



Effect of parent concrete strength on recycled concrete performance

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ABSTRACT. Reusing concrete wastes as a secondary aggregate might be an efficient solution for long-term environmental protection and sustainable development. However, the different properties of waste concrete, particularly compressive strengths might have a negative impact on recycled concrete. The main purpose of this experimental investigation is to evaluate the influence of parent concrete quality on recycled concrete performance. Three categories of compressive strength (10 to 15 MPa), (20 to 25) MPa, and (30 to 40 MPa) are used to complete this assignment. As a random parameter, an unknown compressive strength was also incorporated. The experimental mix contains 40% secondary aggregates (both coarse and fine) and 60% natural aggregates. To achieve the necessary workability, the significant water absorption properties of recycled concrete aggregate necessitate water content adjustment. As a result, the compressive strength of recycled concrete decreases by 14 to 23.7 percent when compared to conventional concrete. To compensate for this loss, a quantity of cement content deemed to be absorbed by porous attached mortar equal to 4% of the weight of the recycled aggregate was added. The results show that the strength qualities of the original concrete have only a little impact on the compressive strength of the recycled concrete. When crushed, low compressive strength parent concrete produces a considerable volume of fine aggregate and a high proportion of clean recycled coarse aggregates with less attached mortar and has the same compressive strength as excellent parent concrete. In comparison, cement content adjustment does not enhance flexural strength; This appears to be due to a weak interface zone between the aggregate and the old adhering mortar.



Citation: Kebaili, B., Benzerara, M., Menadi, S., Kouider, N., Belouettar, R., Effect of parent concrete strength on recycled concrete performance, *Frattura ed Integrità Strutturale*, 62 (2022) 14-25.

Received: 06.05.2022

Accepted: 15.07.2022

Online first: 24.07.2022

Published: 01.10.2022

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KEYWORDS. Recycled concrete; Waste recovery; Environment; Aggregates; Mechanical behavior.

INTRODUCTION

Algeria is now undergoing a massive development program that includes nearly one million new homes, basic infrastructure, and a 1200 km east-west motorway [1,2]. This task necessitates the use of massive volumes of raw materials in concrete, road construction, and engineering fill, which harms the natural environment [3,4]. Concrete debris, which is generated by the demolition of old buildings and seismic disasters, has somehow been overlooked as a source of aggregate [5]. This waste is disposed as trash. Fig. 1 shows an uncontrolled landfill rubble discharge that affects the natural landscape.



Figure 1: Uncontrolled concrete waste dumping (Annaba, Algeria).

Reusing concrete waste as substitute aggregates would be a feasible solution to the aforementioned challenges, as well as a strategy to protect the environment by allowing for far more effective use of natural resources. Construction waste consumption in Algeria is 5%, with the remaining disposed of, providing a management and environmental policy issue [6]. The primary aim of this study is to show the potential benefits of employing concrete waste in the production of concrete. Recycled concrete aggregate (RCA) exhibited a wide variety of properties when compared to natural aggregate (NA). The percentage of RCA employed in concrete manufacturing varies from 25% to 100%; this range of replacement has been used to generate excellent recycled concrete. The substitution of natural aggregates by recycled aggregates in the production of fresh concrete provides a new aggregate supply while also allowing for the conservation of natural resources [6,7].

When 100 percent RCA was employed, the loss was determined by [8] to be decreased by roughly 20–25 percent when compared to normal concrete. Other research [7] observed a similar trend for strength to decline by roughly 8% when strength exceeds 60MPa. According to [9] the RCA has a high level of water absorption due to the porosity induced by the attached mortar, absorbing up to 8%. As a result, the RCA need more water to be as usable as NA. When crushed, RCA from low strength concrete has less attached mortar than RCA from high strength concrete as seen by [10].

When compared to NA, the increase in water content associated to RCA's porosity is thought to be responsible for the loss of compressive strength [11]. The water absorption coefficient may differ from the free water absorption calculated in the laboratory, and the pores of recycled aggregate are most likely filled with cement paste during mixing. This might result in an excess of water in the mixture [12]. Even when the fraction of coarse RCA replacement approaches 80 percent, structural concrete may be produced [10]. Some efficient and easy approaches, such as adjusting the water-cement ratio, aggregate water content, mixing technique, and additive [13], can enhance the concrete within a given range. Furthermore, increasing the cement content in recycled aggregate concrete (RAC) by around 6.2 percent without affecting the w/c ratio results in compressive strength and consistency comparable to that of ordinary concrete [14]. They also observed that compressive strength loss was just approximately 2.5 percent and 0.4 percent lower. According to [15], when RAC is mixed, a thin layer of cement slurry is generated on the surface, which penetrates through the porous attached mortar and fills cracks and voids. In the flexure strength it was found that the crack originated not just at the interfaces of the recycled aggregates and the mortar, but also at the RCA themselves [16]. Some studies revealed that the compressive strength of RAC decreased with

