C&D WASTE TREATMENT AND UTILISATION – BACKGROUND, EXPERIENCES, PROPERTIES AND APPLICATIONS

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10/06-2019, Ghaziabad

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What is C&D waste?

~50% by weight is concrete and masonry

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Generation of C&D waste

Volume (mill. tons)	Europa[a]	USA[a]	India[b]	Japan[a]	Norge
C&D waste	510	317	530	77	1.9[c]
Municipal waste	241	228	62	53	2.4[d]

[a] The Cement Sustainability initiative - Recycling Concrete; World Business Council for Sustainable Development
[b] Planning Commission 2014; Sekhar et al. 2016, Resource efficiency in the construction sector, GIZ report.
[c] Statistics Norway 2014 – waste from civil engineering sector is not included
[d] Statistics Norway 2014 – from private households

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TREATMENT AND REYCLING C&D WASTE

= RECYCLED AGGREGATES

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Circular Economy approach

Prevent "linear use and dump" economy

- Waste management and recycling are important components but also increased use of existing capacity, smart concepts, product designs etc.
- SINTEF has strong focus on R&D projects that contribute to Circular Economy.

The concepts needs to be economic and ecologic sustainable

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Modern recycling facility for C&D waste

Velde Industri AS, Sandnes Norway

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Potential use for recycled C&D waste

- Ready-mix concrete
- Concrete products
- Road construction
- Landscaping and covering masses
- Cement production
- Other mineral building products

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Multi-step approach

- **Prior and during demolition:** Developing rational guidelines for stripping the building, pre-sorting of components, etc., that ensures easier processing and a high quality end product at later stages. The guidelines must be implemented and enforced.
- **Processing and recycling stage:** Technical guidelines for the production of recycled concrete aggregates needs to be in place in order to have sufficient confidence among the end-users. Existing guidelines may be modified and converted to any local scenario. The crushing technology is advancing for both mobile and stationary recycling facilities and end products with the prescribed technical quality can in most cases be achieved. Depending on the local conditions, the most rational option should be chosen.
- **Demonstration:** The recycling technology should be demonstrated through dedicated pilot projects. This should include the production of recycled material and also the application of the end-product in the building and construction sector.
- **Capacity building and dissemination of results:** Dedicated training courses, seminars, workshops.

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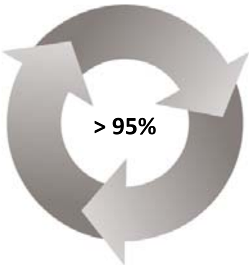
Circular economy approach

Transport of waste in

Waste supply from local area is important to secure the feedstock

Recycled aggregates used in service life again



Adequate facility with high efficiency increase the cost effectiveness

Advanced treatment processes ensure high quality

Large capacity ensures that the market demand is met

Recycled aggregates out on the same truck

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Demolition process and
pre-sorting rules:
60% needs to be sorted

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Case study Old Hospital in Oslo
> 90% of the heavy C&D waste
recycled (2002)

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Sørumsand high school 2001-2003
Sub-base in entrance lane to E6 2004-2005
Retaining wall E6 Taraldrud 2005
Leca
lydskilleblokk
med 30% resirkulert bygningsmasse levert av BA Gjenvinning.
(Normalvekt 15 kg p.g.a. db-krav)
LECA masonry sound insulation block with 30% recycled aggregates
Demonstration in shot concrete 2000

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Concrete recipe used at RMC

Material	Reference (kg/m³)	With RCA (kg/m³)
Sand (0/4 mm) Manufactured	305	297
Sand (0/8 mm)	776	749
Coarse aggregates (8/22 mm)	847	494
Recycled concrete aggregates (10/22 mm)	-	269
Brick content in RCA	0 %	5 %
Fly ash cement	319	341
Water	179	191
P (Scancem LP)	2	3
Effective v/c+s	0.57	0.57

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Properties tested at RMC

Parameter	Results from RMC plant
w/c	0.57
Slump (mm)	> 200
Water absorption recycled aggregate (%)	4.5
Surface dired particle density (kg/m^3)	2520
Strength 7 days (MPa)	91 % of reference concrete
Strength 28 days (MPa)	93 % of reference concrete

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Concrete recipe used at RMC

Material	Reference (kg/m³)	Water conent (%)	With RCA (kg/m³)
Sand (0/8 mm) 1	412.5	- 1.0	408.3
Sand (0/8 mm) 2	410.4	- 0.9	406.7
Recycled aggregates (10/22 mm)	835	- 5.6	788.3
Brick content in RCA	0 %	-	5 %
Portland cement	407		407
Microsilica	14.8		14.8
Water	171	100	225.6
SP (Scanflux AD 18)	3.256	82	3.256
Air entrainer (L-14 F)	0.936	95	0.936
Total amount	2254.9		2254.9

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Properties tested at RMC

Parameter	Results from RMC plant
w/c	0.40
Slump (mm)	190
Water absorption recycled aggregate (%)	5.6
Particle density (kg/m³)	2479
Strength 7 days (MPa)	35
Strength 28 days (MPa)	44 (80 % of reference strength)

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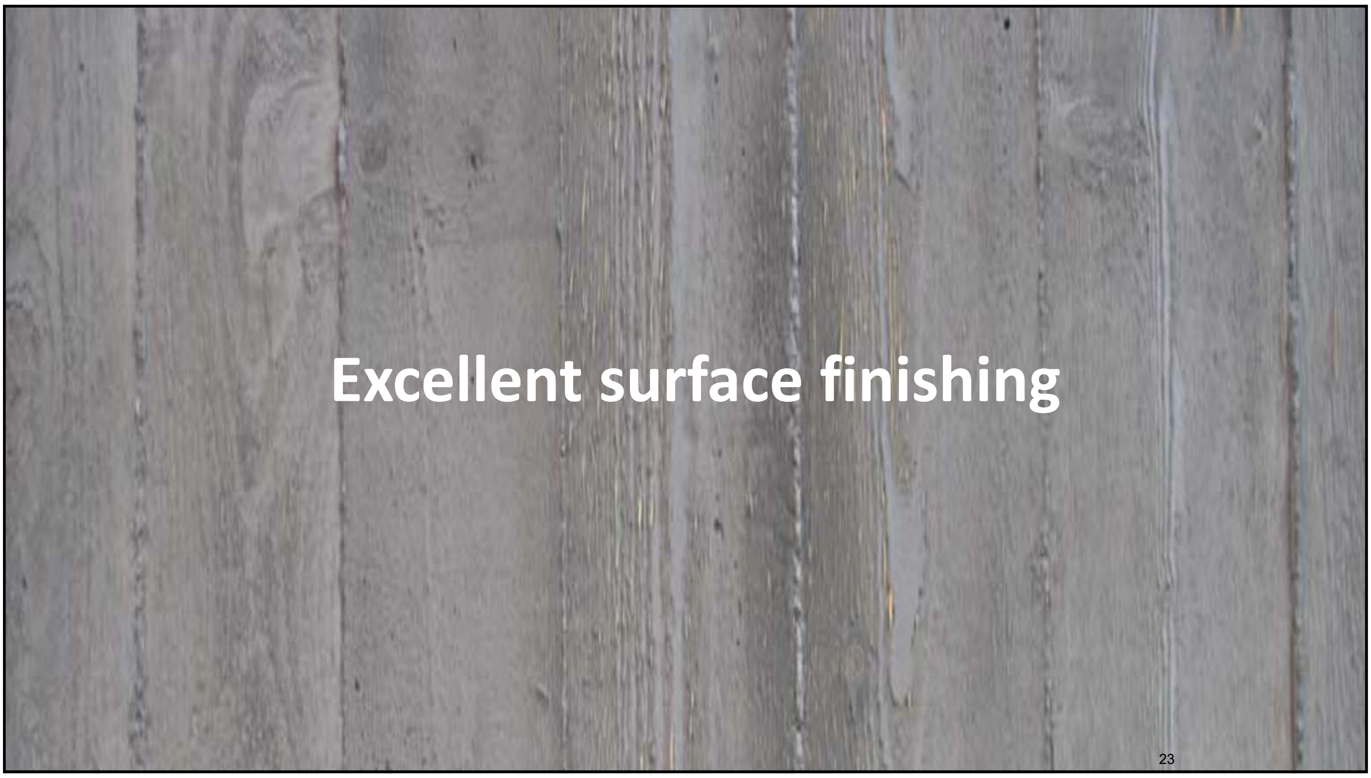

