PHARMAKAS QUARRIES GROUP

Construction Industry and Concrete Recycling

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ΛΑΤΟΜΕΙΑ ΓΕΝΝΑΔΙΟΣ · powermix · PHARMAKAS BETON · PHARMAKAS CEMENT · ΚΑΖΑΝΟΣ BETON · ERIK · PHARMAKAS KEDRIS ASPHALT · UNIFAST

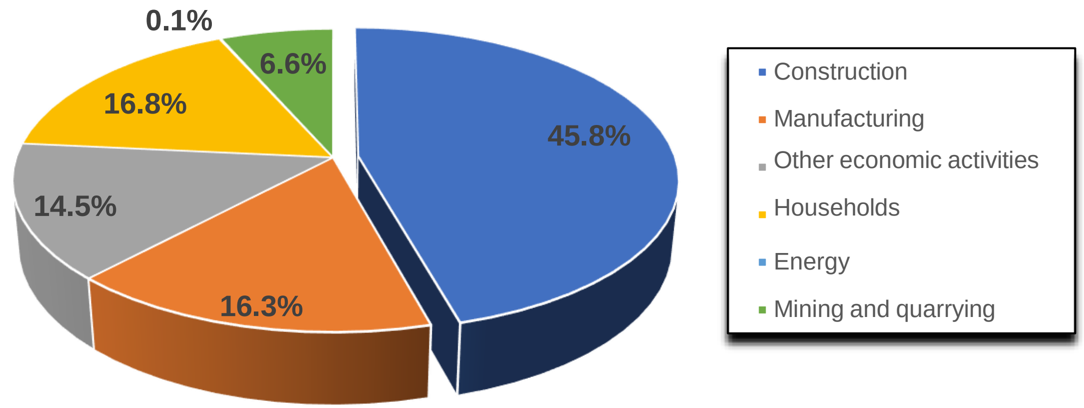
Legislation covering the CDW recycling in Cyprus

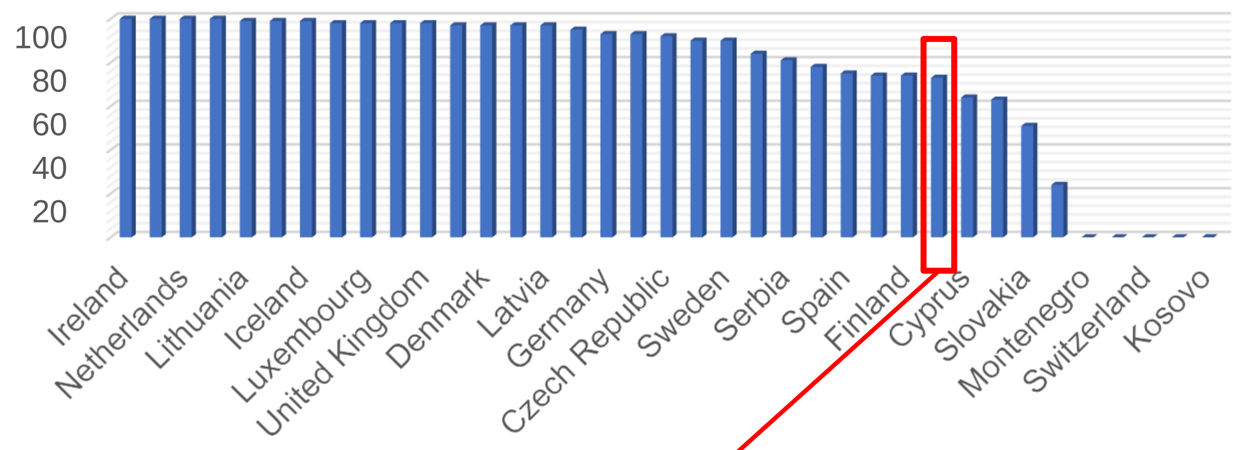
CDW materials according to Cyprus Legislation (N.185(I)/2011)
and (Κ.Δ.Π. 159/2011 & Κ.Δ.Π. 220/2013)

Concrete, bricks and tiles

- Non-hazardous asphalt mixtures
- Soil, rocks and excavation materials
- Insulating materials
- Gypsum based building materials
- Disposable materials from demolitions

Waste Generation and Recovery Rate of CDW in Cyprus





- Lowest EU rates→ **64%**
- Increased compared with 2014 **(38%)** and 2016 **(57%)**

- CDW in EU → 36%
- CDW in Cyprus → 45.8%

↑ **10%**

2008/98/EK

- Recycling /Reused /Recovered at least 70% of CDW up to 2020
- Several European members did not comply, managing to reach below 50%
- Main issues were located on the lack legislations and observance
- An uncertainty is also located within the buyer's mind, mostly due to the lack of awareness and motivation
- Cyprus has decided to implement the installation of GPS tracking system because several trucks were disposing in unknown and hard to track areas (philenews, 28.12.21)

