11.15 – 11.45 COFFEE

11.45 – 12.15 Viable recovery options for construction and demolition waste.

Christian J. Engelsen, SINTEF, Norway

12.15 – 12.45 OSAMAT – oil shale ash use in road construction – monitoring intermediate results

Andres Brakmann, Ramboll Estonia

Arina Koroljova, Eesti Energia AS

Euroopa Liit
Euroopa
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EJKL
ESTONIAN RECYCLING
COMPETENCE CENTER

TEEDEKLASTER
ESTONIAN ROAD CLUSTER

Viable recovery options for construction and demolition waste

Dr. Christian J. Engelsen

Senior Scientist, SINTEF

C&D waste generation

Amount of waste (Mt)	Europe[1]	USA[1]	Japan[1]	Norway[2]
Construction and Demolition waste (C&DW)	510	317	77	1.6
Municipal waste	241	228	53	2.2

[1] The Cement Sustainability initiative - Recycling Concrete; World Business Council for Sustainable Development

[2] Statistics Norway 2011

Generation and recovery[1]

Country	Total C&DW (Mt)	Total C&DW Recovery (Mt)	% C&DW Recovery
Australia[15]	14	8	57
Belgium[16]	14	12	86
Canada[17]	N/A	8 (recycled concrete)	N/A
Czech Republic[18]	9 (incl. 3 of concrete)	1 (recycled concrete)	45 (concrete)
England[19]	90	46	50 – 90
France[20]	309	195	63
Germany[21]	201	179	89
Ireland[22]	17	13	80
Japan[23]	77	62	80
Netherlands[24]	26	25	95
Norway[25]	N/A	N/A	50 – 70
Portugal	4	Minimal	Minimal
Spain[26]	39	4	10
Switzerland[27]	7 (incl. 2 of concrete)	2	Near 100
Taiwan[28]	63	58	91
Thailand[29]	10	N/A	N/A
US[30]	317 (incl. 155 of concrete)	127 (recycled concrete)	82

[1] The Cement Sustainability initiative - Recycling Concrete; World Business Council for Sustainable Development

Waste Framework Directive (2008/98/EC)

Requires that at least 70 % (by weight) of the C&D waste is recycled within 2020 (natural occurring materials are not included).

Recycling in this context: “any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. Excluding energy recovery.

Important stages for successful use

- **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.

Norwegian legislation (and European drivers)

- The Norwegian Planning and Building Act: regulation on technical requirements for building works (TEK10).
- The Norwegian Regulation on waste (Avfallsforskriften)
- Norwegian Pollution Control Act (Section 32).
- Waste Framework Directive.
- European standards for aggregates

Norwegian Waste Handling rules before demolition are implemented and enforced

Selective removal

Oslo, October 2000

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

C&D waste

Processing: crushing and fractionation

Recycled aggregates (RA or RCA)

Bound use | **Unbound use**

Crushing technology

Brief description: BA Gjenvinning AS, Norway	
Crushing equipment	Kleemann EVO 130 – total weight 65 ton
Charged material	C&D waste (concrete, masonry and asphalt)
Feed size	900 x 1300 mm
Feed capacity	250-300 t/h
End products	According to the end use
End product quality	Best obtainable – good cubic shape, stable, firm curve of end product (i. e. EU Norms)


Feed stock: Pre-stressed hollow core concrete
~ 45 000 tons
Hokksund, February 2013

4 basic equipment's at site

Hokksund, February 2013

Feeding with reinforcement

Hokksund, February 2013

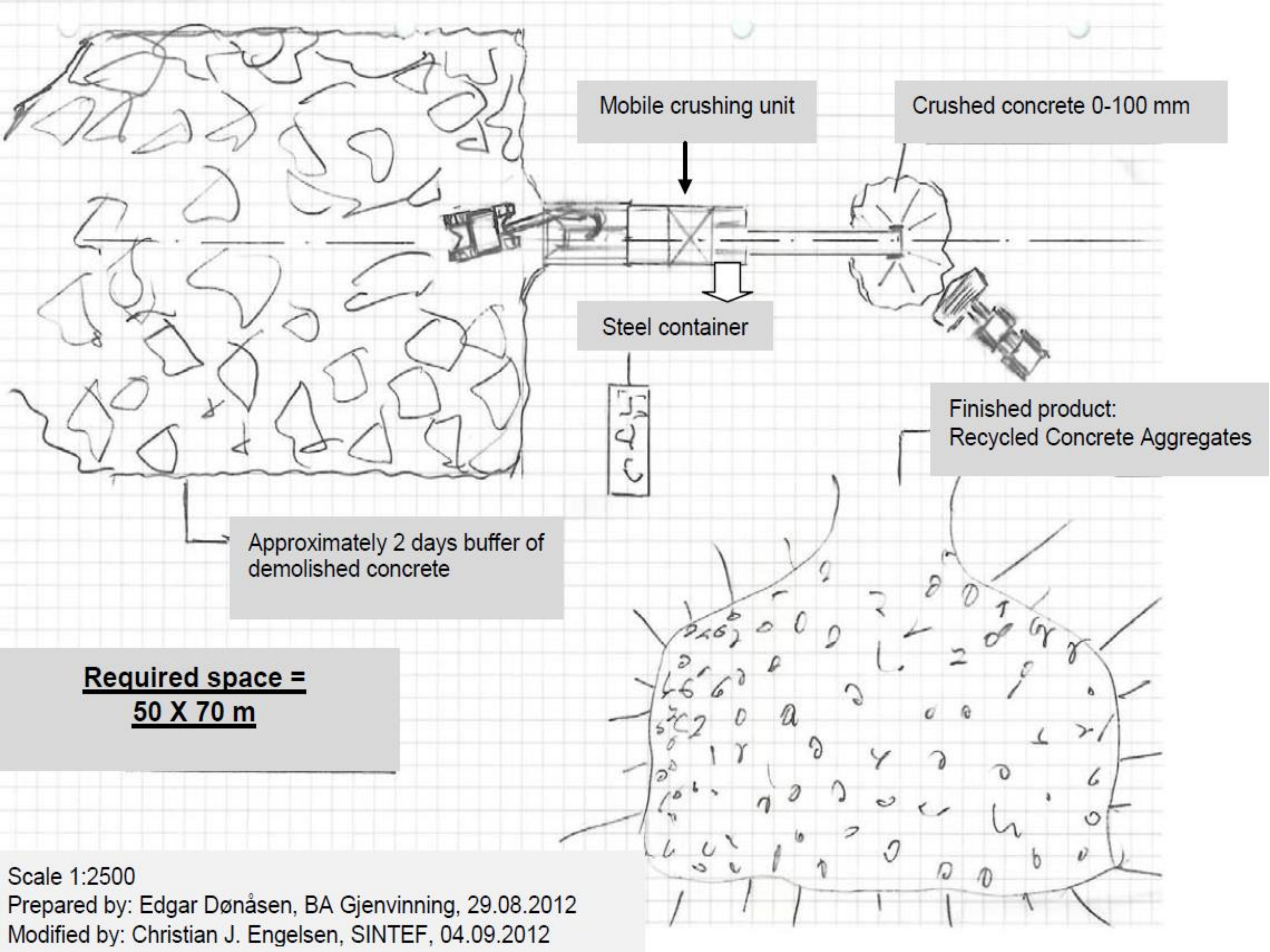
Final product 0/100 mm

Hokksund, February 2013


Space might be limited
How much area is needed?
Delhi, April 2012

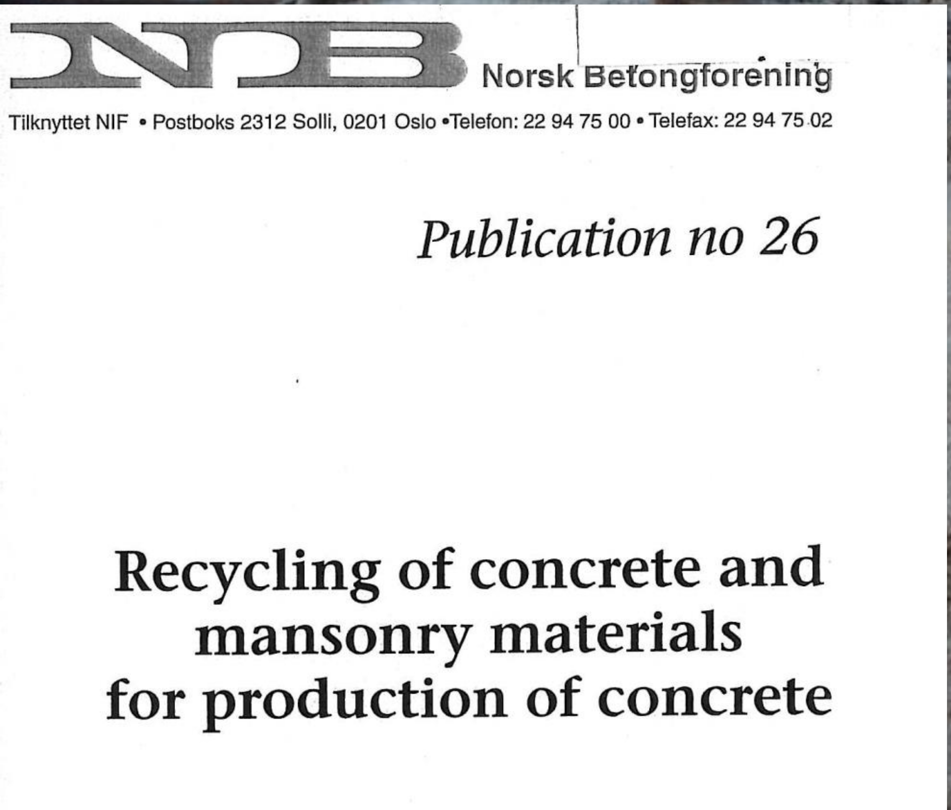
Manual demolition

Delhi, April 2012


Mobile crushing unit
Crushed concrete 0-100 mm
Steel container
Finished product:
Recycled Concrete Aggregates
Approximately 2 days buffer of demolished concrete
Required space =
50 X 70 m
Scale 1:2500
Prepared by: Edgar Dønåsen, BA Gjenvinning, 29.08.2012
Modified by: Christian J. Engelsen, SINTEF, 04.09.2012