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Practical experience

Action	Day	Where	Critical
5 drilled cores before crushing	Friday	Recycling plant	Ensure chlorides before RCA can produced (< 0.1%)
RCA 8/22 mm is produced	Monday	Recycling plant	
RCA is visually inspected and thereafter delivered to the RMC plant	Monday	Recycling plant	
Water absorption, density and particle grading	Monday	RMC plant	Checking that water absorption and grading is suitable
3 RCA batches full verification	Tuesday	Laboratory	
Trial cast of 1 m^3 in the concrete truck	Tuesday	RMC plant	Check for suitable workability
Casting, fresh concrete properties and casting of cubes for laboratory tests	Tuesday	Construction site and laboratory	Slump loss
Removing formwork	Thursday	Construction site	Satisfying surface finish

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Economy

- RCA material could be delivered at 60-90 % of the costs for natural aggregates
- RMC conducted extended tests at the plant according to Norwegian guidelines due to high % replacement of NA
- RMC already used low-alkali cement (FA cement) to mitigate ASR
- No extra monitoring at construction site
- Cost – effective documentation programme for RCA and NA can be developed to decrease the need for external consultancy

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Data gained in Oslo area

Parameter	Type 1	Type 2
Particle density (ssd), g/cm³	2.3-2.6	2.3-2.6
Water absorption, %	2.7-8.2	2.7-14.7
Los Angeles	23-34	24-41
Flakiness index	10-13	10-15
Organic materials %	4.1	2.4-11.4
Chloride content, %	0.003-0.007 (water sol) 0.007-0.013 (acid sol)	0.003-0.013 (water sol)
Extractable sulphate, %	0.0095-0.045 (water sol) 0.42-0.909 (acid sol)	0.041-0.246 (water sol)

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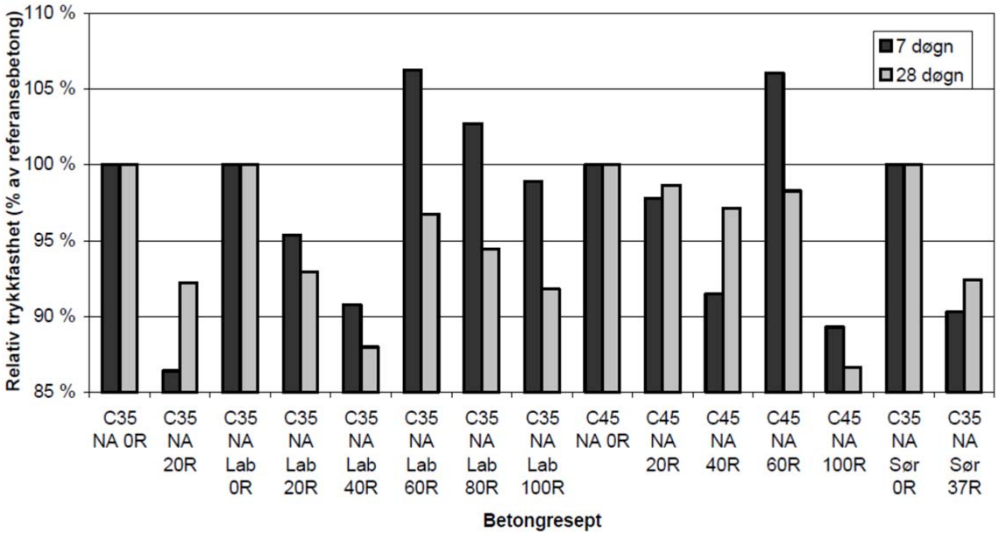
Data gained at SINTEF



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Heavy metal leaching at field site

Test section[a]	Year	Concentration (µg/L)		
		Cr	Cu	Pb
FGA (F1)	2004/2005	< 0.5 -1.9	11 - 81	< 1.4 - 15
FGA (F1)	2006-2010	< 0.5 – 2.7	17 - 154	< 1.4 - 13
RCA (F3)	2004/2005	11 - 156	7.2 - 237	< 2.5 - 5.3
RCA (F3)	2006-2010	2.0 - 241	< 0.2 - 28	< 2.5 - 2.7
Natural agg. (F5)	2004/2005	< 0.3 - 4.1	0.8 - 6.9	< 2.5
Natural agg. (F5)	2006-2010	0.6 - 3.2	0.2 - 26	< 2.5 - 4.2
RCA (F7)	2004/2005	7.9 - 187	0.8 - 156	< 2.5
RCA (F7)	2006-2010	1.6 - 13	0.4 - 3.0	< 2.5
Acceptance criteria				
Groundwater[b]		50	100	10
Fresh water[c]		3.4	7.8	1.2

Field leaching data complied with the pre-defined acceptance criteria for groundwater and nearly all for surface water, considering the mixing of pore water with ground water

Norwegian water regulation. [c] Norwegian fresh water Class II: represents good quality water (Norwegian Climate and Pollution Agency, 2016) and the criteria are in accordance with the annual average-environmental quality standard (AA-EQS) in The EU Water Framework Directive.

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Risk based limit values – recycled aggregates (mg/kg)

Prøve	Forsterkningslag	Normverdi[1)]
Arsen	< 20	< 8
Bly	< 200	< 60
Kadmium	< 3	< 1,5
Kobber	< 250	< 100
Krom, total	< 110	< 50
Kvikksølv	< 1	< 1
Nikkel	< 110	< 60
Zn	< 600	< 200
∑PAH-16	< 2	< 2
∑PCB-7[2)]	< 0,25	< 0,01

1) Normverdier angitt i forurensningsforskriften
2) Basert på evaluering, beregning og måling av utlekking [867]

Source: Engelsen, C.J. Recycled aggregates from concrete and masonry, Building Research Design Guides 572.111, SINTEF Byggforsk (2015).

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Heavy metals – Filter press fraction

Element	Sub-base[1] (calculated on the basis of actual leaching) mg/kg	Soil criteria (Norwegian Pollution Act) mg/kg	RESGRAM (results from filter press fraction) mg/kg
As	< 20	< 8	< 0,5 – 5,5
Pb	< 200	< 60	43 – 86
Cd	< 3	< 1,5	< 0,05 – 0,46
Cu	< 250	< 100	10 – 90
Cr	< 110	< 50	10 – 31
Hg	< 1	< 1	0,03 – 0,22
Ni	< 110	< 60	9,0 – 23
Zn	< 600	< 200	96– 195

[1] **Source: Engelsen, C.J. Recycled aggregates from concrete and masonry, Building Research Design Guides 572.111, SINTEF Byggforsk (2015).**

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Implementation in European standards

Table 1 EN standards which include the use of recycled aggregates

User application	EN standard
Concrete production	EN 12620
Lightweight aggregates for concrete, mortar and grout	EN 13055-1
Lightweight aggregates for bituminous mixtures and surface treatments	EN 13055-2
Mortar	EN 13139
Track ballast	EN 13450
Road construction and civil engineering	EN 13242

Ng, S. and Engelsen, C.J., 2018. *Construction and Demolition wastes*, In: Waste and Supplementary Cementitious Materials in Concrete: Characterisation, Properties and Applications. Editors: Rafat Siddique and Paulo Cachim, Elsevier publication, in print.

