Use of alternative aggregates in pavement concrete

Research And Practice In Belgium

Elia Boonen - 29/8/2023

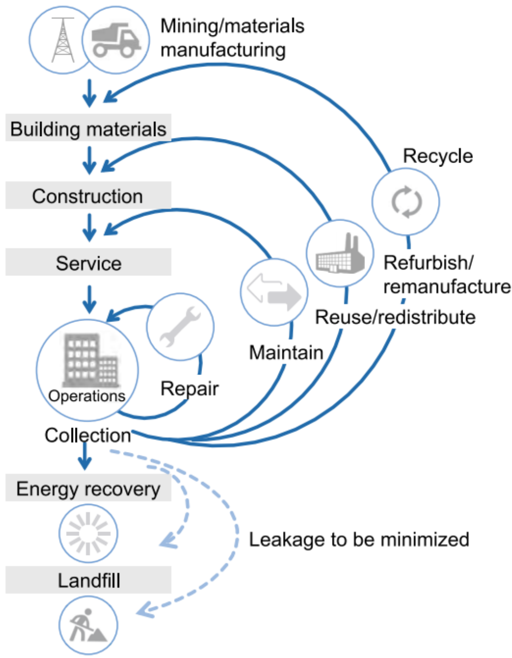
Overview

1. Intro – why?
2. Current regulations – What is allowed now?
3. Recent research results – update
4. Recent pilot applications – what is possible?
5. Future – what's next?

6. Conclusions & perspectives

1. Intro – why alternative aggregates?

- From linear to more circular economy:
  - More than recycling!



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- Use of *recycled or manufactured* aggregates can provide one possible means, but we could go further…


WORLD POLITICS

A sand shortage? The world is running out of a crucial — but under-appreciated — commodity

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Sam Meredith @SMEREDITH19

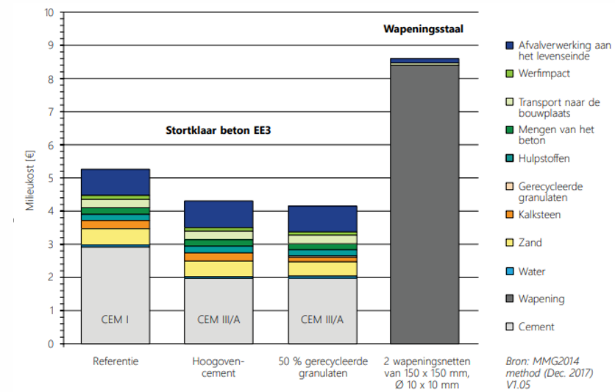

The Guardian

Making concrete green: reinventing the world's most used synthetic material

Concrete has a crushing environmental impact but Australian-led innovations have the potential to dramatically reduce emissions from its production

Example: Impact of (High Quality) RCAs…

- Use of RCA in pavement quality concrete = "green(er) concrete" ?



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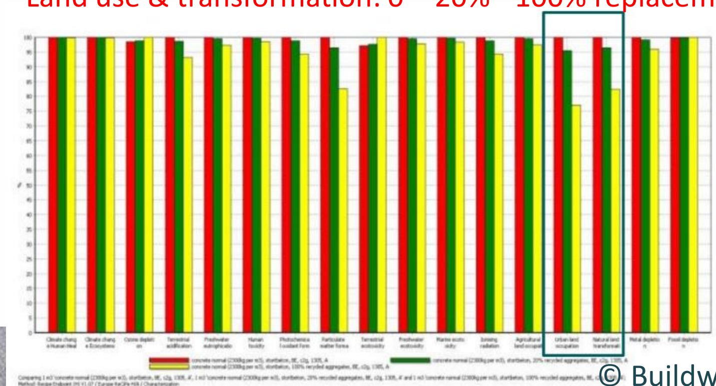
Land use & transformation: 0 – 20% - 100% replacement



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- **Selective demolition leads to more "high quality" raw materials, available locally (*Urban Mining*):**
  - Savings in natural resources
  - Important impact on land use
  - Less transport, CO_2-emissions & traffic nuisance
  - Less landfill with inert waste

