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(RESEARCH ARTICLE)

Mechanical behavior of concrete containing recycled aggregates

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Abstract

Increased demand and decreased supply of aggregates for concrete production necessitate the search for new aggregate sources. Environmental features are increasingly being used to evaluate construction materials. Concrete recycling is becoming more popular since it conserves natural resources and reduces the need for disposal by using readily available concrete as a source of aggregate for fresh concrete. Several studies on the influence of recycled aggregate on the engineering qualities of concrete have been conducted. This investigation was carried out using the use of recycled aggregate as a form of modification. When it comes to the use of recycled aggregate, the percentage of recycled aggregate should be decided. This is because a large proportion of recycled aggregate would not allow for the achievement of the desired level of strength in the concrete. The purpose of the research is to evaluate the similarities and differences between natural aggregate and recycled coarse aggregate with regard to specific gravity, apparent specific gravity, absorption, and Los Angeles. In addition, the comparison of recycled aggregate with 0% replacement, 35% replacement, 50% replacement, and 65% replacement will be the emphasis of this study.

Keywords: Compressive Strength; Recycled Aggregate; Flexural Strength; Mechanical Strength

1. Introduction

Concrete is the material that is utilized in civil engineering the most often and serves as the basis for the majority of infrastructures. It would seem that the only material for building that will be accessible in the not-too-distant future is concrete. Although its strength is the most important quality, concrete also has to be able to withstand wear and tear, be easy to work with, and have a long service life [1].

The manufacture of concrete requires an ever-increasing quantity of aggregates, but the available supply has been decreasing. This has made it necessary to look for new sources of aggregate. Environmental characteristics are being used in an ever-increasing manner in the evaluation of building materials [2, 3]. Recycling concrete is gaining popularity since it helps to preserve natural resources and decreases the amount of waste that has to be disposed of. This is accomplished by using concrete that is easily accessible as a source of aggregate for freshly mixed concrete. The idea of sustainable building development, which is developed via research and development, involves the conservative use of natural resources and the recycling of as much construction waste as possible [4, 5]. [Research and development] The use of recycled aggregate in the production of concrete is one example of such a possible outlet.

The practice of removing sand from riverbeds has been deemed unlawful by the authorities in a number of different places. As a consequence of this, the quality of the sand and the material that is delivered must conform to certain specifications. Dams are constructed on almost every river in the modern world. As a direct consequence of this, these resources are fast running out [6–8]. There is a severe lack of high-quality sand. If excellent sand has to be delivered over a significant distance, then the costs associated with transportation will be higher. On occasion, the sand from a river has been discovered to include mica, coal, fossils, and many other organic pollutants. When the concentration of

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these pollutants in the sand reaches a certain threshold, the sand loses its suitability for use in the manufacturing of concrete [9]– [11]. The durability of the concrete suffers when there are items in the sand, such as bones and shells, which are not removed. The presence of silt and clay in river sand reduces the strength of the concrete, allows moisture to be retained, and prolongs the amount of time it takes for the cement to cure.

As a direct consequence of this, there is an urgent need to locate a replacement to sand. Recycled concrete aggregate is one example of a potential solution. It is common for people to get the word "recycled concrete aggregate" (RCA), which stands for recycled concrete, confused with the term "rock quarry screens." The use of RCA, which is classified as a fine aggregate, is permissible in the production of concrete [8, 12]. RCA, on the other hand, refers, in the context of this research, to the process of crushing destroyed concrete in order to produce a new product, sand, which may then be used in structural concrete applications such as the construction of bridges and pavements.

2. Material and methods

Experiments are being conducted to investigate the behaviour of RCA concrete, with a particular focus on how old the RCA is and how many times it has been recycled. The next sections describe the specifics of the materials utilised as well as the findings of the experimental research conducted with reference to this topic.