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Implementation in European standards- Factory production control of recycled aggregates:

- Geometrical
  - Particle size, grading, shape and fines
- Physical
  - Particle density, water absorption, fragmentation etc.
- Durability
  - Drying shrinkage, ASR, freeze/thaw resistance
- Chemical
  - Chlorides, sulphates, harmful substances, other organic substances that impact hydration in final concrete

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Recommendations d > 4 mm[a]

Propeprty	Type	EN 206 recommendation	Norway
Fines content	A +B	Value to be declared	Value to be declared
Flakiness Index	A + B	≤ 50	Value to be declared
Resistance to fragmentation	A + B	LA ≤ 50 or SZ ≤ 32	Value to be declared
Oven dried particle density	A	≥ 2100 kg/m³	≥ 2000 kg/m³
Oven dried particle density	B	≥ 1700 kg/m³	≥ 1800 kg/m³
Water absorption	A + B	Value to be declared	Type AN < 10% and Type BN < 20%
Constituents	A	Rc_{90}, Rcu_{95}, Rb_{10-}, Ra_{1-}, FL_{2-}, XRg_{1-}	Rcu > 99%
Constituents	B	Rc_{90}, Rcu_{95}, Rb_{10-}, Ra_{1-}, FL_{2-}, XRg_{1-}	Rcu > 95% and Rb < 5%
Water soluble sulphate	A + B	≤ 0.2 %	≤ 0.8% acid soluble
Acid soluble chloride	A + B	Value to be declared	Value to be declared
Influence on initial setting	A + B	≤ 40 min	≤ 60 min and strength reduction < 10%

[a] NS-EN 206:2013 + A1:2016

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Example of classifcation[a]

Parameter	Type AN	Type BN
Mineral containing material: • Rcu99 • (Rcu99 + Rb), where Rb < 5%	 > 99%	 > 95%
Non-mineral containing materials + glass: • Total • Isolation materials • Plant material residues	 < 1 < 0.1 (vol%) < 0.1 (vol%)	 < 1 < 0.1 (vol%) < 0.1 (vol%)
Density • Oven dry • Surface dry	 > 2000 kg/m³ > 2100 kg/m³	 > 1800 kg/m³ > 2000 kg/m³
Water absorption	> 10%	> 20%

[a] NS-EN 206:2013 + A1:2016 + NA 2017

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General limits coarse aggregates 4/32 mm[a]

Concrete class	Type AN	Type BN	Sum AN + BN[b]
Strength class ≤ B25 and durability class M90	30%	10%	30%
Strength class ≤ B45 and durability class M60	20%	0%	-

[a] NS-EN 206:2013 + A1:2016 + NA:2017
[b] If both types are used, maximum 10% of Type BN is allowed

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General limits IS 383

Table 1 Extent of Utilization
(*Clause* 4.2.1)

Sl No.	Type of Aggregate	Maximum Utilization		
		Plain Concrete Percent	Reinforced Concrete Percent	Lean Concrete (Less than M15 Grade) Percent
(1)	(2)	(3)	(4)	(5)
i)	Coarse aggregate:			
	a) Iron slag aggregate	50	25	100
	b) Steel slag aggregate	25	Nil	100
	c) Recycled concrete aggregate[1)] (RCA) (*See* Note 1)	25	20 (Only upto M25 Grade)	100
	d) Recycled aggregate[1)] (RA)	Nil	Nil	100
	e) Bottom ash from Thermal Power Plants	Nil	Nil	25
ii)	Fine aggregate:			
	a) Iron slag aggregate	50	25	100
	b) Steel slag aggregate	25	Nil	100
	c) Copper slag aggregate	40	35	50
	d) Recycled concrete aggregate[1)] (RCA) (*See* Note 1)	25	20 (Only upto M25 Grade)	100

[1)] *See* **A-3** for brief information on recycled aggregates (RA) and recycled concrete aggregates (RCA).

NOTES

1 It is desirable to source the recycled concrete aggregates from sites being redeveloped for use in the same site.

2 In any given structure, only one type of manufactured coarse aggregate and one type of manufactured fine aggregate shall be used.

3 The increase in density of concrete due to use of copper slag and steel slag aggregates need to be taken into consideration in the design of structures.

4 While using manufactured aggregate as part replacement for natural aggregate, it should be ensured that the final grading meets the requirements specified in Table 7, Table 8 and Table 9.

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Specific measures for higher replacement

- Source material varies:
  - ✓ Accumulate data of typical general properties of source material and area (type of buildings, year built, geology of excavation masses, etc.)
  - ✓ Information provided by transporter
  - ✓ Rough segregation of different types of feedstock materials (pure concrete, brick, soil, etc.)

- Durability issues at high replacement levels
  - ✓ Chlorides: Declare the water soluble content (< 0.01%)
  - ✓ Sulphates: Declare sulphate content, change feedstock materials etc.
  - ✓ Carbonation: Good quality source material, low water absorption, testing, experience etc.
  - ✓ ASR: Treat aggregates as AS reactive, testing, etc.
  - ✓ Increased declaration level and/or homogeneous feedstock

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Challenges and countermeasures

- Source material varies:
  - ✓ Accumulate data of typical general properties of source material and area (type of buildings, year built, geology of excavation masses, etc.)
  - ✓ Information provided by transporter
  - ✓ Rough segregation of different types of feedstock materials (pure concrete, brick, soil, etc.)
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  - ✓ ASR: Treat aggregates as AS reactive, testing, etc.
  - ✓ Increased declaration level and/or homogeneous feedstock

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Challenges and importants countermeasures (Cont's)

- Challenge to know which parameters and test frequencies:
  - ✓ Parameters for natural aggregates is the starting point
  - ✓ Documentation level is dependent on the end-use for the recycled aggregates
  - ✓ Test frequencies will decrease after systematic development of data and experience
- Environmental harmful impact
  - ✓ Source material should be free of hazardous components and chemicals
  - ✓ Polluted concrete should be sent to landfill
  - ✓ Limit values on chemical content exist which easily can be adopted