2. Currect practice & regulations

A. Specifications for ***high quality RCA*** according to Flemish standard road specifications SB250 & Belgian standard NBN B15-001:2018 (*type A+):*

(Categories according to EN 12620)

- d ≥ 4 mm & D ≥ 10 mm;
- Minimum Rc_{90}, Rcu_{95}, Ra_{1}, $\mathbf{XRg_{0,5}}$, FL_{2-}
- Minimum $\mathbf{Fl_{20}}$, $\mathbf{f_{1,5}}$, $\mathbf{LA_{35}}$, $SS_{0,2}$, A_{40}
- Particle density ρ_{rd} ≥ **2200 kg/m³**
- **Water absorption (after 24h) ≤ 10%,** with a maximum variation of ±2% to the declared value.

Annex E in EN 206 (2014)

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	≤ FI_{50} or ≤ SI_{55}
Resistance to fragmentation	5.2	A + B	≤ LA_{50} or ≤ SZ_{32}
Oven dried particle density ρ_{rd}	5.5	A	≥ 2 100 kg/m³
		B	≥ 1 700 kg/m³
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	≤ A_{40}

Road concrete with RCAs: what is allowed now?

- Use of high quality RCA in pavement concrete with **up to 20% (***bicycle paths and bottom layers of concrete pavements***) to 40% (***in linear elements***) replacement** of the coarse aggregates (d > 4 mm)
- Since 2017: certification of pavement concrete to assure compliance with the requirements & quality control:

	D_{max}	Min. Cement content	Max. W/C-ratio	Flexural strength 28 d	Compressive strength 28 d	Compressive strength 7 d	Freeze-thaw resistance with de-icing salts
Bottom layer B1-B5	31,5 mm	≥ 375 kg/m³	≤ 0,45	6,0 MPa	55 MPa	35 MPa	≤ 1,5 kg/m²
Bottom layer B6-B10	31,5 mm	≥ 350 kg/m²	≤ 0,50	5,0 MPa	45 MPa	30 MPa	≤ 3,0 kg/m²
Bicycle path BF	31,5 mm 20 or 14 mm 6,3 mm	≥ 350 kg/m² ≥ 375 kg/m² ≥ 400 kg/m³	≤ 0,50 ≤ 0,50 ≤ 0,45	4,0 MPa	40 MPa (air < 3%) 35 MPa (air ≥ 3%	25 MPa (air < 3%) 20 MPa (air ≥ 3%	≤ 3,0 kg/m²
Linear elements	31,5 mm	≥ 350 kg/m²	-	-	40 MPa (air < 3%) 35 MPa (air ≥ 3%)	25 MPa (air < 3%) 20 MPa (air ≥ 3%)	≤ 3,0 kg/m²

COPRO

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Belgian Road Research Centre
Together for sustainable roads

Current practice & regulations

B. Artificial aggregates from ***crushed stainless steel slags*** according to SB 250 (only allowed in asphalt for now!)

(Categories according to EN 13043)

- d ≥ 2 mm & D ≥ 10 mm;
- percentage of crushed and broken surfaces C90/1
- PSV50, with PSV measured after 7 days under water;
- category D1 according to PTV 411 (dimensional stability);
- Stainless steel slags can **only comprise up to 50 % of the aggregate (d ≥ 2 mm) fraction** of mixtures of SMA (split-mastic asphalt) or ZOA (very open asphalt).