(a) (b) **(c)**

Figure 1 Used RCA for the study (a) RC 1 (b) RC 2 (c) N2 RC1

The RCA for this experiment came from a combination of smashed concrete cubes and beams from a structural engineering lab and a collapsed concrete wall that had been used for drainage but was three years old (aged about zero to one year old). Source (a) is a non-load-bearing type with a design characteristic strength of 20 MPa, and Source (b) is a mixture of concrete with different design characteristic strengths (from 25 MPa to 30 MPa), and all of them were loaded (direct compression or combined shear-bending) to failure. The risks associated with exposure from both sources are far under safe limits. Depending on the age and location of the parent concrete, the collected RCA samples are divided into two categories. In all, 24 permutations are considered during the course of the research. The components and their proportions used to make the finished product will be discussed in the following paragraphs. The binder is Portland slag cement that meets the standards of the Indian Standard (IS) 455-1989. It should be mentioned that OPC has been widely employed in the past to make RCA concrete. However, there are just a few of publications (Myung-Kue, 2005; Sagoe et al. 2001; Hansen, 1990) reporting the outcomes of RCA concrete fabricated from PSC. PSC accounts for 95% of the world's cement production (Indian Cement Review, 2015; Saunders, 2015). Therefore, this research was driven by a need to verify the performance of RCA manufactured from PSC, which might be more advantageous for the current building design.

The cement used is Portland slag cement that complies with the requirements of Indian Standard (IS) 455-1989. It's important to note that OPC was formerly frequently used to produce RCA concrete. Results of RCA concrete made from PSC are hardly reported, however (Myung-Kue, 2005; Sagoe et al., 2001; Hansen, 1990). PSC is responsible for 95% of global cement production (Indian Cement Review, 2015; Saunders, 2015). The necessity for this study was prompted by the potential benefits of PSC-made RCA to the present building design. All of the sand used in construction abides with the standards set out in IS: 383-1970, and it is sourced from a nearby river. According to the available data, two distinct kinds of destroyed parent concrete are distinguishable by a defining compressive strength of 20MPa. A small jaw crusher is used to break up the original concrete. In order to meet the specifications of the Indian Standard (IS) 456-

2000, the maximum size of the coarse aggregate produced by the jaw crusher was kept at 20 millimetres. Due to the age difference between the two parent concrete samples, we have classified them as RC-1 (less than 1 year) and RC-2 (more than 1 year) (3 years). To analyse the impact of many recycling cycles, we demolished and crushed concrete made from RC-1 aggregate. Excavated material from Route RC-1. Concrete with the designation of N2-RC-1 suggests that the aggregate has been recycled not once but twice. The RC-1 and N2-RC-1 recycles had a lifespan of less than three months at that point. The first presentation method has previously been gone through in great depth. After the first recycling and before the second recycling, these aggregates (RC-1) were used in the laboratory specimens that encountered failure load (N2-RC-1).

For the compressive strength tests, several concrete mixtures with variable w/c ratios were prepared in accordance with the standards outlined in the international standard IS: 10262-1982. As the water/cement ratio varies, the cement concentration varies from 620 kg/m^3 to 286 kg/m^3, however the water concentration stays constant at 186 kg/m3 throughout the board. The cement content, water-to-cement ratio, and water content of the samples used in the air permeability, shrinkage, and capillary action tests were maintained at 372 kg/m^3, 0.5, and 186 kg/m^3 correspondingly. The different combination proportions that were taken into consideration are shown in Tables 1-4.

Table 1 Mix Proportion for batch RC-1

Mixture	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**	**Mix 8**
Cement (kg/m^3)	620	531	465	413	372	338	310	286
Sand (kg/m^3)	429	469	500	531	560	587	614	639
RCA (kg/m^3)	1007	1072	1120	1132	1140	1155	1171	1185
w/c	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
Water (kg/m^3)	186	186	186	186	186	186	186	186

Table 2 Mix Proportion of batch RC-2

Mixture	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**	**Mix 8**
Cement (kg/m^3)	620	531	465	413	372	338	310	286
Sand (kg/m^3)	428	469	500	531	560	587	614	639
RCA (kg/m^3)	964	999	1020	1033	1039	1041	1039	1035
w/c	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
Water (kg/m^3)	186	186	186	186	186	186	186	186

Table 3 Mix Proportion for batch N2 RC 1

Mixture	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**	**Mix 8**
Cement (kg/m^3)	620	531	465	413	372	338	310	286
Sand (kg/m^3)	429	469	500	531	560	587	614	639
RCA (kg/m^3)	1016	1052	1075	1087	1094	1096	1112	1120
w/c	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
Water (kg/m^3)	186	186	186	186	186	186	186	186

According to an earlier version of the Indian standard IS: 10262 (1982), Natural Aggregate Concrete has a prescribed relationship between the w/c ratio and compressive strength (NAC). In a similar fashion, this article investigates the relationship between the w/c ratio and compressive strength in RCA concrete. Here, Table 3 presents a variety of RCA concrete mixture proportions for use with a broad range of water-to-cement (w/c) ratios while maintaining a constant amount of water.

