RECYCLING CONCRETE
-The present state and future perspective-

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Concrete

**Constituents:** coarse aggregate, fine aggregate, cement (limestone and clay), and water

“The most bountiful resources on the Earth”

**Therefore, concrete is the second most consumed material on the Earth after water.**

at present: more than 20 billion tons
1950: 2 billion tons
Environmental Problems in Concrete Sector

- Global warming
- Resource depletion
- Waste disposal
World Cement Production by Regions and Main Countries

2.83 billion tons

CO₂ emission from cement: 2.46 billion tons

*Including EU27 countries not members of CEMBUREAU
Warning by IPCC Report

“CO₂ emissions must be reduced by 85 - 50% by 2050 compared with the 2000 level to limit CO₂ to 350 - 400 ppm. Even if we could do it, a temperature rise of 2.0 – 2.4 °C will be inevitable.”

What is the current situation?
CO₂ Observation in Hawaii

Atmospheric CO₂ at Mauna Loa Observatory

Keeling Curve

YEAR


CONCENTRATION (parts per million)

320 340 360 380

1974-2007 NOAA/ESRL
## Consumption of Natural Resources on Earth

<table>
<thead>
<tr>
<th>Category</th>
<th>Consumption (billion tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates</td>
<td>20</td>
</tr>
<tr>
<td>Steel production (iron ore)</td>
<td>1</td>
</tr>
<tr>
<td>Gold production (gold ore)</td>
<td>0.7</td>
</tr>
<tr>
<td>Wood</td>
<td>3</td>
</tr>
<tr>
<td>Others</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26</strong></td>
</tr>
</tbody>
</table>

CO\(_2\) emissions from aggregate production: 160 million tons
Total CO$_2$ Emissions from Concrete Sector

- Total: about 5.9 billion tons (Cement, aggregate, steel, execution, transportation)
- It corresponds to 20% of the total fossil fuel origin CO$_2$ emissions, which is 30.0 billion tones in 2007.
Resource Input into Construction Sector in Japan

**Total**
- Total: 2,000 (million t/year)
  - Construction: 1,000 (million t/year) 50%

**Construction**
- Total: 1,000 (million t/year)
  - Others
  - Wood
  - Concrete: 500 (million t/year) 50%
  - Steel
## Amount of waste in Major Regions

<table>
<thead>
<tr>
<th>Amount of waste (Mt)</th>
<th>Europe</th>
<th>USA</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction and demolition waste</td>
<td>510</td>
<td>317</td>
<td>77</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>241</td>
<td>228</td>
<td>53</td>
</tr>
</tbody>
</table>

Source: CSI - Recycling concrete
Waste Output from Construction Industries in Japan

**Industrial Waste**

Total: 412 (million t/year)

- **Construction Waste**
  - Total: 75 (million t/year) 18%
  
**Construction Waste**

Total: 75 (million t/year)

- Concrete 32 (million t/year) 41%

**Chemical**

**Steel**

**Pulp**

**Asphalt concrete**

**Energy**

**Agriculture**

**Wood Sludge**

**Others**

**Concrete**

**Others**

**Asphalt concrete**
Construction Waste in Each Country

- Germany: 6900 t
- UK: 3000 t
- France: 2400 t
- Italy: 2000 t
- Spain: 1300 t
- Netherland: 1100 t
- Belgium: 700 t
- Austria: 500 t
- Portugal: 300 t
- Denmark: 300 t
- Greece: 200 t
- Sweden: 200 t
- Finland: 100 t
- Ireland: 100 t
- Luxembourg: 0 t
- EU 15 countries: 18000 t
- USA: 13500 t
- Japan: 8500 t

Construction Waste (x10,000 t)
Final Disposal Sites for Waste in Japan

Possible waste in final disposal area (million ton)

<table>
<thead>
<tr>
<th>Year</th>
<th>General</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
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<td>2001</td>
<td></td>
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<tr>
<td>2002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Utilization Form of Recycled Concrete

- **Reuse in original form by cutting them into smaller blocks (very limited)**
  - slab reuse
- **Use as aggregate**
  - road sub-base or
  - underground stabilization
  - concrete
Use of Recycled Aggregate

% Recycled Aggregate of Total Aggregate Use

Croatia  Denmark  Norway  Portugal  Turkey  Spain  Finland  Slovakia  Ireland  Italy  Sweden  Romania  France  Austria  Poland  Czech Republic  Germany  Switzerland  Belgium  Netherlands  United Kingdom
Recycling Ratio of Concrete in Japan

Emission of Concrete Lumps (million t)

- 1990
- 1995
- 2000

Recycle
Disposal

Mostly used as road sub-base
Predicted Amount of Future Concrete Lumps in Japan

Production (million t)