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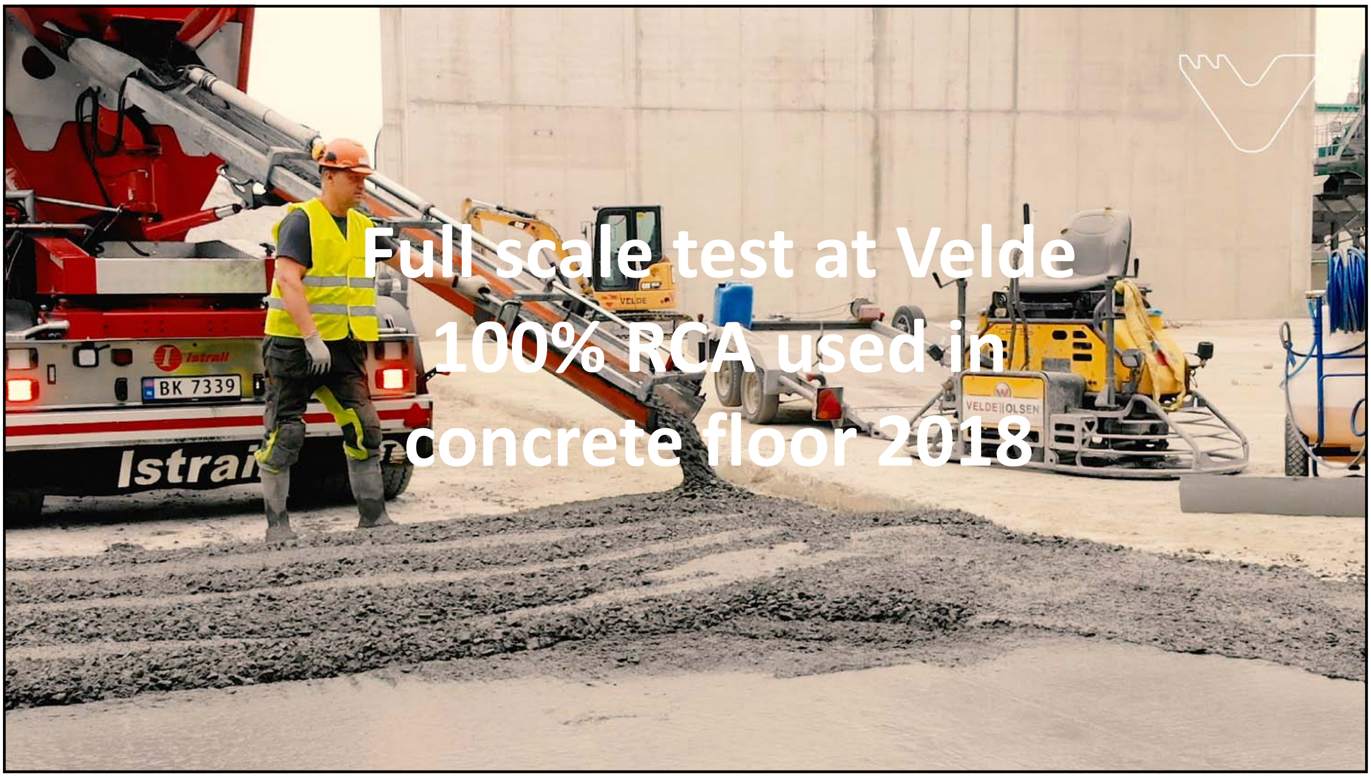

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Concrete mix design

Material	Unit	Amount
Cement content (CEM II/A-V) in concrete	kg/m³	365
Water to cement ratio (w/c)	-	0.45
Admixture (Dynamon SX-N) content of cement weight	%	0.9
Steel fibre in concrete	kg/m³	25
RCA 0/2 mm	kg/m³	750
RCA 4/16 mm	kg/m³	747
RCA 16/32 mm	kg/m³	374

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Results obtained in fresh and harden state[a]

Material properties	Sample 1	Sample 2	Sample 3
Density (g/dm^3)	2388	2380	2367
Slump (mm)	180	200	190
Fresh concrete temperature (^oC)	21.2	22.0	21.0
Compressive strength after 2 days (MPa)	22.1	26.1	25.6
Compressive strength after 28 days (MPa)[b]	56.9	60.4	64.9
Density after 28 days (g/dm^3)	2438	2383	2403

[a] Mujica, H., Velde E., Engelsen, C.J., Nodland, M.S., Recycled aggregates produced from two different feedstock materials – Applied in ready-mixed concrete, RILEM Spring Convention 2019, Croatia (Submitted)

[b] Typical reference strength of concrete produced with crushed natural aggregates is 58 MPa

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Indo-Norwegian project on C&D waste treatment and utilisation (2017-2020)

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TREATMENT AND UTILIZATION OF CONSTRUCTION AND DEMOLITION WASTE (C&D WASTE) IN INDIA

SINTEF · ROYAL NORWEGIAN EMBASSY · CPWD

OVERALL GOAL & PROJECT PURPOSE

Overall Goal	Increase the utilisation level of recovered C&D waste in the building and construction sector in India.
Project Purpose	The purpose of the project is to provide assistance to Central Public Works Department (CPWD) and ULBs in the implementation of safe and sound treatment and utilisation of C&D waste.

PROJECT SCHEDULE

ACTIVITY	2017	2018	2019	2020
(1) Indian baseline information gathering				
(2) International best practice				
(3) Capacity building and training				
(4) Pilot demonstrations				
(5) Amendments to guidelines				

OUTPUTS & INDICATORS

Overview of the utilization potential of C&D waste	Updated overview including the waste reduction potential and saving of natural resources is available by the end of the project
Proposed guidelines on treatment and use of C&D waste aspects	Proposed guidelines on demolition planning, stripping and presorting, treatment and use of C&D waste by the end of the project
Systemised technical data for recycled concrete aggregates	Report on systemised technical data for recycled concrete aggregates are made public available by the end of the project
Pilot demonstrations	Recycled concrete aggregates from processed C&D waste have been used under SINTEF guidance have been completed and reported
Capacity building workshops	8 workshop and seminars on C&D waste management with more than 400 attendees from industry and authorities have been arranged in India
Study tours for the key stakeholders	International study tours gathering in total 40 participants from to learn about state of the art practice of C&D waste treatment and utilisation
Providing input to stakeholders	SINTEF is attending the meetings in the relevant C&D waste committee minimum two times per year (e.g. Bureau of Indian Standards, Indian Road Congress (IRG).
Publications and input to universities	Four papers regarding treatment and utilisation of C&D waste are published in Indian technical journals for information dissemination. SINTEF personnel has provided supervision at Indian and Norwegian universities

STAKEHOLDERS

- CPWD and ULBs
- Property owners, building, demolition and recycling contractors, waste collectors
- Standardisation bodies (e.g. BIS)
- Universities in India and Norway
- Norwegian MFA (funding authority to SINTEF)

SUCCESS FACTORS

- Good quality recycled products
- Availability in time and space
- Cost-effective recycled products to make them competitive

SINTEF EXPERT TEAM

- Dr. Christian J. Engelsen, Project Leader
- Dr. Kåre H. Karstensen, Chief Scientist
- Dr. Harald Justnes, Chief Scientist
- Mr. Palash K. Saha, Scientist
- Ms. Cristina Martinez, Scientist

Project Target Areas

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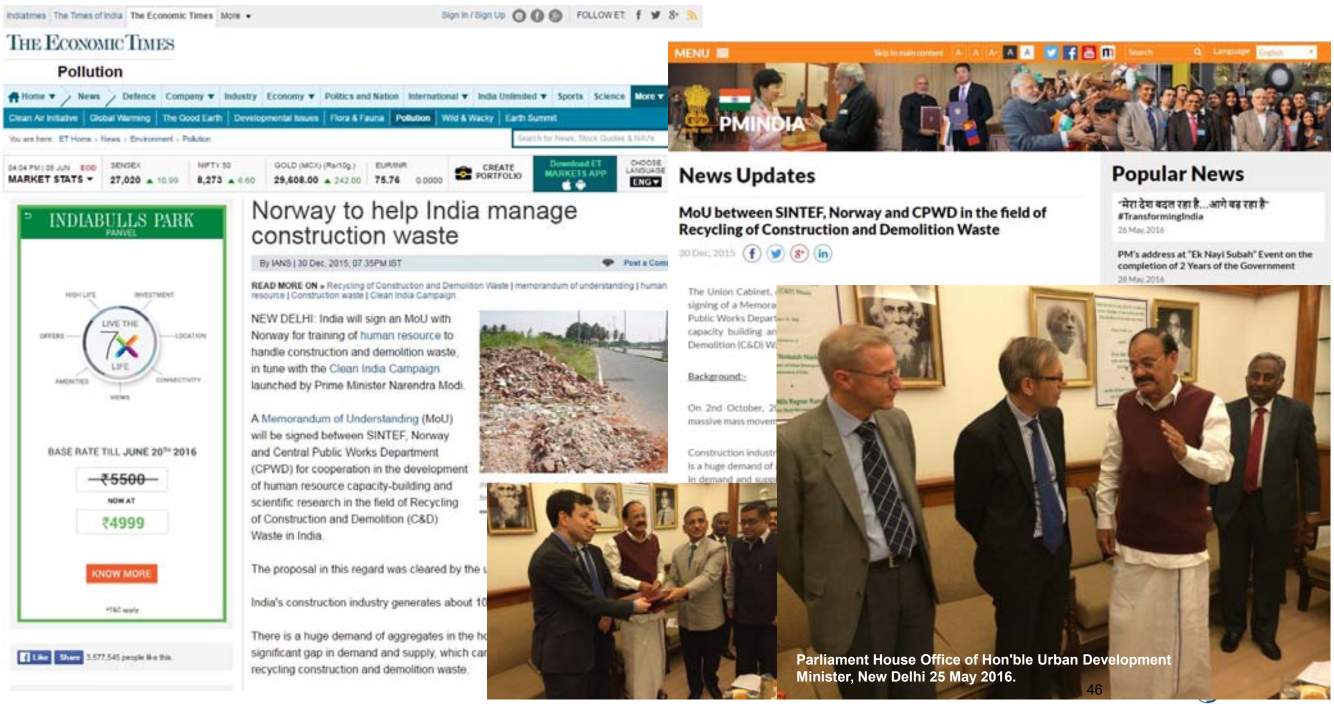