Table 4 Mix Proportion for the different Lab Tests

Mixture	Cement (kg/m^3)	NCA (kg/m^3)	RCA (kg/m^3)	FA (kg/m^3)	w/c	Water (kg/m^3)
RC-1	338	-	1142	587	0.55	186
RC-2	338	-	1041	587	0.55	186
N2-RC-1	338	-	1096	587	0.55	186
NCA	338	1253	-	587	0.55	186

An industrial rotary concrete mixer is used to mix all of the concrete here in the lab. In accordance with IS:516-1999 and IS:1199-1959, cube moulds of 150 mm on all sides, prism moulds of 75 mm on all sides, cylinder moulds of 150 mm in diameter and 300 mm in length, and prism moulds of 100 mm on all sides and 500 mm in length, width, and depth are used to conduct tests of compressive strength, drying shrinkage, tensile splitting strength, and flexural strength, respectively. A particular concrete casting mould is called for in International Standard 1199-1959 for the purpose of determining the amount of air in the concrete. After 24 hours, the moulds are broken down and the castings spend the next 28 days curing in a water tank set at 27 degrees Celsius.

3. Results and discussion

3.1. Material Properties

Tables 5–8 provide a synopsis of the characteristics of cement, sand, and RCA. These characteristics are in accordance with IS: 2386 (Part III)-1963. We can see that RC-1 is superior than RC-2 based on its water absorption, specific gravity, crushing strength and impact characteristics. As can be seen in Fig. 1, the RC-2 has a greater quantity of mortar covering its outside than the RC-1 does. The parent coarse aggregate's low specific gravity is another possible explanation. In the case of N2-RC-1, which has weaker physical qualities than RC-1, the same behaviour is seen. The PSD of all RCA utilised in this analysis is shown in Fig.2.

Table 5 Properties of different RCA

Type of Aggregate	Age/ No. of recycling	Specific Gravity	Bulk Density (kg/ l)	Loose Bulk Density (kg/ l)	Water Absorption (%)	Impact Value (%)	Crushing Value (%)	Fineness Modulus
RC-1	0-1 Yr	2.48	1.409	1.24	4.469	26.910	26.514	3.38
RC-2	3 Yr	2.26	1.312	1.19	5.360	28.194	26.817	2.45
N2-RC-1	2	2.38	1.174	1.03	5.403	31.703	28.449	3.12
NCA	0	2.83	1.97	1.73	1.1	23.84	23.16	2.84

Table 6 Properties of FA and Cement

Type of material	Specific Gravity	Water Absorption (%)
Portland Slag Cement (Konark)	3.015	-
Sand	2.658	0.0651

Table 7 Chemical properties of Cement

Chemical Components	**Percentage (%)**
SiO_2	12
CaO	43
MgO	6.7
Fe_2O_3	12
Al_2O_3	26

Table 8 Physical properties of PSC

Properties	**Values**
Specific Gravity	3.015
Fineness by Sieve Analysis	2%
Normal Consistency	32%