Technical guidelines

Technical guidelines for processed C&D waste in new concrete


NB Norsk Betongforening

Tilknyttet NIF • Postboks 2312 Solli, 0201 Oslo • Telefon: 22 94 75 00 • Telefax: 22 94 75 02

Publication no 26

Recycling of concrete and mansonry materials for production of concrete

Published:1999

Recommended levels of RCA according to the Norwegian Guideline

Class	Particle size	Type 1	Type 2	Type 1 and 2
B20 LA	0-4 mm	5%	10%	10%
B20 LA	4-32 mm	10	30	30
Up to B45 Up to NA	4-32 mm	0	20%	-

Norwegian guidelines for processing C&D waste has been developed

C&D waste recovery in Norway

Year	C&DW Total	C&DW Concrete and Masonry part
2001	< 15%	Not estimated
2004	15%	25%
2011	55 %	88%

Material properties to be declared according to Norwegian guideline

- Particle size grading
- Fines (< 0.063 mm out of < 19 mm)
- Fines (< 0.020 mm out of < 19 mm)
- Material composition
- Organic content
- Particle shape (of fraction > 8 mm) Flakiness index
- Mechanical properties (Los Angeles)
- Particle density
- Water absorption
- Acid soluble sulphate and chloride content
- Leaching

<table>
<tr><th></th><th></th><th></th><th colspan="2">Frequency at continuous production</th></tr>
<tr><th>Property</th><th>Method</th><th>LAB</th><th>Bound use</th><th>Unbound use</th></tr>
<tr><td>Particle grading</td><td>EN 933-1</td><td>L</td><td colspan="2">Weekly or min. per 2000 tons</td></tr>
<tr><td>< 0,063mm of < 19mm</td><td>EN 933-1</td><td>L</td><td colspan="2">Weekly or min. per 2000 tons</td></tr>
<tr><td>< 0,020mm of < 19mm</td><td>NPRA</td><td>L</td><td>-</td><td>When required</td></tr>
<tr><td>Material constituents</td><td>EN 933-11</td><td>L</td><td colspan="2">Weekly or min. per 2000 tons</td></tr>
<tr><td>Organic material</td><td>EN 1744-1</td><td>L</td><td>Weekly or min. per 3000 tons</td><td>-</td></tr>
<tr><td>Shape – Flakiness index</td><td>EN 933-1</td><td>L/C/E</td><td colspan="2">Monthly</td></tr>
<tr><td>Los Angeles</td><td>EN 1097-2</td><td>L/C/E</td><td></td><td>Every second week or per 3000 tons</td></tr>
<tr><td>Density</td><td>EN 1097-6</td><td>L/C/E</td><td colspan="2">Every second week or per 10 000 tons</td></tr>
<tr><td>Water absorption</td><td>EN 1097-6</td><td>L/C/E</td><td colspan="2">Every second week or per 10 000 tons</td></tr>
<tr><td>Chloride</td><td>EN 1744-1</td><td>L/C/E</td><td>Every second week or per 10000 tons</td><td>When required</td></tr>
<tr><td>Sulphate</td><td>EN 1744-1</td><td>L/C/E</td><td>When required</td><td>When required</td></tr>
<tr><td>Leaching</td><td>EN 1744-3</td><td>A</td><td>-</td><td>Every second week or per 10000 tons</td></tr>
</table>

Krav til mekaniske egenskaper, korngradering, komprimering	Kvalitetskrav: Krav – Verdi	Kvalitetskrav: Krav – Kategori	Kvalitetskrav: Tole-ranser [5]	Kvalitetskrav: Maks. avvik	Kontrollomfang: Min. 1 prøve for hver påbegynt mengdeenhet
Los Angeles-verdi, øvre forst.lag	≤ 35 [2]	LA_{35}			10 000 m³ [9]
Los Angeles-verdi, nedre forst.lag	≤ 40	LA_{40}			10 000 m³ [9]
Micro-Deval-verdi, øvre forst.lag [3]	≤ 15	$M_{DE}15$ [4]			10 000 m³ [9]
Micro-Deval-verdi, nedre forst.lag [3]	≤ 20	$M_{DE}20$ [5]			10 000 m³ [9]
Maks pass. 63 µm av mat. <22,4mm [6]	7 % [6]		20 %	+2 %	1000 m³ [6]

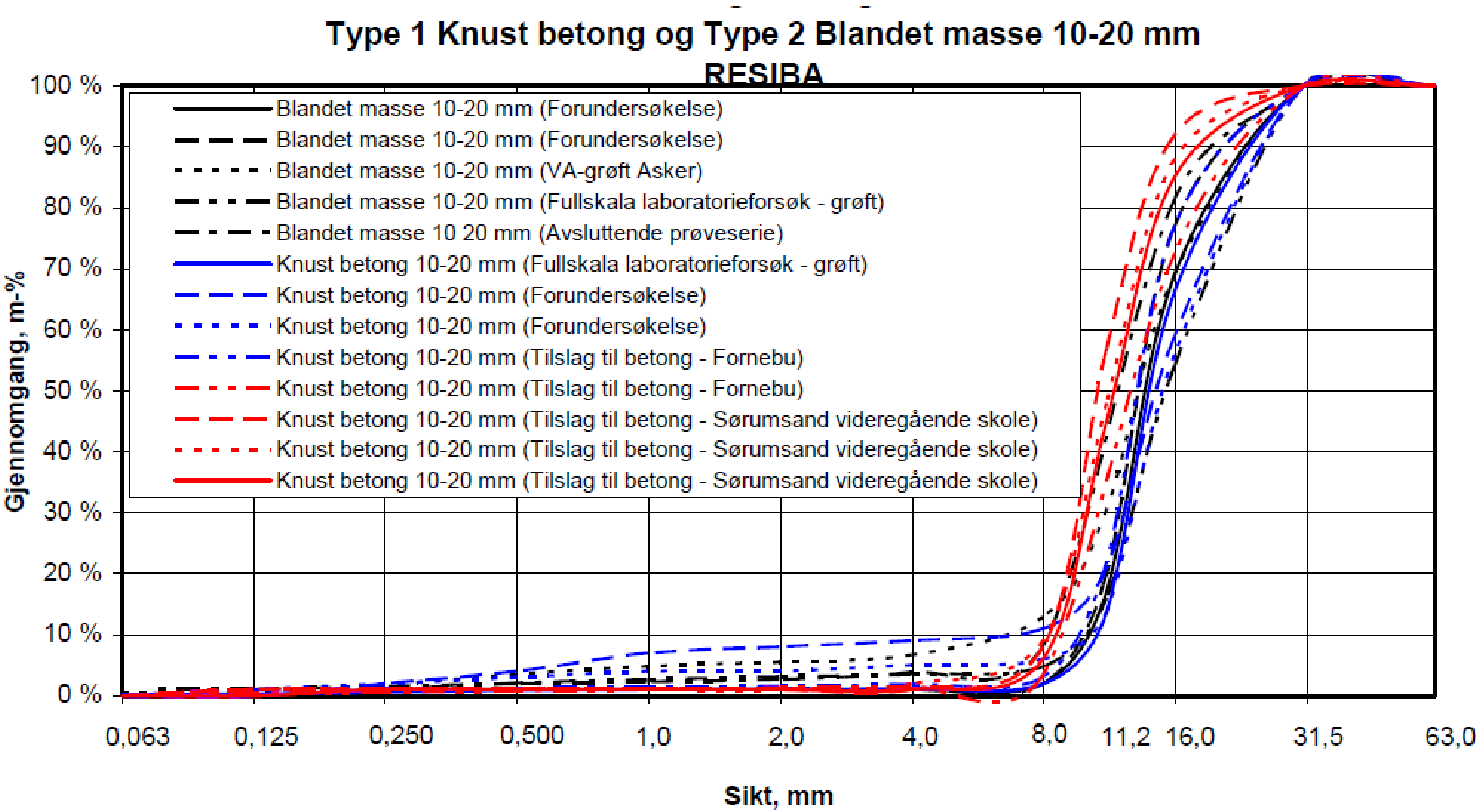
Experience and findings are implemented in Norwegian Roads Public Administration Handbook 018

Hoveddelmateriale:		
Knust betong (R_c)	≥ 90 %	
Knust betong, naturtilslag og knust murverk (Rc+ Ru+ Rb)		≥ 90 % [1]
Andre granulære delmaterialer:		
Knust murverk (Rb)	≤ 10 %	
Knust gjenbruksasfalt (Ra)	≤ 5 %	≤ 5 %
Ikke-mineralsk innhold:		
Glass (Rg)	≤ 2 %	≤ 2 %
Treverk, papir, metall, plast, gummi, annet (X)	≤ 1 %	≤ 2 %
Flytende partikler	≤ 5 cm³/kg	≤ 5 cm³/kg
Densitet: [2]		
Ovnstørr	> 2000 kg/m³	> 1500 kg/m³
Vannmettet overflatetørr	> 2100 kg/m³	> 1800 kg/m³
Vannabsorpsjon [2]	< 10 %	< 20 %

