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Lecture 1: Closed loop of concrete rubble?

Lecture 2: Closed loop of masonry rubble?

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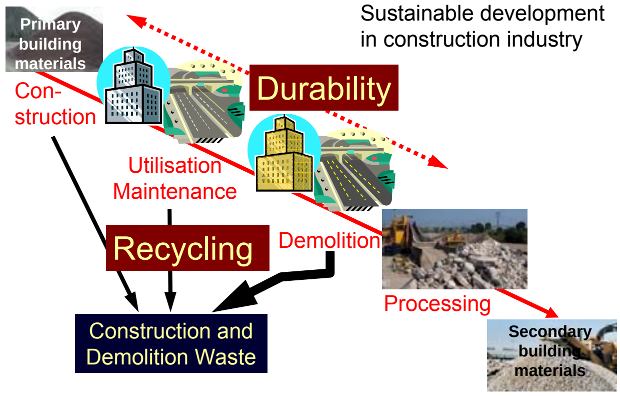
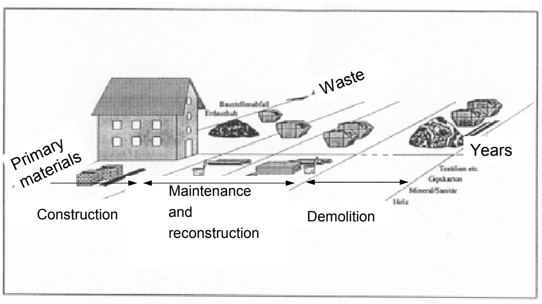


Definition Construction and Demolition Waste (CDW)

CDW is the 'umbrella' term for very wide range of materials which are generated by all construction activities. Categories are:

(i) Waste arising from the construction of buildings, civil infrastructure and/or roads
(ii) Waste arising from the maintenance of buildings, civil infrastructure and/or roads
(iii) Waste arising from the total or partial demolition of buildings, civil infrastructure and/or roads
(iiii) Soil and rocks arising from land leveling, civil works and/or general foundations

Categories related to the life cycle of a building



Classification acc. to the origin

The source of CDW is considered as parameter for classification. Categories are:

(i) Waste arising from buildings
(ii) Waste arising from civil infrastructure
(iii) Waste arising from roads

Classification acc. to the material

The kind of material which dominates in CDW is considered as parameter for classification. Categories are:

(i) Concrete waste
(ii) Masonry waste
(iii) Asphalt waste
(iiii) Mixed construction and demolition waste

Composition of CDW in Europe	
Concrete	2…39 %
Asphalt	6...21 %
Masonry CDW	42…92 %
Mixed rubble	2…11 %

Classification acc. to the environmental properties

The content of hazardous constituents in CDW is considered as parameter for classification. Most frequent hazardous constituents in CDW are:
(i) Asbestos-based construction materials
(ii) Gypsum
(iii) Tar and tarred products

Classification acc. to the European Waste Catalogue (EWC)

EWC code	
17 01 00	Predominantly inert concrete, bricks, tiles and ceramic materials
	17 01 01 Concrete 17 01 02 Bricks 17 01 03 Tiles 17 01 04 Mixture of concrete, bricks, tiles
17 02 00	Wood, glass, plastics materials
	17 02 01 Wood 17 02 02 Glass 17 02 03 Plastics
17 03 00	Asphalt, tar and tarred products
17 04 00	Metals (including their alloys)
17 05 00	Soil and dredged spoil
17 06 00	Insulation materials
17 07 00	Mixed construction and demolition waste

CDW streams in Europe: Sources of information

(i) "Official" statistics of governments or EU

European Topic Centre on Resource and Waste Management
Topic Centre of European Environment Agency
http://waste.eionet.eu.int/

Spain 1999: 20.628.000 t

(ii) Statistics of associations

Fédération Internationale du Recyclage F.I.R.
http://www.fir-recycling.nl/

Spain 2004: 39.000.000 t

(iii) Reports

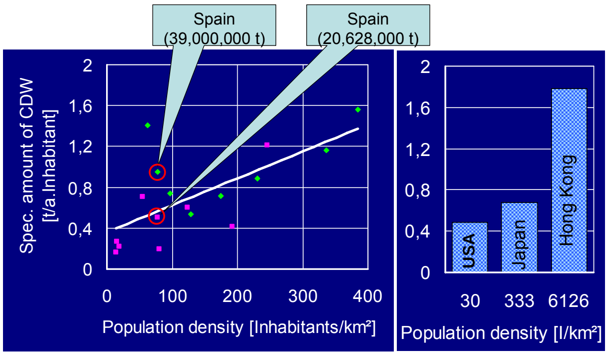
Report to DGXI, European Commission
"Construction and Demolition Waste management practices and their economic impacts" Final Report, February 1999
Report by Symonds, in association with ARGUS, COWI and PRC Bouwcentrum

Spain 1999: 13.000.000 t

Reasons of the differences
- Small companies are not considered
- Types and numbers of recorded materials differ

…
→Plausibility check

CDW streams in Europe: Population density as main influence



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1.2 Generation of CDW in Europe

Factors affecting the technical feasibility of CDW recycling

- Amount of available CDW = f (population density) ↑
- Raw material resources ↓
- Conditions for disposal ↓

Factors affecting the economic prospects for CDW recycling

- Level of industrialisation ↑
- Current economic conditions ↑

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Factors affecting the technical and economic feasibility of CDW recycling

Area code	Population density	Natural raw materials deposits	Level of Industrialization	Example	Prospects of Successful recycling of C&D waste
I	High	Adequate	High	Many cities in EU, USA and the Far East. e.g. Hong Kong (China), Copenhagen (Denmark)	+++
II	High	Adequate	Low	Many megacities in the Third World: Mexico City (Mexico), Jarkarta (Indonesia)	+++
III	High	Scarce	High	Amsterdam (The Netherlands)	++++
IV	High	Scarce	Low	Dacca (Bangladesh), Calcutta (India), Shanghai (China)	++++
V	Low	Adequate	High	Rural Scandinavia	++
VI	Low	Adequate	Low	Rainforests and mountain regions in developing countries	+
VII	Low	Scarce	High	Kuwait Abadan/ Khorramshahr (Iran)	+++
VIII	Low	Scarce	Low	Steppelands or sandy deserts or tundras in developing countries	+

Ref.: Lauritzen, London 1998

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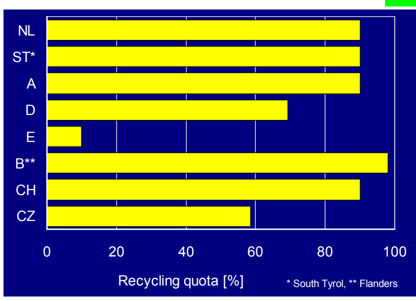
Rates of recycling of CDW in some European countries

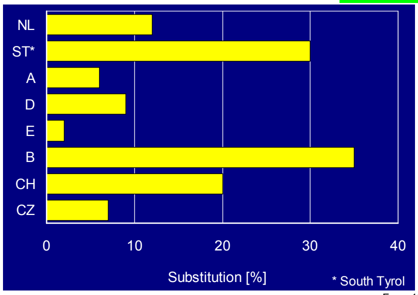
Rate of recycling = Amount of reused CDW / Total amount of CDW



Ref.: 13. F.I.R.-Interforum, Salzburg 2005

Rate of substitution of primary building materials by recycled materials in some European countries

Rate of substitution = Amount of reused CDW / Total amount of raw materials



Form 13. F.I.R.-Interforum, Salzburg 2005

Engineering specifications for delivery of natural and secondary aggregates for base courses in road construction from Germany

Asphalt in the fraction > 4 mm	max. 30 %
Clinker, dense clay brick in the fraction > 4 mm	max. 30 %
Calcium silica brick, plaster etc. in the fraction > 4 mm	max. 5 %
Mineral lightweight and insulating materials in the fraction > 4 mm	max. 1 %
Foreign materials like wood, rubber, plastic, textiles in the mixture	max. 0,2 %

Ref.: TL-Gestein 2004: Technische Lieferbedingung für Gesteinskörnungen im Straßenbau. Forschungsgesellschaft für Straßen- und Verkehrswesen, Arbeitsgruppe „Mineralstoffe im Straßenbau", Ausgabe 2004.