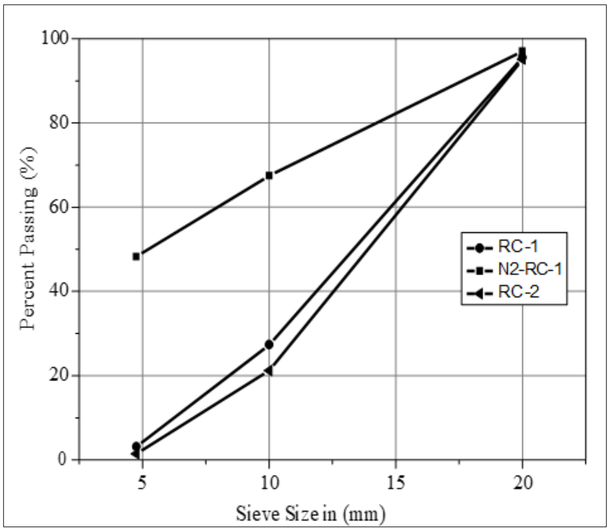

Figure 1 Particle Size Distribution

3.2. Effect of Aging of the used RCA on the Compressive Strength

After 28 days, all of the samples are compressed in a machine to determine their compressive strengths. The resulting compressive strength values for all samples are shown in Fig. 2 as a function of their w/c ratios. The compressive strength of RCA concrete is shown to correlate positively with its w/c ratio, as shown by the corresponding trend lines. The suggested relationship for NCA concrete according to IS: 10262-1982 is compared to this one. This chart illustrates the responses of RCA concrete to the aforementioned.

3.3. Effect of Recycling Stages of RCA on Compressive Strength of Concrete

The variation in compressive strength of N2-RC-1 concrete is shown as a function of w/c ratio in Figure 3. The compressive strength of N2-RC-1 concrete is lower than that of RC-1 concrete, and this difference is roughly constant across all w/c ratios. If compared to RC-1, N2-RC-1 is around 2% weaker. Table 4.1 suggests that the lower specific gravity of N2-RC-1 compared to RC-1 is the probable reason of strength decrease. It seems obvious that recycling would be to blame for the decrease in specific gravity. For w/c ratios over 0.42, the compressive strength of N2-RC-1 concrete is greater than that of NCA concrete, confirming previous results. This w/c ratio may be thought of as the bare minimum water needed to obtain the required strength from N2-RC-1 concrete.

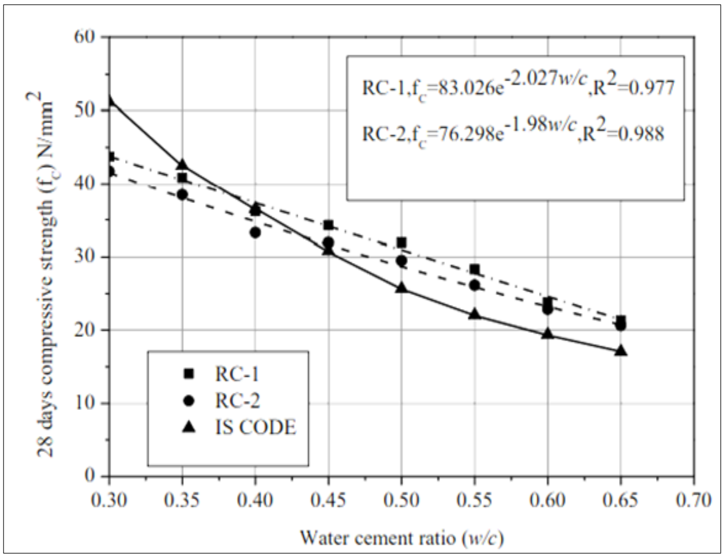

Figure 2 Compressive strength and w/c ratio correlation ship

3.4. Capillary Water Absorption

The amount of water absorbed per unit area in a capillary network is shown as a function of the square root of the time in hours below. A comparison of the capillary water absorption curves of RC-1, RC-2, and NCA concrete is shown in Fig.5. A comparison of the capillary water absorption of RC-2 and NCA concrete reveals a significant disparity, with the former absorbing over 76% more water. RC-2's mortar is more firmly connected to its surface than RC-1's because of the reduced specific gravity (see Table 3.1) that arises from this operation. It's possible that older RC-2 samples are more porous and can absorb more water than younger RC-1 ones. RC-1 concrete is of worse quality than NCA concrete because it absorbs around 11% more water due to the recycling function.

In Fig. 6, we see the water-absorption curves produced by capillary action for N2-RC-1, RC-1, and NCA concrete. The N2-RC-1 is capable of capillary absorption of water at a rate around 9 times higher than the RC-1 or NCA. This unanticipated change in water-absorbing behavior shows that using recycled aggregates several times might produce much lower-quality concrete.