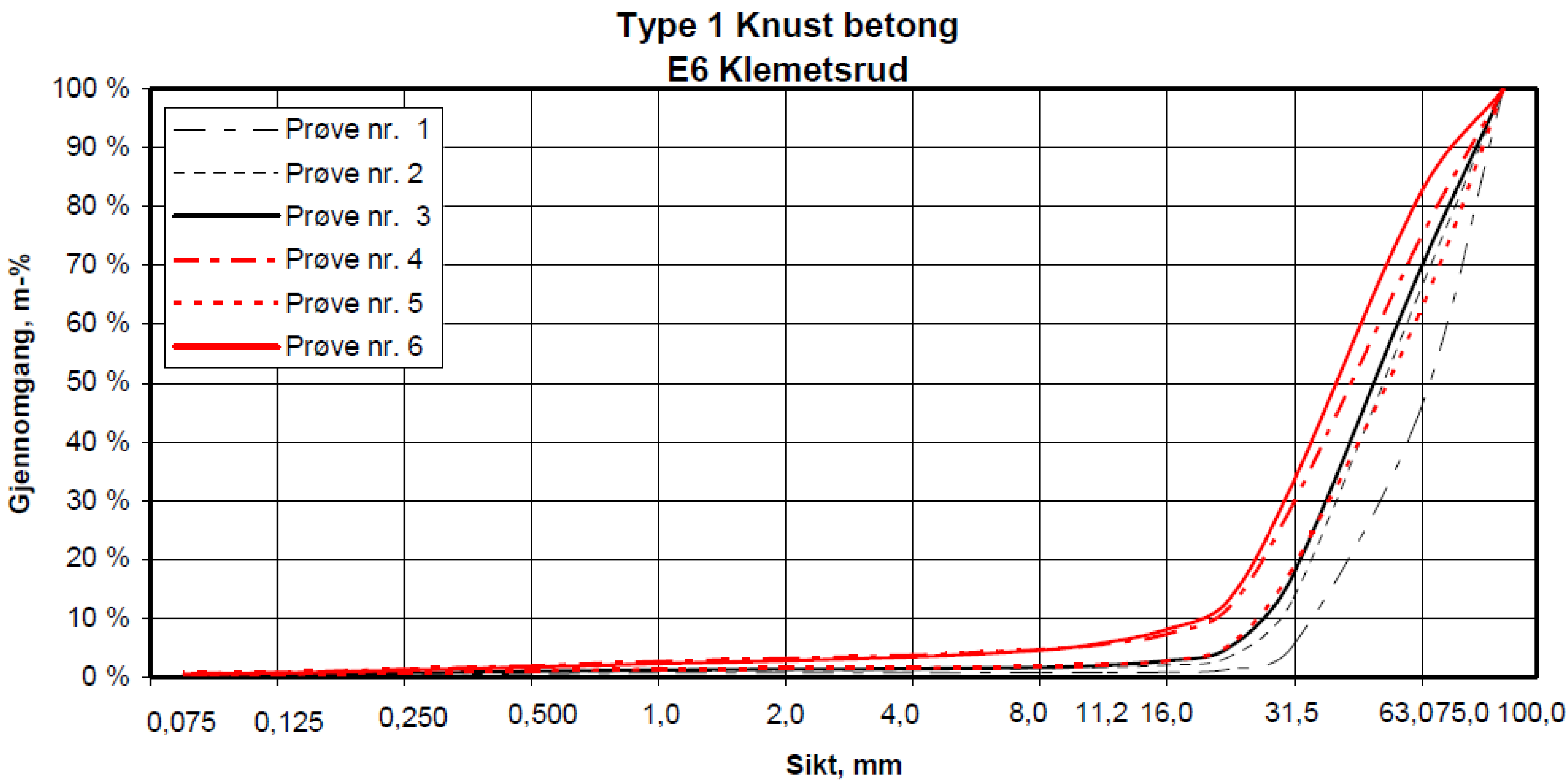
Typical data from Oslo area

Parameter	Type 1	Type 2
Particle density (ssd), g/cm^3	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)

