The Role of Parent Concrete in Recycled Aggregate Concrete

Luisa Pani, Lorena Francesconi, James Rombi, Flavio Stochino(✉), and Fausto Mistretta

Department of Civil, Environmental Engineering and Architecture, University of Cagliari, 09123 Cagliari, Italy
fstochino@unica.it

Abstract. A current promising way towards sustainable construction is the concrete construction and demolition waste recycling. Indeed, the use of recycled concrete aggregates instead of natural aggregates promotes the natural resources conservation and reduces the environmental impact of concrete. This paper presents the results of an experimental investigation on the mechanical properties of concretes with recycled aggregates obtained from two different parent concretes, belonging to the structure of old Cagliari football stadium. The main target of this work is to verify the effectiveness of adopting concrete debris as recycled aggregates in the new structural concrete. The influence of parent concrete on the characteristics of coarse recycled aggregates and of new structural concrete with these aggregates are investigated. Modulus of elasticity, compressive strength, splitting tensile strength of recycled concretes have been assessed and discussed in order to highlight the role of parent concrete.

Keywords: Reinforced concrete · Environmental impact · Recycled aggregate · Sustainability

1 Introduction

The deterioration of natural resources is partially due to concrete constructions techniques. Thus, concrete construction and demolition waste (C&DW) recycling aimed at producing recycled concrete aggregates, can be a very promising strategy to reduce the important impact on the environment. Actually, the use of recycled aggregates instead of Natural Aggregates (NA) for new concrete structures promotes natural resources preservation and reduces landfill disposal.

The Italian Ministry of the Environment, Land and Sea protection, has published the National Action Plan on Green Public Procurement, see [1]. This document, in agreement with the European Commission guidelines, defines the Minimum Environmental Criteria for the assignment of design and work services for new buildings, retrofitting, maintenance, energy requalification and management of construction sites. These criteria give highlight to the environmental aspects of each construction contract, with the aim of recycling and reusing a large part of non-hazardous C&DW. The need of applied research on the use of recycled aggregates of concrete in structural concretes is patent.

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12255, pp. 368–378, 2020.
https://doi.org/10.1007/978-3-030-58820-5_28

Furthermore, it is important to know if the new concrete chemical, physical and mechanical characteristics are influenced by the parent concrete.

Available experimental data on concrete made with Recycled concrete Aggregate (RA) are variable [2–6] claim that the quality of RA mostly depends on the quality of parent concrete. Even if some results are contradictory, some general conclusions can be drawn about the effects of coarse RA. Recycled concrete with low to medium compressive strength can be easily obtained irrespective of the specific quality of parent concrete [7–11]. Instead, in [12] the quality of parent concrete is considered more significative in a weak concrete than in a stronger one. Indeed, according to these authors the strength of concrete depends on both the coarse aggregate and cement.

Actually, the adhered cement mortar quality strongly influences the physical properties of RA. In [8, 13] it is shown that the quantity of adhered mortar increases with the decrease of the recycled aggregate size. Actually, the production process of recycled aggregates (see [14]) has a key role on the final performance because it can strongly modify the amount of adhered mortar. The latter one allows RA to have a lower density and higher water absorption, compared to natural one. Moreover, the presence of potentially unhydrated cement on the surface of RA can further affect the concrete properties [15] and the crack propagation characteristics [16–18].

Compressive strength, splitting tensile strength and modulus of elasticity of concrete with RA were found to decrease with the increase of the aggregates replacement percentage: [19–21]. Instead flexural strength and modulus of elasticity of concrete containing RA are similar to concrete made with natural aggregates according to [22].

In this context additional experimental tests are of paramount relevance.



Fig. 1. View of old Cagliari football stadium.

This paper reports on the experimental tests developed at University of Cagliari aimed at evaluating the mechanical performance of concrete with coarse RA obtained by crushing structural concrete with low compressive strength ($R_{ck} \leq 20$ MPa). The RA derive from concrete structures (cantilever beams and foundations) of the old football stadium located in Cagliari (Sardinia, Italy, built in 1968) see Fig. 1.