the degree of aggregate replacement [17]. As a substitute, the RCA raises the water absorption coefficient [18]. It has also been examined to utilize recycled fine aggregate (RFA) instead of natural sand. According to published research, the high porosity of RFA may influence the RAC's long-term durability. For a 100 percent replacement, the compressive strength drops by up to 30% [19]. Replacement levels ranging from 30% to 60% RFA showed minimal effect on RAC characteristics [20]. The increased porosity of the RCA can be mitigated by maintaining a consistent water-cement ratio (w/c) and adding a plasticizing admixture [21]. The RCA, according to the findings, had the same properties as the NA. Few studies have explored the influence of recycled aggregate RA derived from parent concrete (PC). The results for 28-day nominal cube crushing strengths of 20 MPa, 40 MPa, and 60 MPa indicated that the grade of initial concrete had no effect on mechanical features, despite all of them reporting lesser strength than the concrete created just with NA [22]. Few researchers investigated RAC made from various PC strengths and discovered that the reduction in compressive strength of concrete achieved by adding RCA derived from a low concrete was greater than the drop observed for RAC derived from an excellent concrete. The flexural strength of concrete 25 and 50 percent replacement of natural fine aggregate by RFA was similar after 28 and 56 days, but at 75 and 100 percent replacement, the flexural strength was lower than conventional concrete [23]. The 28-day flexural strength of RAC produced by substituting 50% and 100% of coarse NA with RCA revealed a 7.5–13.8 percent drop for 100% [20]. When RCA is employed, compressive and flexural strength drop, however the reduction is less pronounced in low strength concrete than in stronger concrete [12]. Using RCA composed of concrete with strength of 50 MPa resulted in concrete compressive and tensile strengths equivalent to natural coarse aggregate [24]. A good amount of concrete waste may be recycled; however it is worth considering whether it is essential to classify concrete waste based on compressive strength before usage. This will result in a difficult, if not impossible, procedure. The primary goal of this experimental investigation is to establish if a concrete mixture design integrating recycled concrete aggregates derived from varying strength parent concrete as a replacement for raw aggregates may achieve appropriate performance for structural purposes.

EXPERIMENTAL PROGRAM

The recycled aggregates were obtained from laboratory grade concrete that had not yet been utilised. The specimen was kept in an open room for preservation. The RCA was produced by testing until demolishing various concrete test specimens 16x32 cm² of unknown age, but over than six months, (Fig. 2). The compressive strength was measured as the failure of cylindrical concrete specimens in the compression-testing machine, and sorted according to their compressive strength. The PC crushed as described before, exhibited a wide range of compressive strength with lower and higher limits ranging from 10 to 40 MPa. Three PC strength classes arrangement were considered, (10 to 15) MPa, (20 to 25) MPa and (30 to 40) MPa. Three PC grades were established: (PC15), (PC25), and (PC40), which are described as low, up to 15MPa, normal, up to 25 MPa, and excellent concrete, up to 40 MPa, as is typical for concrete in Algeria. As an arbitrary RCA, an unknown PC strength was also put into the investigation.



Figure 2: Test specimen crushed as concrete waste.



Crushing of concrete

As indicated in Fig. 3, the damaged concrete was crushed to sizes smaller than 25 mm using a small jaw crusher. The aggregates were separated by size via mechanical sieving, providing the 03 RCA proportions, fine (0/5) mm and coarse (5/10), (10/20) mm. The resulting RCA were heterogeneous, consisting of natural coarse aggregate with attached mortar as seen in Fig. 4.

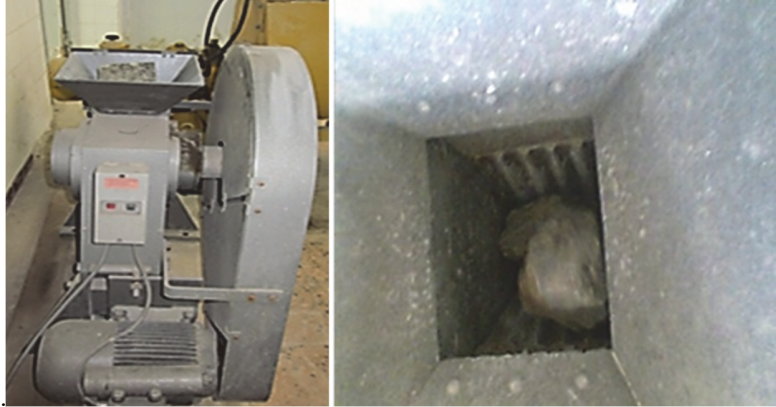


Figure 3: Jaw crusher apparatus and the machine in operation.



Figure 4: Produced recycled concrete aggregates fine and coarse.