3. Recent research results

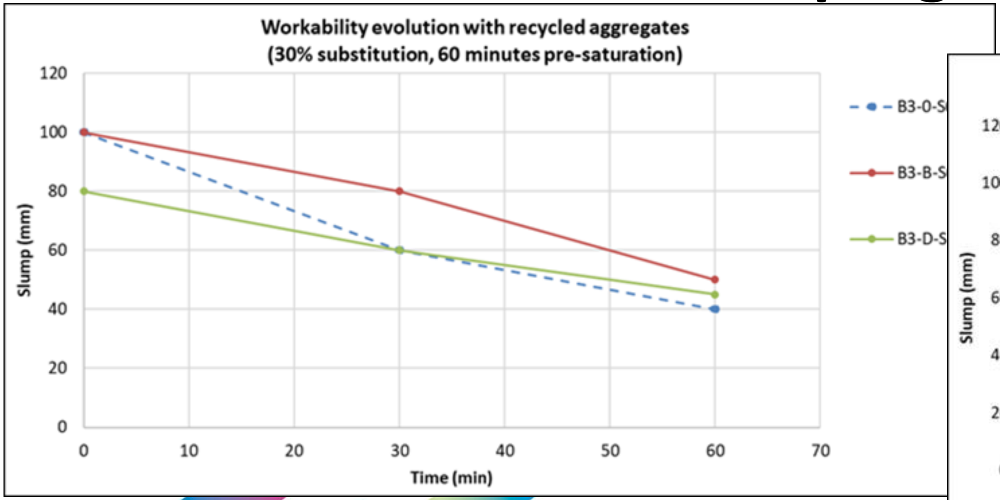
- **Characterisation and quality of typical RCA in Belgium (Recybeton [2016,2018], PXL [2017]):**

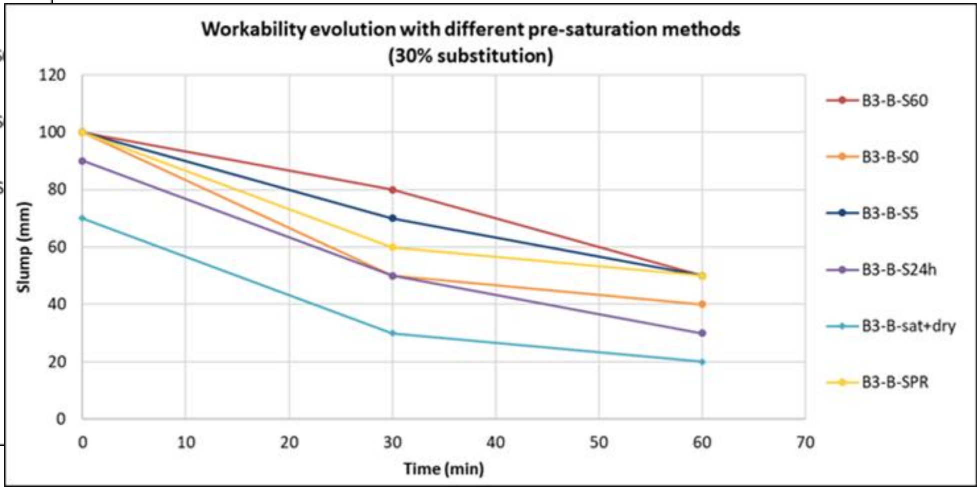
RCA type	Fines content	Particle density	Water absorption	LA	MDE	Flakiness index
	[%]	[kg/m³]	[%]	[%]	[%]	[%]
A-1	1.7	2500	2.9	25	18	6
B-1	1.6	2320	5.3	30	23	7
C-1	2.1	2280	6.6	36	24	9
D-1	2.0	2400	4.3	25	18	7
G-1	2.3	2320	5.8	31	29	5
I-1	4.4	2310	5.7	31	21	5
Requirements NBN B 15-001	***≤ 1.5***	***≥ 2200***	***≤ 10***	***≤ 35***	***-***	***≤ 20***

- Important aspects remain water absorption and fines content – water balance
- Correlation between LA-coefficient & particle density - water absorption

Influence of RCA on concrete properties *(Boonen et al. 2018 – ISCP Berlin)*

- Typical concrete compositions for bicycle paths and agricultural roads (from 20 to 75% of replacement):
  - Equal mechanical properties *up to 30 (or 50%)* without jeopardizing durability
  - Challenge remains water balance and workability in time
- **Mode & time of impregnation has little influence:**





