Ανακύκλωση Σκυροδέματος-Έρευνα και Προοπτικές

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Συνδιοργανωτές

ΣΥΛΛΟΓΟΣ ΠΟΛΙΤΙΚΩΝ ΜΗΧΑΝΙΚΩΝ ΚΥΠΡΟΥ
CYPRUS ASSOCIATION OF CIVIL ENGINEERS

Πανεπιστήμιο Κύπρου
Τμήμα Πολιτικών Μηχανικών και Μηχανικών Περιβάλλοντος

Χορηγός

PHARMAKAS QUARRIES GROUP

Recycling of Construction Waste-Cyprus

Ε.Ε. Παρ. Ι(Ι), Αρ. 4550, 5.2.2016 — Ν. 3(Ι)/2016

3(Ι)/2016

ΝΟΜΟΣ ΠΟΥ ΤΡΟΠΟΠΟΙΕΙ ΤΟΥΣ ΠΕΡΙ ΑΠΟΒΛΗΤΩΝ ΝΟΜΟΥΣ ΤΟΥ 2011 ΕΩΣ 2015

Η Βουλή των Αντιπροσώπων ψηφίζει ως ακολούθως:

Συνοπτικός τίτλος. 185(Ι) του 2011 6(Ι) του 2012 32(Ι) του 2014 55(Ι) του 2014 31(Ι) του 2015.

1. Ο παρών Νόμος θα αναφέρεται ως ο περί Αποβλήτων (Τροποποιητικός) Νόμος του 2016 και θα διαβάζεται μαζί με τους περί Αποβλήτων Νόμους του 2011 έως 2015 (που στο εξής θα αναφέρονται ως «ο βασικός νόμος») και ο βασικός νόμος και ο παρών Νόμος θα αναφέρονται μαζί ως οι περί Αποβλήτων Νόμοι του 2011 έως 2016.

Τροποποίηση του άρθρου 2 του βασικού νόμου.

2. Το άρθρο 2 του βασικού νόμου τροποποιείται με την αντικατάσταση του ορισμού του όρου «Υπουργός» με τον ακόλουθο νέο ορισμό:

"«Υπουργός» σημαίνει τον Υπουργό Γεωργίας, Αγροτικής Ανάπτυξης και Περιβάλλοντος".

Αντικατάσταση του άρθρου 5 του βασικού νόμου.

3. Το άρθρο 5 του βασικού νόμου αντικαθίσταται με το ακόλουθο νέο άρθρο 5:

«Αρμόδια αρχή.

5.-(1) Αρμόδια αρχή για την εφαρμογή του παρόντος Νόμου, του Κανονισμού (ΕΚ) αριθ. 1013/2006 και του Κανονισμού (ΕΚ) αριθ.1102/2008, εξαιρουμένου του Άρθρου 1 αυτού, ορίζεται ο Υπουργός.

(2) Ο παρών Νόμος δε θίγει τις αρμοδιότητες και τις εξουσίες των αρχών τοπικής διοίκησης που

111 του 1985 απορρέουν από τον περί Δήμων Νόμο και τον περί

CYS EN -206 Concrete (Specification, Performance, Production and Conformity)

E.3 Recommendation for the use of coarse recycled aggregates

(1) This clause provides recommendations for the use of coarse recycled aggregates with $d \geq 4$ mm.

(2) Table E.2 gives limits for the replacement of natural normal-weight coarse aggregates by coarse recycled aggregates in relation to exposure classes. Table E.2 is valid for coarse recycled aggregates conforming to EN 12620 and the categories stated in Table E.3.

Table E.2 — Maximum percentage of replacement of coarse aggregates (% by mass)

Recycled aggregate type	Exposure classes			
	X0	XC1, XC2	XC3, XC4, XF1, XA1, XD1	All other exposure classes [a]
Type A: (Rc_{90}, Rcu_{95}, Rb_{10-}, Ra_{1-}, FL_{2-}, XRg_{1-})	50 %	30 %	30 %	0 %
Type B [b]: (Rc_{50}, Rcu_{70}, Rb_{30-}, Ra_{5-}, FL_{2-}, XRg_{2-})	50 %	20 %	0 %	0 %

[a] Type A recycled aggregates from a known source may be used in exposure classes to which the original concrete was designed with a maximum percentage of replacement of 30 %.

[b] Type B recycled aggregates should not be used in concrete with compressive strength classes > C30/37.

NOTE For the risk of alkali-silica reaction with recycled aggregates, see EN 12620:2002+A1:2008, G.3.2.