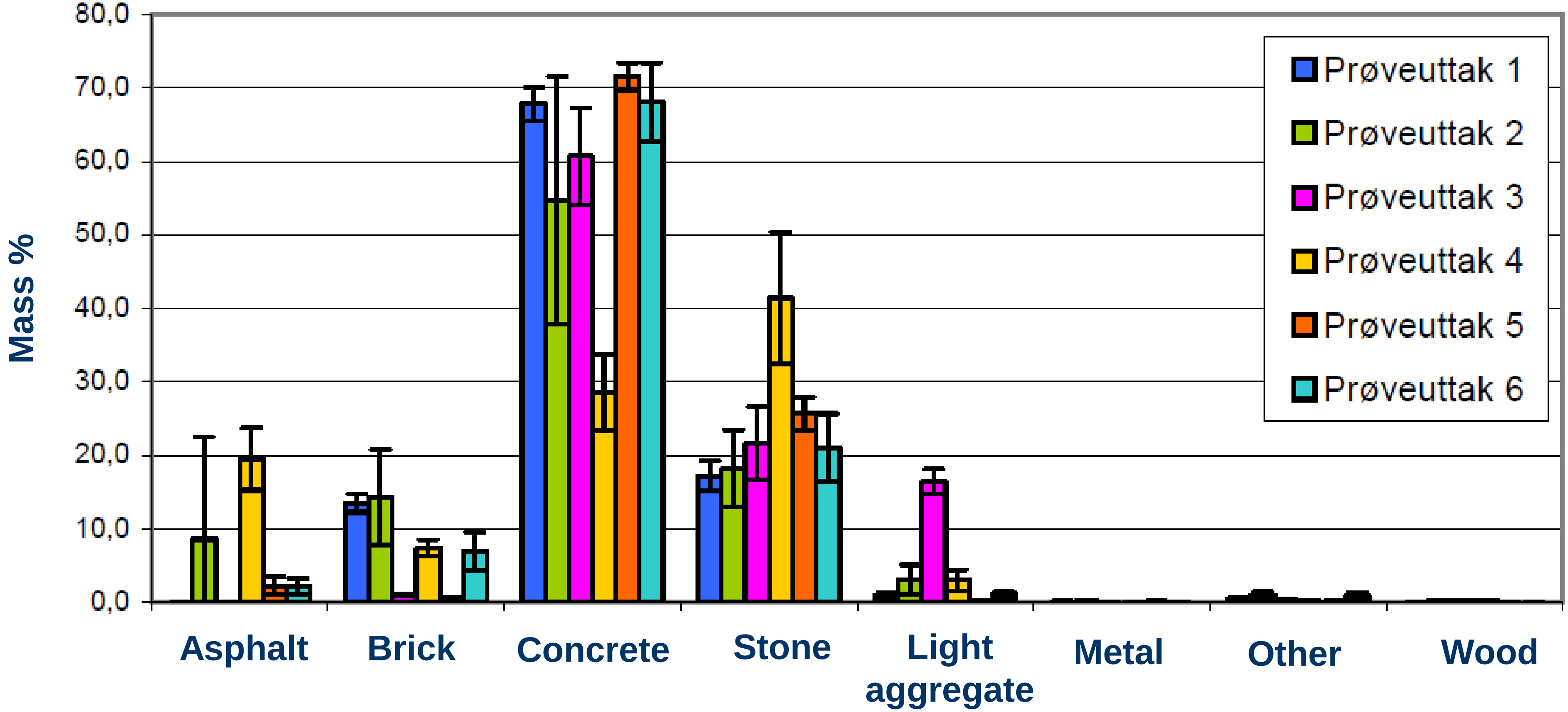
Particle grading 10/20 mm



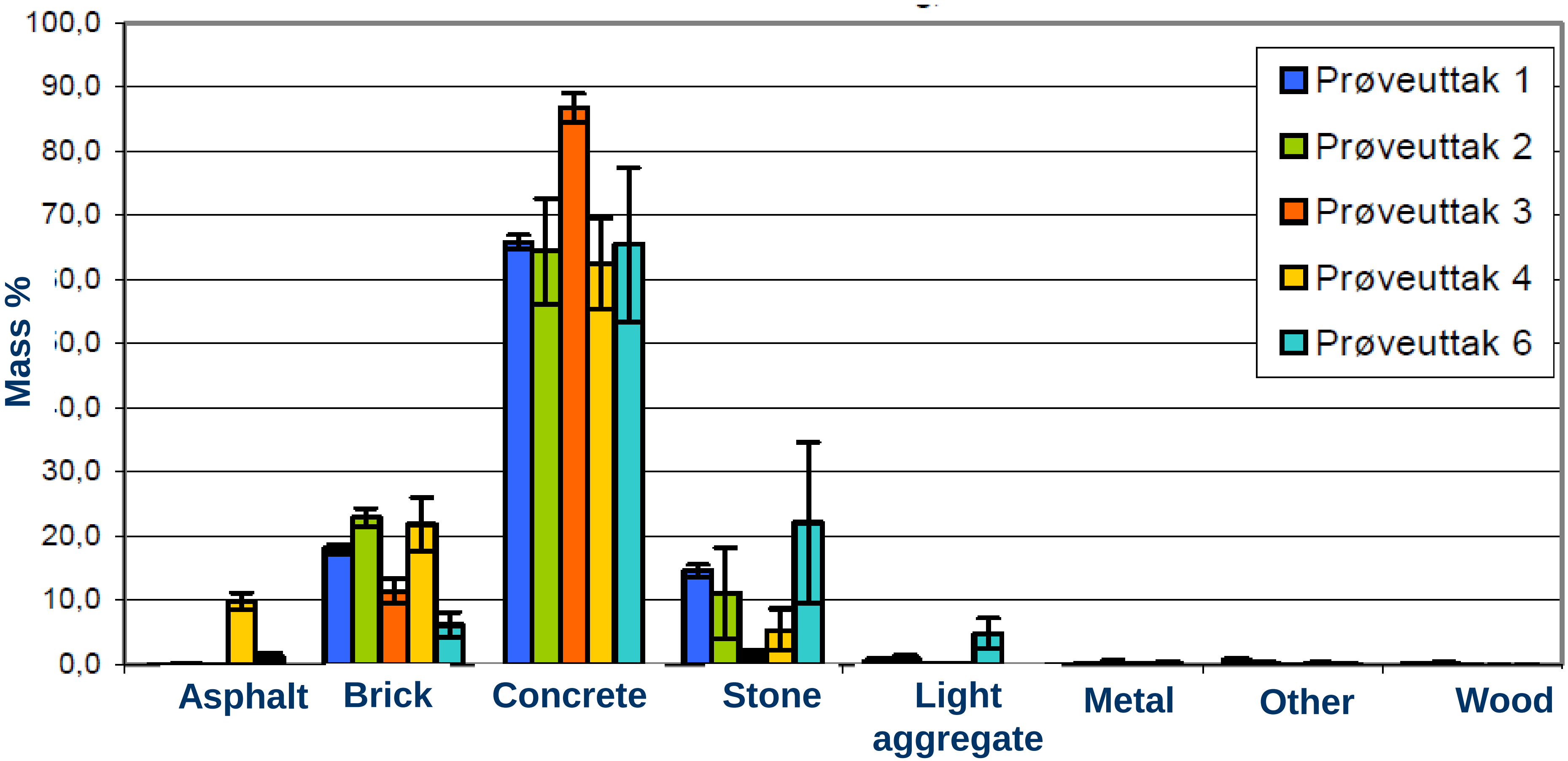
Particle grading 20/100 mm



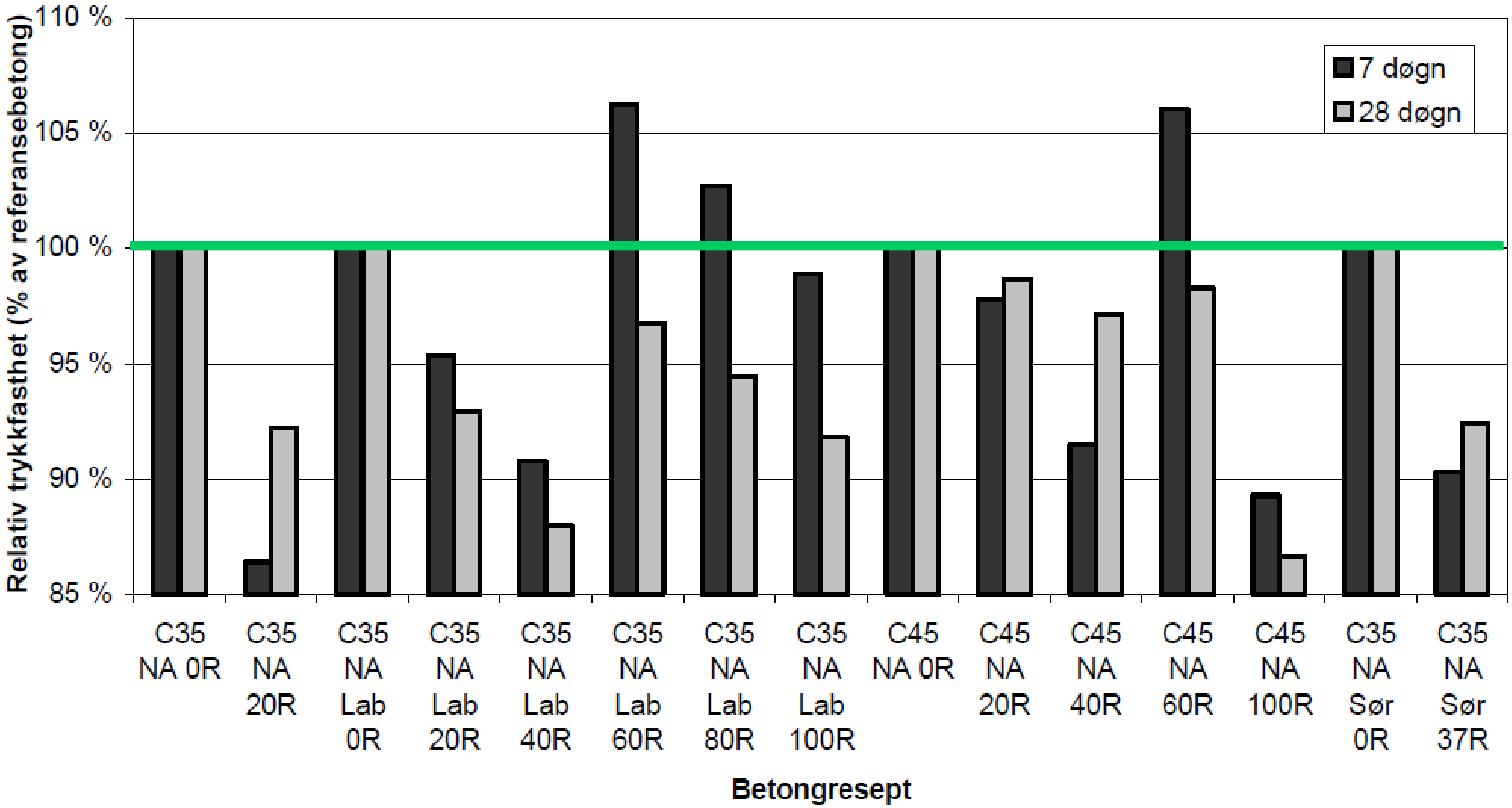
Material constituents 10/20 mm



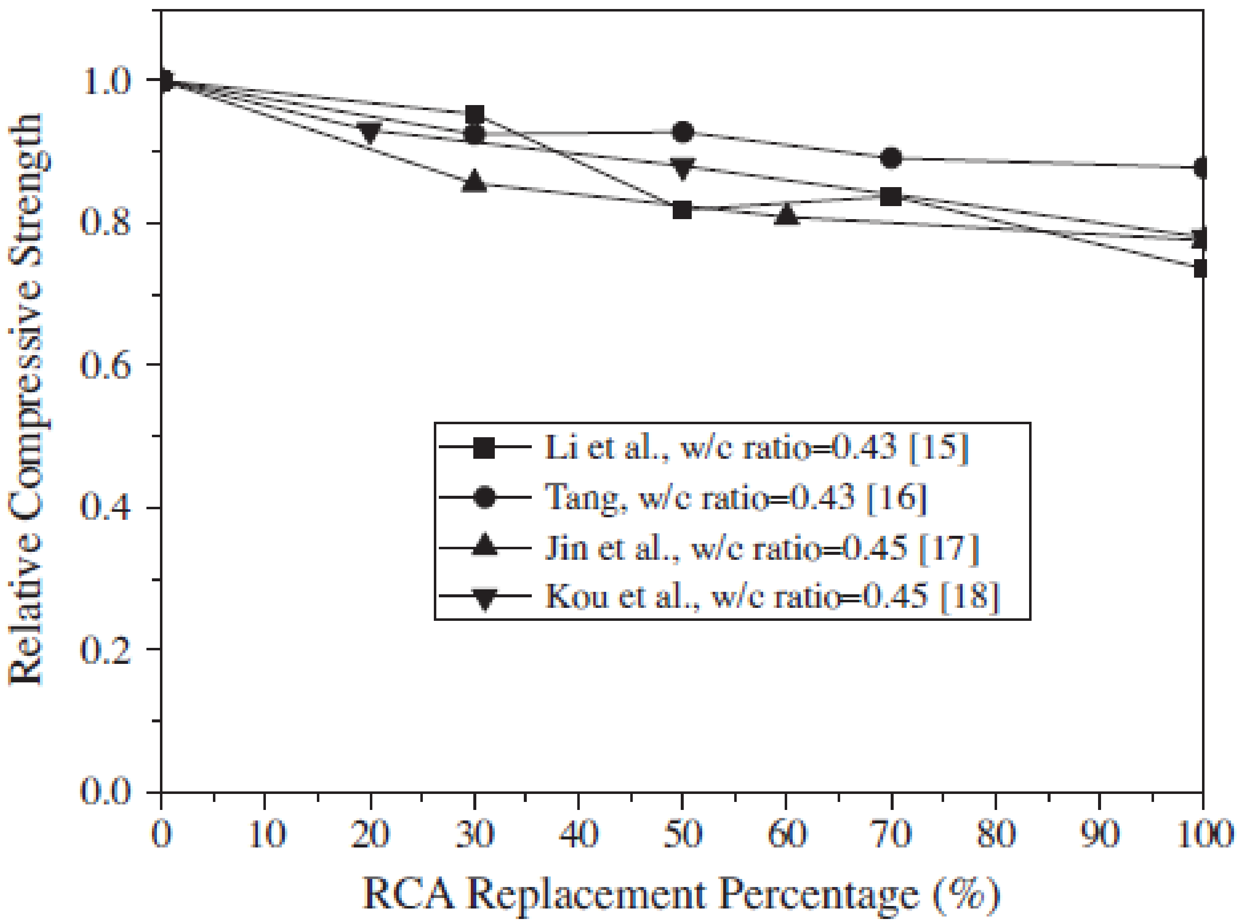
Material constituents 38/120 mm



Compressive strength



Other results



J. Xiao et al. / Construction and Building Materials 31 (2012) 364–383

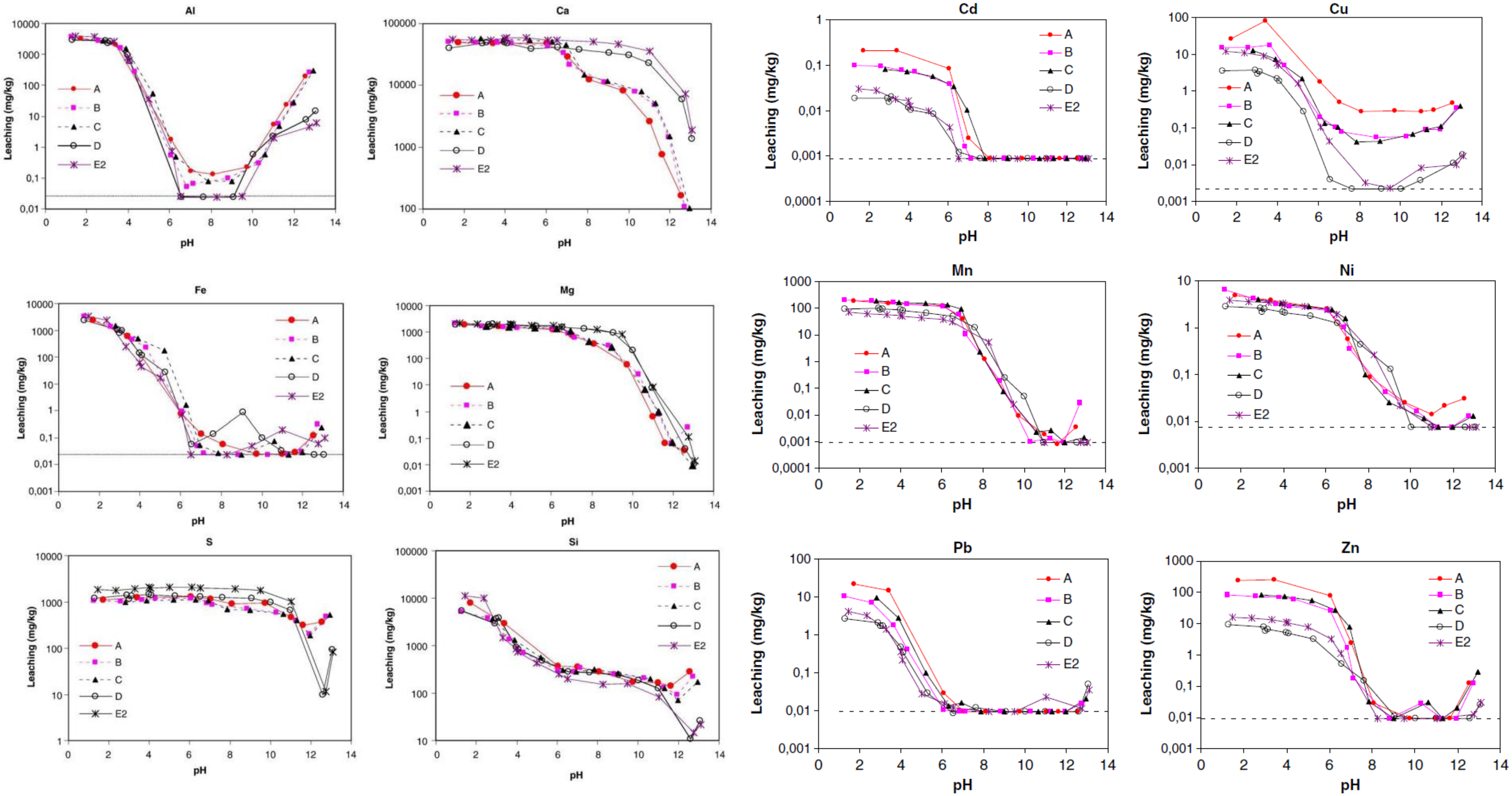
European standards for aggregates and recycled aggregates