Recent research results – artificial aggregates

- **Purified, crushed stainless steel slags** in road concrete
- Trial section of 300 m at highway A8 (2017):
  - Dmax of 14 mm – 100% of Stinox® aggregates d> 4mm
  - Minimum 400 kg/m³ of CEM III/A 42,5 N LA;
    W/C-ratio ≤ 0,45
  - Air content between 3-6% (air entraining agent)
  - Slump value S1 (10-20 mm at 30 minutes after production)

- Follow-up by BRRC

(Rc – WAI – scaling)

Results for trial section at A8 highway

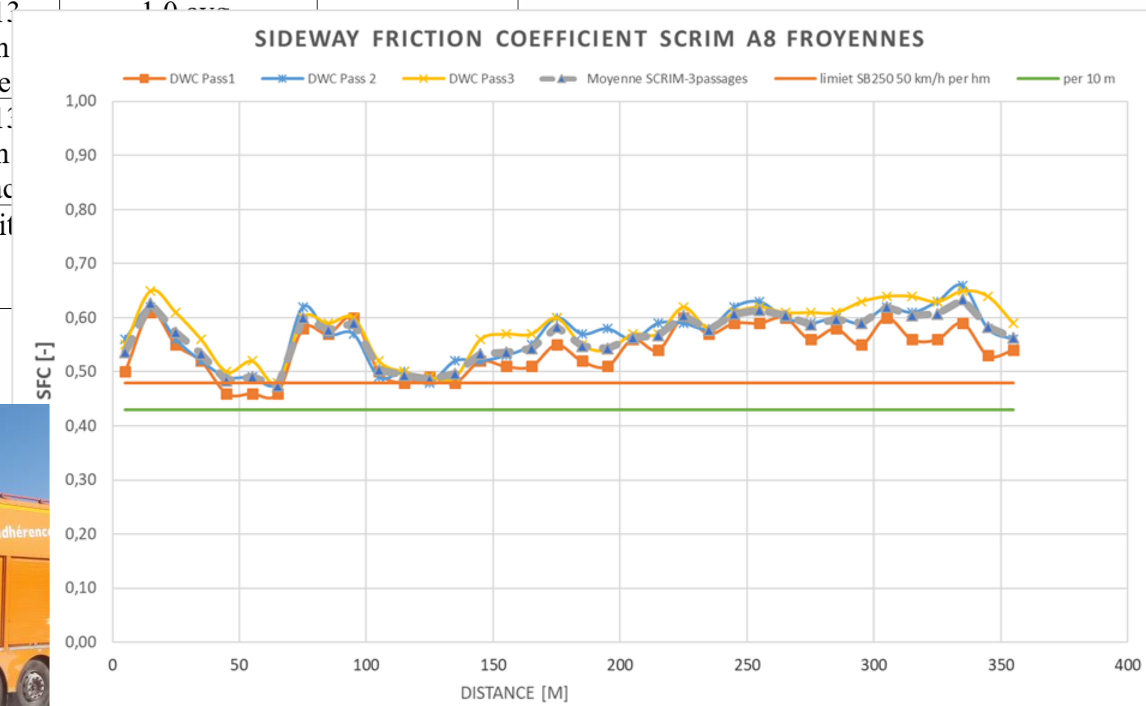
Property	Date of concrete	Sample type	Result	Requirement Qualiroutes
R_c 28d (MPa)	6/3/2017	2 Cubes 150 mm	62,8 avg.	39,6*
R_c 28d (MPa)	21/3/2017		62,6 avg.	
R_c 90d (MPa)	6/3/2017	3 Cores Φ 113 mm, H 100 mm	79,3 avg.	50 ind.
R_c 90d (MPa)	21/3/2017		72,3 avg.	
Water absorption (%)	6/3/2017 21/3/2017	4 Cubes 100 mm 4 Cubes 100 mm	6,4 avg. 6,0 avg.	6,8 ind. 6,3 avg.
Scaling after 30 cycles (g/dm²) **	6/3/2017 21/3/2017	4 Cores Φ 11 mm, H 50 mm sawn surface		
	6/3/2017	4 Cores Φ 11 mm, H 50 mm exposed surfac		

* Re-calculated based on: 50 MPa for cores at 90 d (wit
cubes at 90 d
** Based on former ISO/DIS 4846.2:1984

Hanoteau & Hontoy (2018)

But:

Skid resistance in time?