Concrete production
Demand for road subbase
Concrete waste

Year
1950
2000
2050
Recycling process of concrete lumps

Demolished Concrete Lumps

Jaw Crusher

Impact Crusher

Vibratory Sieves

Road Subbase, Backfill

Vibratory Sieves

Cone Crusher

Vibratory Sieves

Heating Tower

Coarse Aggregate Scrubber

Fine Aggregate Scrubber

Vibratory Sieves

High Quality Recycled Coarse Aggregates

High Quality Recycled Fine Aggregates

Powder

(a) Road Subbase

(b) Low Quality Recycled Aggregates

(c) High Quality Recycled Aggregates
The Most General Technologies for Concrete Recycling

- Road sub-base material
- Non-structural concrete
Properties of Recycled Aggregate

<table>
<thead>
<tr>
<th>Water Absorption (%)</th>
<th>Recovery Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10mm not less than 10mm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Crushing Treatment</th>
<th>Number of Crushing Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>No 1st 2nd</td>
<td>Original Concrete</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size of Supplied Concrete Lumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled Fine Aggregate</td>
</tr>
<tr>
<td>Recycled Coarse Aggregate</td>
</tr>
<tr>
<td>Powder</td>
</tr>
<tr>
<td>• Gravel</td>
</tr>
<tr>
<td>• Sand</td>
</tr>
<tr>
<td>• Cement Paste</td>
</tr>
</tbody>
</table>

Graph showing the relationship between water absorption and recovery percentage with number of crushing treatments.
Recycling Technologies of Demolished Concrete in Japan

(1) Heating and rubbing method
(2) Eccentric-shaft rotor method
(3) Mechanical grinding method
Heating and rubbing method

- Concrete rubble
- Heating: 300°C
- Packed bed heater
- Recycled fine aggregate
- Recycled coarse aggregate
- Coarse aggregate recovering equipment (Ball Mill)
- Fine aggregate recovering equipment (Mill)
- Dust extractor
- Powder
- Vibrating screen
- Heating: 300°C
Heating and Rubbing Method Plant
Mechanism of Heating and Rubbing Method

Concrete rubble → Heating at 300°C → Rubbing process → Weakening of hardened cement paste → Removal of powdered cement hydrate
Recycled Aggregates & By-product Powder by H&R Method
Quality of Recycled Aggregates
An Example of Application of Heating and Rubbing Method
On-site Concrete Resource Recycling System and CO₂

P1: Road sub-bases production, P2: Recycled aggregate recovering, P3: Concrete mixing and delivery, P4: Ground improvement
Eccentric-Shaft Rotor Method

Crushed concrete lumps are passed downward between an outer and inner cylinder.
An Example of Application of Eccentric-Shaft Rotor Method

Old apartment Houses
12 x 4-storied
Concrete lump: 11,500 t

New apartment Houses
7 x 9-19-storied
Recycled coarse aggregate: 3,000 t
Recycled concrete volume: 3,000 m³
( Total concrete volume: 40,000 m³ )
Coarse and fine aggregates are produced by separating a drum into small sections with partitions.
Japan Industrial Standards for Recycled Aggregate

- **JIS A 5021**
  - Recycled aggregate for concrete - Class H
- **JIS A 5022**
  - Recycled concrete using recycled aggregate Class M
- **JIS A 5023**
  - Recycled concrete using recycled aggregate Class L
# Specified Values of Recycled Aggregate in JIS

<table>
<thead>
<tr>
<th></th>
<th>Class - H</th>
<th>Class - M</th>
<th>Class - L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
<td>Fine</td>
<td>Coarse</td>
</tr>
<tr>
<td>Oven-dry density (g/cm³)</td>
<td>not less than 2.5</td>
<td>not less than 2.5</td>
<td>not less than 2.3</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>not more than 3.0</td>
<td>not more than 3.5</td>
<td>not more than 5.0</td>
</tr>
</tbody>
</table>
# Limits of Amount of Deleterious Substances for RA-H

<table>
<thead>
<tr>
<th>Category</th>
<th>Deleterious substances</th>
<th>Limits (mass%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Tile, Brick, Ceramics, Asphalt concrete</td>
<td>2.0</td>
</tr>
<tr>
<td>B</td>
<td>Glass</td>
<td>0.5</td>
</tr>
<tr>
<td>C</td>
<td>Plaster</td>
<td>0.1</td>
</tr>
<tr>
<td>D</td>
<td>Inorganic substances other than plaster</td>
<td>0.5</td>
</tr>
<tr>
<td>E</td>
<td>Plastics</td>
<td>0.5</td>
</tr>
<tr>
<td>F</td>
<td>Wood, Paper, Asphalt</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>3.0</strong></td>
</tr>
</tbody>
</table>
## Application of Recycled Aggregate

<table>
<thead>
<tr>
<th>Class</th>
<th>Scope of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class - H</td>
<td><strong>No limitations</strong> are put on the type and segment for concrete and structures with a nominal strength of 45MPa or less</td>
</tr>
<tr>
<td>Class - M</td>
<td><strong>Members not subjected to drying or freezing-and-thawing action</strong>, such as piles, underground beam, and concrete filled in steel tubes</td>
</tr>
<tr>
<td>Class - L</td>
<td><strong>Backfill concrete, blinding concrete, and leveling concrete</strong></td>
</tr>
</tbody>
</table>
Utilization of By-product Powders