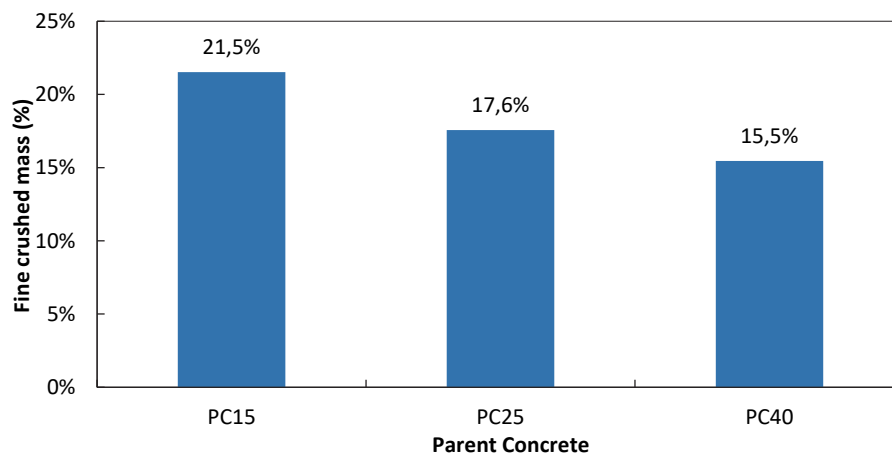


Figure 5: Fine crushed mass of parent concretes.

Mass of fine recycled aggregates

When PC is crushed, each class generates a different amount of RFA. The quantity of RFA in PC15 is more than in PC25 and PC40. Because the bond between mortar and aggregate is weaker in low PC crush, most of weak attached mortar was separated from the aggregate, which is hardly removed by mechanical sieving.

Because of the strong link between aggregate and attached mortar, the quantity of attached mortar grows as PC strength increases. As a result, the mass of fine particle formed in the form of RFA is substantially higher for aggregates produced from low PC than for aggregates produced from normal and excellent PC Fig. 5. After sieving, the RCA from PC15 are slightly cleaner and contain less attached mortar.

Apparent density

The main distinction between NA and RCA is the attached mortar. It has a porous structure and a low bulk density. The RCA made from high-quality concrete had the most attached mortar. As PC strength grows, so does bulk density (Fig. 6). Except in the case of low PC, the RCA has less attached mortar and an apparent density that is fairly equivalent to RCA derived from excellent parent concrete. This property influences other characteristics such as specific density, porosity, and strength.

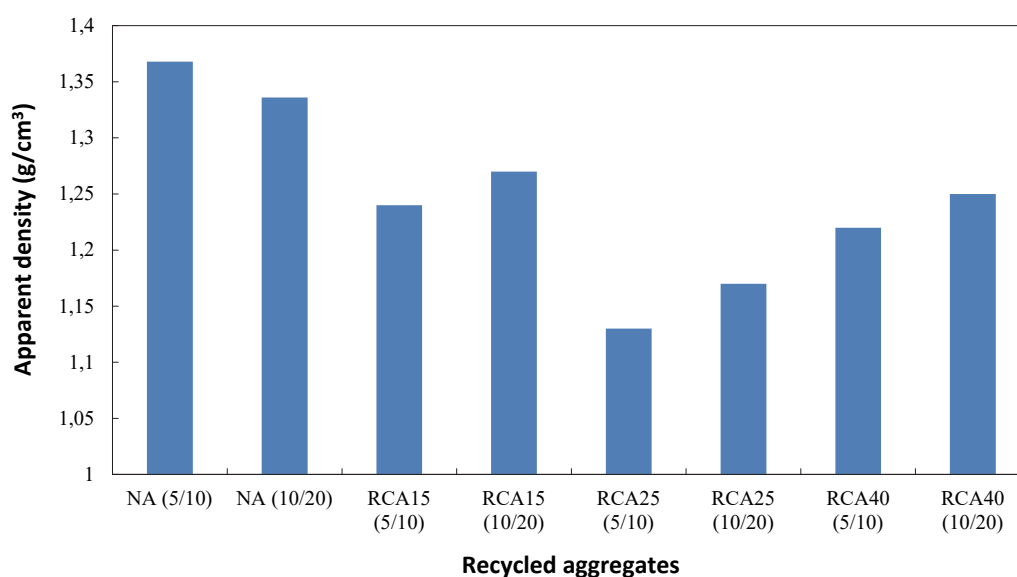


Figure 6: Apparent density of recycled aggregates.

Water absorption coefficient

The capacity of RCA and NA to absorb water distinguishes them (NF EN 1097-6) [25]. In reality, it is related to the quantity of attached mortar, and it must be analysed in order to compare the diverse RCA obtained from different PC. The absorption capacity is another key property that determines the characteristics of both fresh and hardened concrete. The proportion of water absorption increases when the strength of the PC from which the recycled aggregate is produced increases, due to a large amount of attached mortar in RCA obtained from higher strength PC, as shown in Fig. 7. This attached mortar is more porous, which increases RCA's water absorption capacity. Because of that, water content must be adjusted to get the necessary workability. In contrast, as the amount of attached mortar decreases, so does the water absorption, which is most likely for low PC.