Application area	Standard
Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction	NS-EN 13242
Aggregates for concrete	NS-EN 12620
Lightweight aggregates - Part 1: Lightweight aggregates for concrete, mortar and grout Lightweight aggregates - Part 2: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications	NS-EN 13055-1 NS-EN 13055-2
Aggregates for mortars	NS-EN 13139
Aggregates for railway ballast	NS-EN 13450

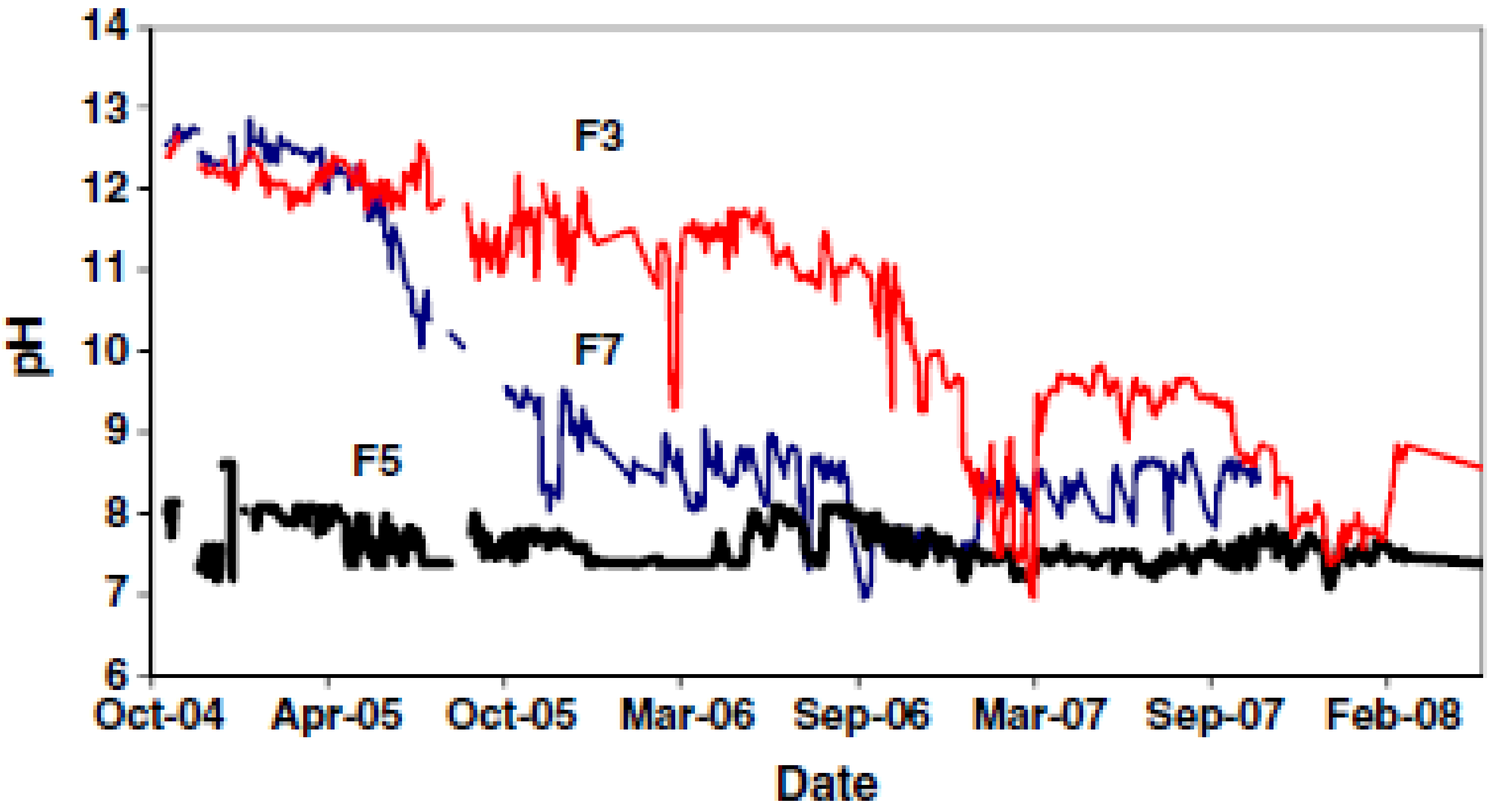
Engelsen, C.J. Recycled aggregates from concrete and masonry, Building Research Design Guides 572.111, SINTEF Byggforsk (in Norwegian), in print.