Problems arising during recycling

Problems located from the Recycling Bodies

- A Gap between the Public works and Private Works has been observed, indicating lack of compliance
- There is no circular information to record the exact data of the quantities reintegrated in the market

Problems located from the units that receive and Manage CDW

- There is a lack of quality and proper state of the materials upon delivery, that increases the complexity and work-load
- There is no competitive advantage and thus no interest from people and private companies towards purchasing and using recycled materials

Problems located during our long research experience

- The products screening is not easy to be executed by hand, because large volumes are inserted
- We are developing innovative methods of screening within an ongoing research project under the supervision of Dr. Demetris Nicolaides
- The legislation exists, the supervision and motivation need to be enhanced in order to enforce each body to act consciously and consistently

The effort of the researching bodies involved is to develop the required technical knowledge to use recycled materials without compromising the final quality. The legislators and supervising bodies have to fulfil the gaps within, in order to close this cycle of recycling and allow a fully reintegration and environmental preservation

Lack of political will

- There is low political will to tackle the issue of illegal CDW disposal.
- Major delays in the application of the laws and complementary regulations for CDW.
- Low organizational capacity for implementation and/or enforcement of the law.
- Delays in administration of fines or non-conviction of CDW management rules violators

Mentality in the construction sector

- General mentality in the construction sector (and of the general public in Cyprus) is that CDW is not considered to be a waste stream that requires immediate attention and treatment. It can be disposed somewhere and left there, since its inert nature makes it harmless for human health and the environment.
- Contractors prefer to avoid the cost of CDW management.
- General lack of skills and knowledge to organize effective systems of CDW management.
- No market/no demand for recycled CDW, natural materials are always preferred over recycled materials in the construction works.

Lack of treatment facilities and low territorial network

- The current network of CDW treatment facilities is not sufficient to cover the total amount of generated CDW in the whole territory of Cyprus

Lack of incentives for recycling

- There is no landfill tax or other adequately deterrent financial instruments for diverting CDW from landfilling to recovery.
- Cost of recovery activities is higher than the prices of the recycled end-product. No pull effect from market conditions.
- No standards for recycled materials

One-day academic & workgroup seminars

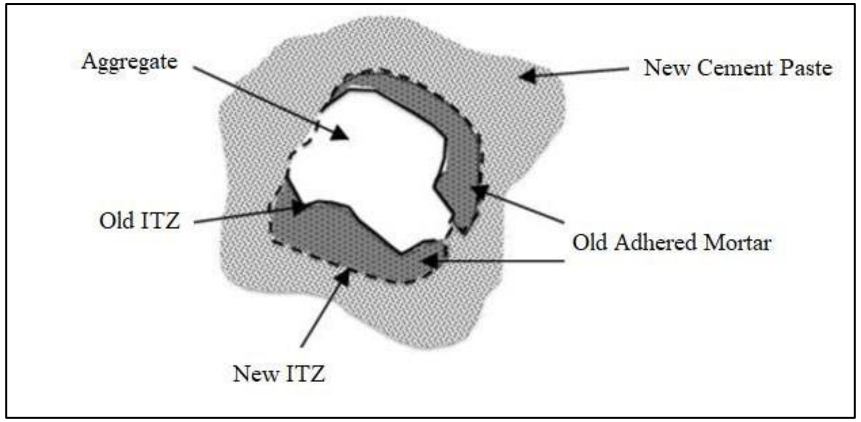
Characteristics of RCA

+ Advantages

- Reduce CO2 emissions
- Decrease production cost
- Preserve natural resources
- Decrease Landfill Waste
- Less energy consumption

− Disadvantages

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



WP4

RCA Treatment and Internal Curing Design

- Partial removal of adhered RCA mortar
- **Small-Scale:** Rotating drum mixer (0.5 rps) for RCA
- Time intervals 1,2,3,4 and 5 hours → optimum
- Inclusion of water (weakens the adhered mortar)
- 8/20 mm and 4/10 mm RCA fractions
- **Large-scale:** Rotating drum mixer (0.2 rps) for RCA and NA
- Mass Loss and Circularity → Significance
- GIPM and ImageJ

$$Residual\ Mortar = \frac{m_1 - m_2}{m_1} * 100$$

where

m_1 dried mass before treatment (g)

m_2 dried mass after treatment (g)

and

$$Circularity = \frac{4 * \pi * A}{P^2}$$

where

A area of the aggregate (mm^2)

P perimeter of the aggregate (mm)