The grading curve incorporating 40% RCA and 60% NA, including RFA, was obtained for each PC category. The study team assumed that 40% was a suitable quantity to maximize usage without impacting other concrete qualities. The grading size analysis enabled the concrete mix to be evaluated using the Bolomey dosages method [13], with a desired slump range from 50 to 70 ±10 mm as a plastic concrete. The mix design was developed for the second phase of concrete testing; RCA and NA, taking into account varied Water/Cement ratios. The compressive strength objective was 20 MPa, as specified by the Algerian seismic standard [26].

Concrete mix

The cement-water ratio was adjusted to generate a plastic concrete slump in the mix. Four RAC categories were investigated: RAC15, RAC25, and RAC40, which were derived from PC15, PC25, and PC40, respectively, and RAC for unknown recycled aggregates. Tab. 1 displays the mix proportions obtained using the Bolomey dosage method. The cement content amount of CEM.II 42.5 was 350 kg/m³.

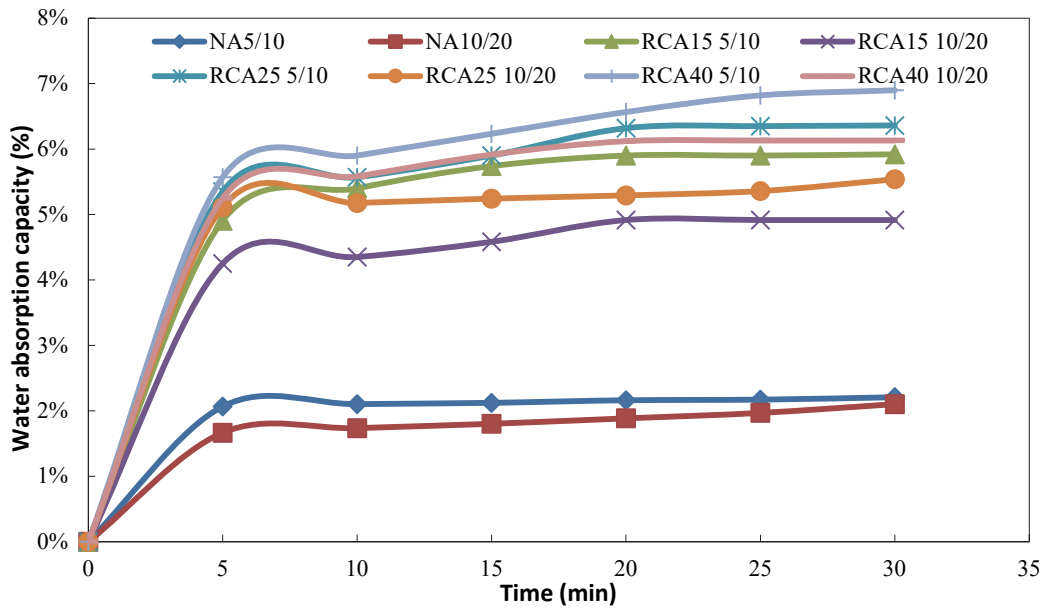


Figure 7: Water absorption capacity.