Project is anchored in the following regulation, guidelines and supporting documents:

- The Urban development Strategy for next 20 years (India Habitat III - National Report, October 2016)
- Solid Waste Management Rules 2016 (MoEFCC, 2016);
- Construction and Demolition Waste Management Rules 2016 (MoEFCC, 2016);
- Green Building Norms, (CPWD, 2012);
- Management Manual on Municipal Solid Waste (MoH&UA, 2016);
- Manual on Municipal Solid Waste Management (MoH&UA, 2000);
- TAG Report on Municipal Solid Waste Management, (MoH&UA, 2005);
- National Mission on Sustainable Habitat (MoH&UA, 2010);
- National Environmental Policy, (MoEFCC, 2006);
- CPWD manual for sustainable habitat, (CPWD, 2014).

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Mr. Abhai Sinha (Director General, CPWD) and Arild Oksnevad (Counsellor, Norwegian Embassy) during inauguration at CPWD-SINTEF workshop 28. November 2017.

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Workshop on business models for C&D waste recycling organised by IL&FS Academy of Applied Development, Resilient Energy and SINTEF 2. February 2018

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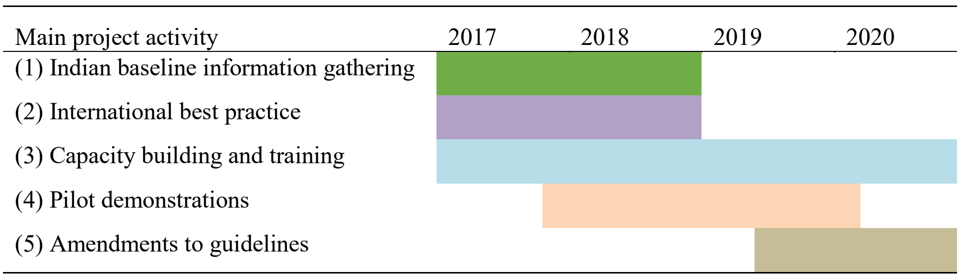
Main project activities and tentative time schedule



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On-going quality assessment at Burari and Shastri Park C&D facility, Delhi

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Shastri Park C&D facility, Delhi

State of the art technology

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Shastri Park C&D facility, Delhi
State of the art technology
EvoWash
AquaCycle A400

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Shastri Park C&D facility, Delhi
High quality products

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Quality assessment at Burari C&D facility, Delhi

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Quality assessment at Burari C&D facility, Delhi
High quality aggregates

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Quality assessment at Burari C&D facility, Delhi
High quality end products

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Quality assessment at Burari C&D facility, Delhi
Basic properties of aggregates

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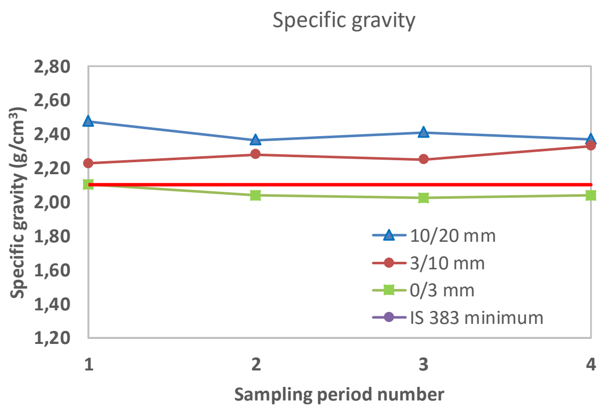
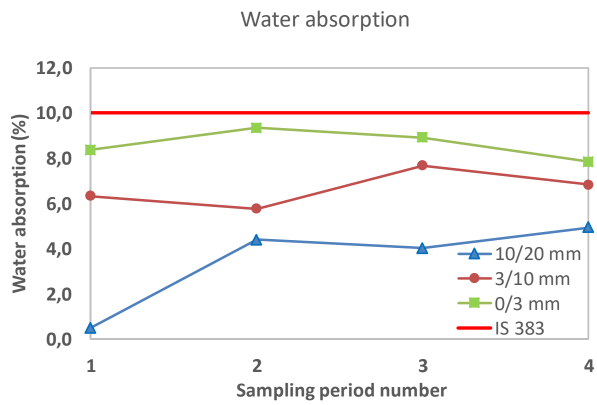
Specific gravity and water absorbtion





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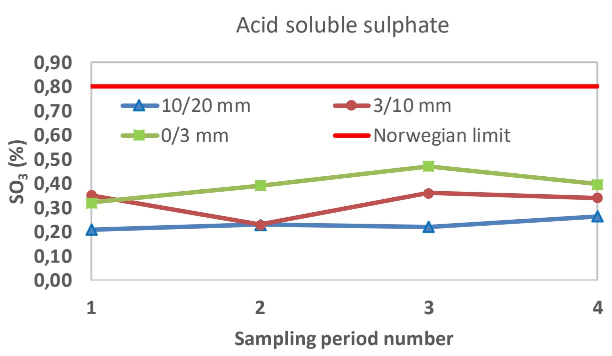
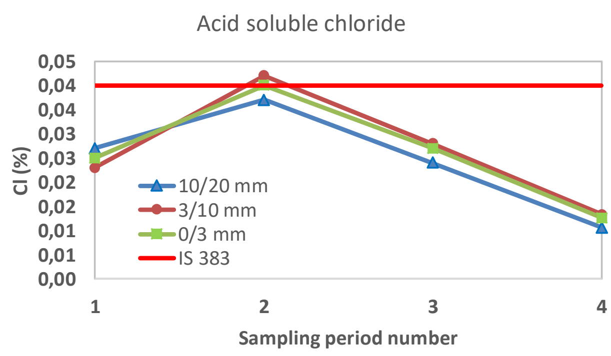
Acid soluble sulphate and chloride