Environmental impact

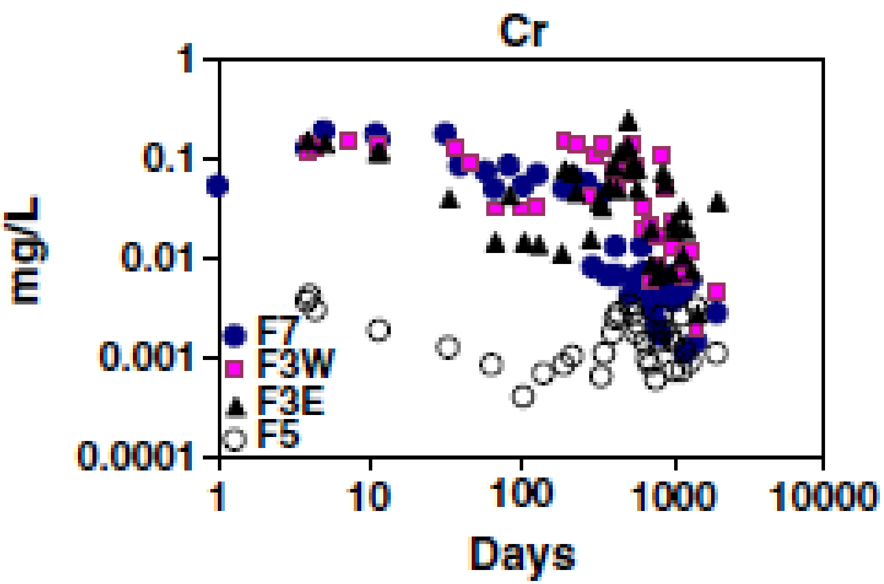
pH dependent leaching fingerprints

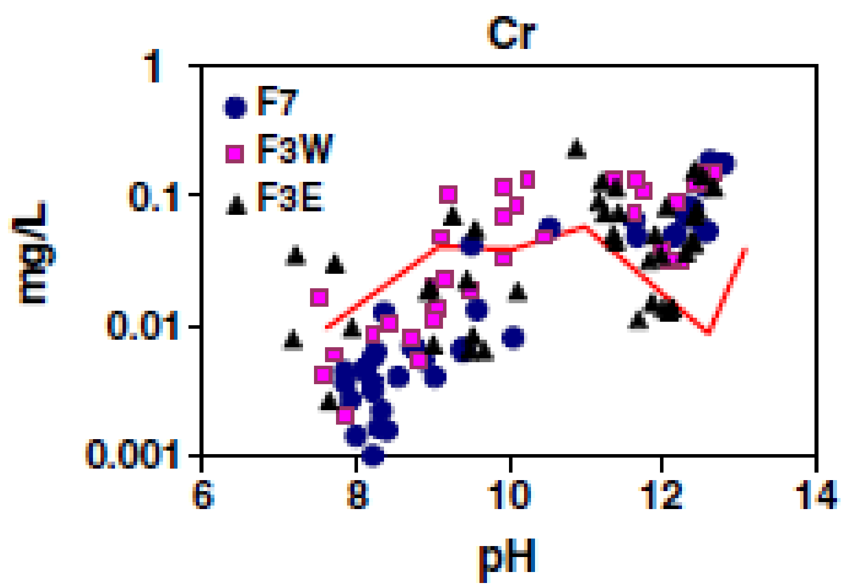


Field site pH VS time

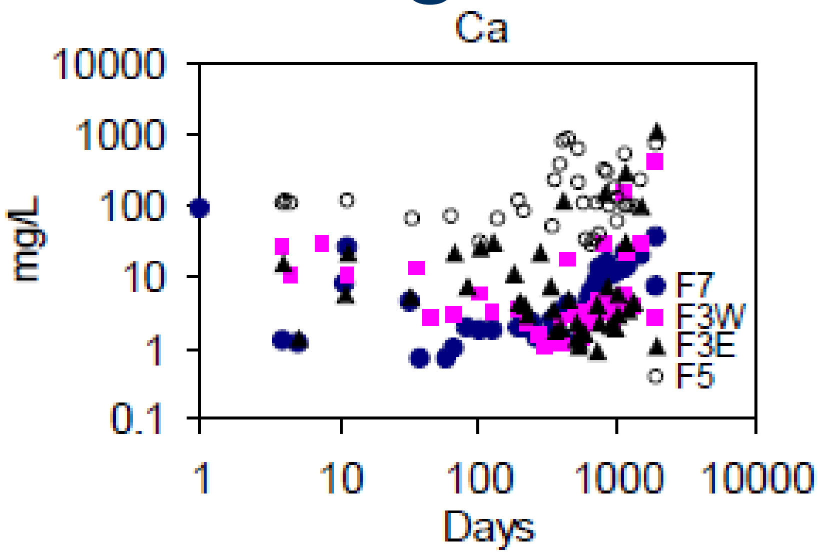


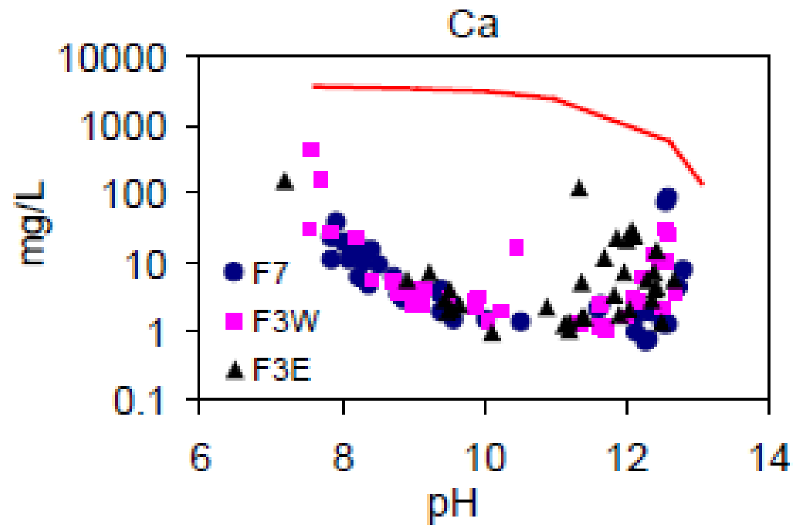
Field site leaching of Cr

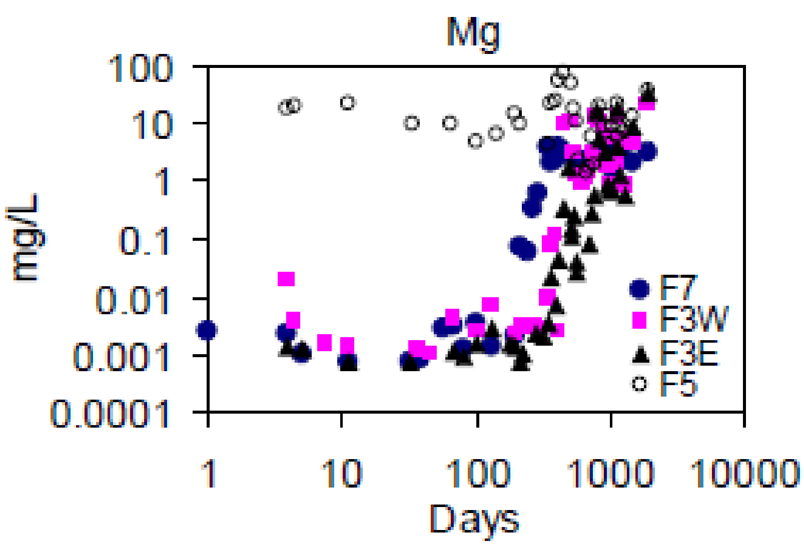


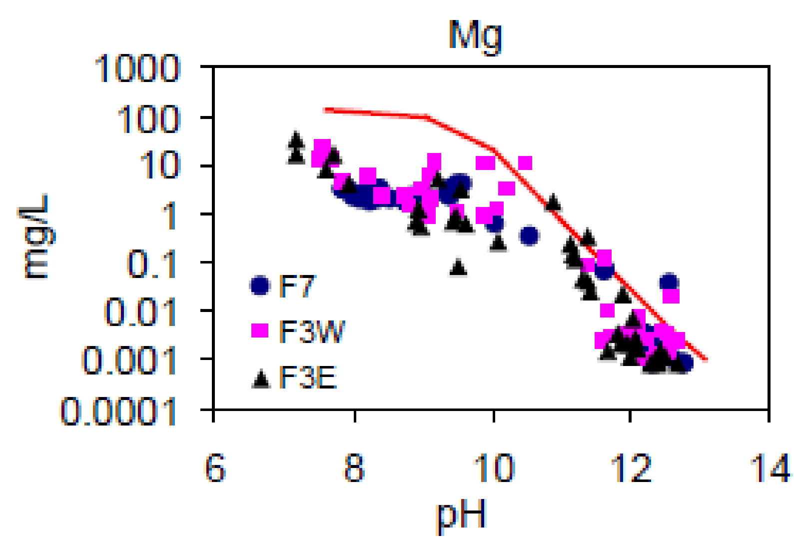


Ca and Mg in drainage water VS time

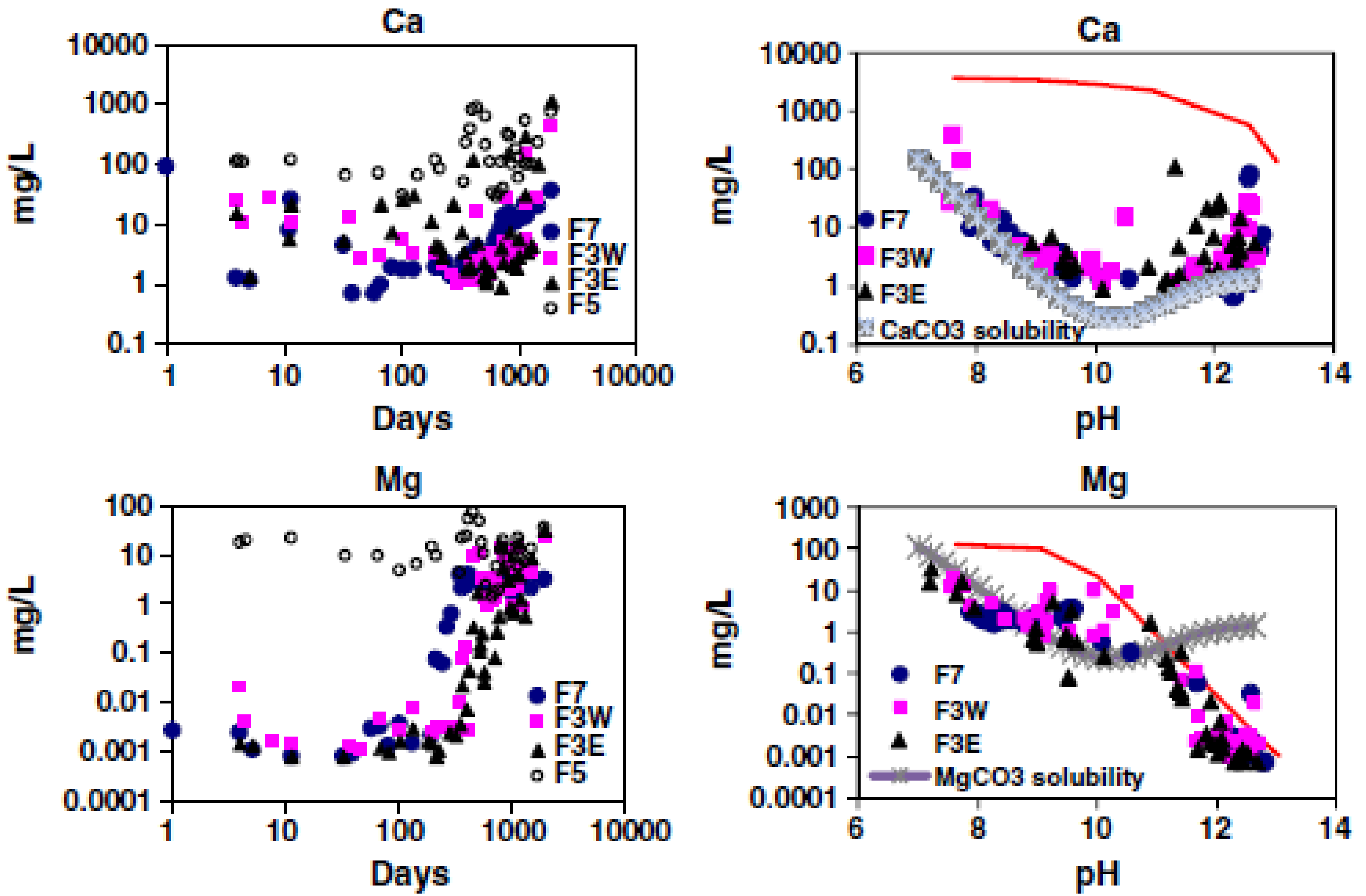




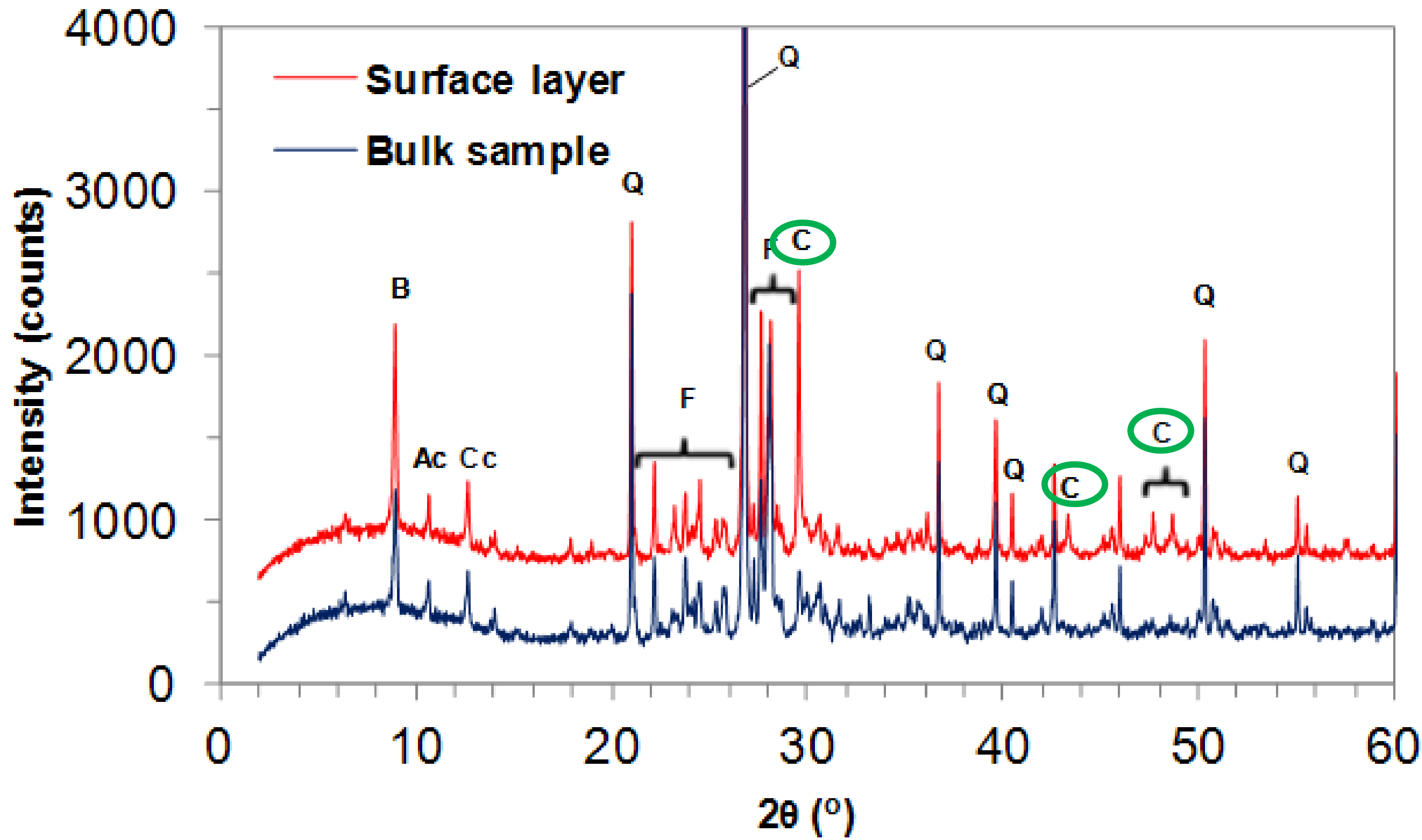




Thermodynamic modelling explains…



XRD of bulk and surface layer



Environmental Impact Assessment

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Resources, Conservation and Recycling 42 (2004) 249–264
Resources Conservation & Recycling
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Environmental impact from the use of recycle materials in road construction: method for decision-making in Norway

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Received 27 February 2004

Abstract

This paper presents the approach chosen by the Norwegian Public Roads Administrat way of obtaining more practical acceptance criteria for recycled materials in road construct approach is based on a combination of the European standard for characterization of was 12920, and Guidelines for evaluating impact on health and ecosystem; SFT 99:01, issue Norwegian Pollution Control Authority. The possibility of using generalized default assu contrary to site-specific data is the key issue. Norwegian conditions concerning natural resou waste are described with the aim of pointing out major differences from European countries t achieved high recycling levels. Traditionally, Norway is not a typical "recycling country", es

Cement and Concrete Research 39 (2009) 446–459
ELSEVIER
Contents lists available at ScienceDirect
Cement and Concrete Research
journal homepage: http://ees.elsevier.com/CEMCON/default.asp

Release of major elements from recycled concrete aggregates and geochemical modelling

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ARTICLE INFO

Article history:
Received 25 May 2007
Accepted 5 February 2009

Keywords:
pH
Hydrate phases
Leaching
Equilibrium
Geochemical modelling

ABSTRACT

The pH dependent leaching characteristics were assessed for different types of recycled concrete aggregates, including real construction debris and crushed fresh concrete samples prepared in laboratory. Carbonation effects were identified from the characteristic pH dependent leaching patterns for the major constituents Al, Ca, Fe, Mg, Si and SO_4^{2-}. The original particle size ranges were different for the samples investigated and this factor influenced the cement paste content in the samples which in turn controlled the leachable contents. Cement paste contents for concrete samples with fine particle size fractions (0–4 mm) were found to be higher than the originally present amount in the hardened concrete. Geochemical speciation modelling was applied over the entire pH range using the speciation and transport modelling framework ORCHESTRA, for which mineral saturation, solution speciation and sorption processes can be calculated based on equilibrium models and thermodynamic data. The simulated equilibrium concentrations by this model agreed well with the respective measured concentrations. The main differences between the fresh and aged materials were quantified, described and predicted by the ORCHESTRA. Solubility controlling mineral phase assemblages were calculated by the model as function of pH. Cement hydrate phases such as calcium silicate hydrate, calcium aluminate hydrate (AFm and AFt) and hydrogarnet were predominating at the material pH. The concentration of carboaluminates was found to be strongly dependent on the available carbonates in the samples. As the pH was decreased these phases decomposed to more soluble species or precipitates were formed including iron- and aluminium hydroxides, wairakite and amorphous silica. In the most acid region most phases dissolved, and the major elements were approaching maximum leachability, which was determined by the amount of cement paste.

Guideline values for RCA[1]

Parameter	Sub-base	Normverdi [1)]
As	< 20	< 8
Pb	< 200	< 60
Cd	< 3	< 1,5
Cu	< 250	< 100
Cr	< 110	< 50
Hg	< 1	< 1
Ni	< 110	< 60
Zn	< 600	< 200
∑PAH-16	< 2	< 2
∑PCB-7 [2)]	< 0,5	< 0,01

1) Normverdier issued in Norwegian regulation.
2) Based on evaluation, estimation and determination of leaching (Engelsen and Justnes, 2012).

[1]Engelsen, C.J. Recycled aggregates from concrete and masonry, Building Research Design Guides 572.111 (SINTEF Byggforsk), in print.

Cement paste in RCA varies dependent on the grain size[1]

Sample	Grain size mm	Cement paste %	Relative SD %
E1–1	0/4	28,4 ± 0,56	2,0
E2–1	4/8	18,2 ± 0,32	1,8