Engineering specifications for the properties of recycled aggregates for concrete

RILEM recommendation from 1994
Classification of recycled aggregates acc. to density and composition

	Type I	Type II	Type III
OD density (oven dry)	≥ 1500 kg/m³	≥ 2000 kg/m³	≥ 2400 kg/m³
Composition	Aggregates from masonry rubble	Aggregates from concrete rubble	Mixture of natural and recycled aggregates

Further requirements

- Content of foreign materials (metals, glass, soft materials, bitumen)
- Content of metals
- Content of organic material
- Content of filler < 80 µm
- Content of sand
- Water-soluble sulfate (SO_3)

Requirements on concrete with recycled aggregates

	Type I	Type II	Type III
Portion of recycled aggregates > 4 mm	up to100 %		
Use of recycled sand < 4 mm	no recommended		
Maximum strength class	C16/20	C50/60	no upper limit
Exposure conditions	• No additional testing for concrete used under dry conditions or in non-aggressive soils and/or water, not exposed to frost • Additional testing for concrete used under other exposure conditions		

Design and properties of concrete with recycled aggregates

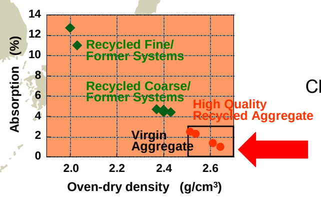
	Type I	Type II	Type III
Design	EC 2 (today DIN EN 206) with corrections		
Tensile strength	1	1	1
Modulus of elasticity	0.65	0.8	1
Creep coefficient	1	1	1
Shrinkage	2	1.5	1

European standards and recommendations

	Classification		Replacement	
	Density	Composition	Fine aggregates	Coarse aggregates
Belgium	+	+	allowed with restrictions	up to100 %
Denmark	+	+	limited (20%)	up to 100 %
Germany	+	+	not allowed	up to 45 %
The Netherlands	+	+	limited (20%)	up to 20 %
Switzerland	-	+	allowed	in dependence of application
United Kingdom	-	+	not allowed	up to 20 %

Standards and recommendations in Japan

- **Quality of Recycled Aggregates**



Class L: Low quality

Class M: Medium quality

Class H: High quality

Ref: T. Noguchi 2006

- **JIS A 5021, March 2005**
  - **Recycled aggregate for concrete - class H (RA-H)**
    - **High quality recycled aggregate and used as aggregate for JIS A 5308 (Ready-mixed concrete)**
    - **The amount of deleterious substances tested through comparison with several confirmatory samples including each deleterious substance**

    - **The minimum rate of testing and the criteria of alkali-silica reactivity dependent on the identification of the attribute of original aggregates**
    - **Unless identified, tested at frequent intervals and treated as an aggregate of potential alkali-silica reactivity**
    - **Must be produced in a plant assessed, surveyed and certified by an approved body**

Ref: T. Noguchi 2006

- **Physical Properties Requirements for RA-H**

	Coarse aggregate	Fine aggregate
Oven-dry density (g/cm^3)	not less than 2.5	not less than 2.5
Water Absorption (%)	not more than 3.0	not more than 3.5
Abrasion*1 (%)	not more than 35	NA
Material passing 75 m sieve (%)	not more than 1.0	not more than 7.0
Percentage of solid volume for evaluation of particle shape (%)	not less than 55	not less than 53
Chloride ion content (%)	not more than 0.04	

*1 : for pavement

- **Limits of Amount of Deleterious Substances for RA-H**

Category	Deleterious substances	Limits (mass%)
A	Tile, Brick, Ceramics, Asphalt concrete	2.0
B	Glass	0.5
C	Plaster	0.1
D	Inorganic substances other than plaster	0.5
E	Plastics	0.5
F	Wood, Paper, Asphalt	0.1
Total		3.0

Ref: T. Noguchi 2006

German standard on recycled aggregates DIN 4226-100

Constituents [% by mass]	Type 1	Type 2	Type 3	Type 4
DIN 4226-100: Recycled aggregates	Concrete chippings + crusher sand	Construc-tion chip-pings + c. sand	Masonry chippings + c. sand	Mixed chippings + c. sand
Concrete and natural aggregates acc. DIN 4226-1	≥ 90	≥ 70	≤ 20	≥ 80
Clinker, no porous clay bricks	≤ 10	≤ 30	≥ 80	
Calcium silicate bricks			≤ 5	
Other mineral materials (i.e. porous brick, lightweight concrete, no-fines concrete, plaster, mortar, porous slag, pumice stone)	≤ 2	≤ 3	≤ 5	≤ 20
Asphalt	≤ 1	≤ 1	≤ 1	
Foreign substances (i.e. glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others)	≤ 0.2	≤ 0.5	≤ 0.5	≤ 1
OD density/oven dry [kg/m^3]	≥ 2000	≥ 2000	≥ 1800	≥ 1500
Max. water absorption/10 min [%]	10	15	20	No limit

Ref.: DIN 4226-100

Additional requirements on recycled aggregates acc. to DIN 4226-100

- Fines content (< 0.063 mm) < 4 % by mass
- Content of leachable contaminations

All other requirements like acid-soluble chloride (< 0.04 M.-% Cl^-), acid-soluble sulfate (< 1.0 M.-% SO_3), organic matter, particle size distribution, particle shape corresponding to natural aggregates.

Guideline of the German Committee for Reinforced Concrete (DAfStb) for use of recycled aggregate in concrete

Philosophy: No changes of properties of concrete with recycled aggregates compared with normal concrete

- Only chippings > 2 mm of recycled aggregates type 1 and type 2 can be used for the production of structural concrete
- Crusher sand is excluded from the reuse as aggregate
- Maximum strength class C30/37
- No lightweight concrete, no prestressed concrete
- Evidence of resistance against frost and ASR must be proofed
- Application in dry environments or in environments with low humidity
- Replacement of natural by recycled coarse aggregates is reduced when environmental effects or "attacks" on concrete increase

Ref.: RiLi DAfStb

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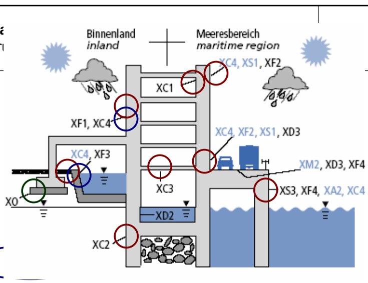
1 Overview a
1.3 Technical r

Allowed replacement of recycled aggregates versus exposure classes acc. to DAfStb guideline

X 0 | XC 1 to XC 4 | XF



Field of application				Replacement by RCA [vol.-%]	
ASR-guideline	DIN EN 206-1 and DIN 1045-2			Type 1	Type 2
	Exposure class	Effect	Stress		
WO (dry)	XC 1	Carbonation	dry	≤ 45	≤ 35
WF (humid)	X 0	No concrete attack			
	XC 1 to XC 4	Carbonation	dry to wet		
	XF 1 and XF 3	Freeze-thaw **without** salt	moderate **and** high water saturation	≤ 35	≤ 25
	XA 1	Chemical attack	weakly corrosive	≤ 25	≤ 25

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1 **Overview about Construction and Demolition Waste**
1.3 Technical rules and standards

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Additional requirements and recommendations for the use of recycled aggregates acc. to the Guideline DAfStb

Technical approval: Extended initial testing necessary

Processing
Aggregates shall be produced of a feed material of > 32 mm
→ prevention of fine foreign materials and soft materials

Quality control during production
- Visual inspection
- Measurement of density and water absorption weekly
- Measurement of density and air content of fresh concrete

Placing
Instruction for addition of superplasticizer on site prepared
→ prevention of loss of workability by water absorption of recycled aggregates

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2 **Processing of CDW**
2.1 Mobile versus stationary plants

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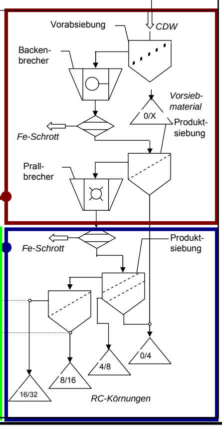
Aim of the processing:
Production of recycling building materials with defined particle size distribution and defined material composition.

Crushing

Sieving

Sorting



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2 **Processing of CDW**
2.1 Mobile versus stationary plants

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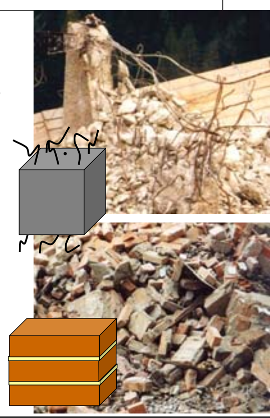
Crushing
- Reduction of particle size
- Mechanical „disconnection“ of bonds between the different components

Sieving
- Generation of fractions with defined upper and lower particle size

Sorting
- Removal of hazardous substances
- Separation of constituents



Recycling plants in Germany

	Stationary plants	Mobile plants	Total
Number	1,600	3,313	4,913
Amount of processed material [tons/year]	26,696,200	33,079,100	59,775,300
Throughput (average) [ton/year]	16,685	9,985	12,167

- Processing in stationary plants dominates in 5 federal states of Germany.
- Processing in mobile plants dominates in 7 federal states.