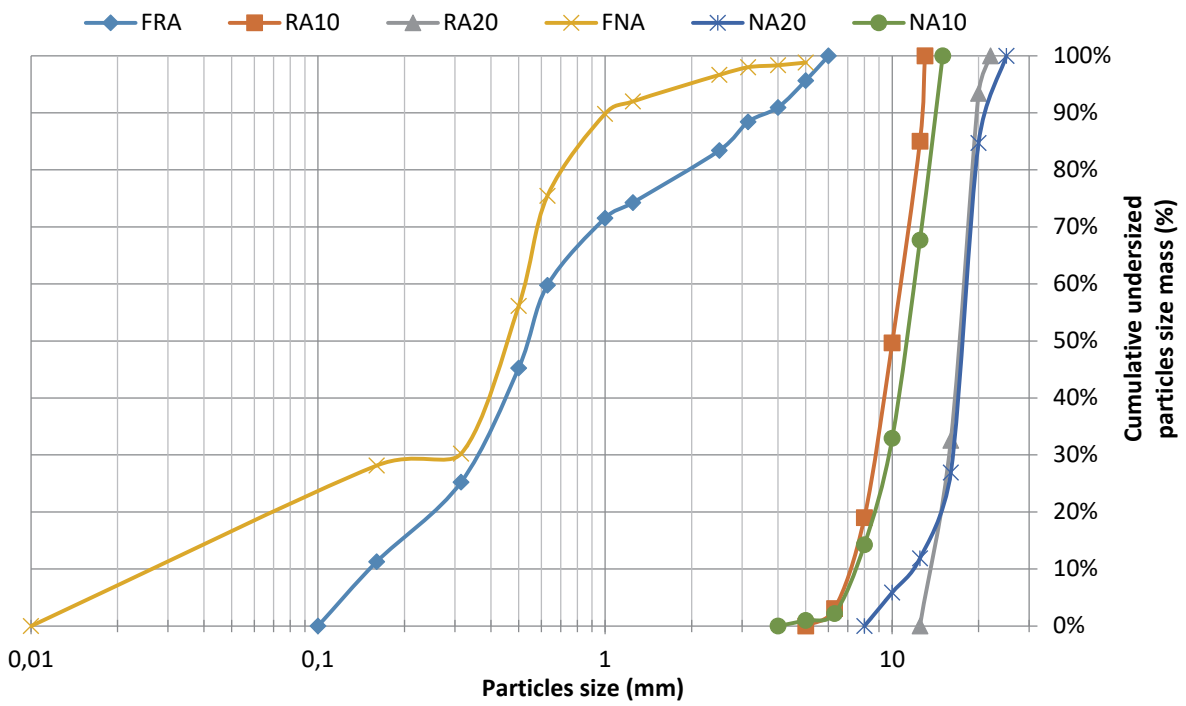


Figure 8: Grading size analysis.

Categories	FA	NA (5-10)	NA (10-20)	RFA	RAC (5-10)	RAC (10-20)	Cement	w/c
RAC15								0.65
RAC25	418	172	482	279	114	321	350	0.7
RAC40								0.65
RAC								0.7
NC	697	286	803					0.5

Table 1: Amount of aggregate, cement and water.

The trial mix concrete was required to comply with the NF P 480-1 standard [27], and the consistency was assessed using the NF EN 12350 standard slump test [28]. The slump test results for all recycled aggregate concrete, RAC15, RAC25, RAC40, RAC and NC, varied between 50 and 70 mm, confirming the assumption of plastic concrete. For the same workability, the W/C ratio was higher for the RAC than for conventional concrete; this was mostly attributed to the porosity of recycled aggregate and the nature of attached mortars with their larger absorption coefficient. In this manner, 12 specimens were cast in 10x10x10 cm³ and 10x10x40 cm³ for compression and flexural testing for each type of mix. The specimens were made on a shaking table in accordance with the NF P18-422 standard [29]. A comparison is done with a NA for a minimum compressive strength objective of 20 MPa, which is typical for construction applications.

Mechanical behaviour

Under the NF P18-405 [30], tests on the four categories of RAC and NC were conducted at 28 days, with the specimens conserved and covered by a plastic tray to avoid moisture loss. The compression test was carried out on a calibrated 500 kN hydraulic press at a constant speed in accordance with the standard NF EN 12390-3 [31]. Three-point bending tests were performed on 10x10x40 cm³ specimens to assess the flexural strength characteristics using a hydraulic press with a capacity of 150 KN in accordance with the standard NF EN 12390-5 [32].

RESULTS AND DISCUSSION

Compressive strength

When recycled coarse aggregates are employed, the strength of RAC15, RAC25, and RAC40 decreases; the drop in compressive strength was 23% for PC25 and 15% for PC15 and PC40. This finding is analogous to that of Etxeberria M et al [8]. This loss is due to water absorption; the RAC requires more water than the NC to attain the same workability. When tested, Tabsh Sami W et al [11] observed that the porosity of attached mortar affects the compressive strength. Also, the bond between the coarse aggregate and the old attached mortar, which was impacted by the crushing machine when it was made, appears to be accountable for that loss. The reduction in RAC compressive strength was less severe when the PC was low. The strength decrease was around 16.0 percent, which is the same as excellent PC. Contrary to expectations, the compressive strength of RAC is not related to the grade of PC [21]. When the PC has a lower strength, the RAC has the same characteristics as when the PC is excellent. This can be explained by the old mortar-aggregate bond; with PC40, the bond was stronger than with PC25. Whereas the RAC strength obtained from PC15 dropped at the same rate as the compressive strength produced from PC40. The loss in RAC resulting from unknown PC strength was 10.34 percent, as shown in Fig. 9.

