM C1585. The procedure involves taking a concrete cylinder of 200 mm height and 100 mm diameter. The sample shall be divided into 4 parts having 50 mm height. The two middle samples are then taken in a place having nearly 80% humidity and 50°C for 3 days when there is not oven. When there is an oven, samples should be kept inside it and in separate containers for 3 days making sure that they do not touch the bottom of the container; the temperature should be 50°C at 80% humidity. At the end of 3 days, keep those samples which are inside containers for 15 days at room temperature. After this step, seal the side parts (Circumference) of all the samples with water resistant medium such as epoxy or paraffin wax then cover the top of sample with a sheet of plastic in a such a way it may be a bit loose (Not so much tight). Now place supports inside the container and pour water in such a way that it passes the support by 3 mm above. Place the sample in the container keeping the bottom touching the supports for different time (in minutes) intervals say 0, 1, 4, 10, up to 6h for primary check, the secondary absorption is checked up to 7 days. For each time, the weight of the specimen is recorded in a time not more than 15 seconds between the removal and
the reinsertion of the sample back in the container. The sample should be well wiped after each removal from the container.

Formula to calculate sorptivity is as follow:

$$Sw = \frac{Wca - Wdr}{Ac.\delta.t^{0.5}}$$  \hspace{1cm} (1)

Where $S_w$ is the water sorptivity, $Wdr$ is the dry weight of specimen, $Wca$ is the weight of specimen after capillary, $Ac$ is the area of the bottom part after capillary, $\delta$ is the water density and $t$ is the time in minutes. The below Figure 1 shows the sorptivity test setup.

Alexandridou et al. [19] specified in their paper that the sorptivity of concrete containing RCA is affected by the replacement percentage of RCA. 25 and 50% does not affect more but behind these levels, let us say 60% and above, the value increases considerably.

5.2. Carbonation
One of the major causes for the rebar’s deterioration in a concrete medium is carbonation. This issue affects seriously the durability since it attacks the main material that protects the concrete against tension [20]. Therefore, studying about this parameter is of importance. Carbonation is produced when carbon dioxide (CO2) percolates into concrete pores and dissolves in water so as to form carbonic acid; this issue is so bad for concrete because it decreases the pH of concrete and thereby permits attack to rebars; that’s why the produced concrete should resist this problem so as to expect a good durability performance [21]. Silva et al. [22] found that the increase in the RCA content, led to high carbonation depth. Finer recycled aggregate is known to have more porosity, so it is the main constituent that contributes to the increase in carbonation depth. The suggestion is to decrease as far as possible the finer RCA content. Another suggestion is to increase the cement content, reduce w/c ratio and add water reducing agent in order to obtain a concrete with desirable target strength. Bravo et al. [23] found that the carbonation depth depends up on the type of RCA used and varies from 22% to 182%. According to them, carbonation of concrete made using RCA gave very bad results. Additionally, carbonation test is performed by spraying phenolphthalein indicator on a concrete sample having a depth around 50 mm and 100 mm diameter. The part of concrete that will exhibit pink colour indicates no carbonation.

5.3. Chloride penetration
The test to determine the rapid penetration of chloride ions is specified in ASTM C1202, AASHTO T277 and other standards. This test involves the preparation of saturated sample cylinders of 100 mm diameter and 50 mm height. The testing set up or apparatus includes testing moulds, multimeters and AC power unit. Then solutions are poured in two moulds (Reservoir). The positive cable gets connected to 0.3N concentration of sodium hydroxide (NaOH) solution and the negative one to a
solution of 3% sodium chloride (NaCl). Then a 60V power is supplied. The first reading is taken then intermediate readings will be taken each 30 minutes for a total period of 6 hours. The result is taken from the given output known as charge (Q in Coulomb). However, even if this test got approved, it is still not accurate since it tests the movement of ions and this situation affects the final result. The below figure 2 shows the test setup for chloride as per ASTM 1202.