Beams with cantilevers and foundation blocks are the concrete structures chosen for the preliminary analysis (see orange elements in Fig. 2).

At first, the parent concrete mechanical performance was tested. Part of cantilever beams and foundations have been demolished and crushed separately, to obtain two types of coarse RA with size 4–16 mm. Using three different replacement percentages (30%, 50% and 80%) of NA with RA a set of six concrete mixes with RA has been produced. For comparison purposes an additional mix of conventional concrete with only natural aggregates was also produced.

This paper is organized as follows. After this introduction Sect. 2 presents the quality of parent concrete while Sect. 3 describes the characteristics of RA. In Sect. 4 the mechanical characteristics of the obtained concrete mixes are shown. Finally, some conclusive remarks are drawn in Sect. 5.

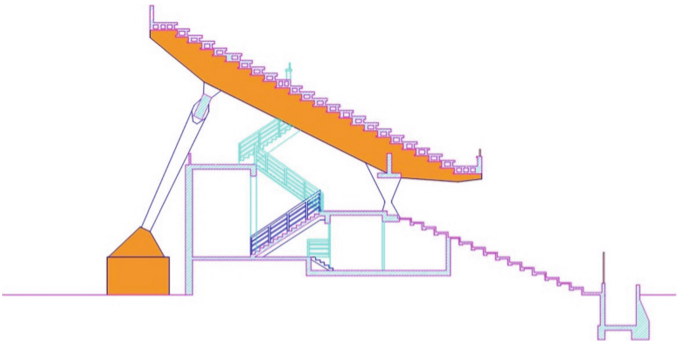

Fig. 2. Transversal cross section of old football stadium reinforced concrete structures. The analyzed structures are highlighted in orange. (Color figure online)

2 Parent Concrete

In the first phase of the research, the integrity and mechanical behavior of Cagliari RC football stadium were analyzed. The concrete structures chosen for the preliminary analysis are the cantilever beams and the foundation blocks. A total of 12 cored specimens were collected from both the foundation and the beams, respectively named C. Found. and C. Beam. A preliminary visual inspection performed on the cored specimens did not highlight any abnormalities. In Table 1 the test results on cored specimens and average values of parent concrete are reported.

Table 1. Mechanical characteristics of Parent Concrete.

C. Found.	1	2	3	4	5	6	Average value
R_c (MPa)	26.8	32.2	24.7	–	–	–	27.9
f_{ct} (MPa)	–	–	–	2.04	1.83	2.28	2.05
E_c (MPa)	24470	27751	23785	–	–	–	25335
C. Beam	1	2	3	4	5	6	Average value
R_c (MPa)	22.2	22.1	18.7	–	–	–	21.0
f_{ct} (MPa)	–	–	–	1.50	1.58	1.40	1.49
E_c (MPa)	19774	18537	15845	–	–	–	18042

The experimental data show that the beams and foundations were made with two types of concrete characterized by different mechanical properties and composition. The mechanical behavior of the foundation is better than that of the beam. Moreover, definite compositional differences between the two materials are confirmed from petrographic analyses on thin sections. The samples are characterized by the presence of several types of aggregates, embedded in a fine cement matrix, which may be distinguished both by mineralogical composition and by size distribution. Polarized light microscopy analyses performed on sample labelled C. Found revealed, in the fine cement matrix, the presence of a coarse fraction entirely made of centimetric angular fragments of micritic (cryptocrystalline) limestone. This component contrasts with a very varied siliciclastic fine-grained (millimetric to sub-millimetric) fraction, made of granite and metamorphic rock fragments, with quartz and feldspar free crystals; all the fragments are sharp-edged. Analyses on sample C. Beam indicate a more homogeneous siliciclastic com-position, with a millimetric-centimetric fraction prevalently made of angular fragments of granite rocks with various types of metamorphic rocks (quartzites to metavolcanics), and a fine-grained, sub-millimetric fraction consisting of the same materials associated to free crystals of quartz, feldspars and biotite.

3 Recycled Aggregated

Two types of RA have been produced, called respectively Recycled Aggregate Foundation (RA_F), obtained from crushed foundation blocks, and Recycled Aggregate Beam (RA_B), obtained from crushed cantilever beams, both with size 4–16 mm.