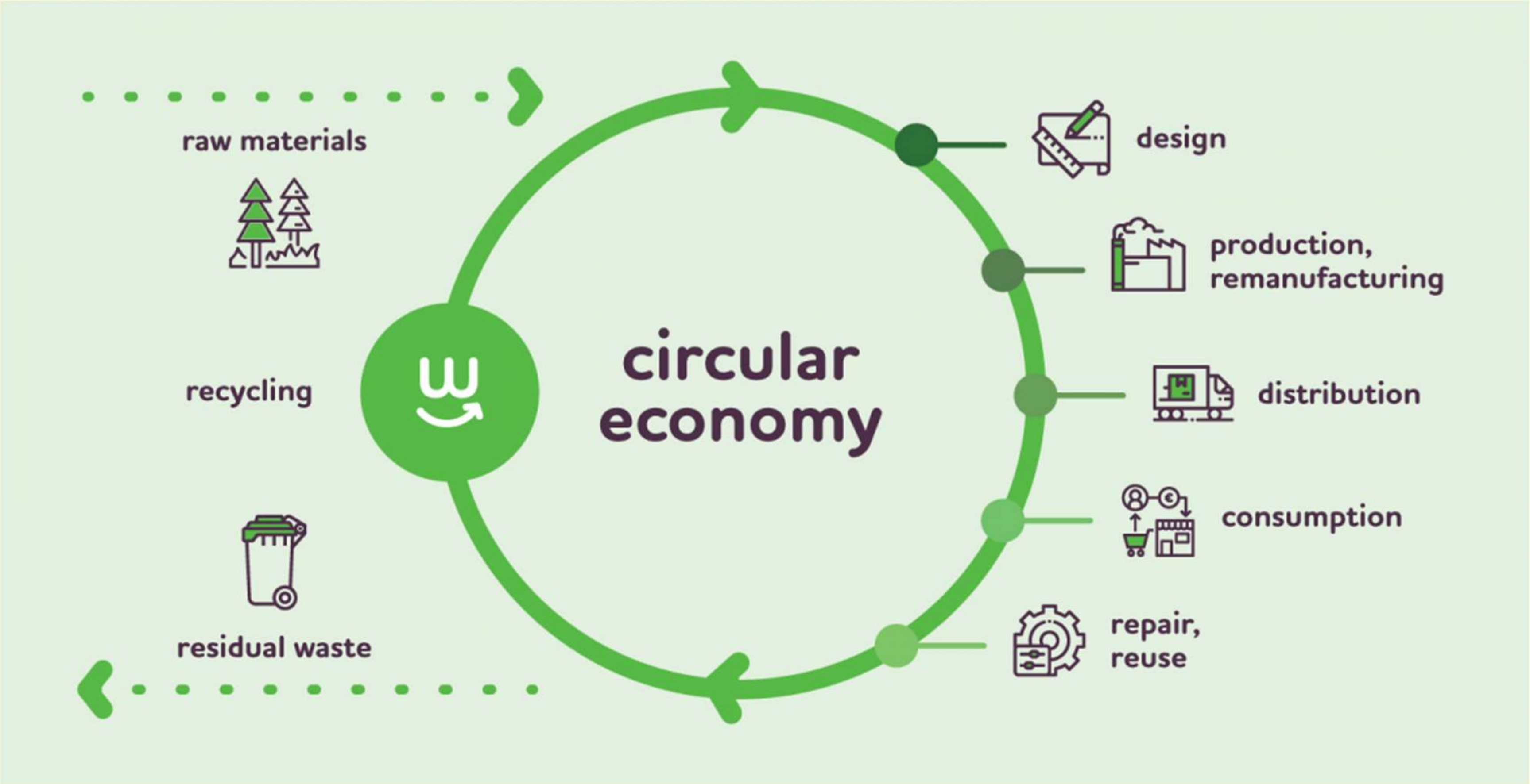
Table E.3 — Recommendations for coarse recycled aggregates according to EN 12620

Property [a]	Clause in EN 12620:2002+A1:2008	Type	Category according to EN 12620
Fines content	4.6	A + B	Category or value to be declared
Flakiness Index	4.4	A + B	$\leq FI_{50}$ or $\leq SI_{55}$
Resistance to fragmentation	5.2	A + B	$\leq LA_{50}$ or $\leq SZ_{32}$
Oven dried particle density ρ_{rd}	5.5	A	≥ 2 100 kg/m^3
		B	≥ 1 700 kg/m^3
Water absorption	5.5	A + B	Value to be declared
Constituents [b]	5.8	A	Rc_{90}, Rcu_{95}, Rb_{10-}, Ra_{1-}, FL_{2-}, XRg_{1-}
		B	Rc_{50}, Rcu_{70}, Rb_{30-}, Ra_{5-}, FL_{2-}, XRg_{2-}
Water soluble sulfate content	6.3.3	A + B	$SS_{0,2}$
Acid-soluble chloride ion content	6.2	A + B	Value to be declared
Influence on the initial setting time	6.4.1	A + B	$\leq A_{40}$

[a] Category NR (no requirements) applies for all other properties not stated in this table for which a category NR can be declared according to EN 12620.

[b] For special applications requiring high quality surface finish the constituent FL should be limited to category $FL_{0,2-}$.