E3–1	8/16	12,6 ± 0,41	3,3

[1]Engelsen, C.J. Recycled aggregates from concrete and masonry, Building Research Design Guides 572.111, SINTEF Byggforsk (in Norwegian), in print.

Demonstrations

20/120 produced on-site for unbound use in sub-base

E6 Taraldrud south of Oslo, November 2004

UNBOUND USE

RCA in sub base (entrance lane)
E6 - Highway 25 km south of Oslo
November 2004

Science of the Total Environment 427–428 (2012) 86–97

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Field site leaching from recycled concrete aggregates applied as sub-base material in road construction

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ARTICLE INFO

Article history:
Received 15 December 2011
Received in revised form 6 April 2012
Accepted 7 April 2012
Available online 2 May 2012

Keywords:
Leaching
De-icing salt
Crushed concrete
Sub-base
Risk assessment

ABSTRACT

The release of major and trace elements from recycled concrete aggregates used in an asphalt covered road sub-base has been monitored for more than 4 years. A similar test field without an asphalt cover, directly exposed to air and rain, and an asphalt covered reference field with natural aggregates in the sub-base were also included in the study. It was found that the pH of the infiltration water from the road sub-base with asphalt covered concrete aggregates decreased from 12.6 to below pH 10 after 2.5 years of exposure, whereas this pH was reached within only one year for the uncovered field. Vertical temperature profiles established for the sub-base, could explain the measured infiltration during parts of the winter season. When the release of major and trace elements as function of field pH was compared with pH dependent release data measured in the laboratory, some similar pH trends were found. The field concentrations of Cd, Ni, Pb and Zn were found to be low throughout the monitoring period. During two of the winter seasons, a concentration increase of Cr and Mo was observed, possibly due to the use of de-icing salt. The concentrations of the trace constituents did not exceed Norwegian acceptance criteria for ground water and surface water Class II.

1. Introduction

Experimental leaching studies are normally carried out under controlled laboratory conditions and with certain fixed test parameters. In the pH dependence test CEN/TR 14429, the aim is to study the equilibrium based release from the test material at different pH values. This type of leaching behaviour has been addressed for recycled concrete aggregates (RCA) in earlier studies (Engelsen et al., 2009, 2010). The laboratory data and the subsequent speciation modelling provide valuable information regarding the leaching behaviour under real exposure conditions at field site, and in particular for materials that change pH over time as a result of ageing (e.g. carbonation of materials with a high pH). Thus, in a percolation scenario with RCA (water is infiltrating through the voids and the pores in the material), the pH of the material will gradually decrease due to carbonation, which may lead to a change in the concentration of released substances. Moreover, the external field conditions, such as exposure to slow moving ground water, or exposure directly to rainfall will also have an influence due to differences in pH, buffer capacity, water contact and the degree of saturation. As a result, the release of substances may vary in scenarios with different external pH, which in a qualitative way can be predicted from the leaching characterisation carried out in the laboratory, even if the field conditions may not be in chemical equilibrium.

However, at the field site the recycled material is affected by a number of parameters which are not easily dealt with in laboratory tests, such as the amount of precipitation, the degree of saturation, temperature, the embedding material (e.g. soil) and the external load (e.g. from heavy traffic). These conditions vary in time and space. Therefore, the release of chemical species measured over time at field site is of great importance and will provide actual release values. Combining the results from field site studies with results obtained in the laboratory may be used to further improve the long term leaching predictions and risk assessment calculations.

The aim of the present study was to monitor the constituent release from recycled concrete aggregates used in the sub-base of a road section. Infiltration water from the sub-base was drained in a closed system into sampling containers and the field pH was monitored on-line. In addition, the inorganic constituent release as a

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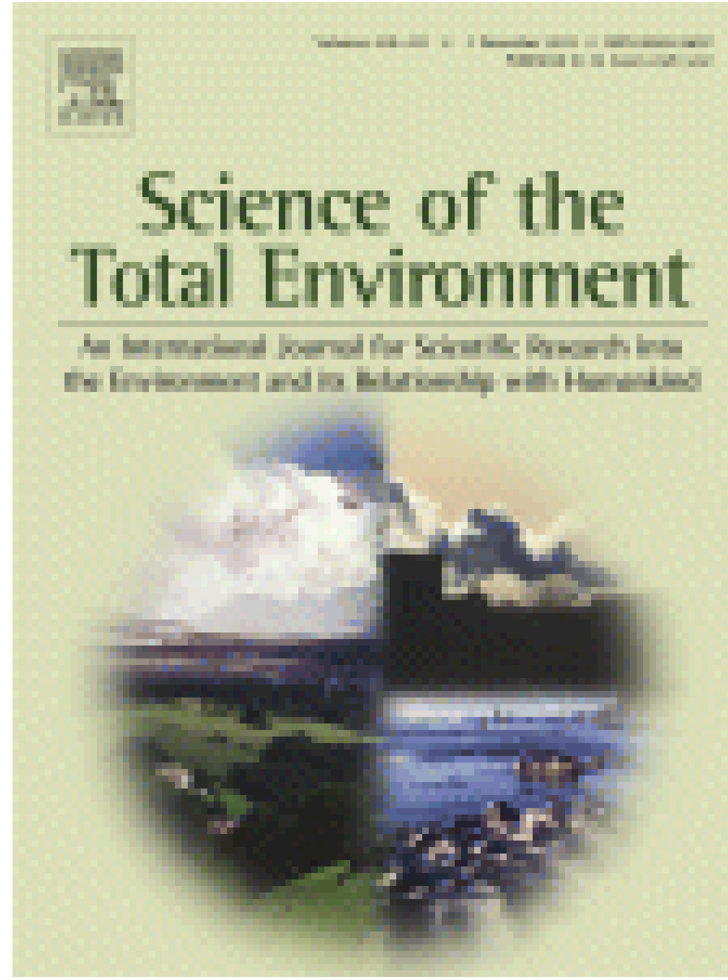
doi:10.1016/j.scitotenv.2012.04.021