Features of mobile plants

- suitable for demolition sites with a large amount of CDW, i.e. re-build of expressways, large industrial complexes
- economic feasible from an amount of 5000 to 6000 t per site
- units with a throughput up to 250 t/h
- all plant components on road semi-trailern, long loading trucks etc. therefore easily replaceable
- single-stage crushing partly with additional mobile screening generally applied
- good quality of the products only if the input is homogenous
- re-use in situ preferred
- limited variety of products

Features of stationary plants

- suitable for recycling centers in high density areas
- input and sales quantity must be realisable for a longer period
- capacities about 200.000 t/year
- no limitations regarding to the processing technology
- additional effort for the set-up of the factory ground and infrastructure
- good quality products even if the input is heterogeneous by controlling the input, pre-sorting and temporary storage
- no limitation of variety of products
- quality control
- considerable hauling costs for the material

Comparison of mobile and stationary plants (1)

	mobile	stationary
steps of processing	pre-screening + crushing + magnetic separation + (product screening)	additional: second stage crushing + wet or dry sorting
required space	low	high
preparation of the site	low	high
investment costs	depends on the technical equipment	
operating costs	depends on the technical effort	
transportation costs	equipment: high material: low	material: high, haul distance below 30 km
environmental impact	high	low, if adequate technical facilities are installed

Comparison of mobile and stationary plants (2)

	mobile	stationary
input material	Better homogeneity can be expected, because material derives mostly from the demolition of one larger structure.	Higher heterogeneity must be expected. Therefore targeted input control and pre-treatment necessary.
variety of products	low	high
quality of products	low possibilities of taking targeted influence	high possibilities of taking targeted influence by processing
sales	re-use in place	RC-building materials compete with natural aggregates

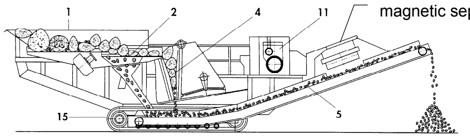
Main components of a mobile crusher

feeding hopper (1)
5 m³

oscillating conveyor (2)
900 mm x 3500 mm
2 x 2,7 kW

jaw crusher (4)
throughput 120 t/h
required power 120 kW
jaw dimensions 1000 x 600 mm

magnetic separator



dimensions for transport
L = 11.000 mm
B = 2.500 mm
H = 3.100 mm

diesel engine as power unit (11)

discharging transport belt (5)
600 mm x 6500 mm
4 kW

mobile by wheels, crawlers or skids (15)

Ref: Prospekt BTZ Dietlas

Example of a mobile recycling plant

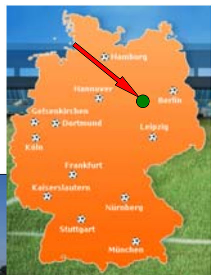
Example of a stationary recycling plant with an advanced technology

BBW Recycling Mittelelbe GmbH Magdeburg

Capacity: 150,000 tons/year

Employees: 10 (2 engineers, 8 workers)

Products: Concrete and masonry RC in different fractions or as material 0/8 and 0/45 mm



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2 Processing of CDW
2.1 Technological scheme of stationary recycling plant

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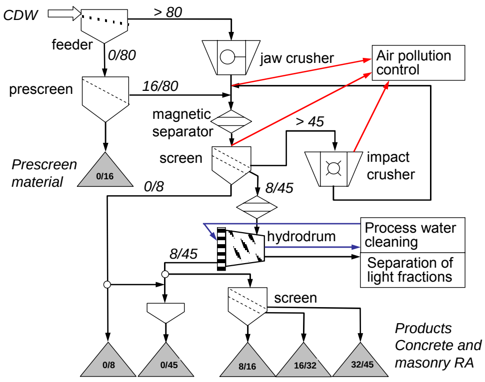
Flow sheet



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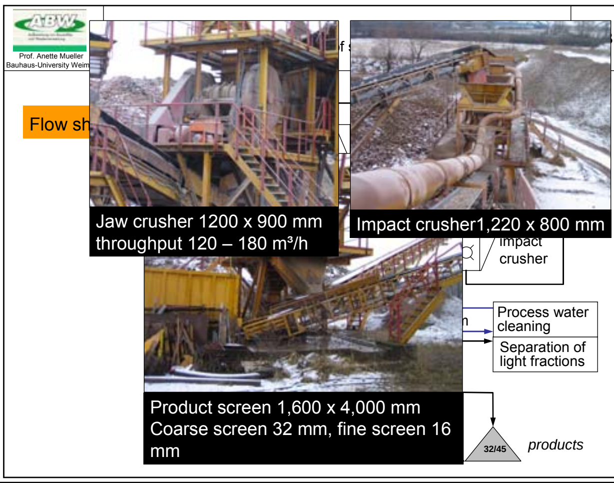

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2 Processing of CDW
2.1 Technological scheme of stationary recycling plant

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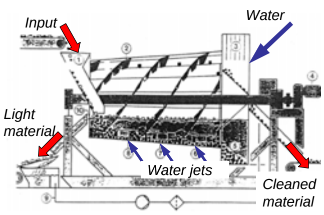
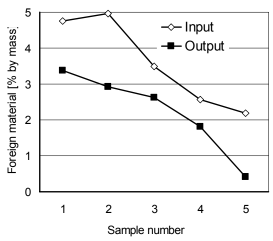
Hydrodrum





Ref.: Walther 2006

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3 Features of processed concrete rubble
3.1 Properties of processed material

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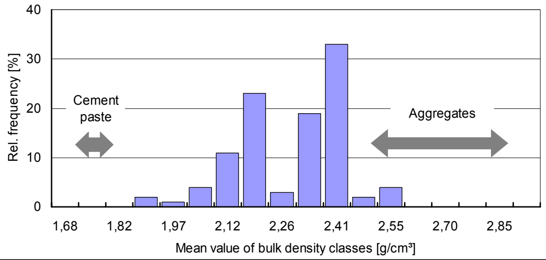
Effects of recycled aggregates as composites of cement paste and natural aggregate

→ Reduction of the bulk density
→ Increase of water absorption
→ Increase of total content of cement paste in the secondary concrete (= sum of old and new paste)
→ Increase of range of variation of properties

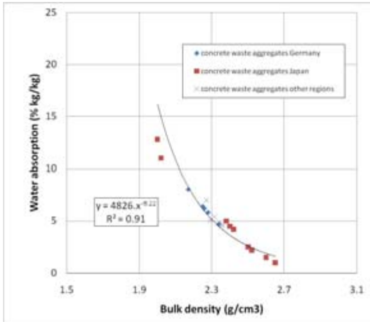
Consequences of the composite structure on densities of secondary aggregates

Range of 102 measured data	Mean bulk density
1.86…2.59 g/cm³	(2.26 ± 0.13) g/cm³ or 2.26 g/cm³ ± 5.8 %



The density of concrete aggregates is the key parameter for water absorption, grain strength and frost resistance

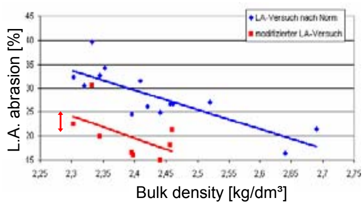
Water absorption versus bulk density



Ref: Sérgio Angulo 2007

Grain strength/L.A. test versus bulk density

L.A. test describes the resistance of the grains against abrasion.

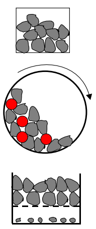


fraction x/y $m_{x/y}$

abrasion treatment in a L.A. drum

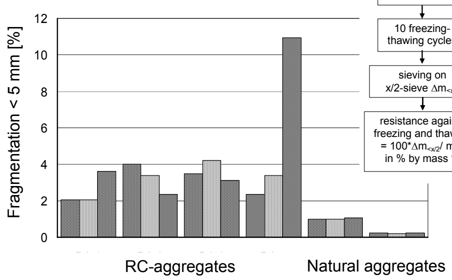
sieving on a sieve „x-1“ $\Delta m_{<x-1}$

L.A. abrasion = $100*\Delta m_{<x-1}/m_{x/y}$ in % by mass



Frost resistance

Frost resistance describes the resistance of the grains against freezing and thawing



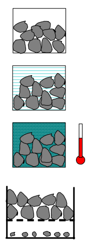
fraction x/y mm $m_{x/y}$

24 h storage under water

10 freezing-thawing cycles

sieving on x/2-sieve $\Delta m_{<x/2}$

resistance against freezing and thawing $= 100*\Delta m_{<x/2}/ m_{8/10}$ in % by mass



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3.2

Features of processed concrete rubble
Effects of recycled aggregates on properties of concrete

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Consequences of the composite structure on properties of secondary concretes

Increase of porosity caused by additional porosity of the adhered cement paste
→ loss of workability
→ compensation by addition of superplastiziser

Increase of porosity caused by additional porosity of the adhered cement paste
→ loss of compressive strength

Increase of porosity **and** total content of CSH phases
→ loss of modulus of elasticity

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Features of processed concrete rubble
Effects of recycled aggregates on properties of concrete