Circular Economy



Recycling of Construction Waste-Cyprus

Advantages of RCA

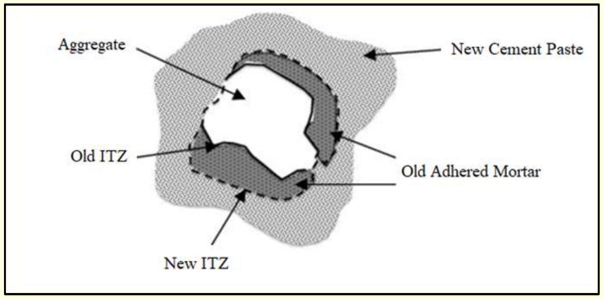
- Preserve natural resources
- Decrease landfill waste
- Less energy consumption
- Reduce CO_2 emissions
- Decrease production cost

Disadvantages of RCA

- Decrease mechanical and durability properties
- Bonding between new and old adhered mortar → Secondary IT
- Reduced workability
- Increase porosity and water absorption

Recycled Concrete Aggregate

- Lower quality due to existence of cement paste, impurities and micro-cracks
- Non-uniform quality



The interfacial transition zones in the recycled aggregate concrete

Property	Result	Reference
Mortar amount	up to 60%	Sanchez de Juan and Gutierrez, 2009, Butler et al. 2011, Tu et al., 2005
Absorption	3-15%	Rao et al, 2006, Poon et al. 2004
LA value	up to 30% more losses	Tabsh and Abdelfatah, 2009, Thomas et al., 2013, Tu et al., 2005
Soundness	up to 30% more losses	Tu et al. 2005, Nagataki et al., 2004
Density	2200 to 2400 kg/m^3	Poon et al. 2004

Effect of RCA on Concrete

Property	Result	Reference
Compressive strength	drop up to 30%	Etxeberria, et al., 2007, Katz, 2003, Poon et al. 2004
Flexural stength	drop up to 10%	Rao et al. 2006, ACI 555R-01
Modulus of Elasticity	drop up to 45%	Xiao et al. 2012, Kou & Poon, 2013, Rao et al. 2006
Splitting tensile strength	drop up to 35%	Xiao et al. 2012., Tabsh et al. 2009, Matias el al. 2013
Resistance to Chloride penetration	drop up to 10%	Kou & Poon, 2013
Sorptivity	38% higher	Olorunsogo & Padayachee, 2002
Porosity	16% higher	Rao et al., 2006

Mineral Admixtures

Fly ash

Spherical, 10-15 μm

Surface Area: 300 m^2/kg

- Delayed pozzolanic reaction
- Low early strength
- Improved durability properties
- Better workability

Silica fume (microsilica)

Spherical, less than 1μm

Surface Area: 15000 m^2/kg

- Quick pozzolanic reaction
- High level of fineness
- Improved durability properties
- Increased water demand
- Increased shrinkage

Synergistic effect:

- Much higher resistance to chloride ion penetration
- Denser microstructure “filler effect”

Research Significance

Examine the effect of:

- Different replacement ratios of RCA, 50% and 100%
- Shape and texture of aggregates on workability

Key elements:

- Three types of RCAs
- Use of a treatment method that decreased the amount of cement paste
- Quantification of the cement paste before and after the treatment
- Mineral admixtures as partial replacement of cement and their combined effect
- Cost analysis of the actual mixtures that were cast

Recycled Concrete Aggregates (Coarse)

- RCA-L, Laboratory
- RCA-F, Field
- RCA-T, Treated

(Skyrra Vassas Ltd)

Field vs. Treated Recycled Aggregates

Experimental Procedure

Property	Standard
Aggregates	
Density/absorption	EN 1097-6:2000
Resistance to fragmentation (Los Angeles)	EN 1097-2:2010
Soundness (magnesium sulphate test)	EN 1367-2:2009
Hardened concrete	
Compressive strength	EN12390-3:2009
Flexural strength	EN 12390-5:2009
Splitting tensile strength	EN 12390-6:2009
Modulus of elasticity	ASTM C 469 – 02
Rapid chloride permeability	ASTM C 1202-97

Experimental Procedure

Constituents	Quantity (kg/m³)
Cement	400
Water	192.5
Coarse Aggregates 8/20 mm	655.4
Coarse Aggregates 4/10 mm	263.8
Sand 1 (natural sand) 0/4 mm	559.5
Sand 2 (extra fine limestone)	108.4
Superplasticizer	6.4

Experimental Procedure

Series 1

Mixtures	Replacement ratio	Type of aggregate
Control	0%	Natural
RL100	100%	RCA-L
RF100cs	100%	RCA-F
RF100ps	100%	RCA-F
RF100	100%	RCA-F
RT100	100%	RCA-T
RF50	50%	RCA-F
RT50	50%	RCA-T

Series 2

Mixtures	Replacement ratio	Type of aggregate	Fly Ash	Microsilica
RF100F25	100%	RCA-F	25%	0%
RF100F25S5	100%	RCA-F	25%	5%
RT100F25	100%	RCA-T	25%	0%
RT100F25S5	100%	RCA-T	25%	5%