Case study Old Hospital in Oslo

> 90% of the heavy C&D waste recycled (2002)

Retaining wall
E6 – Taraldrud (built 2004)
100% replacement of coarse aggregates

Final concrete recipe at RMC

Material	Content (kg/m^3)
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

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/m^3)	2479
Strength 7 days (MPa)	35
Strength 28 days (MPa)	44

Application
Shot concrete

Application in new products

Indian concrete bricks

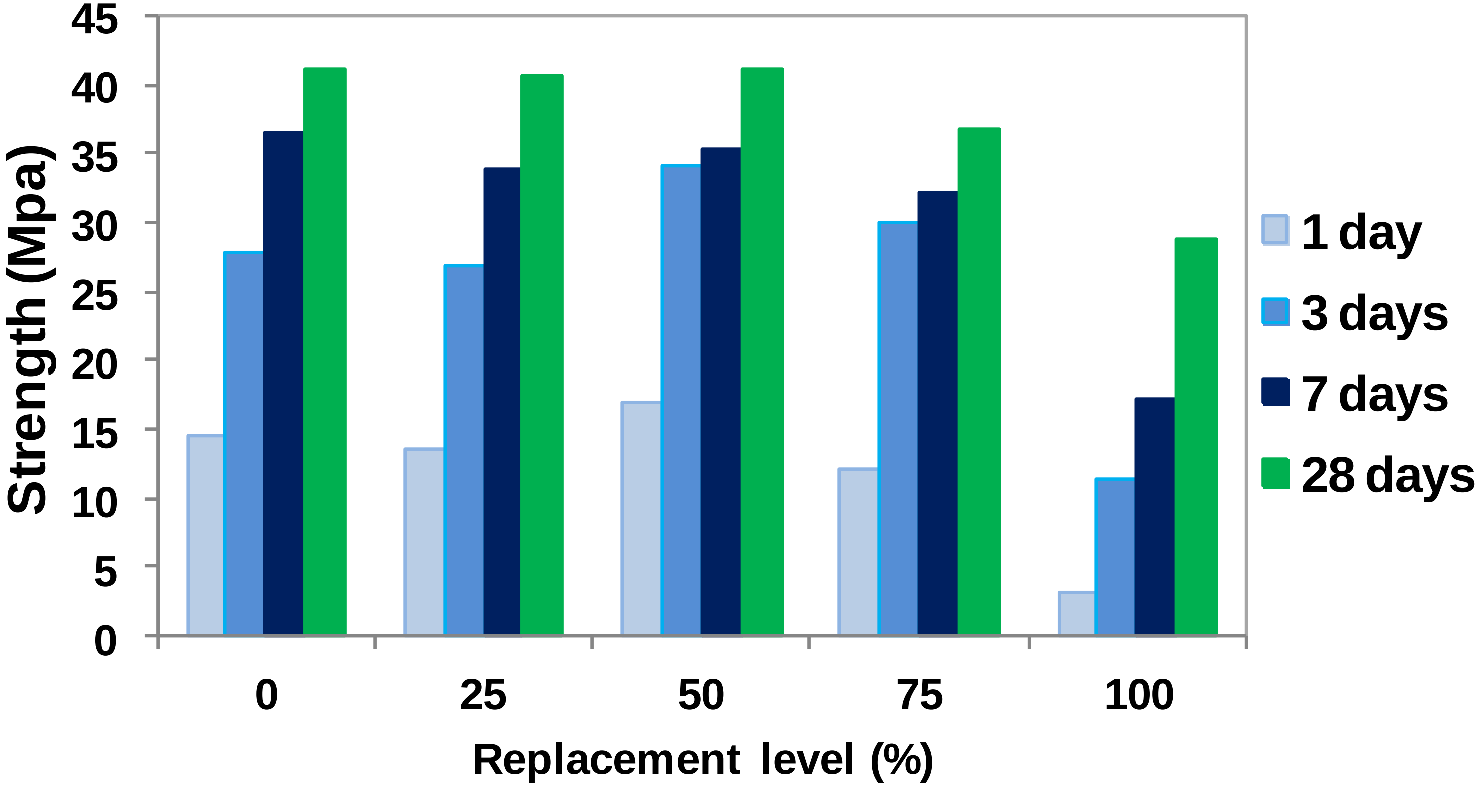

Indian pavement tiles

Case study in India: RCA as aggregate replacement in new concrete

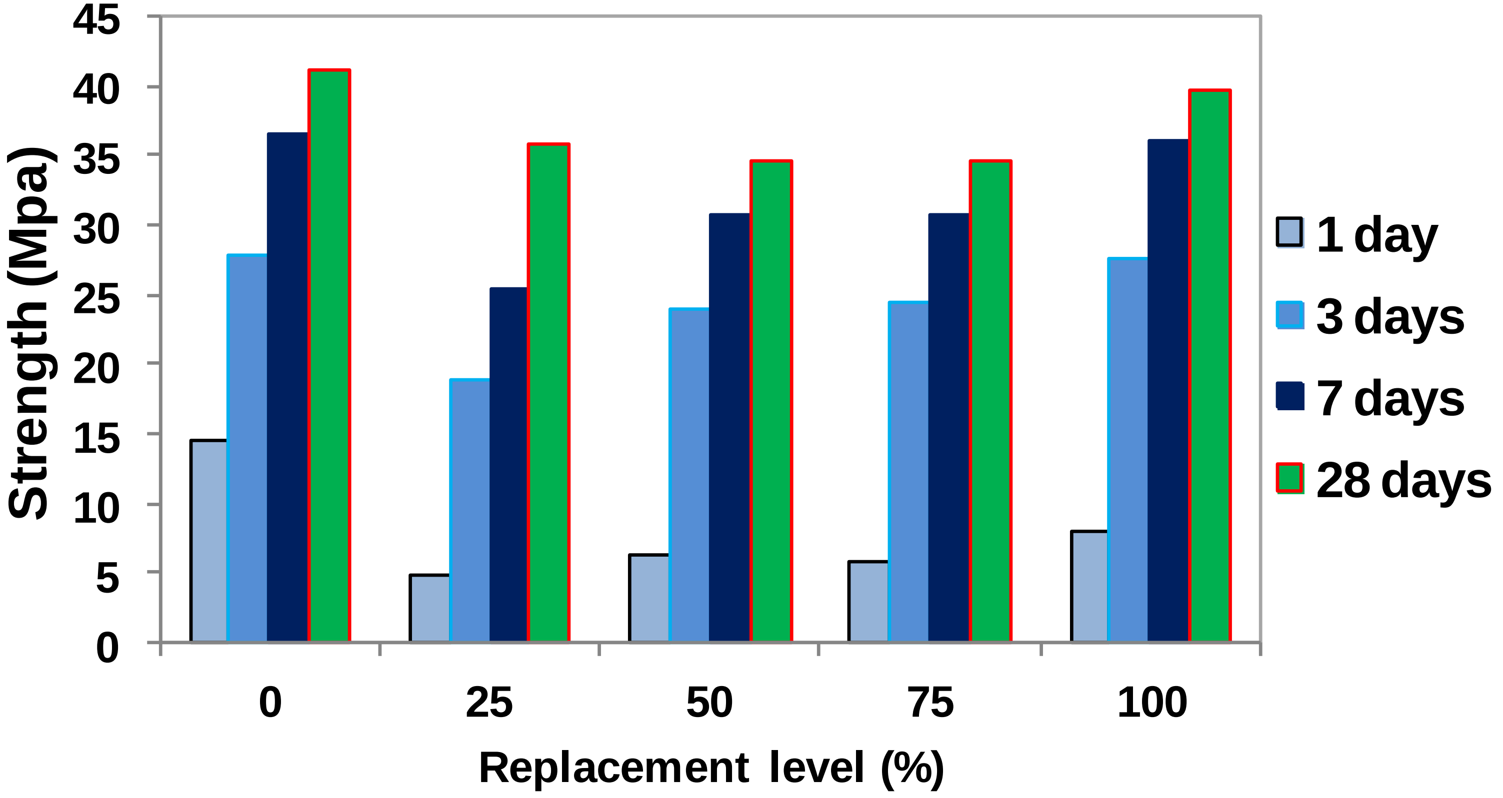
- ~ 5 tonnes of C&D waste sampled from the demolition of a housing estate in Delhi
- Carbonation assessment
- Grain size fractions according to IS 383 obtained by crushing
- Water absorption corrections
- Replacement of course and fine fractions by RCA
- Substitution levels up 100%
- Admixture content: 0.250 % by weight of binder
- w/b = 0.55


C&D waste site
Delhi, April 2011

Replacement of course fraction



Replacement of fine fraction



Closing remarks

- The whole waste management chain needs to be supported by rules and guidelines (prior, during and after demolition).
- Existing guidelines may be modified and converted to local scenario (e.g. metropolitan areas).
- 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.

Closing remarks (continues)

- **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.
- Authorities globally are putting high focus on C&D waste recycling.

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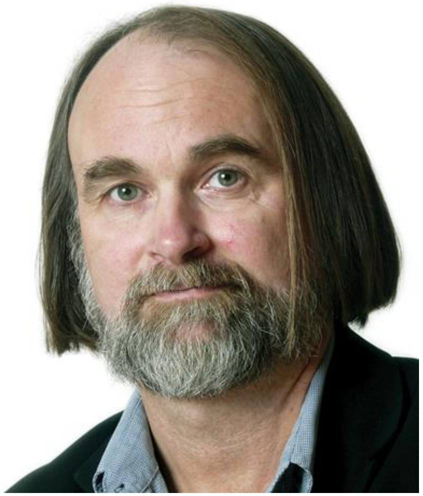

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Thank you for the attention