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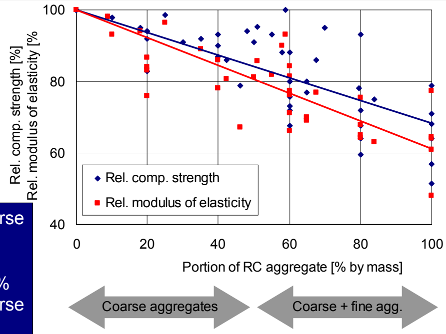

Replacement of coarse and fine aggregates
Δ Strength → 32 %
Δ E-modulus → 39 %
Replacement of coarse aggregates only
Δ Strength → 16 %
Δ E-modulus → 20 %

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Features of processed concrete rubble
Effects of recycled aggregates on properties of concrete

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Consideration of effects of porosity **and** CSH content of recycled aggregates in theoretical approaches

Main influence on strength:
Porosity (caused by water/cement ratio or aggregate porosity)

$$f_c = 93{,}0 \cdot X - 16{,}5$$

$$X = \frac{0{,}68 \cdot \alpha}{(w/c)_{eff} + 0{,}32 \cdot \alpha}$$

from Hendriks [2000]

Main influence on E- modulus:
Strength
(~ porosity, see above)

+
CSH content
(~ density of aggregate)

$$E = 2{,}1 \cdot 10^4 \cdot \left(\frac{f_c}{20}\right)^{0,5} \cdot \left(\frac{\rho_{c,\,bulk}}{2300}\right)^{1,5}$$

from Hendriks [2000]

$$E = 9100 \cdot (f_c)^{0,33} \cdot \left(\frac{\rho_{c,\,bulk}}{2400}\right)^{2} \cdot \left(1 - \frac{A_Z}{500}\right)$$

A_z: brick content in %

from Roos [2002]

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3.2

Features of processed concrete rubble
Effects of recycled aggregates on properties of concrete

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Further effects of the composite structure on properties of secondary concretes on
- Shrinkage
- Creep
- Durability

→ Cement paste as constituent of recycled aggregates causes systematic changes of those properties of secondary concrete which are directly correlated with porosity and content of CSH phases.

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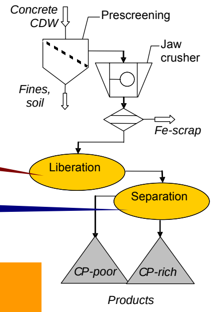
3 | 3.2 — **Features of processed concrete rubble**
Methods for quality improvement of recycled aggregates — 49

Possible concepts of treatment of recycled aggregates and/or concrete for quality improvement

Concept 1
Removal of cement paste by suitable technologies for liberation and separation

Mechanical or thermal liberation

Separation by particle size or density



Concept 2
Technological adjustment of proportioning, mixing and curing of concrete with recycled aggregates

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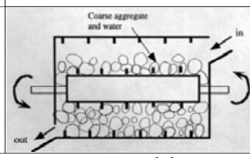
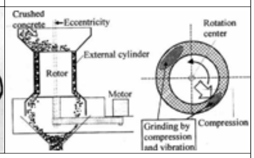
3 | 3.2 — **Features of processed concrete rubble**
Methods for quality improvement of recycled aggregates — 50

Removal of the cement paste by applying of abrasion stress

Treatment of coarse aggregates

External cylinder: Ø 720 mm; height 800 mm
Rotor: Ø 720 mm; height 800 mm; 500 U/min
Eccentricity: 11.7 mm

Reference	KASAI 1997	YANAGIBASHI 2002
Operating mode		
	Material parameter	
Virgin aggregates	**ρ = 2.62 g/cm³** **WA → 0**	**ρ = 2.5...2.61 g/cm³** **WA = 1.2...3.6 %**
Treated aggregates	**ρ = 2.52 g/cm³** **WA = 3.0 %**	**ρ = 2.4...2.53 g/cm³** **WA = 1.8...5.4 %**

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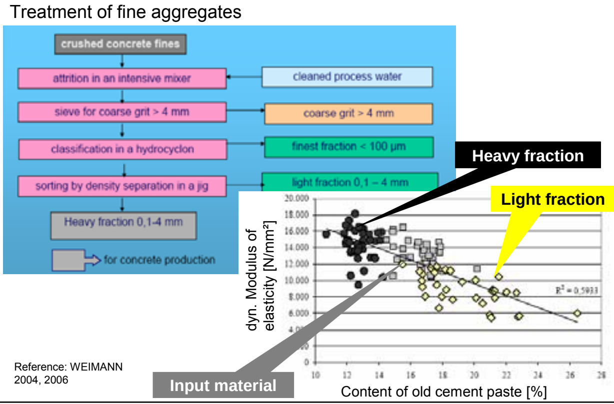
3 | 3.2 — **Features of processed concrete rubble**
Methods for quality improvement of recycled aggregates — 51

Treatment of fine aggregates



Reference: WEIMANN 2004, 2006

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3 | 3.2 — **Features of processed concrete rubble**
Methods for quality improvement of recycled aggregates — 52

Alternative methods of treatment

Applying of sonic impulses generated by disruptive electrical discharges under water

Electrical energy

Disruptive electrical discharge under water

Shock waves
Pressure amplitudes up to 100 MPa
Rise time < 5 µs

Generation of pressure and tensile stresses

Reflexions at interfaces of different density

Failure at the interfaces

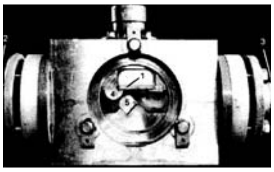
Portion of cement paste free aggregates 16/31.5 mm

Impact crusher	71 %
Jaw crusher	79 %
HPSI 1	9.5 %
HPSI 2	4.3 %

Ref.: LINSZ 2004

Alternative methods of treatment

Cavitation erosion



Flow cavitation chamber with specimen (1)

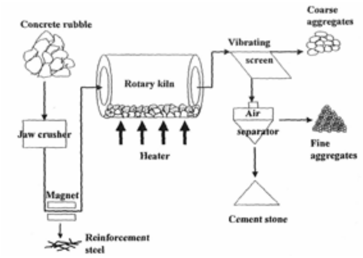
Stresses generated by flow cavitation - that means the growth and implosion of gas bubbles in a liquid.

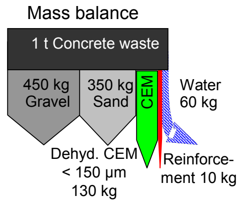
Cavitation erosion causes considerable damages of all tested concrete specimen.
- Exposure time of only 10 s
- Degree of separation between 46 and 90 %.

Ref.: MOMBER 2004

Removal of the cement paste by applying of thermal stress

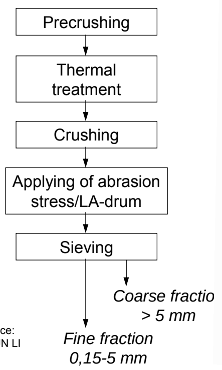
Treatment at 700 °C

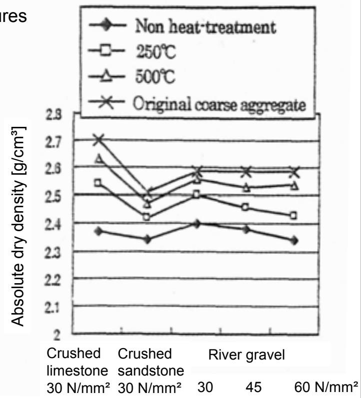




Reference: MULDER 2002

Treatment at different temperatures





Reference: BAOQUN LI 2002

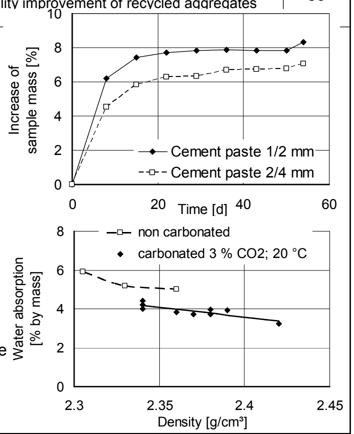
Transformation of cement paste in dense, inert state

Watched effect: Increase of mass of samples of crushed concrete during long period of storage

Reason: Carbonation, also detectable on aggregates from recycling plants

Idea: Carbonation as tool for improvement of properties of recycled aggregates

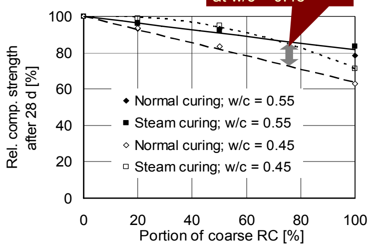
First test results: Effects are detectable after a rather long time



Ref.: SCHINDLER 2006

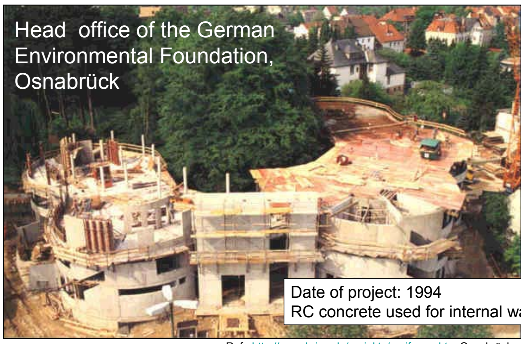
Technological adjustment of proportioning, mixing and curing of concrete with recycled aggregates