Experimental Results

- Properties of aggregates

Properties	NA	RCA-T	RCA-F	RCA-L
LA	29	15	32	29
Apparent Particle Density (Mg/m^3)	2.69	2.74	2.72	2.60
Particle Density (Mg/m^3)	2.52	2.49	2.28	2.21
Particle Density in SSD (Mg/m^3)	2.58	2.58	2.44	2.37
Moisture Content (%)	0.5-0.6	2.6-2.8	2.7-2.9	2.1-2.2
W.A. 24 (%)	2.5	3.7	7.2	7.0
Soundness (%)	30	14	41	-
Mortar content (%)	0	9	24	23

Experimental Results

- Slump test results (slump target value 200 ± 30 mm)

Mixtures	Slump (mm)	Superplasticizer (Kg/m^3)	Superplasticizer/ cement ratio (%)
Control	198	3.50	0.87
RL100	220	3.00	0.75
RF100cs	50	3.50	0.87
RF100ps	190	2.50	0.62
RF100	170	4.60	1.15
RT100	185	2.50	0.62
RF50	194	3.25	0.81
RT50	195	2.00	0.50
RF100F25	170	5.90	1.48
RF100F25S5	190	6.25	1.56
RT100F25	196	2.58	0.65
RT100F25S5	195	2.90	0.73

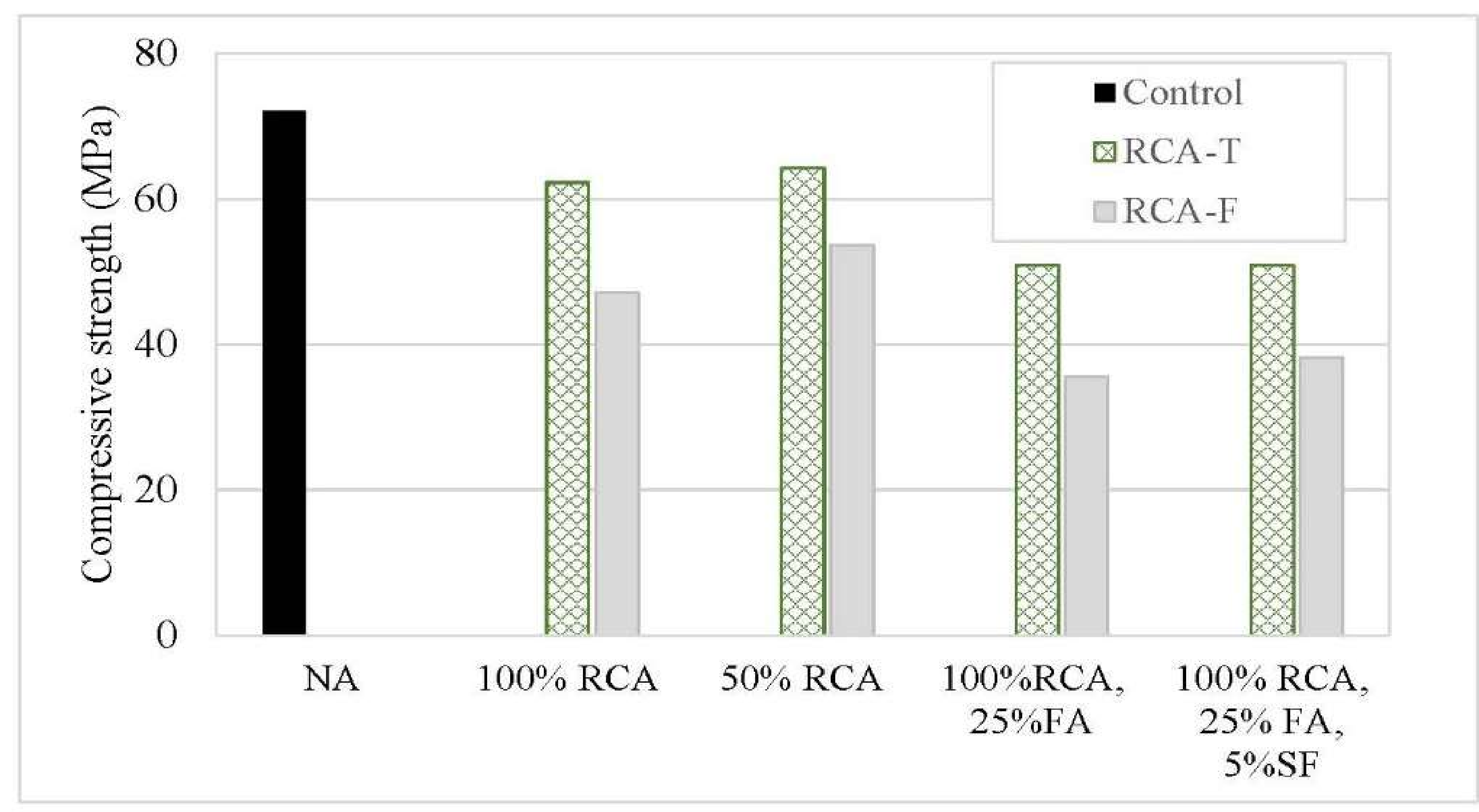
Experimental Results

- **Compressive strength test results (MPa)**

Mixtures	7 days	28 days (S.D)	56 days
Control	58.5	72.1 (0.8)	
RL100	45.8	60.0 (3.1)	
RF100cs	38.6	47.5 (1.9)	
RF100ps	39.5	50.6 (1.7)	
RF100	39.1	47.1 (2.2)	
RT100	40.8	62.2 (4.1)	
RF50	43.6	53.6 (1.0)	
RT50	50.6	64.2 (1.7)	
RF100F25	29.1	35.6 (2.4)	46.4
RF100F25S5	26.0	38.2 (1.4)	45.8
RT100F25	36.0	50.8 (3.0)	58.2
RT100F25S5	34.2	50.9 (3.0)	60.3