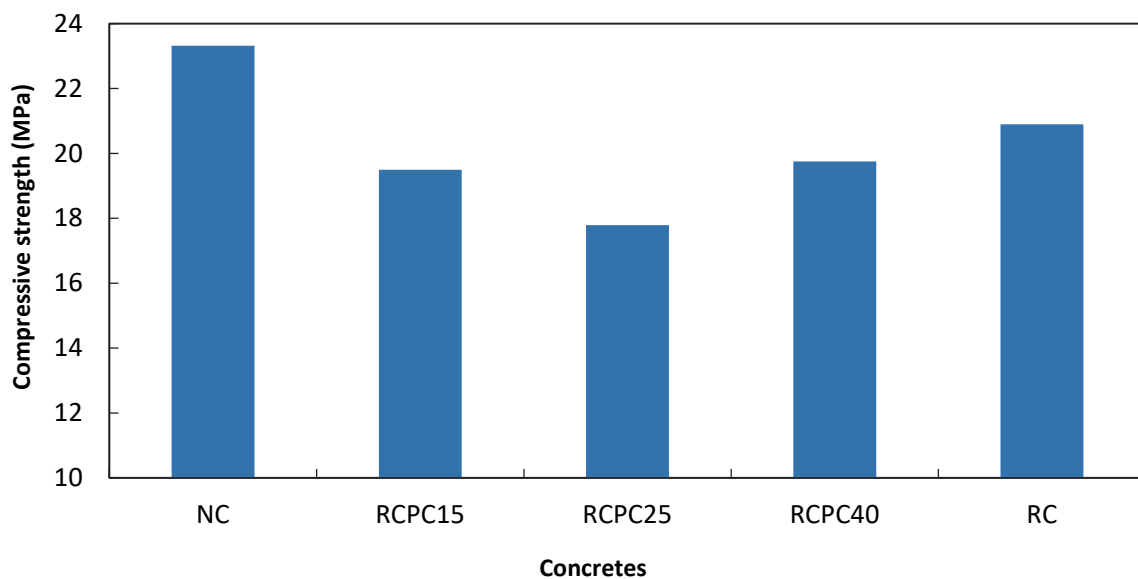


Figure 9: Compressive strength of recycled and normal concrete before the mix correction.



Further analysis was required to clarify this experimental distinction of the assertion that more PC has lower compressive strength; hence, the impact on the RAC strength will be negative. The coarse aggregates formed while crushing PC15 are more like natural aggregates since the bond between the mortar and aggregates is weak. The interface was significantly cleaner, with less adhered mortar, as noticed by [5], which increased the bond in the new mix. As a consequence, the compressive strength of the RAC significantly increased. According to the comparative study of the findings obtained from different RCA, the percentage reductions in compressive strength for the RAC15; RAC40 were roughly 16 percent, but this depletion was 23.7 percent for the RAC25. In contrast to prior research [16], which linked RAC strength to parent concrete strength, this claim was seen for RAC generated from strong PC, despite the fact that the results were obtained without using a low concrete as low as 15 MPa. It is observed that for unknown PC, the compressive strength drops by less than 13.9 percent. As a result, the impact of the RCA's origins may be less substantial than originally thought. The necessity of sorting concrete waste according to compressive strength, which may make reuse of concrete waste practically more difficult, is unnecessary. Statistical analysis of concrete test results is important for understanding the concrete failure stress; the strength characteristic may be reliable by using the standard deviator to assess the dispersion of this data to evaluate the strength characteristic and to compare different concrete Tab. 2.

N°	1	2	3	4	5	6	7	8	9	10	Average	Deviator	fc MPa	Loss %
NC	23.76	23.88	23.88	23.88	24.24	24.96	25.20	25.44	25.68	25.80	24.67	3.35	23.32	0.00
RAC15	21.20	20.16	20.64	20.88	21.00	21.12	21.36	21.48	22.32	24.48	21.46	5.59	19.50	16.40
RAC25	18.36	18.60	18.60	18.60	18.96	18.96	18.96	19.20	19.56	21.12	19.09	4.15	17.79	23.70
RAC40	22.30	20.40	20.40	20.40	20.52	21.72	21.84	21.84	21.96	23.64	21.50	4.98	19.75	15.30
RAC	20.16	20.88	21.00	21.60	21.60	21.96	22.98	22.92	23.04	23.88	21.95	5.17	20.09	13.90

Table 2: Strength characteristics for different RAC.

RAC's strength properties were slightly different. The amount and quality of attached mortar determine the strength of RAC. The standard deviator, which demonstrates the disparity of compressive strength is greater for RAC than NC, might be a source of confusion due to the heterogeneous and variable quality of the recycled aggregates. The standard deviation was minimal in all concretes. When compared to the target concrete, the findings obtained for recycled concrete demonstrate that the PC strength characteristic has a minimal influence on the compressive strength of the RAC. Thus, it may be argued that RCA can be reused without regard for their origin and without sorting. It may also be claimed that unknown PC has the same compressive strength, which confirms the previous conclusion.

Concrete mix correction

The study was done to describe a way to improve the compression strength of RAC as a regular concrete, which would most likely be employed as structural concrete. Because of the attached mortar, the RCA has a higher superficial porosity, which affects the RAC compressive strength. When the concrete is mixed, a certain quantity of cement powder is supposed to be absorbed by these pores [14], requiring the addition of extra water to maintain the same workability.