- Addition of fly ash, silica fume or powdered concrete aggregates
- Changes of mixing procedure
- Applying of curing



Ref.: POON 2006

Use of CDW recycled aggregates in concrete in research projects in Germany



Date of project: 1994
RC concrete used for internal walls

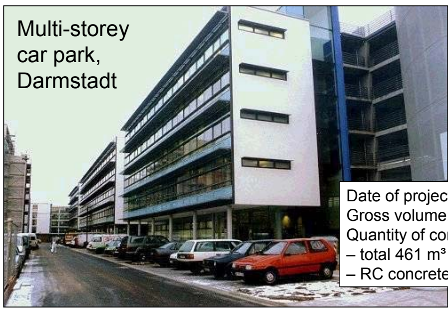
Ref.: http://www.b-i-m.de/projekte/projframe.htm Osnabrück

Material information
Portion of RC coarse aggregates (> 4 mm): 100 %
application for interior elements

Composition

		quantity [kg/m^3]
Nat. aggregate	0/4 mm	669
RC aggregate	4/16 mm	669
	16/32 mm	294
Portland cement	PZ 45 F	290
water/cement		0.65
admixtures	fly ash	70
water reducing admixture		1.8 kg/m^3

Characteristic of concrete
Workability: flow table test value 460-490 mm
Density of fresh concrete 2280 kg/m^3
Air content 2.6 vol.-%
Compressive strength after 28 d: in average 41 N/mm^2



Date of project: 11.11.97 – 10.02.98
Gross volume: 4.000 m^3
Quantity of concrete:
– total 461 m^3
– RC concrete 461 m^3

Ref.: http://www.b-i-m.de/projekte/projframe.htm Parkhaus Darmstadt

Material information
Application for interior elements (pillars, walls, floor slabs) and outside decorative concrete

Composition

		quantity [kg/m³]
Nat. aggregate	0/2a mm	585
RC aggregate	2/8 mm	545
	8/16 mm	568
Portland cement	CEM I 42,5 R	310
Water		170
Admixtures	fly ash	40
Water reducing admixture	5-18 ml/kg cement	

Characteristic of concrete
Workability: flow table test value 550 mm
Compressive strength after 28 d: in average 45.0 N/mm²

Apartment house "Waldspirale" of architect Friedensreich Hundertwasser, Darmstadt

Date of project: start at 09.11.1998
Quantity of concrete:
– total ?
– RC concrete 12000 m³

Ref.: http://www.b-i-m.de/projekte/projframe.htm Hundertwasser, Darmstadt

Material information
Application for interior elements, waterproof foundation slab

Composition

		quantity [kg/m³]	
		B 35 (≡ C 30/37)	B 25 (≡ C 25/30)
nat. aggregate	0/2 mm	616	615
RC aggregate portion acc. to RiLi	2/8 mm	530	290
	8/16 mm	569	334
	16/32 mm		554
Portland cement	CEM I 42,5 R	300	
Portland cement	CEM I 32,5 R		290
water/cement		0.59	0.59
admixtures	fly ash	50	40
water reducing admixture		1.5 kg/m³	

Characteristic of concrete
Workability: normal (KR)
Compressive strength after 28 d: in average 42.9 N/mm²
36.4 N/mm²

Use of CDW recycled aggregates in concrete in commercial projects in Switzerland

Large range of concrete with recycled aggregates for application in different fields of construction. Examples of offered RC concretes:

Concrete with recycled concrete aggregates acc. to SN EN 206-1
- Strength classes: C25/30 and C30/37
- Exposure classes: XC1, XC2, XC3, XC4, XF1, XD1
- Maximum aggregate size 16 mm, 32 mm
- Available as normal concrete, pumped concrete, face concrete, as Self Compacting Concrete

Concrete with mixed recycled aggregates acc. to SN EN 206-1
- Strength class: C25/30
- Exposure classes: XC1, XC2
- Maximum aggregate size 16 mm, 32 mm
- Available as normal concrete and pumped concrete

Ref.: http://www.eberhard.ch

Apartment house, Bahnhaldenstrasse, Zürich
5,000 m³ concrete with recycled concrete aggregates
• pumped concrete for the basement
• normal concrete for the upper floors


Apartment and business house, Max-Bill Platz, Zürich
Total 20,000 m³ concrete with recycled concrete aggregates
• Basement: dense concrete in groundwater
• First floor: RC concrete, black colored, sandblasted and protected against graffiti


School building in Birch, Zürich
15,000 m³ concrete with recycled concrete aggregates

School building, Bullingerplatz, Zürich
5,000 m³ face concrete with recycled concrete aggregates

Apartment house Zürich

- 16,000 m³ concrete with recycled concrete aggregates for guaranteed waterproof concrete basement

Conclusions Lecture 1

European standards

- Classification mostly acc. to density and composition
- Use in concrete limited to coarse aggregates

Effects of recycled aggregates in concrete

- Increase of porosity and content of CSH phases with negative effects especially on E-modulus and shrinkage

Quality improvement

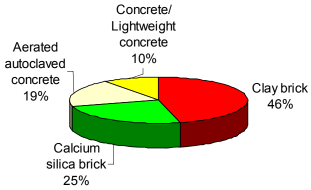
- Liberation of recycled aggregates from adhered cement paste as option for improvement of recycled aggregate concrete

Commercial use of recycled aggregates in concrete only at the beginning

Main constituents of masonry waste

Masonry Blocks	+ Mortar	+ Plaster
• Clay brick • Aerated autoclaved concrete • Calcium silicate brick • Concrete blocks	• Lime mortar • Lime-cement mortar • Cement mortar	• Lime plaster • Gypsum plaster

Share of the market 2004 in Germany



Ref: Deutsche Gesellschaft für Mauerwerksbau e.V. Jahresbericht 2004

Clay brick

Clay + sand + pore forming agent	thermal treatment 900–1200°C →	**Clay brick: Mullit, Hämatit, Amorphes** Porosity: up to 50 % Strength: up to 100 N/mm²

Blocks of aerated autoclaved concrete, calcium silicate brick

Sand + lime + water + (pore forming agent, anhydrit)	hydrothermal treatment 160–220°C →	**AAC: C-S-H-phases** High porosity and low strength **Calcium silicate brick: C-S-H** Porosity: up to 50 % Strength: up to 100 N/mm²

Concrete blocks

Aggregates + cement + water	curing →	**Concrete: C-S-H-phases** Porosity: up to 20 % Strength: up to 100 N/mm²

Composition of masonry CDW: Classification acc. to the content of clay brick and tile

Pure brick and tile waste
Generated by replacement of roofing or by pre sorting of brick enriched masonry CDW.

Clay brick enriched masonry CDW
Generated by demolition of pure clay brick masonry. Content of brick 95 % by mass maximum and 80 % by mass average.

Masonry CDW
Contains in addition to clay brick, mortar and plaster further masonry blocs like calcium silicate brick, AAC, concrete.

Hazardous substances: Organic or inorganic compounds with negative effects on health or environment

Examples: Tar, tar-based emulsions, asbestos-based materials, mineral fibers for insulation, some paints and coatings, treated timber, resins, gypsum plaster and plasterboard

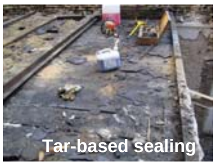
Sources of hazardous substances in CDW:
- Originally used hazardous materials. Examples: asbestos, lead, tars, paint and preservative residues, adhesives, bonding agent and sealants, certain plastics.
- Contamination of originally non-hazardous materials from industrial processes. Examples: Hydrocarbons, fuels…

Hazardous substances → Must be dismantled before demolition.
Impairing substances → Should be dismantled before demolition to improve the structural properties.

Asbestos boards for cladding

Mineral fibers for insulation

Wood preserver

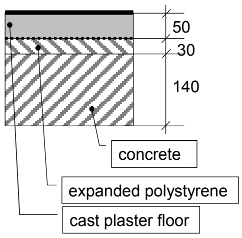


Impairing substances: Constituents of the CDW that affect the constructional properties negatively.

Examples: Glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others

Example: Floor construction

	Bulk density	Thick -ness	Mass per m²	Portion
	[kg/m³]	[m]	[kg]	[% by mass]
Cast plaster floor	2000	0,05	100	24,5
Polystyrene	30	0,03	0,9	0,2
Concrete	2200	0,14	308	75,3
			408,9	100,0



Products after processing acc. to the material composition

Pure brick and tile waste → Clay brick and tile RC material

Clay brick enriched masonry CDW → Masonry chippings/ Masonry crusher sand ≡ type 3 material acc. to DIN 4226-100

Masonry CDW → Mixed chippings/ Mixed crusher sand ≡ type 4 material acc. to DIN 4226-100

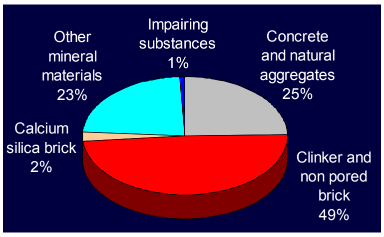
Products after processing acc. to the particle size distribution

Aggregates 0/32 mm, 0/45 mm, 0/56 mm etc.