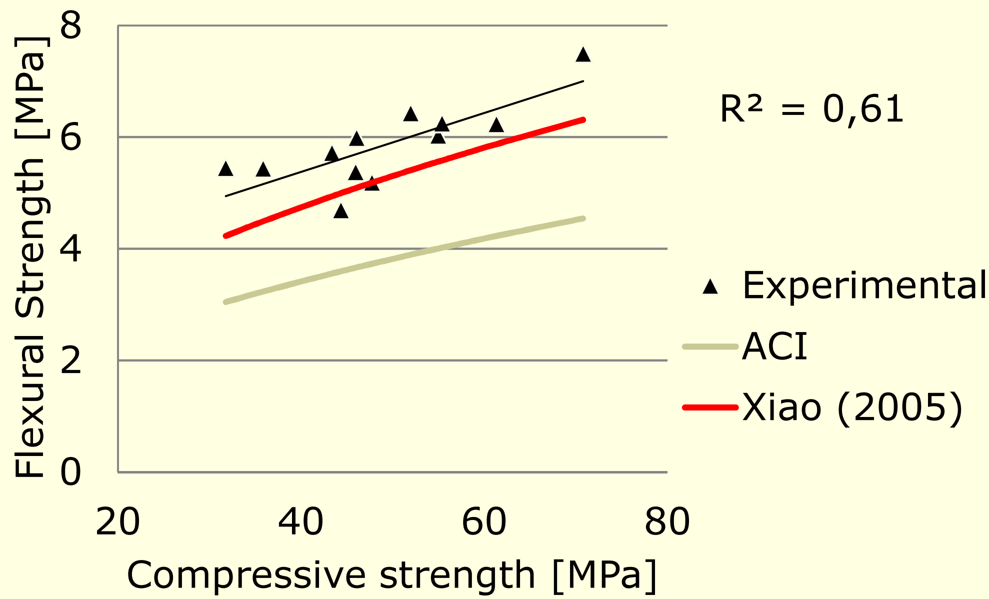
RL (Laboratory) - RF (Field) - RT (Treated)

Effect of Treatment



Experimental Results

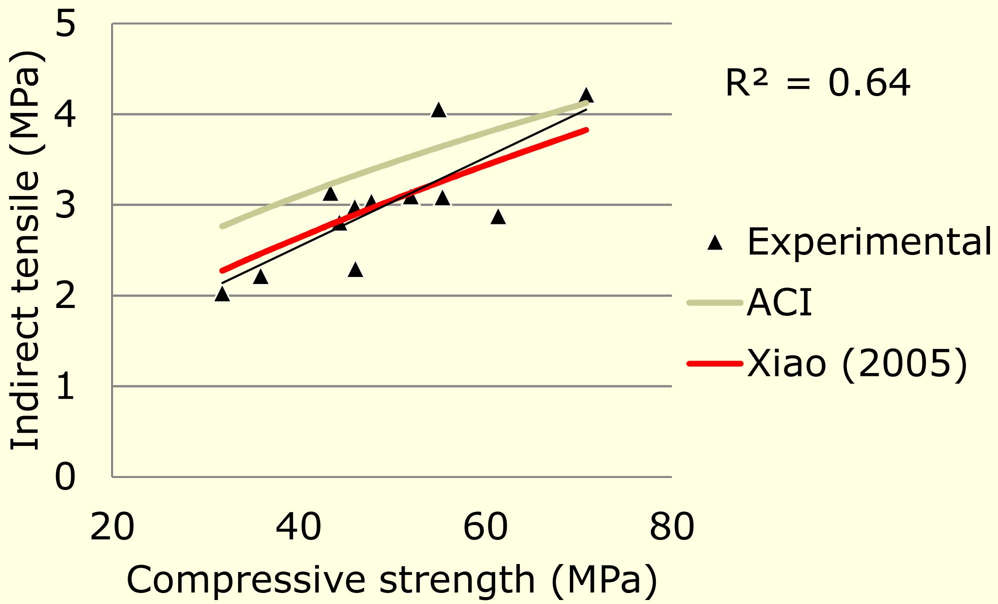
Mixtures	Flexural strength (MPa)
Control	8.6
RL100	6.9
RF100cs	5.4
RF100ps	6.0
RF100	6.6
RT100	7.2
RF50	7.4
RT50	7.2
RF100F25	6.3
RF100F25S5	6.3
RT100F25	6.2
RT100F25S5	6.9