Preparation and Testing of Aggregates

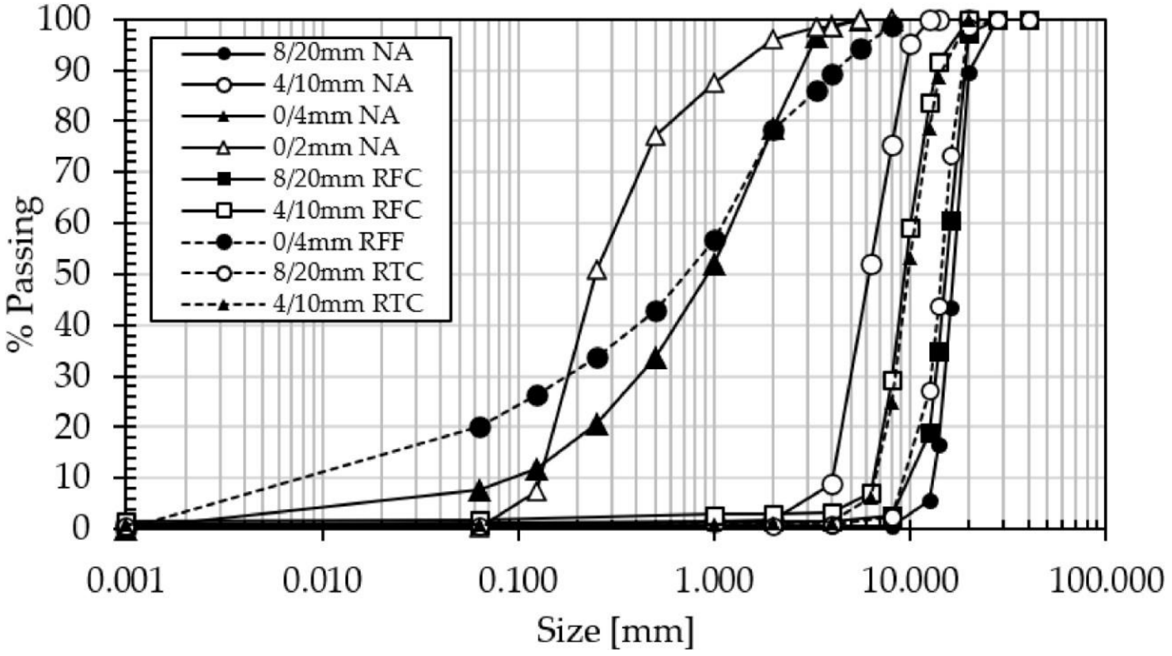


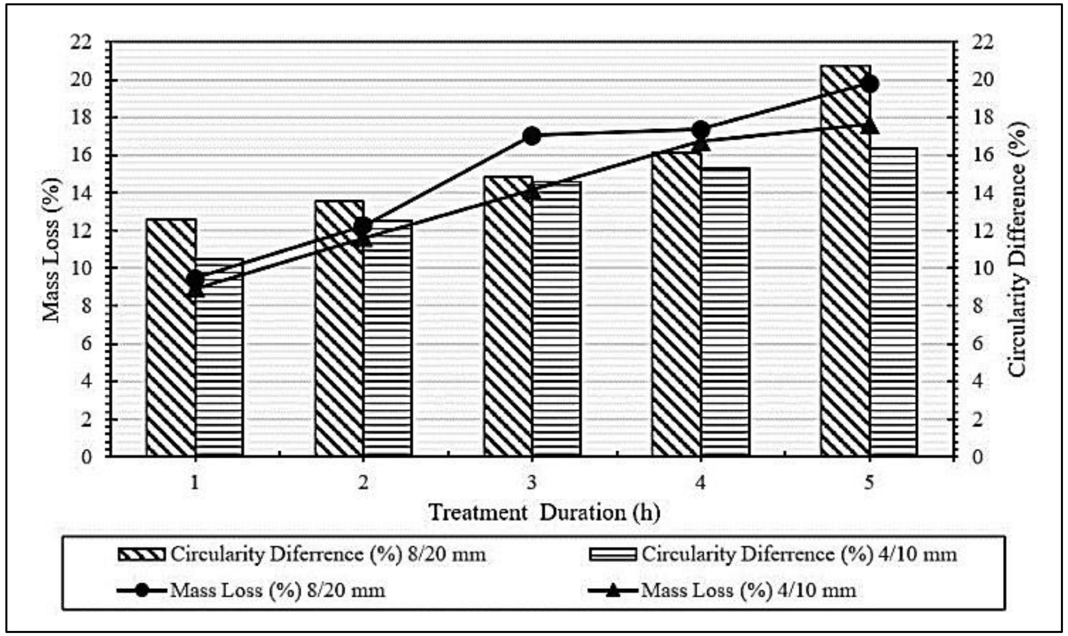
Table 2: Aggregate Density and Absorption