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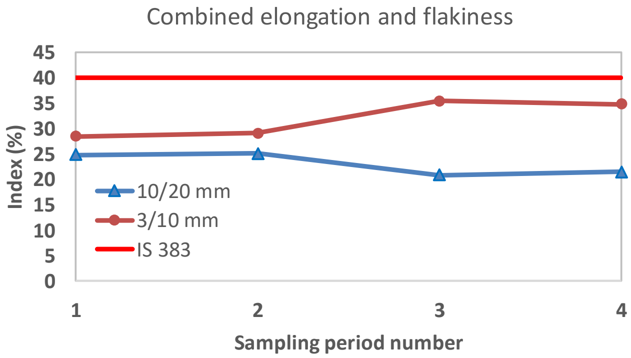
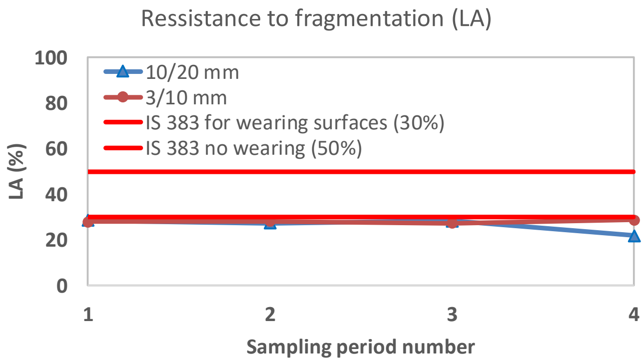
Elongation/flakiness index and Los Angeles





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Performance of mobile crushing units and space reuirements

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"Combi crusher" for wood and concrete

- Costs: 100 - 150 000 USD
- Engine: diesel and electric
- Transportable: only 13.5 ton

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Eddy current separator

- Costs: 100 - 200 000 USD
- Engine: diesel and electric
- Transportable

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Large mobile impact crusher


BA Gjenvinning, Oslo, Norway

- Kleeman EVO 130
- Installed at BA Gjenvinning in Norway
- Feedstock: concrete, masonry, asphalt
- Feed size: 900 x 1300 mm
- Capacity: 250-300 tph
- Engine: diesel and electric
- Transportable

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Hokksund, February 2013

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4 basic equipment's at site
CAT
Hokksund, February 2013

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Feeding with reinforcement
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Hokksund, February 2013

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Final product 0/100 mm
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Hokksund, February 2013

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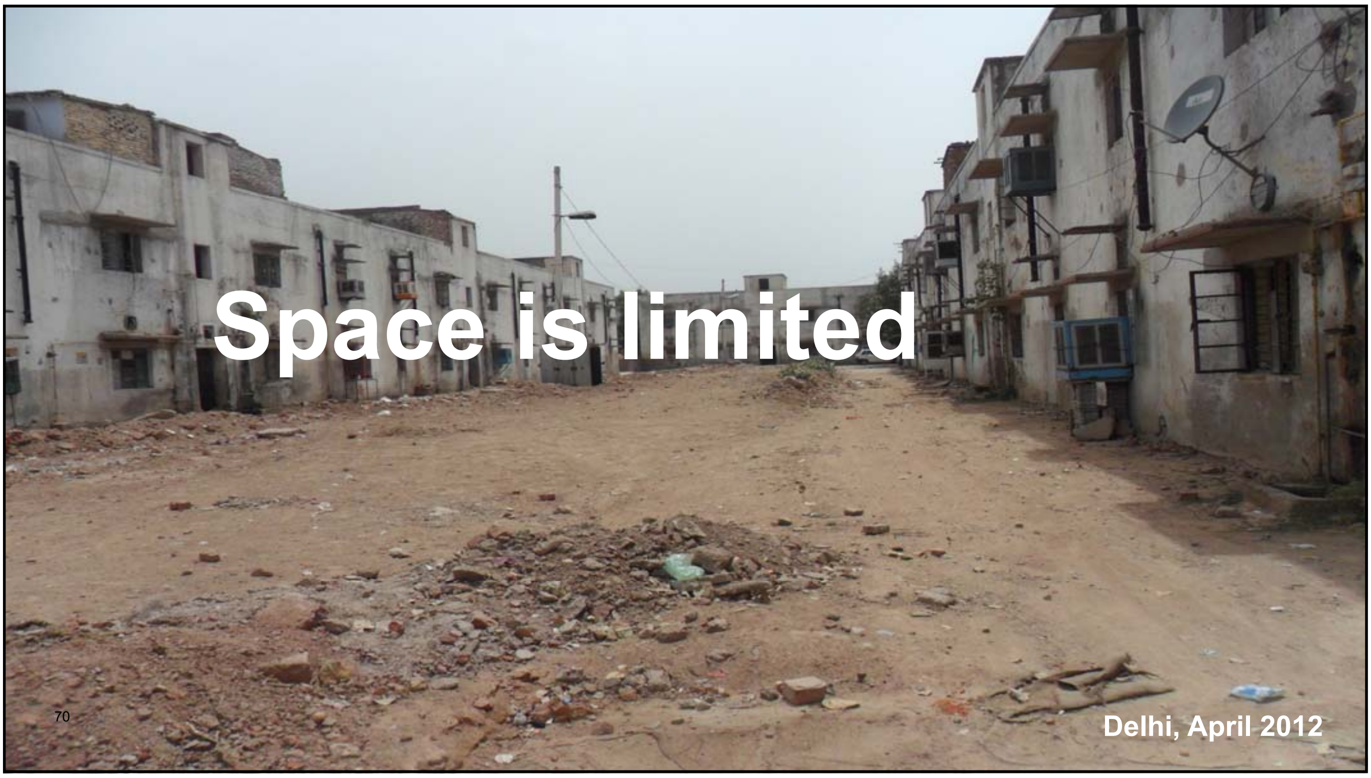
Space is limited
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Delhi, April 2012

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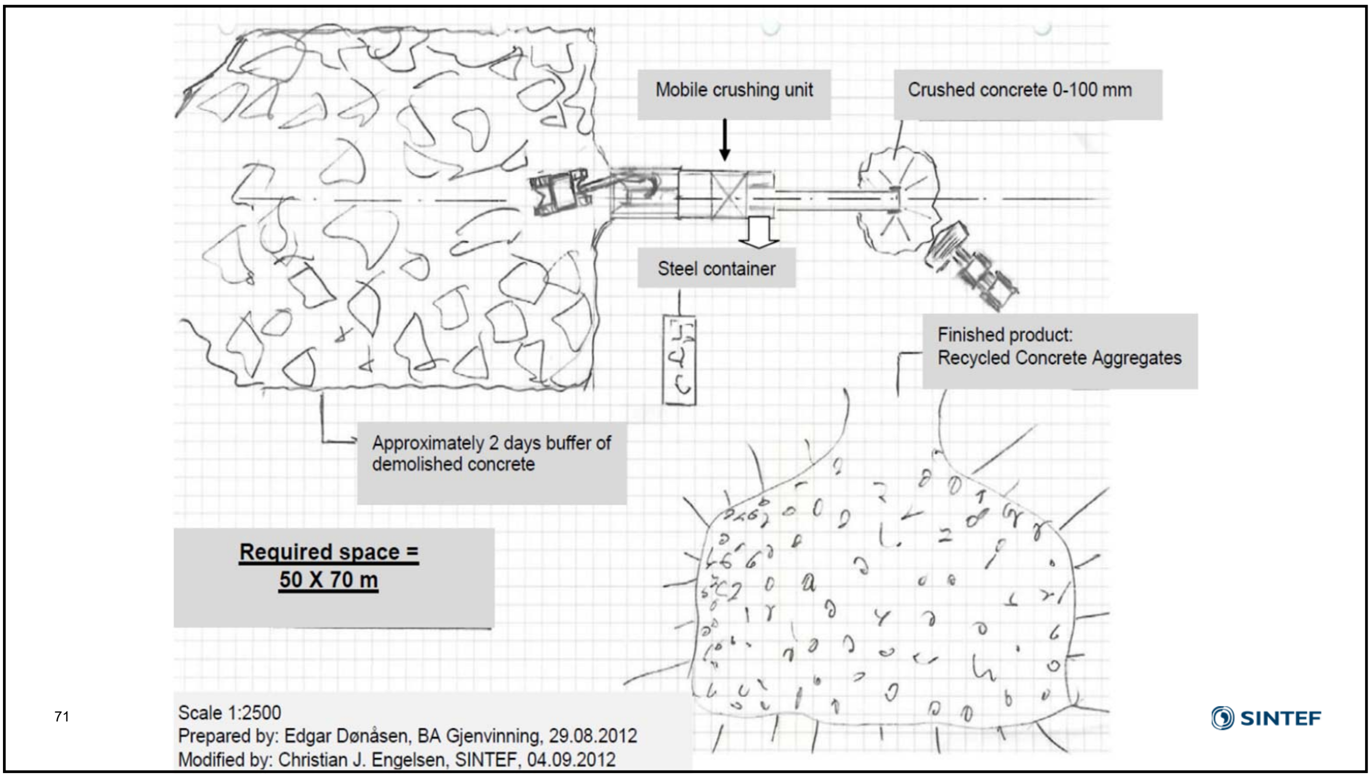