Sand 0/4 mm or 0/8 mm, chippings 4/16 mm, 8/16 mm, 16/32 mm etc.

Material composition of masonry CDW

27 samples of processed masonry rubble from 8 recycling plants



Variation of material composition

Clinker and non pored brick: (48,2 ± 10,1) %
Concrete and natural aggregates: (24,2 ± 15,5) %
Other mineral materials: (22,8 ± 11,6) %

→ Main feature of processed masonry rubble: Large range of variation of material composition

Material composition as classification feature

Engineering specifications for delivery of natural and secondary aggregates for base courses in road construction

Asphalt in the portion > 4 mm	max. 30 %
Klinker, dense clay brick in the portion > 4 mm	max. 30 %
Calcium silica brick, plaster etc. in the portion > 4 mm	max. 5 %
Mineralic lightweight and insulating materials in the portion > 4 mm	max. 1 %
Foreign materials like wood, rubber, plastic, textiles in the mixture	max. 0,2 %

Engineering specifications for the properties

Constituents	Type 1	Type 2	Type 3	Type 4	
Germany DIN 4226-100: Recycled aggregates	Concrete chippings/ Concrete crusher sand	Construction chippings/ Construction crusher sand	Masonry chippings/ Masonry crusher sand	Mixed chippings/ Mixed crusher sand	
Concrete and natural aggregates acc. DIN 4226-1	≥ 90	≥ 70	≤ 20	≥ 80	(✓)
Clinker, non-pored bricks	≤ 10	≤ 30	≥ 80		
Sand-lime bricks			≤ 5		
Other mineral materials such as pored brick, lightweight concrete, no-fines concrete, plaster, mortar, porous slag, pumice stone	≤ 2	≤ 3	≤ 5	≤ 20	(✓)
Asphalt	≤ 1	≤ 1	≤ 1		
Foreign substances such as glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others	≤ 0.2	≤ 0.5	≤ 0.5	≤ 1	✓
OD density (oven dry) [kg/m³]	≥ 2000	≥ 2000	≥ 1800	≥ 1500	
Maximum water absorption after 10 min [%]	10	15	20	No requirement	

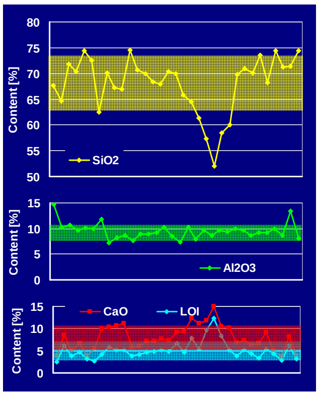
DIN 4226-100. Gesteinskörnungen von Beton und Mörtel, Teil 100: Rezyklierte Gesteinskörnungen. DIN-Deutsches Institut für Normung e.V., Beuth-Verlag, Berlin 2002.

Chemical composition

Composition of 33 samples of processed masonry rubble

Variation of chem. composition

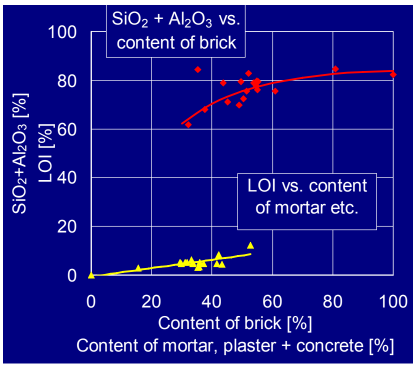
SiO_2: (68,0 ± 5,4) %
Al_2O_3: (9,5 ± 1,5) %
CaO: (8,0 ± 2,8) %
LOI: (5,1 ± 2,0) %



Correlation between material and chemical composition ?

→ Key parameter for content of brick: $SiO_2 + Al_2O_3$

→ Key parameter for content of mortar, plaster + concrete: LOI



Leachable substances

- Leachable heavy metals practically occur only in buildings with an “industrial history”.
- Salts especially sulfate appear.

→ Sulfate containing building materials like plaster board, anhydrite plaster floor or autoclaved aerated concrete must be dismantle before demolition.

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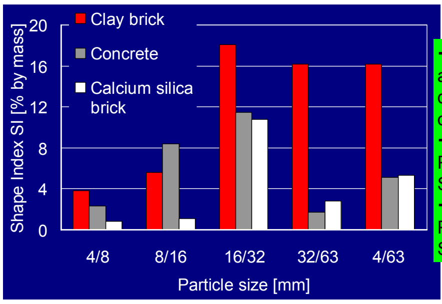
Particle size distribution and particle shape

- Steady grading curve with a rather high portion of fines.
- Particles of clay brick tends to non cubic, flat shape.



→Portion of fines and particle shape depend on the type of crusher
→ Jaw crusher: Portion of fines ↓ Shape index ↑
→ Impact crusher: Portion of fines ↑ Shape index ↓

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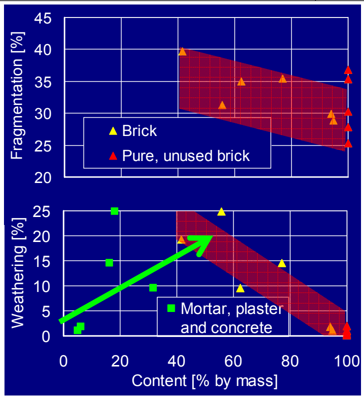
Grain strength

Conclusion from similarity of variation ranges → Grain strength of pure bricks as acting parameter

Frost resistance

Conclusion from differences of variation ranges → Low frost resistance of mortar as acting parameter

Ref: Ruhr-Universität Bochum, Institut für Strassenwesen und Eisenbahnbau 2002



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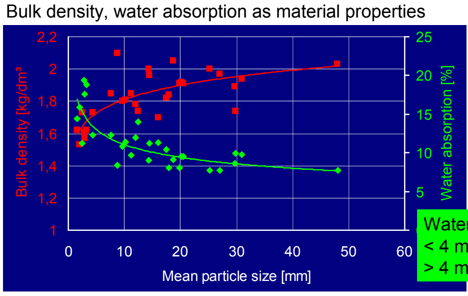
Bulk density, water absorption as material properties



Water absorption
< 4 mm: > 12 %
> 4 mm: ≈ 8...12 %

Bulk density
Particles < 4 mm: < 1,8 kg/dm³
→ Enrichment of components with low strength
Particles > 4 mm: > 1,8 kg/dm³

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Bulk density as classification feature

Engineering specifications for the properties of recycled aggregates for concrete

Constituents	[% by mass]			
Germany DIN 4226-100: Recycled aggregates	Type 1 Concrete chippings/ Concrete crusher sand	Type 2 Construction chippings/ Construction crusher sand	Type 3 Masonry chippings/ Masonry crusher sand	Type 4 Mixed chippings/ Mixed crusher sand
Concrete and natural aggregates acc. DIN 4226-1	≥ 90	≥ 70	≤ 20	≥ 80
Clinker, non-pored bricks	≤ 10	≤ 30	≥ 80	
Sand-lime bricks			≤ 5	
Other mineral materials such as pored brick, lightweight concrete, no-fines concrete, plaster, mortar, porous slag, pumice stone	≤ 2	≤ 3	≤ 5	≤ 20
Asphalt	≤ 1	≤ 1	≤ 1	
Foreign substances such as glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others	≤ 0.2	≤ 0.5	≤ 0.5	≤ 1
OD density (oven dry) [kg/m³]	≥ 2000	≥ 2000	≥ 1800 ✓	≥ 1500 ✓
Maximum water absorption after 10 min [%]	10	15	20	No requirement

DIN 4226-100. Gesteinskörnungen von Beton und Mörtel, Teil 100: Rezyklierte Gesteinskörnungen. DIN-Deutsches Institut für Normung e.V., Beuth-Verlag, Berlin 2002.