4. (More) Recent pilot applications in Belgium: what is possible?

A. The “Circular Road” in Veurne [2018]

Demolition of existing agricultural concrete road + base layer and recycling of:

- RCA 8/20 in new pavement concrete (*30% of inert fraction – 50% of coarse aggregates*)
- Crusher sand 0/8 + old base layer 0/56 in cement treated base

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CIRCULAR FLANDERS

Circular road in Veurne: results

Table 6. Test results on fresh and hardened concrete for the "Circular Road" in Veurne

	Slump [mm]	Air content [%]	Apparent density [kg/m^3]	Compressive strength after 28 days [MPa]	Water absorption NBN B15-215 [%]	Scaling* mass loss after 28 cycles [kg/m^2]
Road concrete with 50% of RCA, construction class B6-B10 (with air)	20 mm	4,1	2336	58,9	5,7	0,28

*tested on the formwork surface of the samples

- Scaling on cores: < 3 kg/m^2

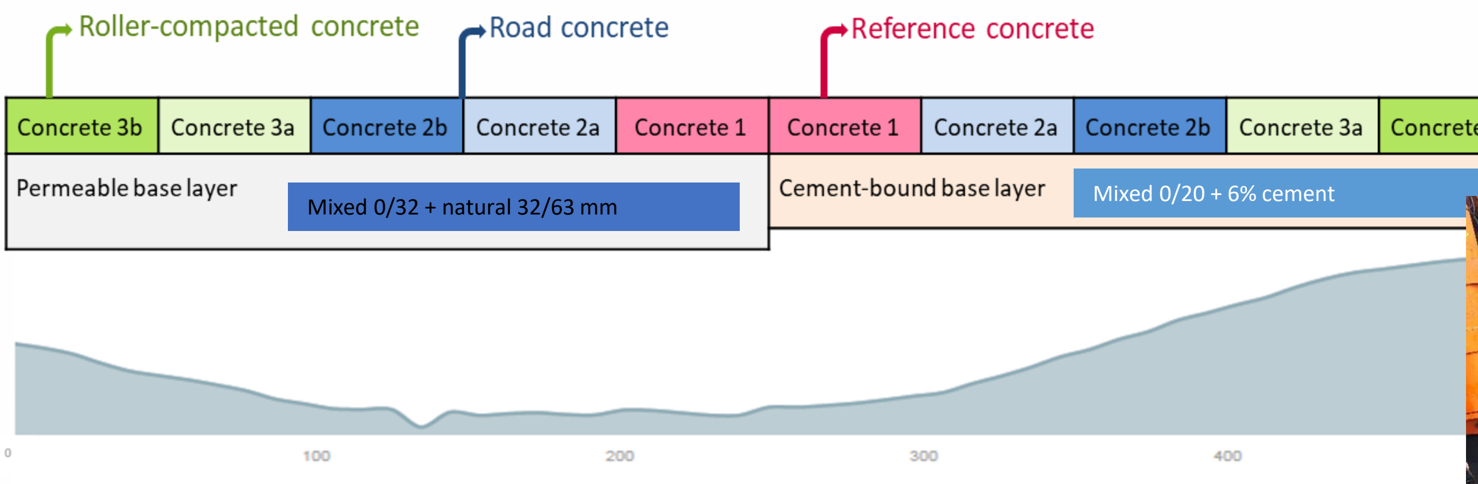
B. Ridias project in Gembloux [2017-2019]

- Test sections on agricultural road « Chemin du Ridias » to be renovated
- Opportunity to test different innovative solutions incorporating recycled materials (even *mixed* recycled aggregates)

TRADECOWALL S.C.R.L.