The two types of RA were subjected to all the tests complying with UNI EN 12620: 2008 [23] and UNI 8520-1: 2015 [24]. In Table 2 the results are shown and in Fig. 3 RA size distribution is reported.

The analysis carried out showed that RA, even if obtained by crushing two different concretes, have very similar characteristics. In Table 2 it can be observed that only four parameters (Shape Index, Percentage of fines, Content of acid-soluble sulfate, Content of water-soluble sulfates) are slightly different.

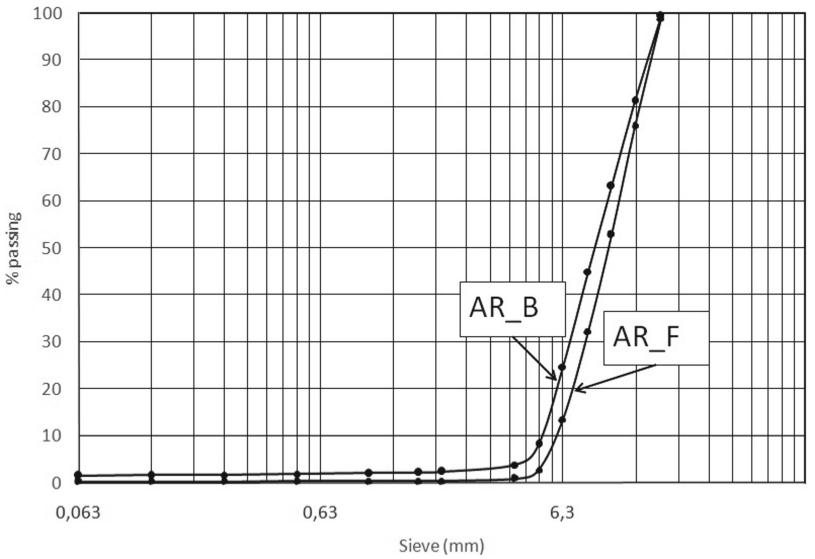

Fig. 3. RA size distribution.

Table 2. Characteristics of RA.

Requirements		RA_Foundation	RA_Beam
Requirements		RA_Foundation	RA_Beam
Geometrical	Aggregate sizes	4/16	4/16
	Grading	GC 90/15, GT 17.5	GC 90/15, GT 17.5
	Shape Index	59	34
	Flakiness Index	4	4
	Shell content of coarse aggregate	Absent	Absent
	Fines content	0.15%	0.59%
Physical	Resistance to fragmentation of coarse aggregate	39	39
	Saturated surface-dried particle density	2.39	2.38
	Bulk density	1.23	1.14
	Voids%	45	49
	Water absorption	7.0	6.7
	Classification of the coarse recycled aggregates constituents:		
	X	0	0
	Rc %	74	78
	Ru %	27	22
	Rb = Ra = Rg %	0	0
Chemical	Content of water-soluble chloride salts	0.005%	0.005%
	Content of acid-soluble chloride salts	0.325%	0.325%
	Content of acid-soluble sulphate	0.43%	0.26%
	Content of Total Sulfur	<0.1%	<0.1%
	Content of water-soluble sulphates	0.148%	0.068%

3.1 Residual Mortar Content in Recycled Concrete Aggregates

In RA the adhered cement mortar to the original natural aggregate particles influences significantly physical properties, workability and mechanical performances of recycled concrete.

The determination of the Residual Mortar Content (RMC) has critical importance to better estimate the properties of concrete incorporating RA. However, there is currently no standard method for the RMC determination.

The method used in this research, proposed by [25], consists in submitting representative samples of RA to daily freezing and thawing cycles in a solution of sodium sulphate. The RMC obtained in RA_F and RA_B, divided into two fraction sizes (retained 4 mm and 10 mm sieve), is shown in Table 3. The test shows that RMC is significantly similar for RA_F and RA_B.

Table 3. Residual mortar content (%).