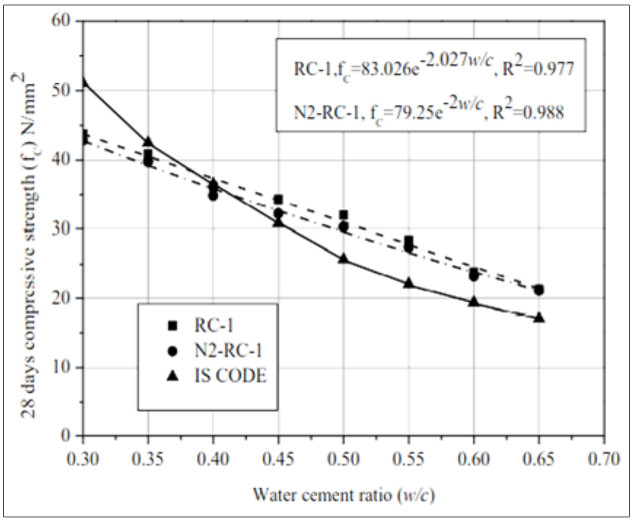

Figure 3 Compressive strength and w/c ratio correlation ship of N2 RC1 concrete

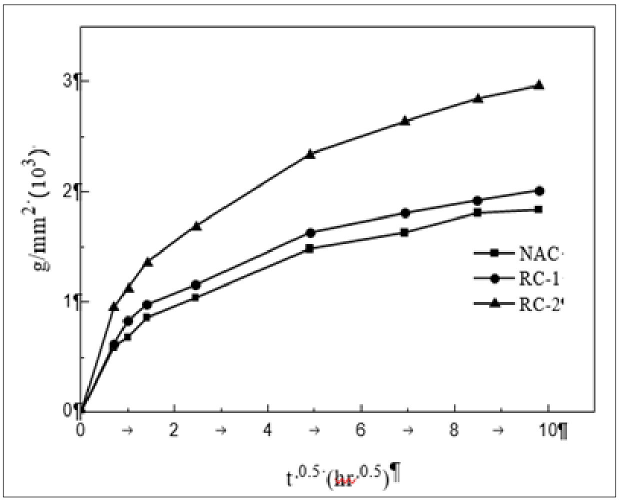

Figure 4 Water absorption value for NCA, RC1 and RC2

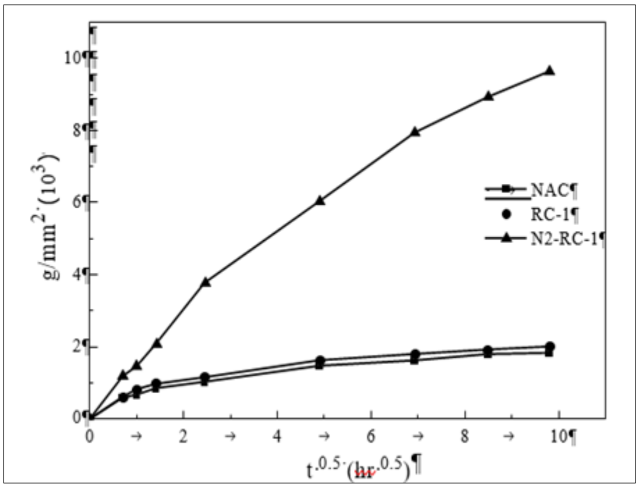

Figure 5 Water absorption value for NCA, RC1 and N2 RC1

3.5. Drying Shrinkage Test

Reduction in volume of a hardened concrete mixture caused by capillary water loss is known as drying shrinkage. Due to the increase in tensile stress brought on by the concrete's shrinkage, cracking, internal warping, and outward deflection may occur even before the material is loaded. All of the RCA concrete samples and the NCA concrete sample were evaluated for drying shrinkage according to the method described in Chapter 2, and the results are shown in Table 9. We find that the drying shrinkage strain of RC-1 and RC-2 is around 1.9 and 2.6 times that of NCA concrete, respectively. The higher concentrations of ancient mortar bonded to the surface of RC-2 are a possible explanation for this. Consecutive recycling raises the drying shrinkage strain, as seen by N2-RC-1's shrinkage strain being almost 1.2 times that of RC-1.