We may suppose that pores contribute to a drop in cement content as well; as a result, compressive strength diminishes proportionate to the rate of replacement. After 10 minutes, the differential porosity between the NA and RCA was determined to approximate the cement powder ratio roughly absorbed by the clear porosity of the RCA. This may be the time it takes to mix the concrete Fig. 8. This trend can be used as a basis for cement content adjustment. Given that the RCA porosity was determined to be 5.90%, meanwhile the NA porosity was 1.90%. The apparent porosity of the RCA is defined as the difference between the two porosities. This permitted for the consideration that the difference between the absorption coefficients of the RCA and the NA is the loss of cement content, which filled the attached mortar pore at the start of the mix. The addition of cement content, roughly 4 percent of the weight of the RCA, is probably acceptable to improve the compressive strength of the RAC. Using the same proportions and adding 4% of the weight of the RCA introduced in the mix, a new recycled aggregate concrete corrected (RACC) mix was created. Tab. 3 displays the modified mix proportions.

When the cement amount is adjusted to increase the strength of the concrete, the cement water ratio for the RACC drops, and the slump test on the revised mix showed a slump between 70 and 90 mm. This new mix performed was tested under the same conditions as the previous recycled concrete. The results demonstrate that the extra cement content enhanced compressive strength, as seen in Fig. 10.



Categories	FA	NA (5-10)	NA (10-20)	RFA	RAC (5-10) kg	RAC (10-20)	Cement	w/c
RACC15								0.6
RACC25	418	172	482	279	114	321	350+4%.RAC	0.65
RACC40								0.6
RACC							367	0.65
NC	697	286	803					0.5

Table 3: Amount of aggregate, cement corrected and water.

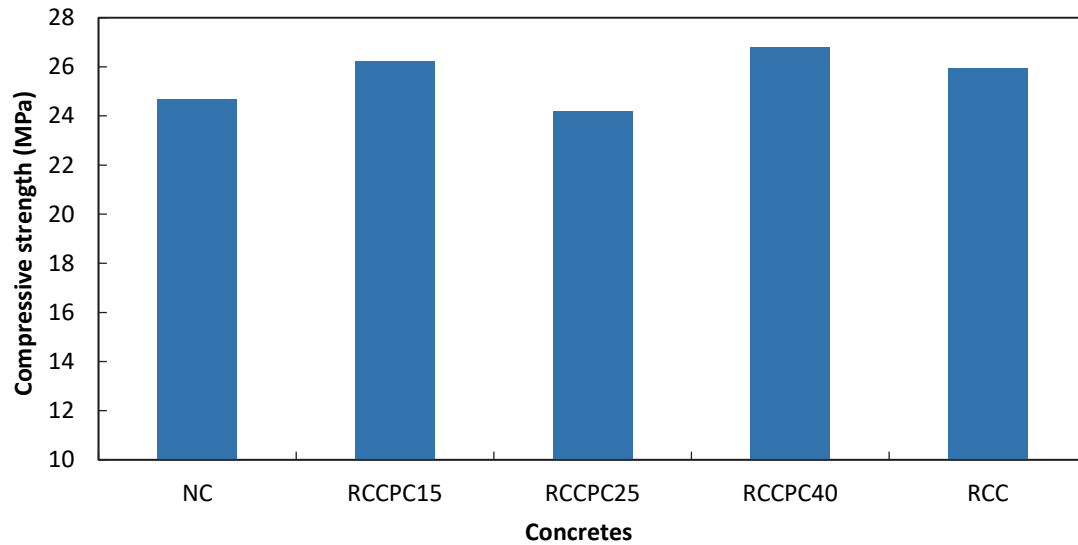


Figure 10: Compressive strength for normal and recycled corrected concrete after the mix correction.