![Test setup for chloride as per ASTM 1202](image)

Bravo et al. [23] found that finer RCA in concrete increases the chance for chloride attack. When curing is well done, the chloride ions decrease with the increase in curing. The below table gives the relation between charge passed and chloride Ion penetrability.

| Sl. No. | Chloride Ion penetrability | Charge passed, Q (Coulomb) |
|--------|---------------------------|---------------------------|
| 1      | High                      | > 4000                    |
| 2      | Moderate                  | 2000 – 4000               |
| 3      | Low                       | 1000 – 2000               |
| 4      | Very low                  | 100 – 1000                |
| 5      | Negligible                | < 100                     |

6. Conclusive Remarks

This study focused on the experimental methods for the evaluation of properties and the durability performance of RCA-containing concrete. The aim was to present the essential information on the evaluation of properties and durability performance of RCA-containing concrete in a compact manner for engineers and researchers aiming to work on this topic. It has been shown that the first step was to do a nice selection of the source of waste materials. As it is not easy to detect the type of concrete to be recycled without performing tests, this study proposed many test that have to be done in order to produce a good concrete containing RCA. It was found that concrete made using RCA is weaker that that made with NA especially when the replacement percentage is more than 30%. Results obtained
from the literature survey carried out indicate that it is advisable to reduce considerably the amount of old mortar contained in each grain of aggregate since the major problem in RCA is the old mortar. RCA results in high water consumption, so water reducing agent such as super plasticizer need to be added in the mix. In order to produce a concrete with high target strength, more cement is needed, so, cement replacement materials are needed in order to compensate to this requirement. Finally, the long-term durability performance for concrete made using RCA will be considerably affected if finer recycled aggregates are used in a huge quantity. So, when this type of concrete needs to be produced, care should be taken to minimize the use of old mortar in order to expect good results. The details of experimental procedures regarding the performance of RCA-containing concrete have been presented systematically for the use of engineers and researchers.

References
[1] Ahmed AM, Roua SZ, Tuqa W 2020 Case Studies in Construction Materials 12 1-12.
[2] Huang Q, Lin L, Loon T, Singh B 2017 Proc. 1st International Conference on Structural Engineering Research (iCSER 2017) 20-22 Nov 2017, Sydney, Australia 49-55.
[3] Ammar BN, Jasem M 2019 Advances in Materials Science and Engineering 1-7.
[4] Mohammed SI, Khalid BN 2019 Structures 23 34–43.
[5] Ngenge JPL, Nouban F 2020 International Journal of Advanced Engineering, Sciences and Applications (IJAESA) 1(2) 18-25.
[6] Amario M, Santana CR, Pepe M, Dias RTF 2017 Cement and Concrete Composites 84 83-92.
[7] Akpinar P, Al Attar HME 2020 5th International Conference on New Advances in Civil Engineering (ICNACE 2019), IOP Conf. Series: Materials Science and Engineering 800 (2020).
[8] Akpinar P, Khashman A 2017 Procedia Computer Science 120 712-718.
[9] Khashman A., Akpinar P. 2017 Procedia Computer Science 108 2358-2362.
[10] Thomas J, Nazeer NT, Wilson PM 2018 Journal of Building Engineering 19 349–365.
[11] Taffese WZ 2018 Advances in Civil Engineering 1-11.
[12] Ashraf MW, Hossam Z, Magda E, Samir HO 2012 Housing and Building National Research Center (HBRC) Journal 9 193-200.
[13] Safa G.I.E., Fauzan MJ, Ratnasamy M and Salihudin H 2018 Journal of Civil, Construction and Environmental Engineering 3(5) 133-146.
[14] Malešev M, Radonjanin V, Marinković S 2010 Sustainability 2 1204-1225.
[15] Monica BL, JGualberto LJ, Filho F, Paulo RLL 2013 Materials and Structures 46 1765–1778.
[16] Vinod PN, Dushyanth V, Babu R, Shaik N 2018 International Journal of Pure and Applied Mathematics 118(18) 3239-3263.
[17] Yehia S, Kareem H, Abusharkh A, Zaher A, Istaitiyeh H 2015 International Journal of Concrete Structures and Materials 9(2) 219-239.
[18] Pepe M 2014 thesis submitted at universitá degli studi di salerno 1-110.
[19] Christiana A, George NA, Frank AC 2017 Journal of Cleaner Productio 176 745-757.
[20] Sanjuan MA, Andrade C, Cheyrezy M 2013 Advances in cement research 15(4) 171-170.
[21] Akpinar P 2016 Advanced Concrete Technology Lecture Notes, Near East University, North Cyprus.
[22] Silva RV, Neves R, de Brito J, Dhir RK 2015 Cement & Concrete Composites 62 22–32.
[23] Bravo M, Brito J, Pontes J, Evangelista L 2015 Construction and Building Materials 77 357–369.