Ridias project – test sections

- **1-2a,b: JPCP, 18 cm thickness, 0-25-50 % mixed recycled aggregates**
- **3a,b: RCC, 84-90% mixed recycled aggregates + chipping surface dressing**

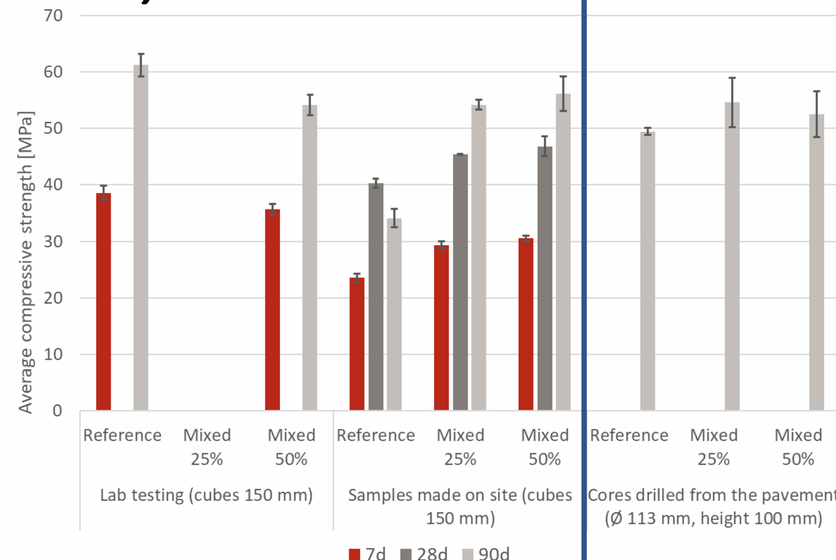


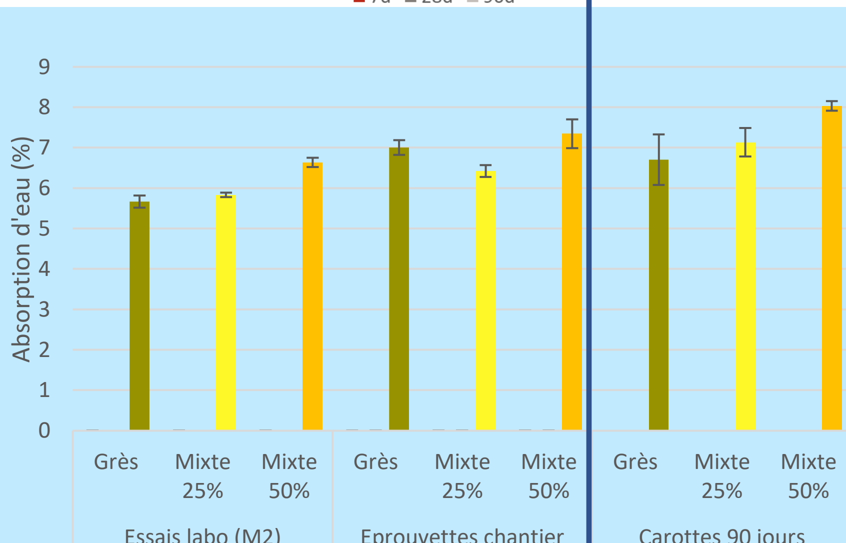
Ridias - results for pavement concrete
(350 kg/m³ C, W/C < 0,50, no AEA)

	Reference		25 vol% mixed agg.		50 vol% mixed agg.		Target value	Requirement Qualiroutes
	plant	*on site*	*plant*	*on site*	*plant*	*on site*		
Slump (mm)	55 65	*46* 35 25	60 30	*35* 16 40	30	15 *17* 30 50	**25-40 at plant**	-
Air content (%)	1,5	*1,7*	1,8	*2,1* 1,5	2	3 *2,4* 2,5	-	-
Water content (% by heating)	10,0	-	10,7	-	10,3	9,9ʳ *10,4*	**Ref: 8,1** **25%: 9,1** **50%: 10,1**	W/C ≤ 0,50
Fresh density (kg/m³)	23[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
R_c 7d (MPa) – cubes 15 cm	-	*23,6*	-	*29,4*	-	*30,5*	-	26,9*
R_c 28d (MPa) – cubes 15 cm	-	*40,3*	-	*45,5*	-	*46,8*	-	39,6*
Water absorption (%)	-	7,0	-	6,4	-	7,4	-	6,0 (if de-icing salts are used)
Scaling @ 28 cycles – Slab test (kg/m²)**	-	*9,95*	-	*6,04*	-	*5,58*	(3,00)	-