Table 9 Values of Drying Shrinkage Test

Type of Concrete	Drying Length (mm)	Drying Shrinkage (%)
RC-1	0.261	0.17
RC-2	0.341	0.23
N2-RC-1	0.312	0.21
NAC	0.135	0.09

Table 10 Values of Air Content Test

Type of Concrete	Air Content (%)
RC-1	12
RC-2	13
N2-RC-1	13
NAC	12

3.6. Air Content

To prevent the concrete from cracking in the face of repeated freezing and thawing, air must be entrained into the mixture. As covered in Chapter 2, the pressure technique is commonly used to detect air content in normal density new concrete. The percentage of air present in each of the chosen concrete samples is shown in Table 10. In its fresh state, RC-2 concrete has a little greater air content than RC-1 concrete. There may be more old mortar stuck to the surface of the RC-2 aggregates, leading to a higher air content in the concrete. N2-RC-1 concrete likewise exhibits higher air content than RC-1 for the same reasons.

3.7. Flexural Strength and Split Tensile Test

Table 11 lists the splitting and flexural tensile strength of 7-day and 28-day RC-1, RC-2, and N2-RC-1. Seven and 28 day RC-2 concrete splitting tensile strengths are determined to be around 28% and 14% lower than RC-1 concrete, respectively. At 7 and 28 days, RC-2 concrete has a flexural strength that is about 6% and 21% lower, respectively, than RC-1 concrete.

The recycled content of N2-RC-1 concrete results in a material with lower strength than that of conventional RC-1 concrete. N2-RC-1 concrete has a flexural strength around 12% lower than RC-1 concrete of the same age, and a splitting tensile strength of 6% lower. N2-RC-1 concrete may not be as strong as RC-1 concrete because its aggregates have lower specific gravities.

Table 11 Values of Flexural Strength and Split Tensile Test

Specimen Name	Split Tensile Strength (MPa)		Flexural Strength (MPa)	
	7 days	28 days	7 days	28 days
RC-1	2.636	2.961	4.937	6.605
RC-2	1.896	2.544	4.643	5.173
N2-RC-1	2.451	2.775	5.591	5.754
NCA	2.853	3.064	6.870	8.171

4. Conclusion

This research aimed to better understand the capillary water absorption, drying shrinkage, air content, flexural strength, and tensile splitting strength of RCA concrete, as well as the link between w/c ratio and compressive strength, taking into account both age and number of recyclings. The aforementioned topics are investigated by experimental analysis, and the following are the most important takeaways from the experiments.

- It is well knowledge that RCA-produced concrete has worse quality than regular concrete. The first section of this chapter focused on the mechanical characteristics of RCA concrete, specifically how factors like the number of recyclings and the age of the RCA affected such qualities. The second half of this chapter detailed the findings of experiments that used two different ureolytic bacteria to improve the mechanical qualities of RCA concrete.
- Older aggregate (RC-2, 2 years) produces concrete with reduced compressive strength (compared to newer RC-1) (1-year-old). About 6 percent of its compressive strength was lost. It's likely that an increase of adhering porous mortar, which weakens aggregate, contributed to a decline in compressive strength.
- At smaller water-to-cement ratios, NCA concrete is stronger than RCA concrete. However, at a certain threshold w/c ratio, the tendency reverses, and RCA concrete has stronger compressive strength than NCA concrete. According to the results of this investigation, the RCA concrete needs a certain minimum amount of water to contribute to the strength based on the parent attached mortar. As measured by the w/c ratio, the bare minimum amount of water required by RC-1 and RC-2 was around 0.37 and 0.42. For RCA to have greater compressive strength (than NCA), the w/c ratio has to be above the aforementioned minimal limitations.
- The concrete's compressive strength decreases by roughly 2% after N2-RC-1 has been recycled twice as many times as RC-1 has, and this is in comparison to the strength of RC-1 after a single recycling. If the w/c ratio is more than 0.42, N2-RC-1 has a higher compressive strength than NCA. Weakening after repeated recycling may be due to deterioration of the adhering mortar caused by the recycling process.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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