	Apparent Particle Density, ρ_a (Mg/m^3)	Particle Density, ρ_{rd} (Mg/m^3)	Particle Density in SSD, ρ_{ssd} (Mg/m^3)	Water Absorption WA24 (%)
NA 8/20 mm	2.79	2.50	2.60	4.1
NA 4/10 mm	2.73	2.47	2.57	3.8
NA 0/4 mm	2.55	2.27	2.38	4.9
VRCA 8/20 mm	2.71	2.43	2.53	4.4
VRCA 4/10 mm	3.01	2.52	2.68	6.5
VRCA 0/4 mm	2.60	2.30	2.41	5.0
TRCA 8/20 mm	2.65	2.40	2.49	4.0
TRCA 4/10 mm	2.73	2.43	2.54	4.5

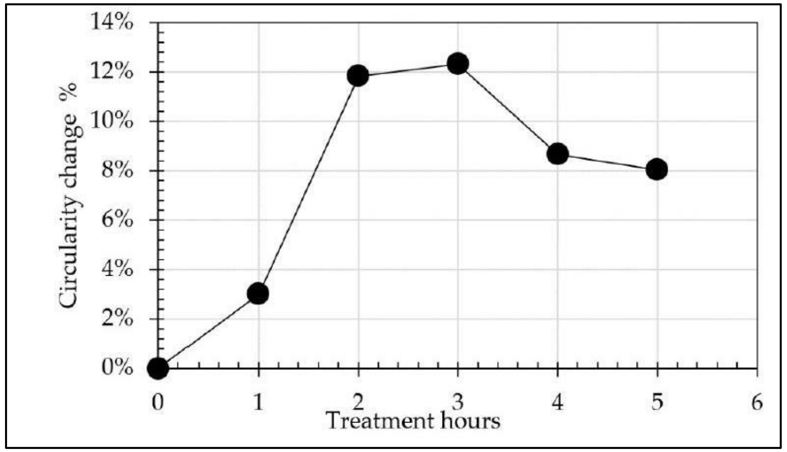
Table 3: Aggregate Flakiness Index, Shape Index and Abrasion Resistance

	Flakiness Index (FI)	Shape Index (SI)	Los Angeles (%)
NA 8/20 mm	7	9	-
NA 4/10 mm	16	9	29
VRCA 8/20 mm	5	16	-
VRCA 4/10 mm	5	7	32
TRCA 8/20 mm	6	15	-
TRCA 4/10 mm	4	5	-

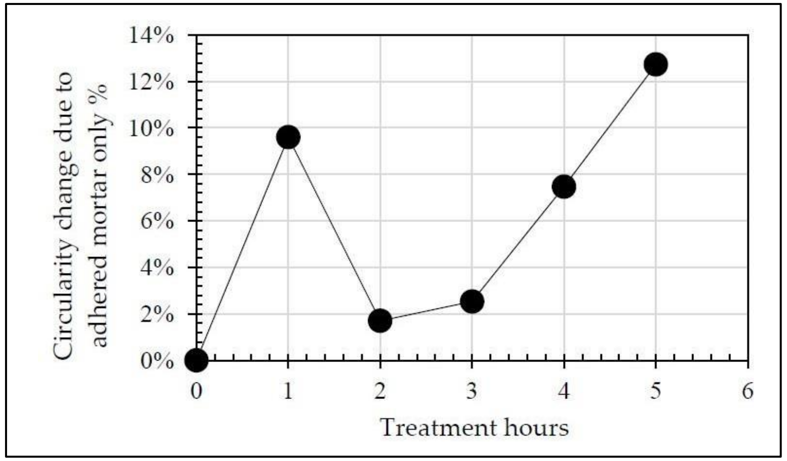
RCA Treatment and Internal Curing Design



- 8/20 mm → 20% mass loss and 21% circularity differences (5 h)
- 4/10 mm → 18% mass loss and 17% circularity differences (5 h)
- Optimum duration: **3 h** → Considering economic parameters and energy consumption
- Circularity beyond 3 h treatment duration
- Sole effect of adhered mortar → 1 h
- Crushing effect > 4 h



Effect of large-scale treatment hours on the particle size distribution on natural crushed aggregates (NA) 8/20 mm



Effect of treatment hours on the difference between circularity changes of RCA and NA 8/20 mm

Concrete Mixture Design

Concrete mixture preparation procedures and tests

Before the mixture:

- Mix design calculations and preparations
- Preparation of moulds and materials

Mixture procedure:

- Wet inner surfaces of drum of concrete mixer, all necessary tools and slump test equipment
- Placed in the mixer coarse aggregates first then sand and then cement
- Dry mixing all the materials for 1.5 to 3 min.
- Gradually add correct quantity of water (mixed with admixtures if necessary) while machine is in motion.
- Add extra admixtures if necessary
- Mix for 2 minutes minimum

Fresh state concrete tests:

- Temperature measurements
- Slump test
- Bulk density test

Concreting:

- Casting mixture to the moulds
- Vibrate
- Covering moulds with wet burlaps for 24h

Fig.1: Preparation of molds

Fig.2: Weighing and preparing materials for the mixture

Fig.3: Adding all the materials to the mixer

Fig.4: Adding admixtures

Fig.5: Measuring temperature

Fig.6: Slump test

Fig.7: Slump measurement

Fig.8: Vibrating table

Fig.9: Bulk density measurement

Fig.10: 24h curing with wet burlap

Concrete Testing

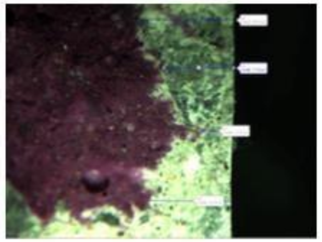


Fig.1: Carbonation Depth

Fig.2: Length Measurements

Fig.3: Rapid Chloride Permeability Cells

Fig.4: Splitting Tensile Strength Cylinders after testing

Fig.5: Modulus of Elasticity Measurements

Fig.6: Open Porosity Vacuum Desiccator

General Remarks about the experimental results

- Compressive strength 25% RCA replacement enhanced **regardless** w/c ratio, RCA type and size

- Reference mixtures have not observed the lowest Rapid Chloride Permeability values

- Mixtures with recycled aggregates have similar and not the highest drying shrinkage in comparison with reference mixtures

- Soaking recycled aggregates benefits the final product due to the internal curing mechanism

Life Cycle Inventory Analysis (LCI)

For the compilation of the LCI dataset, the LCA utilizes data from the following different sources:

- Latomia Pharmakas PLC, a group of companies that operates a quarry with the largest production facility in Nicosia, as well as 3 (another 3 units are being developed, expanding the company services in Larnaca) and ready-mix concrete production facilities

- International Databases, both open-access (ELCD -European reference Life Cycle Database) and also commercially available (Ecoinvent 3)

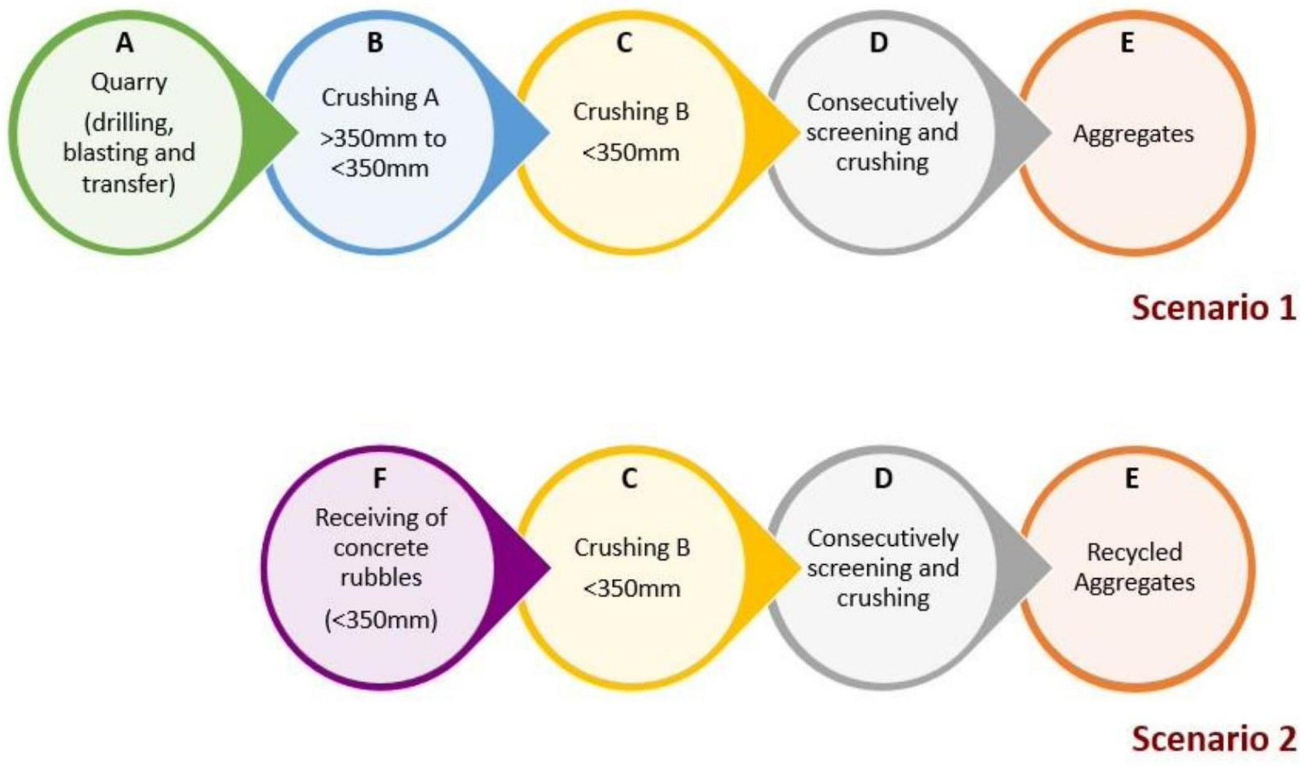
- Existing LCA studies, extracted from Scopus database