Reuse of mixed recycling material from masonry as filling and stabilizing material in unbound “bulk” systems

Low demands for physical properties:

- Only small amounts of foreign components such as wood, glass, twigs allowed
- Adequate volume stability
- No settlement by compaction of the material
- Grain size distribution suitable for particular application
  - Sand bed and fill sand: < 8 mm
  - Embankment and fill material of roads: 0/32 mm, 0/45 mm, 0/56 mm
  - Soil compaction, sub grade improvement > 45 mm

High demands for environmental properties:

- Amount of leachable constituents strictly limited

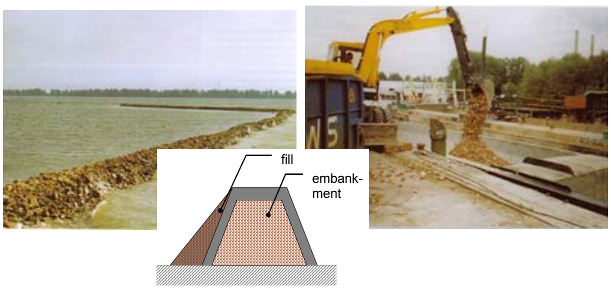
Application in unbound “bulk” systems is limited by

- low strengths of particles
- low resistance against freeze and thaw of material

→ Masonry rubble is excluded as sub-base material acc. to the German regulations in construction of expressways.

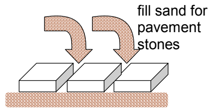
Applications in hydraulic constructions

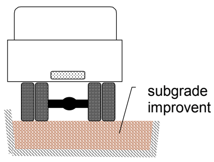
- Material in embankments
- Fill material

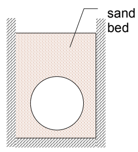


Applications in transportation engineering

- Sand bed and fill sand for pavement stones
- Filling of cable ditches
- Embankment and fill material of side walks, by roads
- Soil compaction
- Sub grade improvement







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7 **Options for re-using of masonry material**
7.1 Mixed Material

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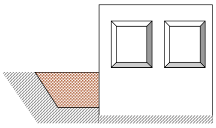
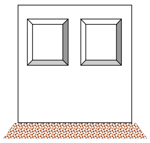
Application in general civil engineering

- Granular sub-grade course
- Filling of hollows and excavations
-
-





Further application

- Fill material in mining,
- Use in construction and re-cultivation of landfill sites

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7 **Options for re-using of masonry material**
7.2 Clay brick enriched material
7.2.1 Reclaim as bricks and tiles

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Reclaiming of bricks and tiles were common practice in Germany after the 2. World War. Undamaged material was deliberated from residues of plaster and mortar and used again. Damaged bricks and tiles were crushed and used as aggregate for concrete.

Cologne 1945

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7 **Options for re-using of masonry material**
7.2 Clay brick enriched material
7.2.1 Reclaim as bricks and tiles

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Today reclaiming of bricks and tiles plays a part only for protection of historic buildings and monuments.
Second-hand shops for building materials offer wood beams, doors, floor boards, parquet, bricks of different sizes, tiles, other ceramic building materials, metal columns etc.

Plain tile
Unit price 0,50 € - 1 €
Comparative price of a new tile
0,36 €

S-pantile
Unit price 0,60 € – 0,80 €
Comparative price of a new tile
0,36 €

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7 **Options for re-using of masonry material**
7.2 Clay brick enriched material
7.2.1 Reclaim as bricks and tiles

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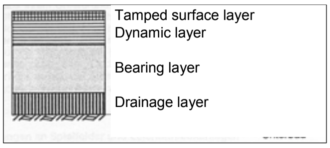
Clay bricks of different sizes
Unit price 0,60 €

Features of the business in Germany:
- Altogether about 150 companies
- Turnover < 1 Mio. € per year
- Large stock of different materials with high capital requirements, high area requirements necessary
- Offer of the material via Internet

Further examples for the applications of used bricks in pavement works and as indoor floor covering

Brick and tile sand for top layers of tennis courts

Construction of a tennis court



- Top layer of tennis courts may consist of scrap of brickyards or mixtures of scrap and used tiles.
- Fractions 0/1 mm, 0/2 mm and/or 0/3 mm
- Requirements on color, resistance against wear, resistance against frost and thawing, permeability, compactibility
- Specific amount of sands: 25 – 30 t/court for new construction and 1,5 t/court for maintenance per year

DIN 18 035 Teil 5, Sportplätze. DIN-Deutsches Institut für Normung e. V., Beuth-Verlag, Berlin 1987

Masonry chippings/Masonry crusher sand as material for green roof planting

Flat roofs or roofs with low slope suitable for of roof gardens. Layers with different functions are required
- Layer for protection of the roof construction
- Layer for drainage
- Filter layer
- Layer of vegetation

Drainage layer and vegetation layer can produced from Masonry chippings/Masonry crusher sand.

Requirements on materials for drainage layers: High permeability, high stability of storage

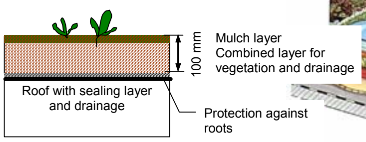
Crushed material with high portion of angular particles → High shear resistance → High stability of storage
Use of fraction 4/16 mm → High permeability.

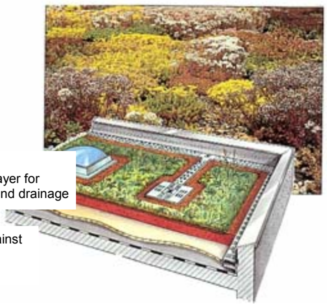
Requirements on materials for vegetation layers : High capacity for storage of air, water and nutrients

Porosity in the clay brick grains and between them → High capacity for storage of air and water
Addition of compost →Adjustment of available nutrients

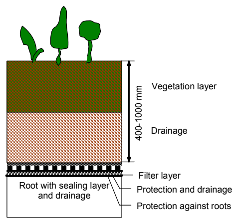
Number and thickness of layers depend on type of plants

(i) Extensive roof gardens
plants < 50 cm, only layers for protection of the roof and vegetation's layer < 10 cm additional load of about 50 – 150 kg/m²





(ii) Intensive roof gardens
Plants up to 10 m, several layers with a tickness up to 100 cm, additional load > 150 kg/m²



Brick and tile sand for top layers of tennis courts

→ Specific feature of tile RC as advantage for this application: Red colour.

Masonry chippings/ masonry crusher sand as material for green roof planting

→ Specific feature of masonry chippings/masonry crusher sand as advantage for this application: Angular particle size, low weight, high open porosity.

→ Ecological advantage: Material is available at many sites, lower effort for transportation compared with natural material like pumice

RC material of masonry CDW as aggregate for ready mixed concrete

Masonry crusher sand: Negative effects on all properties of the produced concrete. Substitution by natural sand recommended.

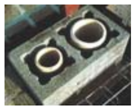
Masonry chippings of can be used as aggregates for low-grade concretes.

Effects of masonry chippings on concrete
⇒ Higher water demand due high water absorption, balancing by pre wetting and use of plasticizer recommended
⇒ Decrease of compressive strength up to 60 %
⇒ Decrease of modulus of elasticity up to 50 % ⇒ Larger deformation of concrete elements with large spans
⇒ Increase of shrinkage and creep up to 40 %
⇒ Decrease of frost resistance

→ No specific feature of masonry aggregates as advantage. Large range of variation as disadvantage.
→ Possible applications in foundations, bottom slabs or as lean concrete. No structural concrete.
→ No practical use of masonry chippings for ready mixed concrete so far.

RC material of pure brick or masonry CDW as aggregate for concrete elements

Examples of an Internet search

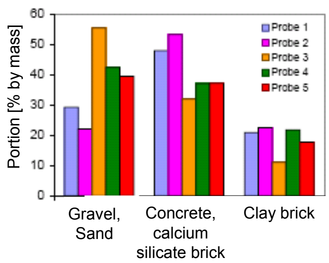
Chimney mantle block with brick chippings as aggregate	
Storage block made from 70% brick chippings and 10% expanded clay and 7% gravel, 13% cement with the following characteristics -high sound protection -high storage-effective mass -lower insulating properties -low primary energy input -easy handling for installations	

RC material of pure brick or masonry CDW as aggregate for concrete elements

Storey-high walls from brick chipping concrete - lightweight brick chipping concrete of strength class LB 225/SI - aggregate: grain-graded brick chippings, low share of natural sand - reinforcement: BST550	
Structural blocks of mixed RC material of corresponding fractions of processed concrete debris and brick rubble - intermediate wall block, basement wall block, prefab element floor - tested according to Austrian Standards Ready mixed concrete with high share of mixed RC material for floor concrete or floor topping concrete	 

Effects of clay brick containing RC aggregates on concrete

Composition of the aggregates



Ref.: Hoffmann, EMPA Abt. Beton/Bauchemie 2004

Composition of the produced concretes

Natural sand 0/2 mm	[%]	9,5-20
RC aggregates 0/32 mm	[%]	80-90,5
Total aggregate	[kg/m³]	1600-1803
Cement	[kg/m³]	323-351
Admixture: PFA	[kg/m³]	0-100
Plasticiser * of cement	[%]*	0,9-1,2
Water/cement ratio	[-]	0,54-0,67

7 7.2 7.2.3	**Options for re-using of masonry material** Clay brick enriched material Aggregates for in-situ and precast concrete, mortars	109