	Sieve retained 4 mm	Sieve retained 10 mm
RA_Found.	55.81	45.82%
RA_Beams	49.67%	45.65%

4 Mechanical Characteristics of Concrete

CEM II/A-LL 42.5 R was used in all concrete mixes. Both NA and coarse RA were used. Crushed natural granite was used as the natural aggregate. Two type of recycled aggregates (RA_F and RA_B) were used. Natural sand was used as the fine aggregate in all concrete mixes. A superplasticizer based on polycarboxylate was used in all the concrete mixtures. Recycled concrete mixes were produced using different replacement percentages (30%, 50% and 80%) of coarse RA in place of coarse NA. Six recycled concrete mixes were produced, using separately the two types of coarse RA. In comparison an additional mix of Normal Concrete (NC) with only NA was produced.

In Table 4 the proportions for each mix produced are shown. The mix of recycled concrete was designated to include type of coarse RA and aggregate replacement ratio. For example, the designation RC_F 30% represents a mix containing RA_F with replacement percentage 30% and RC_B 80% represents a mix containing RA_B with replacement percentage 80%. Each mix is characterized by water to cement ratio equal to 0.463, and an average density of 2283 kg/m^3.

Compressive and splitting tensile strength and secant modulus of elasticity in compression tests were performed according to UNI EN 12390-3: 2019 [26], UNI EN 12390-6: 2010 [27] and UNI EN 12390-13: 2013 [28], respectively. The compressive strength test for each mix was determined at 14 and 28 days, while splitting tensile strength and modulus of elasticity were determined at 28 days. In Figs. 4, 5, 6 and 7 the results of tests are reported.

Table 4. Aggregates proportion for different concrete mixes.

	Fine NA (kg/m^3)	Coarse NA (kg/m^3)	Coarse RA_F (kg/m^3)	Coarse RA_B (kg/m^3)	Additive (kg/m^3)
NC	847.49	880.06	–	–	2.91
RC_B 30%	821.80	616.04	–	263.69	3.31
RC_B 50%	802.97	440.03	–	440.27	3.31
RC_B 80%	778.15	176.01	–	703.96	4.00
RC_F 30%	821.80	616.04	263.69	–	3.31
RC_F 50%	802.97	440.03	440.27	–	4.00
RC_F 80%	778.15	176.01	703.96	–	4.00

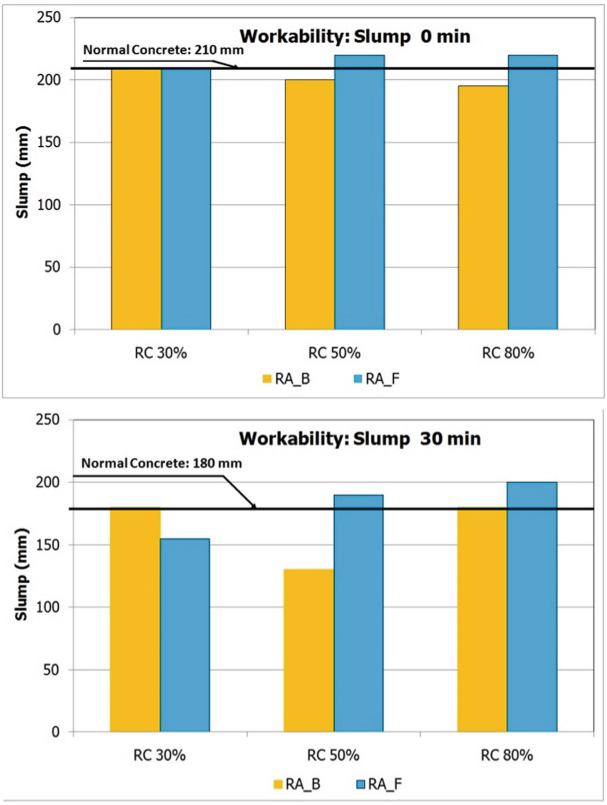

Fig. 4. Slump test immediately (top) and 30 min (bottom) after casting.