- Available scientific literature, such as studies, scientific analyzes and results from research projects on the production of aggregates

- To a low extent, calculated data, derived based on assumptions and on the experience of the authors

Scenarios – Case studies

Two concrete production scenarios were examined with main difference in the method and the type of material supply of the production unit.

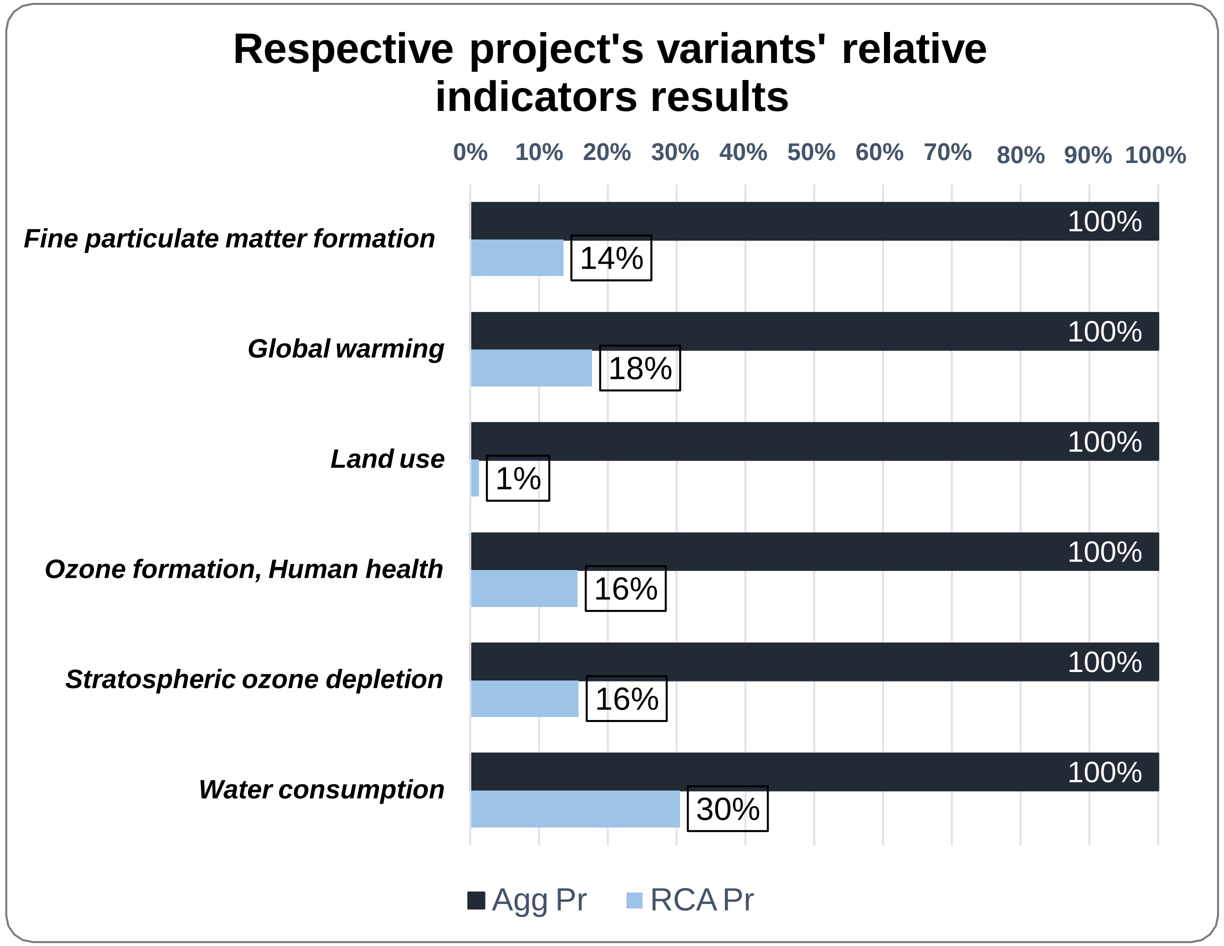


Life cycle impact assessment (LCIA) - Results

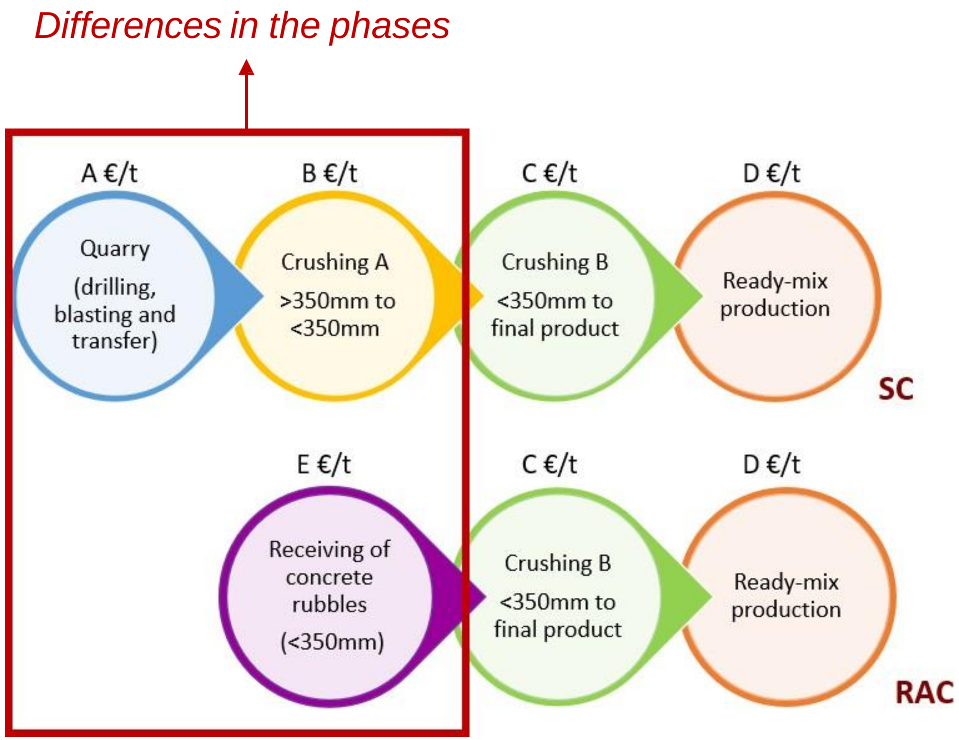
Indicator *	Agg Pr	RCA Pr	Unit
Fine particulate matter formation	0.31	0.042	Kg PM2.5 eq
Global warming	115.33	20.44	Kg CO2 eq
Land use	38.36	0.489	m2a crop eq
Ozone formation, Human health	0.64	0.10	Kg NOx eq
Stratospheric ozone depletion	0.000057	0.000009	Kg CFC11 eq
Water consumption	175.63	53.52	m3

** Six mid-point impact categories have been selected, as defined in the International Reference Life Cycle Data System/ILCD – version August 2016 (Hauschild et al., 2013) and cited by the Joint Research Center (Joint Research Center, 2012)*

Results are given in absolute values and are expressed per module (Functional Unit: 1 kg aggregates).



Techno-economic Analysis (TA)



RAC CAPITAL EXPENSES	
Category	**Cost**
Land purchase	0
Construction of infrastructure	0
Fixed equipment	0
Mobile equipment	0
TOTAL	0

OPERATION EXPENSES		
Category	**Cost (€/t)**	
	Natural A.	**Recycled A.**
Land rent	0	0
Energy consumption	x	x-0.22
Water consumption	0	0
Maintenance - Operating personnel - Consumables	y	y-0.02
Raw materials – extraction	1.25	0
Raw materials – concrete rubbles	0	-1.00
Environmental fee	0	0
TOTAL	**x+y+1.25**	**(x-0.22)+(y-0.02)+(-1)**
	Difference	**-2.49**

Techno-economic Analysis (TA)

The exact amount of natural and recycled aggregates used per m3 of final product is shown in Table below.

The percentage of the recycled aggregates used instead of natural is 33,6%.