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Concluding remarks

- Enormous resources are present in the volume stream C&D waste in India
- International best practice shows that replacement level up to around 40% with recycled coarse aggregates without any significant loss of quality
- At high replacement levels, stricter requirements needs to be given to source material
- FPC is needed for production facilities for recycled aggregates
- Mobile and stationary units are complementary in fulfilling the needs in treatment and utilisation of C&D waste
- Significant amount of data is gained and the project is transferring this to Indian conditions and have also started collecting data from stationary plants in Delhi but will also gain data from mobile units

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Utilising the inherent CO_2-binding capacity of concrete – sustainable initiatives towards circular economy

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Carbon footprints of cement and concrete

- Cement clinker production
  - Burning of the raw meal at 1450 °C
  - Mainly pulverised limestone
  - In addition: Quartz, shale, clay etc.
- Portland cement
  - Finely ground clinker together with gypsum and supplementary cementitious materials (SCM)
  - Emission: 600-900 kg CO_2 per ton of cement
  - 60% or more originate from the calcination in the preheater and pre-calciner

$$CaCO_3 + heat = CaO + CO_2$$

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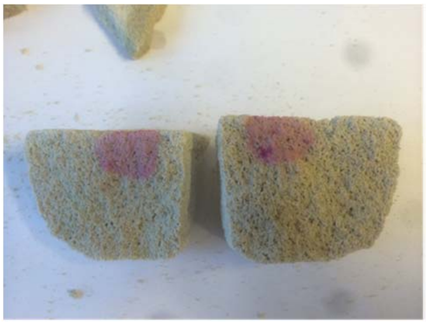
Natural CO_2-binding by carbonation

$CaCO_3$ + heat = CaO + CO_2 **Cement prodcution**

CaO + CO_2 = $CaCO_3$ **Carbonation when exposed to air**



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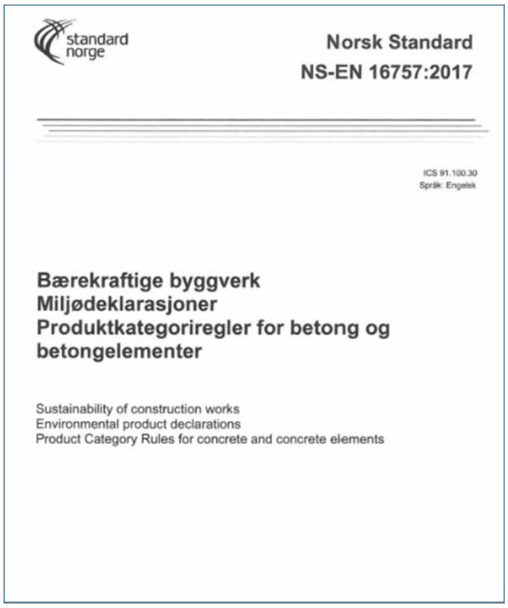
New PCR standard EN 16757



standard norge

Norsk Standard
NS-EN 16757:2017

ICS 91.100.30
Språk: Engelsk

Bærekraftige byggverk
Miljødeklarasjoner
Produktkategoriregler for betong og betongelementer

Sustainability of construction works
Environmental product declarations
Product Category Rules for concrete and concrete elements

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Carbonation of main hydrate phases

$CO_2 + H_2O \Rightarrow H_2CO_3$

$Ca(OH)_2 + CO_2 \Rightarrow CaCO_3 + H_2O$

$(CaO)_3(SiO_2)_2(H_2O)_4 + 3CO_2 \Rightarrow 3CaCO_3 + (SiO_2)_2(H_2O)_{4-w} + wH_2O$

$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O + 3H_2CO_3 \Rightarrow 3CaCO_3 + 3CaSO_4\cdot 2H_2O + 2Al(OH)_3 + 26H_2O$

$(CaO)_3Al_2O_3(CaCO_3)\cdot 11H_2O + 3CO_2 + 3H_2O \Rightarrow 4CaCO_3 + 2Al(OH)_3 + 11H_2O$

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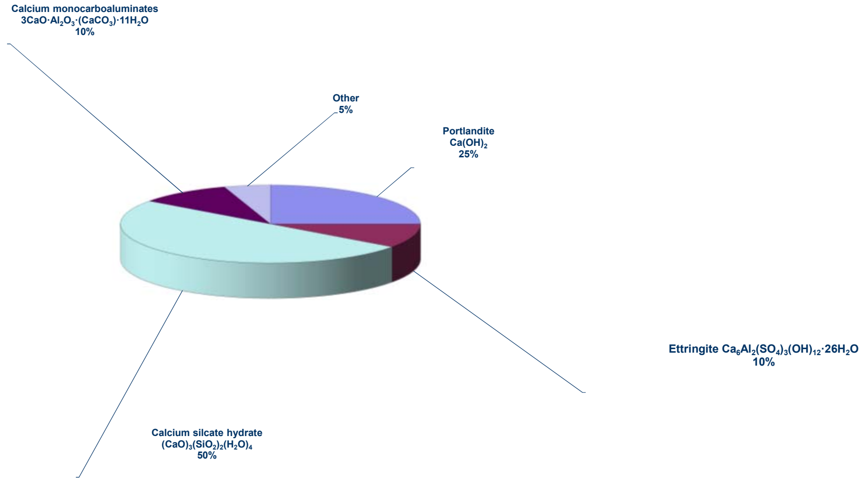
Portland cement paste – phase assembly



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What is the binding capacity of cements?

Cement type	Fly ash (%)	Slag (%)	CO_2-binding capacity (kg/t)
CEM I	Not applicable	Not applicable	330
CEM II/A-V[1]	20	Not applicable	255
CEM II/B-S[2]	-	33	294

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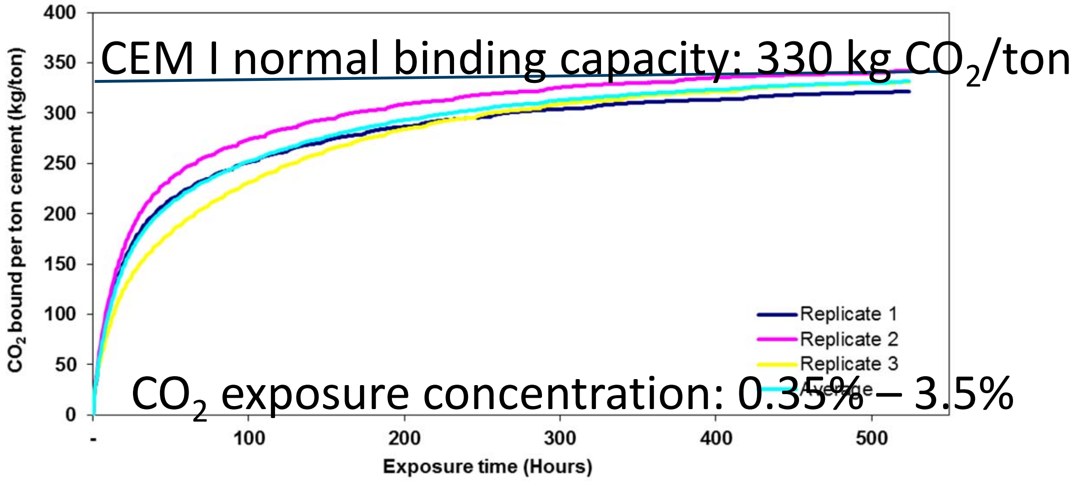
CO_2 - Binding capacity – demonstrated in laboratory on crushed concrete



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What is the binding capacity of concrete?