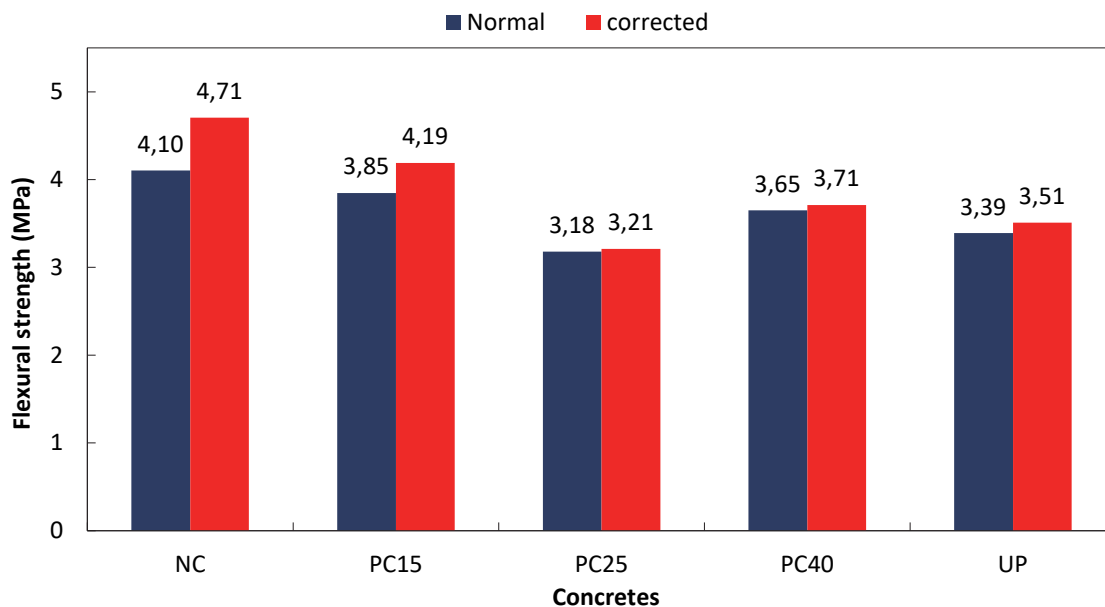


Figure 11: Flexural strength for normal and recycled concrete before and after mix correction.

This method might be used to adjust the RAC mix prepared with a different recycled aggregate by using simply the absorption coefficient of each component. As can be seen, the RACC standard deviator was more than the NA. The RACC has a higher average strength than NA, although the standard deviator reveals that RACC is still more various.

Flexural strength



The results reveal that flexural strength increases for NC and RACC15 but is very moderately influenced for RACC25, RACC40, and unknown parent concrete corrected RACC.

When an amount of cement content is supplied, the changes in flexural strengths indicated in Fig.11 enhance the bond between the aggregate for NC and PC15 due to the characteristic stated above, RACC15, are cleaner with less attached mortar. The cracked surface in the other cases revealed that the majority of failures in parent concrete occurred near the interface between the old attached mortar and the aggregate. The weaker interface zones in RACC impact failure, as observed in PC25 and PC40, where adding cement content has little effect.

CONCLUSIONS

The results show that the strength qualities of the parent concrete have only a little influence on the compressive strength of the recycled concrete. Furthermore, when crushed, low compressive strength parent concrete produces a significant volume of fine aggregate and a high proportion of recycled coarse aggregates with less attached mortar and the same compressive strength as excellent parent concrete. From a methodological point of view, the analyses of the obtained outcomes of the experimental test program have revealed five main issues.

- Low compressive strength concrete, when crushed, generates more amounts of fine recycled aggregates and gives recycled coarse aggregates more clean with less attached mortar than normal and excellent parent concrete.
- For the same workability, the w/c ratio in RAC is more essential than NA, but less critical than RAC25 for RAC15 and RAC40. This has an effect on the compactness of concrete, resulting in a lower RAC25 compressive strength..
- For a given target mean strength, the obtained strength increases with PC quality, as well as with low compressive strength; due to less attached mortar.
- The percentage loss in compressive strength due to 40% recycled aggregate replacement is between 15 and 25%, however the offset in strength can be reduced by correcting the cement content by about 4% of the weight of recycled concrete aggregate replacement.
- Flexural strength is unaffected by cement content adjustment, which appears to be related to interface weakness between aggregate and attached mortar.

NOMENCLATURE

FNA	: fine natural aggregate.
NA	: natural aggregate.
NC	: natural concrete.
NA20	: natural aggregate up to 20 mm.
NA10	: natural aggregate up to 10 mm.
NA (5/10)	: natural aggregate fractions 5 to 10 mm.
NA (10/20)	: natural aggregate fractions 10 to 20 mm.
PC	: parent concrete.
PC15	: parent concrete 15 MPa.
PC25	: parent concrete 25 MPa.
PC40	: parent concrete 40 MPa.
RFA	: recycled fine aggregate.
RCA	: recycled concrete aggregate.
RCA15 (5/10)	: recycled concrete aggregate from PC15 fractions 5 to 10 mm.
RCA15 (10/20)	: recycled concrete aggregate from PC15 fractions 10 to 20 mm.
RCA25 (5/10)	: recycled concrete aggregate from PC25 fractions 5 to 10 mm.
RCA25 (10/20)	: recycled concrete aggregate from PC25 fractions 10 to 20 mm.
RCA40 (5/10)	: recycled concrete aggregate from PC40 fractions 5 to 10 mm.
RCA40 (10/20)	: recycled concrete aggregate from PC40 fractions 10 to 20 mm.
RAC	: recycled aggregate concrete.
RAC15	: recycled aggregate concrete from PC15.
RAC25	: recycled aggregate concrete from PC25.



RAC40	: recycled aggregate concrete from PC40.
RACC	: recycled concrete corrected.
RACC15	: recycled concrete corrected from PC15.
RACC25	: recycled concrete corrected from PC25.
RACC40	: recycled concrete corrected from PC40.
W/C	: water-cement ratio.

ACKNOWLEDGMENTS

The authors would like to thank LGC-Civil Engineering laboratory, Badji Mokhtar Annaba University (Annaba, Algeria) who provided facilities for conducting the various tests in the laboratory.

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