- Decreased with the increase of the replacement ratio
- RF100ps < RF100
- RT100>RF100
- Underestimated by current equations
- Minor effect of mineral admixtures

Experimental Results

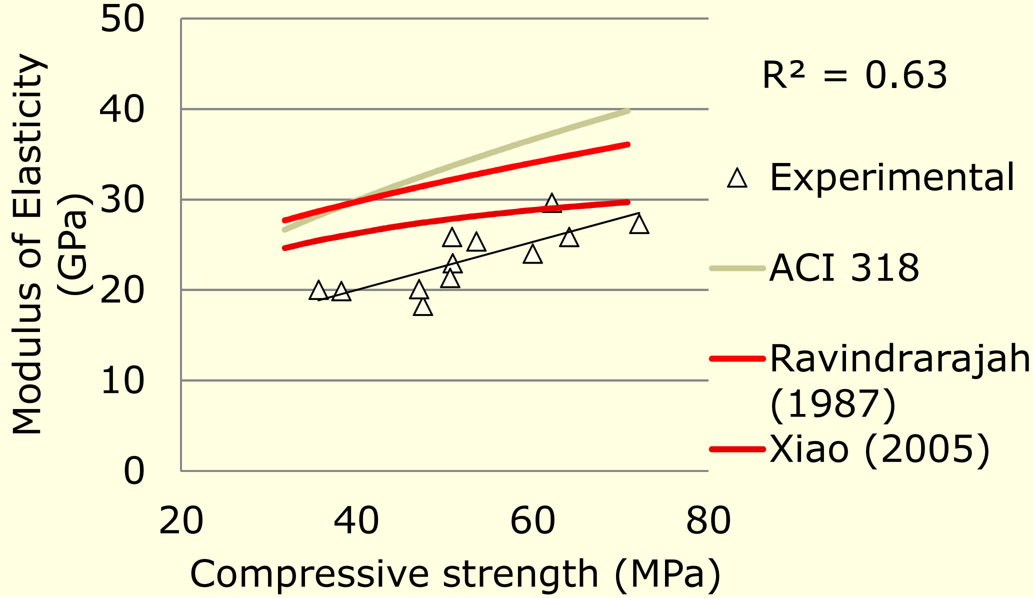
Mixtures	Splitting tensile stength (MPa)
Control	4.22
RL100	4.06
RF100cs	2.81
RF100ps	3.04
RF100	3.14
RT100	3.09
RF50	3.10
RT50	2.88
RF100F25	2.03
RF100F25S5	2.22
RT100F25	2.98
RT100F25S5	2.30



- RF100ps < RF100
- Overestimated by ACI equation
- Minor effect of mineral admixtures
- RL100 > RT100

Experimental Results

Mixtures	Modulus of elasticity (GPa)
Control	27.28
RL100	24.03
RF100cs	18.25
RF100ps	21.33
RF100	20.09
RT100	29.64
RF50	25.37
RT50	25.85
RF100F25	20.00
RF100F25S5	19.89
RT100F25	25.84
RT100F25S5	22.97