Quantity of aggregates (kg)			
Product	**Natural A.**	**Recycled A.**	**Total**
Standard concrete	1,711	0	1,711
RAPCON	1,136	575	1,711

The cost difference is calculated as shown below:

$$\Delta = 33.6\% * (T_{after} - T_{before}) = 33,6\% * (E - (A+B))\ €/t \quad (1)$$

$$\Delta = 33.6\% * ((-1) - (1.25 + 0.24)) = 33.6\% * (-2.49) = \mathbf{-\ 0.84\ €/t}$$

Techno-economic Analysis (TA)

Realistic scenarios

Annual concrete production (< 30 MPa) = 75,000 m3, with aggregates weight 1,000 kg/m3

1) For 10% partial replacement of recycled aggregates instead of natural:

Δ = -0.249 € / t. => Economic benefit ≈ ***€ 18,675.00***

2) For 30% partial replacement of recycled aggregates instead of natural:

Δ = -0.747 € / t => Economic benefit ≈ ***€ 56,000.00***

Academic manuscripts in International Journals

materials MDPI

Article

A Mechanical Treatment Method for Recycled Aggregates and Its Effect on Recycled Aggregate-Based Concrete

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Abstract: Recycle concrete aggregates (RCA) consist of natural aggregates and remnant mortar adhered to their surface. The amount, size, and morphology of the adherent remainder paste influences quality aspects of RCA, such as their bonding potential with new cement matrix in an RCA-based concrete, as well as the concrete's overall rheological and performance characteristics. The objective of this research was to study the effect of reducing the adhered mortar in RCA, by means of a mechanical treatment method, on the performance of concrete containing RCA at different

materials MDPI

Article

Effect of Mechanically Treated Recycled Aggregates on the Long Term Mechanical Properties and Durability of Concrete

Konstantina Oikonomopoulou [1], Sokrates Ioannou [2,*], Pericles Savva [3], Maria Spanou [4], Demetris Nicolaides [4] and Michael F. Petrou [1]

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Abstract: The objective of this research was to study the effect of an optimal mechanical treatment method to reduce the mortar adhered on recycled aggregates (RCA) on the long-term mechanical properties and durability of concretes containing RCA at different replacement levels. It was found that concretes incorporating treated RCA exhibited sharper and more significant increase on 90- and 365-day compressive strengths than any other investigated mixture. The same mixtures also

Academic articles in International Conferences

Mechanical and Durability Properties of Optimally Treated Recycled Concrete Aggregates

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Abstract— **The incorporation of Recycled Concrete Aggregates (RCA) aiming to produce Recycled Aggregate Concrete (RAC) mixtures tends to reduce CO_2 emissions, cost and energy consumptions; however, the existence of old cement paste (adhered mortar) attached to the surface of RCA leads to inferior fresh, mechanical and durability properties compared to conventional concrete. This paper reports on a mechanical treatment method implemented to partially remove the adhered mortar in RCA samples placed inside a rotating concrete truck mixer. The impact of the RCA with the metallic walls was determined in terms of mass loss, circularity index and image analysis within different time frames. Based on the results, the**

RCA's most common components are coarse and fine aggregates and adhered mortar. In general, even though the addition of RCA provides well-known advantages preservation of natural resources, lower quantities of waste materials into the landfills, less energy consumption and decreased cost, some concerns were also associated with concretes incorporating RCA, such as slightly poorer mechanical and durability properties [3–8]. Furthermore, the quantity of fines incorporated in the mixtures plays a crucial role on the quality of the newly formed product. High porous microstructure of RCA and therefore increased water absorption leads to increased porosities and lower densities for RAC concretes. Moreover, the presence of a secondary

Production of Recycled Aggregate Concrete Using Construction and Demolition Waste

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K. Oikonomopoulou, P. Savva, S. Ioannou, D. Nicolaides, and M. F. Petrou

Abstract The objective of this research was to evaluate the performance of concrete containing recycled aggregates of different sizes and replacement percentages. Mixtures were prepared using a combination of natural and recycled aggregates. The recycled aggregates were treated in a concrete mixer truck to partially remove the adhered cement paste in order to compare their performance in concrete as opposed to natural aggregates and non-treated recycled aggregates. One high-strength concrete series of mixtures was prepared to employ the concept of internal curing. The mixtures were tested for their mechanical properties and durability. The results showed that the addition of recycled aggregates in concrete up to a specific replacement percentage did not adversely affect the concrete properties. The specific research suggests that recycled aggregates can be a very good alternative source to reduce natural aggregates consumption and utilize waste material.

Keywords Adhered mortar · Treatment method · Mineral admixtures · Recycled concrete aggregate · Recycled aggregate concrete · Internal curing

1 Introduction

According to the World Commission on Environment and Development (WCED),

Key Organizations and Persons Involved

Professor Michael F. Petrou

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