ʳ before adding of 15 l extra water on site
* Re-calculated based on: 50 MPa for cores at 90 d (*Réseau II and II* without air entraining agent) – 46,7 MPa for cubes at 90 d
** Based on CEN/TS 12390-9 and tested on formwork surface
Italic values pertain to results obtained for the same truck mixer

W/C = 0,58 instead of 0,48!





Ridias project – conclusions & perspectives

Utilisation of mixed recycled aggregates in this pilot site:

- Did not alter way of execution
- Allowed to obtain satisfying performance results (low volume & agricultural roads)
- Enabled substantial economic savings

Points of attention:

- Control of water balance
- Variability!
- Long term behavior (FWD, GPR, visual inspection, etc.)

C. Trial section for Bypass of Antwerp [2019-2021]

Partial replacement of coarse aggregates by crushed stainless steel slags (*Stinox®)* for "*highway concrete*":

- Dmax of 20 mm
- 405 kg/m³ of CEM III/A 42,5 N LA
- W/C-ratio ≤ 0,45
- Air content ≥ 3% (AEA)
- Slump value S1 (10-40 mm for slipform)
- Exposed aggregates surface finishing

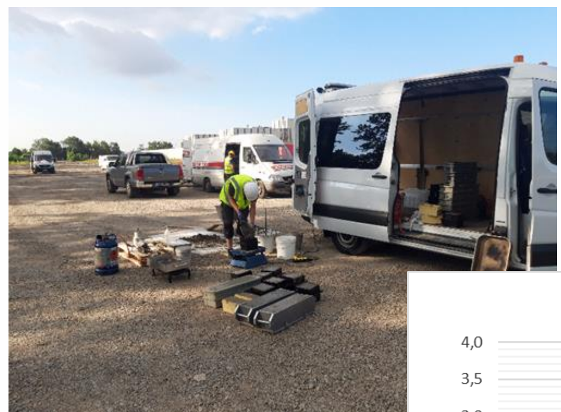
Table 9. Results of test concrete mixes with crushed stainless steel aggregates of type Stino

	Mixture 1 (Stinox 6/10 + 10/14 mm)	Mixture 2 (1 + Stinox sand 0/2 mm)	Requirement SB 250
Slump (mm)	10-7 mm	7-4 mm	20-60 mm
Air content (%)	4,0-4,8 %	4,3-3,7 %	TBR
Fresh density (kg/m³)	2446	2460	TBR
Rc 7d (MPa) – cubes 15 cm	50,3	49,5	30
Rc 28d (MPa) – cubes 15 cm	69,4	68,4	50
Water absorption (%)	5,6	6,1	6,3 avg (for 3% of air)

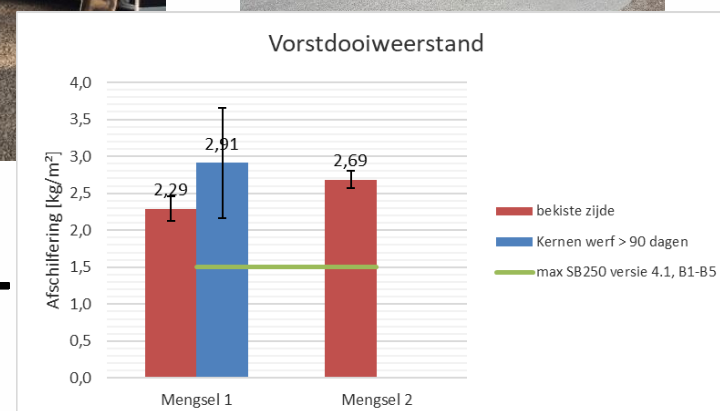
- Lab testing + **field trial of 300 m CRCP**

CRCP trial section with crushed stainless slag aggregates @ Antwerp (2019)

- Construction + follow-up (CPX, skid resistance, Evenness – APL, texture, coring, etc.)