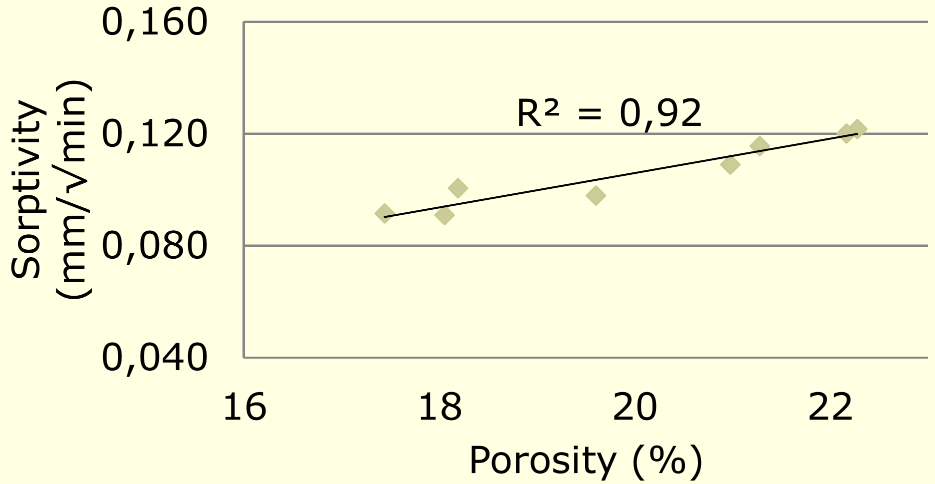


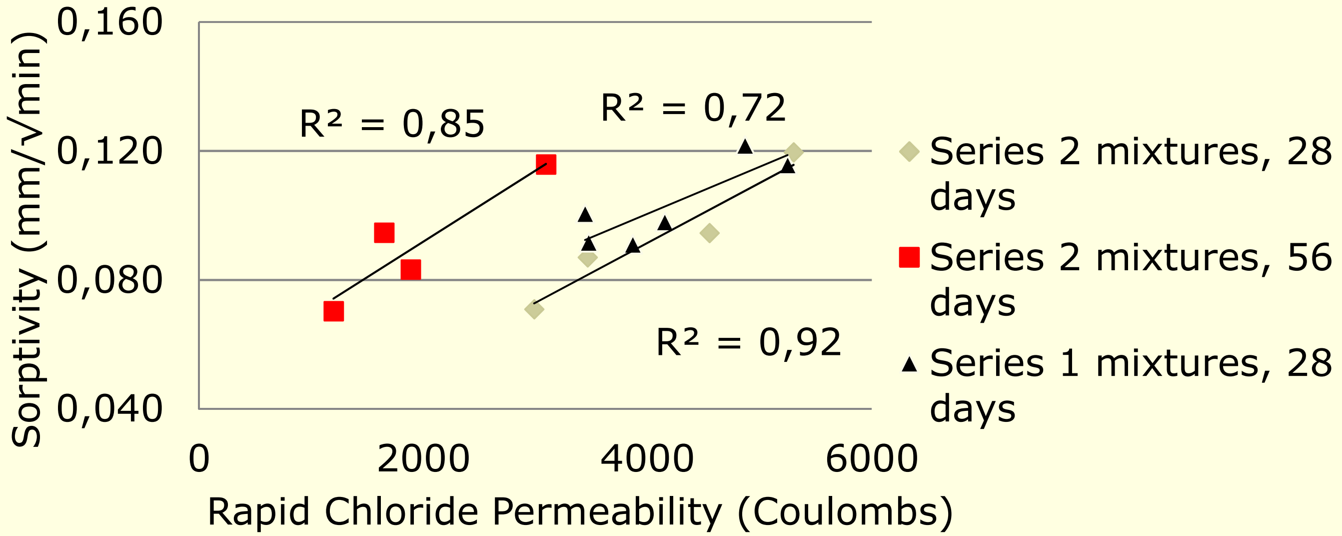
- Overestimated by current equations
- RT100> Control
- Negative effect of mineral admixtures

Experimental Results

Mixtures	Density (Kg/m^3)	Porosity (%)		Rapid Chloride Permeability (Coulombs)		Sorptivity ($mm/\sqrt{min}$)	
Control	2169	17.44		3473		0.092	
RL100	2017	22.28		4870		0.122	
RF100cs	2035	22.17		4861		0.120	
RF100ps	2049	20.98		5822		0.109	
RF100	2033	21.28		5248		0.116	
RT100	2157	18.19		3444		0.101	
RF50	2076	19.60		4154		0.098	
RT50	2139	18.05		3867		0.091	
Days of curing	28	28	56	28	56	28	56
RF100F25	2000	22.47	22.35	5303	3095	0.120	0.116
RF100F25S5	2012	22.41	22.76	3466	1652	0.087	0.095
RT100F25	2122	18.95	18.73	4553	1887	0.095	0.083
RT100F25S5	2101	19.05	18.19	2989	1200	0.071	0.070

Experimental Results





Cost Analysis

Cost of materials

Materials	Cost
Cement	84.0 €/tn
NA	9.3 €/tn
RCA-F	3.5 €/tn
RCA-T	6.5 €/tn
Sand	10.8 €/tn
Superplasticizer	3.3 €/lt
Fly Ash	200.0 €/tn
Microsilica	250.0 €/tn
Water	0.9 €/tn