Ready-mixed concrete	Cement type(s)	Cement content kg/m³	CO_2-Binding kg/m³
Carbonated through	CEM I	300	100
Primary use and exposure of 100 years	CEM I CEM II/A-V CEM II/B-S	Accounted for real consumption	30

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Recycled concrete aggregates

- Ready-mixed concrete
- Concrete products
- Road construction
- Landscaping and covering masses
- Cement production
- Mineral building products

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Beneficial use: Increased surface area

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Beneficial use: Increased CO_2 - binding capacity

Burari C&D waste recycling plant, 29/11-2017 Delhi. Indo-Norwegian C&D waste project between SINTEF and CPWD

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Increased CO_2-binding capacity – full scale demonstration

Material	Amount (kg/m³)
Sand (0-8 mm)	815
Recycled materials (10-22 mm)	788
Portland cement	407
Microsilica	14.8
Water	226
SP (Scanflux AD 18)	3.256
Air entrainer (L-14 F)	0.936

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Increased CO_2-binding capacity – full scale demonstration

Scenario	CO_2-binding capacity (kg/m³)
Without RCA replacement	134
With RCA replacement (actual project)	151
Minimum increase	12%

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New initiative: CO_2-binding to concrete pavement blocks – measured on finished products

- Objective: Develop EPD accounting for real CO_2-absorption data
- Duration: 2017-2020
- Blended cements
- New measurement technology developed
- Consortium: Multiblokk, Aaltvedt Betong, Asak Miljøstein, Cemex, Norcem, Østfoldforskning and SINTEF

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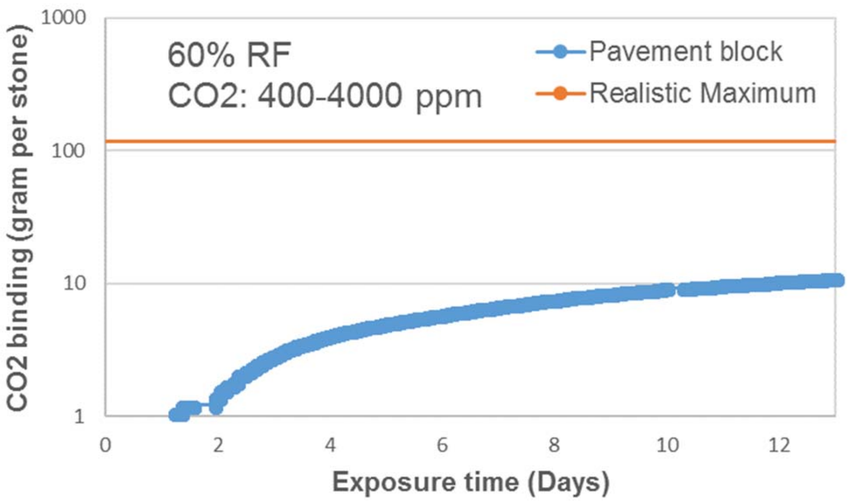
New initiative: CO_2-binding to concrete pavement blocks – measured on finished products (cont's)



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Conclusion

- Carbonation of concrete during primary use has been calculated to bind more than 13% of the CO_2 released during cement production – on average only 30 % of the normal binding potential for RMC
- C&D waste is generated at high volume globally that can relatively easy be refined to recycled aggregates and used in the construction industry
- Crushing of demolished concrete increases the surface and increases the CO_2-binding due to increased ageing by carbonation
- Development should move in a direction where the remaining CO_2-binding capacity is utilised as far as possible

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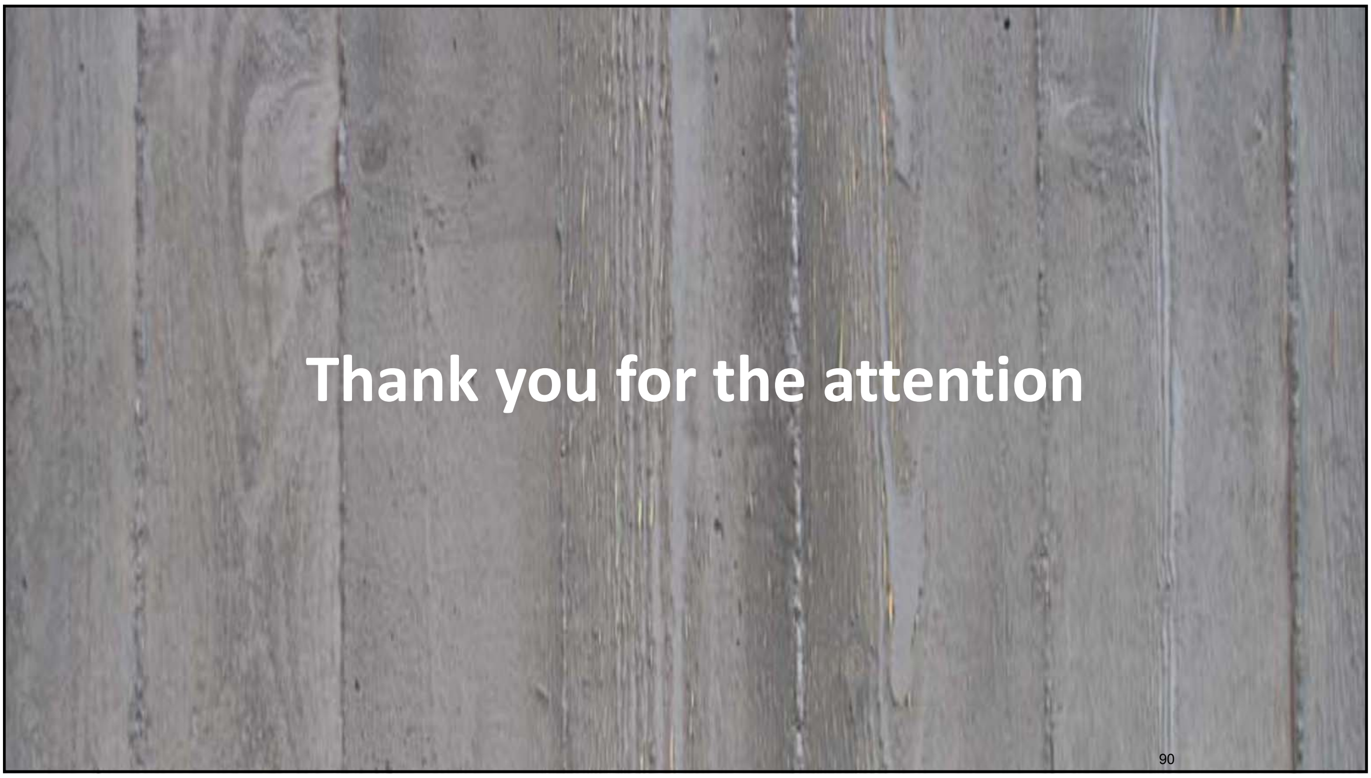

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