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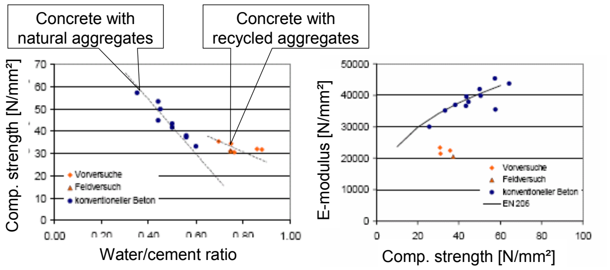
Compressive strength and E-Modulus of the produced concretes



$$E = 9100 \cdot (f_c)^{0,33} \cdot \left(\frac{\rho_{c,\,bulk}}{2400}\right)^2 \cdot \left(1 - \frac{A_Z}{500}\right)$$

$f_c \approx 32{,}5$ N/mm²

$\rho_{c,\,bulk} \approx 2140$ kg/m³

$A_Z \approx 15$ %

$$E = 9100 \cdot (32{,}5)^{0,33} \cdot \left(\frac{2140}{2400}\right)^2 \cdot \left(1 - \frac{15}{500}\right) = 22000 \text{ N/mm}^2$$

Ref.: Hoffmann, EMPA Abt. Beton/Bauchemie 2004

7 7.2 7.2.3	**Options for re-using of masonry material** Clay brick enriched material Aggregates for in-situ and precast concrete, mortars	110

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Apartment house Zürich

- 500 m³ concrete with mixed recycled aggregates for internal walls, research project together with EMPA Zürich

7 7.3	**Options for re-using of masonry material** Calcium silicate brick enriched material	111

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Calcium silica brick

Properties of processed calcium silica brick

- Material composition
- Chemical composition

	[% by mass]
Lost of drying	0,2
LOI at 1000 °C	3,3
SiO_2	86,5
Al_2O_3	2,1
Fe_2O_3	0,41
CaO	7,6
MgO	0
K_2O	0,3
Na_2O	0,09
SO_3	0,1
Cl^-	n.b.

- No leachable substances in the pure original material.

7 7.3	**Options for re-using of masonry material** Calcium silicate brick enriched material	112

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- Steady particle size distribution
- Spherical shape
- Grain strength, frost resistance: no results available
- Unit weight, bulk density, absolute density, calculated porosity, water absorption

	0/2 mm	2/4 mm	4/8 mm	8/16 mm
Unit weight [kg/dm³]	1,10	0,73	0,77	0,83
Bulk density [kg/dm³]	1,50	1,57	1,57	1,76
Absolute density [kg/dm³]	2,6517			
Porosity [%]	43,4	40,8	40,8	33,6
Water absorbtion [%]	24,5	15,7	13,9	11,1

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7 **Options for re-using of masonry material**
7.3 Calcium silicate brick enriched material

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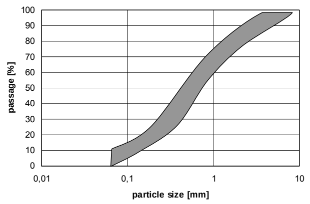
Fields of application
- Raw material for calcium silica brick: clean material or material with small amounts of mortar
- In portions < 10 mass-% without effects
- Addition of 23 mass-% results in a strength loss from 20,9 N/mm² to 13,8 N/mm²

Requirements for reuse as raw material
- Reactivity of quartz high enough
- Total organic material < 0.1 mass
- No humus-like components
- No bitumen
- Chloride < 0.015 mass-%
- Sulfate < 0.1 mass-%
- Sulfide < 0.1 mass-%
- PACs < 50 mg/kg
- Particle size distribution: steady distribution 0/8 mm



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7 **Options for re-using of masonry material**
7.4 Autoclaved aerated concrete enriched material

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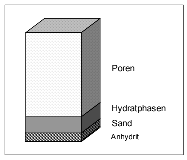
Aerated autoclaved concrete

Properties of processed AAC
- Chemical composition
- Main constituents



	[% by mass]
Lost of drying	1,4
LOI at 600 °C	5,6
LOI at 1000 °C	4,4
SiO_2	57,3
Al_2O_3	3,5
Fe_2O_3	1,11
CaO	23,2
MgO	0,4
K_2O	1,10
Na_2O	0,34
SO_3	2,3 3,0
Cl^-	0,026

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7 **Options for re-using of masonry material**
7.4 Autoclaved aerated concrete enriched material

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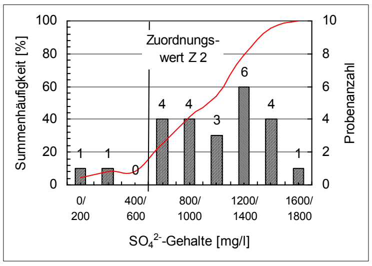
- Leachable sulfate in the pure original material.



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7 **Options for re-using of masonry material**
7.4 Autoclaved aerated concrete enriched material

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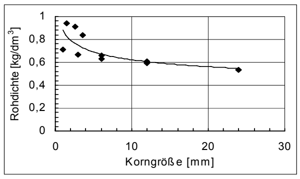
- Steady particle size distribution with a high portion of fine particles
- Spherical shape
- Bulk density of elements of aerated concrete between 0.35 and 1.00 kg/dm³
- Bulk density of crushed material = f (Particle size)
- Water absorption = f (Particle size)



Korn-fraktion [mm]	Wasser-aufnahme [%]
0/4	40
0/8	45
0/16	50

Fields of application

- Raw material for aerated concrete
  - clean materials in portions of about 15 mass-%
  - material with small amounts (< 10 %) of impurities like mortar in portions < 15 mass-%
- Clean material as
  - cat litter
  - material for oil-absorption
  - lightweight bulk material

Objective: Production of bricks again from brick or masonry CDW

(i) Hydrothermal hardened bricks

Raw material: Brick sands and lime.
Consolidation by a hydrothermal treatment.

(ii) Clay bricks

Raw material: Mixtures with approximately equal shares of sands from masonry rubble or pure bricks and clay.
Consolidation by a thermal treatment at temperatures of 1100 °C.

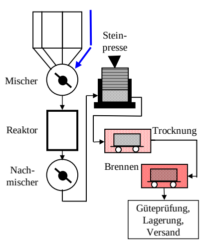
(iii) Plan bricks

Raw material: Mixture of masonry CDW, brick rubble and brown coal fly ash and up to 10 % clay as correction material.
Consolidation by thermal treatment at temperatures from 1120 to 1140 °C.

Raw materials
- masonry RC < 1 mm
- fly ash with high content of free lime
- clay as glue

Process
- mixing and slaking
- drying at 110 °C
- burning at 1120 °C

Product
- bulk density ~ 1,6 g/cm^3
- com. strength ~ 12 N/mm^2



(iiii) Expanded granulates from masonry rubble

Raw materials

- Masonry CDW 0/4 mm from a recycling plant as matrix material

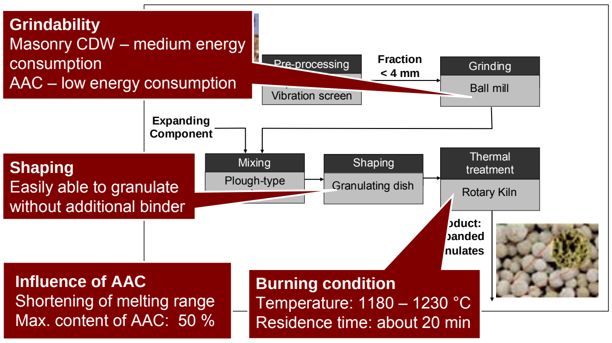
SiO_2	Al_2O_3	FM
[%]		
63,1	17,7	19,1

- Aerated autoclaved concrete from AAC plant as additional material to increase the heterogeneity

SiO_2	Al_2O_3	FM
[%]		
53,0	4,4	42,6

- Silicium carbid waste < 100 µm as expanding component

Technological scheme of the production of expanded, lightweight granulates



First application tests
- Manufacturing of blocs and cubes in a precast concrete plant
- Volumetric substitution of the normally used expanded clay 4/8 mm by CDW aggregate 4/8 mm

	CDW aggregate	Expanded clay
Bulk density of concrete [kg/m³]	1130	870
Com. strength [N/mm²]	11,90	6,16
Thermal conductivity [W/mK]	0,35	0,24
Freeze-thaw resistance: E_{dyn} change [%]	- 2,6	- 67,9

Production of bricks again from brick or masonry CDW

→ Acceptable technical results were achieved, developments could not establish in competition with conventional wall construction materials so far.

Conclusions Lecture 2

Composition
- All kinds of masonry blocs plus mortar, plaster, plasterboard

Features of processed masonry rubble
- Large range of variation of material composition

Options for re-using of masonry material
- Reuse of mixed recycling material from masonry as filling and stabilizing material in unbound “bulk” systems generally applied
- Reuse at higher levels only for processed masonry material consisting of one dominant component

Masonry CDW as raw material
- Different technologies developed, no commercial use so far