Cost of mixtures

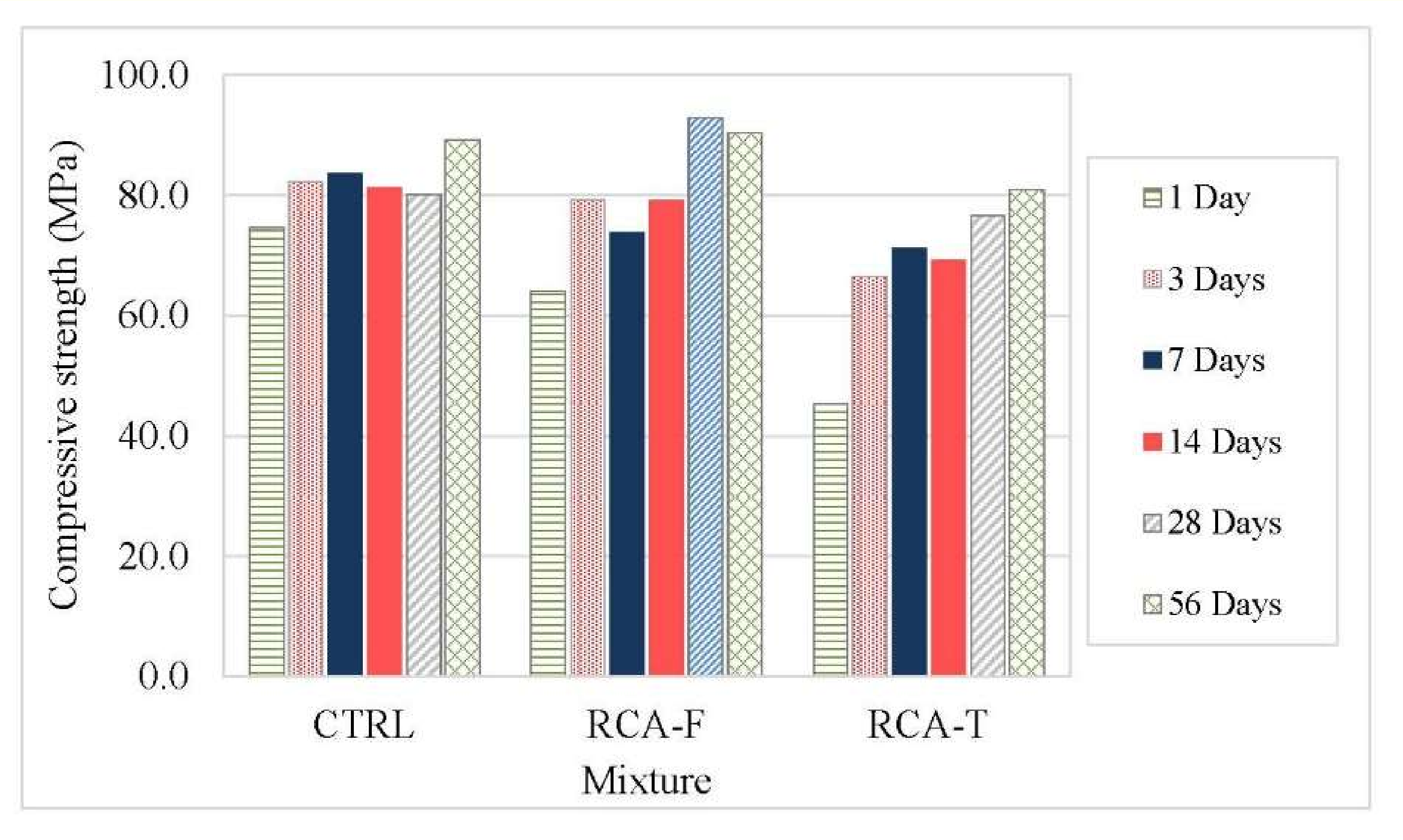
Mixtures	Total cost (€)	€/MPa	Cost (€) with 5% more cement
Control	58.5	0.8	-
RT100	53.4	0.9	55.7
RF100	58.3	1.2	60.6
RF50	55.7	1.0	58.0
RT50	52.6	0.8	54.9
RF100FA25	74.2	1.6	76.5
RF100F25S5	78.7	1.7	81.0
RT100F25	65.3	1.1	67.5
RT100F25S5	69.6	1.2	71.9

- RCA-T mixtures are cheaper than RCA-F due to the less amount of superplasticizer
- RT50 mixtures is cheaper than Control and demands equal €/MPa
- The high cost of mineral admixtures may prohibit their use

Conclusions

- RAC demonstrated adequate strength and durability properties
- The treatment method reduced the cement paste from 24% to 9.2%, that resulted to great improvement on both aggregate and concrete properties
- For a replacement ratio of 100% the compressive strength losses were 16.8%, 34.1% and 13.8% using RCA-L, RCA-F and RCA-T respectively
- The durability properties were greatly improved with the incorporation of mineral admixtures without compromising the mechanical properties
- The slump values were affected negatively using RCA-F aggregates
- Presoaking RCA had some positive effect on compressive strength, modulus of elasticity and sorptivity of concrete

Internal Curing



Conclusions from Literature (ACI 555R-01)

5.5.4 *Mixture proportioning*—The following are guidelines for developing for mixture proportions using recycled concrete aggregates:

- To determine a target mean strength on the basis of a required strength, a higher standard deviation (700 psi [4.83 MPa]) should be used when designing a concrete with recycled concrete aggregates of variable quality than when recycled aggregate of uniform quality or virgin aggregates are used;
- At the design stage, it may be assumed that the *w/c* for a required compressive strength will be the same for recycled aggregate concrete as for a conventional concrete when coarse recycled aggregate is used with conventional sand. If trial mixtures show that the compressive strength is lower than assumed, an adjustment to a lower *w/c* should be made;

Conclusions from Literature (ACI 555R-01)

5.6—Concrete production

Although concrete production (batching, mixing, transporting, and placing) of recycled aggregate concrete is similar to the conventional concrete, additional care should be taken when manufacturing recycled aggregate concrete. The following items are recommended for production of recycled aggregate concrete:

1) An important requirement of all recycled aggregate concrete is presoaking the aggregates to offset the high water absorption of the recycled aggregates (Hansen 1986); and

2) Materials smaller than No. 8 sieve (approximately 2 mm) be eliminated from aggregates prior to production.

Research Team

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Enhancing mechanical and durability properties of recycled aggregate concrete

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Recycling of Construction Waste-Cyprus

ΣΑΛΑΜΙΝΑ