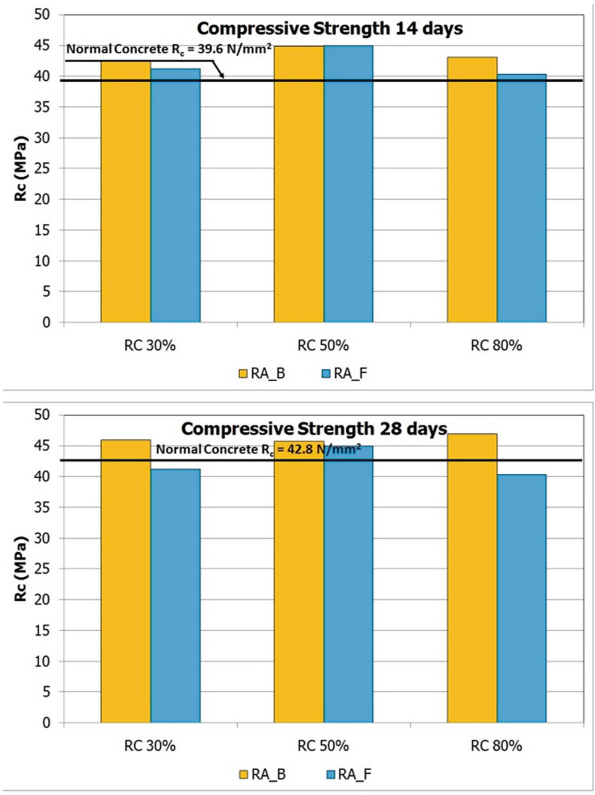

Fig. 5. Average values of concrete compressive strength at 28 (bottom) and 14 days (top) after casting.

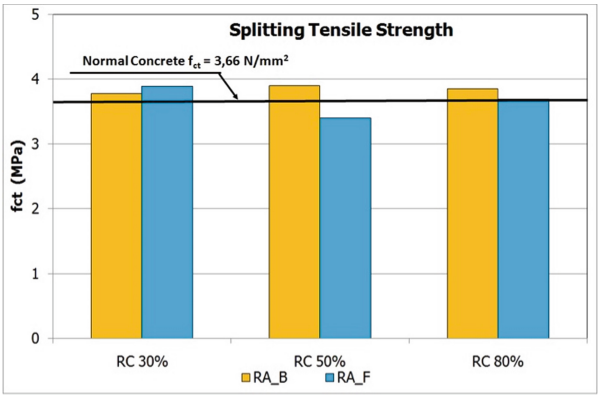

Fig. 6. Concrete splitting tensile strength average values.

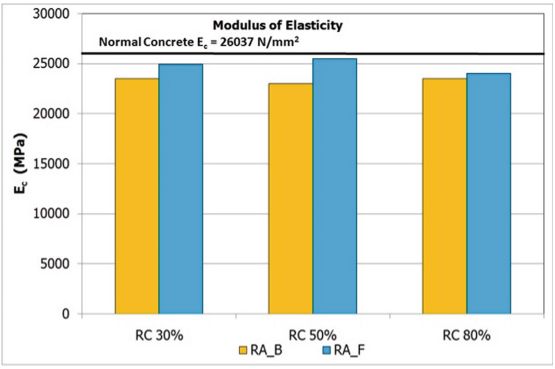

Fig. 7. Concrete modulus of elasticity average values.

The results of the average compressive strength at 14 and 28 days (Fig. 5) show optimal performance even when the percentage of coarse RA reaches 80%. It should also be noted that the compressive strength of recycled concrete does not appear to be influenced by the parent concrete. Rather it results that, in some cases, the compressive strength of recycled concrete is higher than NC. Splitting tensile strength (Fig. 6) is greater or equal for all recycled concrete, compared to NC. This result was expected and can be explained by the greater roughness of RA that produces an increase in tensile strength of concrete. The secant modulus of elasticity in compression (Fig. 7) appears slightly lower (limited to a maximum of 10%) for recycled concrete compared to NC. This result was expected and mainly due to the adherent mortar [29].

5 Conclusions

This experimental campaign shows that the mechanical properties of recycled concrete are not affected by the mechanical characteristics of the parent concrete. Furthermore, it is possible to obtain structural concrete even when the percentage of replacement of coarse RA reaches 80%. This data is very important because it proves the presence of RA does not necessarily lead to a reduction in the performance of the new concrete casted with them. Actually, the design mix of concrete with recycled aggregates plays a fundamental role.