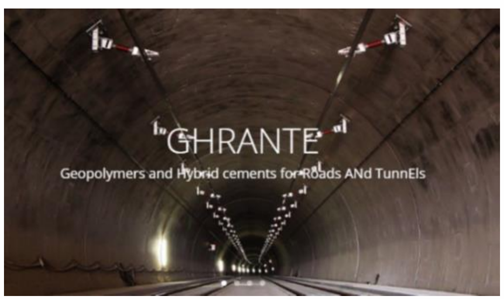


- **Freeze-thaw resistance with de-**



5. Future: where to go from here?

- Integration of recycled "**sand fraction**" (0/4; 0/6,3) and/or mixed recycled aggregates in rich concrete;
- Alternative cements and/or binders based on waste materials (slags, fly ash): geopolymers and hybrid cements…



NEOCEM

CRIC-OCCN cstc.be wtcb CRR - OCW

SARE4BE

- Bridging the gap between research & practice for circular, "green" concrete?

CIRCULAIR BETONAKKOORD VLAANDEREN *[2021-…]*

Interreg Vlaanderen-Nederland Europees Fonds voor Regionale Ontwikkeling — UPCYCLING CONCRETE - BNB

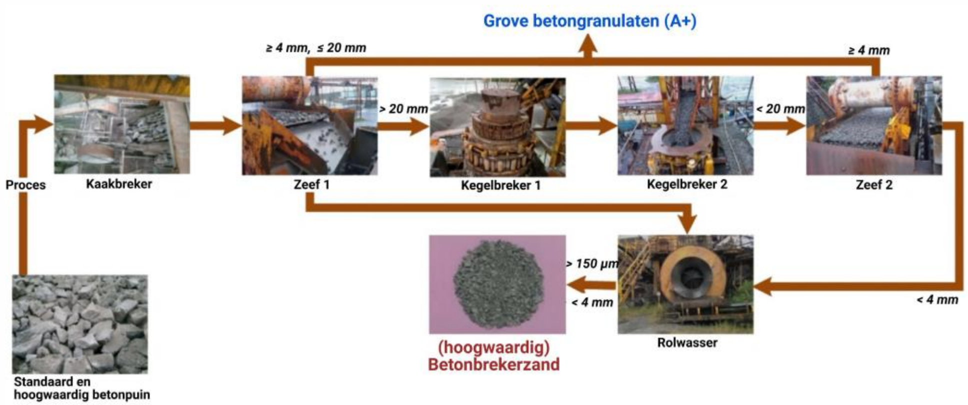
Alternative cements & aggregates

- *Monocrete* project:
  test site with 50% of recycled aggregates and an alternative cement CEM V (experimental)

https://brrc.be/sites/default/files/2023-03/MONOCRETE_FR.pdf

Recycled crusher sand

- “High quality” concrete crusher sand (~15%)
- First (collective) research & pilot projects starting…



https://www.linkedin.com/feed/update/urn:li:activity:6907354235453984768/

6. Conclusions and perspectives

- **Alternative (recycled and/or artificial) aggregates can contribute to the circular economy**: less transport, better land use and preservation of natural resources
  - (High) quality is crucial and can be obtained by proper pre-sorting, adapted process and quality control
  - Use of high standard RCA in pavement concrete is possible without loss of quality and durability (*e.g. freeze-thaw resistance*)
- **Recent test cases and research efforts have shown the possibility to go even further** in replacement rate (*40-60%?*), type of application (industrial pavements, bicycle lanes, rural roads, linear elements,…) and/or even type of aggregate (*RCA, stainless steel slags, crusher sand…)*

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SIM innovating together
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