Further developments of this research are expected considering also the durability properties of these materials and their application to real scale structural elements like columns or beams: [30–32].

It is clear that the use of this kind of concrete can reduce the building impact on the environment and creating new opportunities for the construction companies with beneficial results for all the society. For example: the processing scraps of precast concrete can be successfully used as recycled aggregates.

Finally, given that the transportation costs of these materials it is always a key variable for all economic analysis, they can be useful also in case of the retrofitting of existing structures and infrastructures, see [33, 34]. In particular when the environmental

impact of the retrofitting intervention is taken into account (see [35, 36]) the use of recycled aggregates can reduce the equivalent CO2 cost of that intervention.

Funding Statement. Authors would like to acknowledge Sardegna Ricerche for the financial support of project: Materials for Sustainable Building and Infrastructure - Recycled Aggregates (MEISAR). POR FESR 2014/2020 - ASSE PRIORITARIO I "RICERCA SCIENTIFICA, SVILUPPO TECNOLOGICO E INNOVAZIONE.

References

1. Italian Minister for the environment and protection of land and sea. DM 11/10/17 - Minimum environmental criteria for design services and works for the new construction, renovation and maintenance of public buildings (2017). (in Italian)
2. Pacheco, J., de Brito, J., Chastre, C., Evangelista, L.: Experimental investigation on the variability of the main mechanical properties of concrete produced with coarse recycled concrete aggregates. Constr. Build. Mater. **201**, 110–120 (2019)
3. Francesconi, L., Pani, L., Stochino, F.: Punching shear strength of reinforced recycled concrete slabs. Constr. Build. Mater. **127**, 248–263 (2016)
4. Koenders, E.A., Pepe, M., Martinelli, E.: Compressive strength and hydration processes of concrete with recycled aggregates. Cem. Concr. Res. **56**, 203–212 (2014)
5. Padmini, A.K., Ramamurthy, D.K., Mathews, M.S.: Influence of parent concrete on the properties of recycled aggregate concrete. Constr. Build. Mater. **23**, 829–836 (2009)
6. Kou, S.C., Poon, C.S.: Effect of the quality of parent concrete on the properties of high performance recycled aggregate concrete. Constr. Build. Mater. **77**, 501–508 (2015)
7. Ajdukiewicz, A., Kliszczewicz, A.: Influence of recycled aggregates on mechanical properties of HS/HPC. Cem. Concr. Compos. **24**, 269–279 (2002)
8. Etxeberria, M., Marı, A.R., Vazquez, E.: Recycled aggregate concrete as structural material. Mater. Struct. **40**, 529–541 (2007)
9. Rahal, K.N.: Mechanical properties of concrete with recycled coarse aggregate. Build. Environ. **42**(1), 407–415 (2007)
10. González-Fonteboa, B., Martínez-Abella, F.: Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties. Build. Environ. **43**(4), 429–437 (2008)
11. Pani, L., Francesconi, L., Rombi, J., Naitza, S., Balletto, G., Mei, G.: Recycled aggregates, mechanical properties and environmental sustainability. In: Planning, Nature and Ecosystem Services, INPUT aCAdemy 2019, pp. 431–442 (2019)
12. Tabsh, S.W., Abdelfatah, A.S.: Influence of recycled concrete aggregates on strength properties of concrete. Constr. Build. Mater. **23**, 1163–1167 (2009)
13. De Juan, M.S., Gutiérrez, P.A.: Study on the influence of attached mortar content on the properties of recycled concrete aggregate. Constr. Build. Mater. **23**(2), 872–877 (2009)
14. Pepe, M., Toledo Filho, R.D., Koenders, E.A., Martinelli, E.: Alternative processing procedures for recycled aggregates in structural concrete. Constr. Build. Mater. **69**, 124–132 (2014)
15. Katz, A.: Properties of concrete made with recycled aggregate from partially hydrated old concrete. Cem. Concr. Res. **33**(5), 703–711 (2003)
16. Li, W., Long, C., Tam, V.W., Poon, C.S., Duan, W.H.: Effects of nanoparticles on failure process and micro-structural properties of recycled aggregate concrete. Constr. Build. Mater. **142**, 42–50 (2017)

17. Li, W., Luo, Z., Sun, Z., Hu, Y., Duan, W.H.: Numerical modelling of plastic–damage response and crack propagation in RAC under uniaxial loading. Mag. Concr. Res. **70**(9), 459–472 (2018)
18. Stochino, F., Pani, L., Francesconi, L., Mistretta, F.: Cracking of reinforced recycled concrete slabs. Int. J. Struct. Glass Adv. Mater. Res. **1**(1), 3–9 (2017)
19. Silva, R.V., de Brito, J., Dhir, R.K.: The influence of the use of recycled aggregates on the compressive strength of concrete: a review. Eur. J. Environ. Civ. Eng. **19**(7), 825–849 (2015)
20. Silva, R.V., de Brito, J., Dhir, R.K.: Tensile strength behaviour of recycled aggregate concrete. Constr. Build. Mater. **83**, 108–118 (2015)
21. Silva, R.V., de Brito, J., Dhir, R.K.: Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. J. Clean. Prod. **112**(4), 2171–2186 (2016)
22. Limbachiya, M.C., Leelawat, T., Dhir, R.K.: Use of recycled concrete aggregate in high-strength concrete. Mater. Struct. **33**, 574–580 (2000)
23. UNI EN 12620: Aggregates for concrete (2008)
24. UNI 8520-1: Aggregates for concrete. Additional provisions for the application of EN 12620 Part 1: Designation and conformity criteria (2015)
25. Abbas, A., Fathifazl, G., Isgor, O.B., Razaqpur, A.G., Fournier, B., Foo, S.: Proposed method for determining the residual mortar content of recycled concrete aggregates. J. ASTM Int. **5**(1), 1–12 (2007)
26. UNI EN 12390-3: Testing hardened concrete. Part 3: Compressive strength of test specimens (2019)
27. UNI EN 12390-6: Tests on hardened concrete - Part 6: Splitting tensile strength of the specimens (2010)
28. UNI EN 12390-13: Test on hardened concrete - Part 13: Determination of the secant modulus of elasticity in compression (2013)
29. Salem, R.M., Burdette, E.G.: Role of chemical and mineral admixtures on physical properties and frost-resistance of recycled aggregate concrete. ACI Mater. J. **95**(5), 558–563 (1998)
30. Xu, J.J., Chen, Z.P., Zhao, X.Y., Demartino, C., Ozbakkaloglu, T., Xue, J.Y.: Seismic performance of circular recycled aggregate concrete-filled steel tubular columns: FEM modelling and sensitivity analysis. Thin Walled Struct. **141**, 509–525 (2019)
31. Xu, J.J., Chen, Z.P., Ozbakkaloglu, T., Zhao, X.-Y., Demartino, C.: A critical assessment of the compressive behavior of reinforced recycled aggregate concrete columns. Eng. Struct. **161**, 161–175 (2018)
32. Xu, J.J., Chen, Z.P., Xiao, Y., Demartino, C., Wang, J.H.: Recycled Aggregate Concrete in FRP- confined columns: a review of experimental results. Compos. Struct. **174**, 277–291 (2017)
33. Stochino, F., Fadda, M.L., Mistretta, F.: Assessment of RC Bridges integrity by means of low-cost investigations. Frattura ed Integrità Strutturale **46**, 216–225 (2018)
34. Stochino, F., Fadda, M.L., Mistretta, F.: Low cost condition assessment method for existing RC bridges. Eng. Fail. Anal. **86**, 56–71 (2018)
35. Sassu, M., Stochino, F., Mistretta, F.: Assessment method for combined structural and energy retrofitting in masonry buildings. Buildings **7**(3), 71 (2017)
36. Mistretta, F., Stochino, F., Sassu, M.: Structural and thermal retrofitting of masonry walls: an integrated cost-analysis approach for the Italian context. Build. Environ. **155**, 127–136 (2019)