**Large amount of by-product powders**

- **Possible uses**
  - Cement material
  - Ground improving material
  - Addition to road bottoming
  - Concrete addition
  - Asphalt filler
  - Inorganic board material

- **Demands**
  - Quality stabilization
  - Reduction of quality control cost
Barriers of Concrete Recycling (CSI)

- Low economic cost of virgin aggregate
- Non-regular supply of construction and demolished waste (C & DW)
- C & DW on-site waste management plans are needed
- Misconception that recovered concrete is of low quality
- Classification of recovered concrete as waste can increase reporting and permit requirements. Extra limitations can be placed on use.
Barriers of Concrete Recycling (CSI)

- Processing technology for recovery of concrete should consider possible air and noise pollution impacts as well as energy consumption.
- For specialized application (e.g. high performance concrete), there are some limitations on fitness for use.
Future Technologies for Concrete Recycling

- **Concept of Completely Recyclable Concrete**
  - Recyclable concrete like steel and aluminum
  - Production process of concrete
    - Conventional downstream approach
      - focusing on
        » Cost reduction
        » Efficiency in production
    - New production system
      - incorporating upstream (inverse) processes in consideration of recyclability
Requirements for Ideal Recycling

- Save energy
- Make high performance concrete
- Reduce waste
- Conserve natural resources
Cement-recovery Type Completely Recyclable Concrete (The Uni. Of Tokyo)

- Concrete in which binders, additives and aggregates are all made of cement or materials of cement, and all of these materials can be used as raw materials of cement after hardening
Application of Cement Recovery Type CRC

Precast Concrete Foundations Made from CRC in Kita-kyusyu
Aggregate-recovery Type Completely Recyclable Concrete (The Uni. Of Tokyo)

- Concrete which is designed to reduce the adhesion between aggregate and the matrix to an extent that does not adversely affect the mechanical properties of concrete by modifying the aggregate surfaces beforehand, thereby facilitating recovery of original aggregate.
Mechanism of Aggregate-recovery Type CRC by Surface Modification

**Chemical treatment**

- **Inhibition of cement hydrate formation**
  
  The principal ingredient of the coating agent is mineral oil. The agent hydrolyzes in alkali conditions of fresh concrete, forming acidic matter and indissoluble amalgam on the surface of the aggregate. The surface coating results in decreased amounts of cement hydrate, and leads to decreased adhesive strength between aggregate and paste matrix, allowing easy recovery of the original aggregate.

**Physical treatment**

- **Reduction of mechanical friction**
  
  The coating agent is a water-soluble synthetic resin emulsion, which is applied in process of abrasion, and which is chemically stable in fresh concrete. The uneven surfaces of virgin aggregate become smoother, the shape of the aggregate being roughly maintained. This has the effect of decreasing adhesive strength between aggregate and paste matrix.
Concrete recycle by surface modification treatment to aggregate

- Existing technology was very difficult to ensure trade-off relationship:
  - "Mechanical properties"
  - "Recycling performance"

Proposed technology

- Crush
- < Recycled aggregate >
  - High-quality aggregate with low energy

< Concrete >
- Recycled aggregate
- High-quality aggregate with low energy

To enhance a peeling effect of aggregate from mortar matrix

Existing technology
Energy consumption of the aggregate recycling utilizing microwave heating is small compared to existing technologies.
Recovery of Aggregate from Concrete Waste by Electric Pulsed Power Technology

(Kumamoto University: M. Shigeishi, T. Namihira, M. Ohtsu, and H. Akiyama)
Pulsed Power Method

Marx Generator

Concrete
Fracture of Concrete by EPP

The dielectric breakdown of gas occurs in concrete by the pulsed electric discharge at first. Ionized gas forms plasma and explosive volumetric change tears concrete matrix.

The shock wave is also generated at the same time. The shock wave generates the tensile stress at the boundary and mortar is separated from aggregate.
Controllable Fracture

- 20 shots
- 60 shots
- 100 shots

Concrete can be demolished under the controlled fracture by frequency of discharge and energy of discharge per once.
Environmental Benefit

• For processing of 1000 kg of concrete waste;

<table>
<thead>
<tr>
<th></th>
<th>Rubbing method with pre-heating</th>
<th>Pulsed Power method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Consumption</strong></td>
<td>29 kWh/t (*)</td>
<td>17.8 kWh/t (+)</td>
</tr>
<tr>
<td><strong>CO₂ Emission</strong></td>
<td>11.32 kg-CO₂/t (*)</td>
<td>7.24 kg-CO₂/t (+)</td>
</tr>
</tbody>
</table>

(*) refer to RECOMMENDATION OF ENVIRONMENTAL PERFORMANCE VERIFICATION FOR CONCRETE STRUCTURES (DRAFT), JSCE, 2006.

(+) estimated from experimental results of processing of 4 kg of concrete.
Green Building Design and Practices to Foster Recycling (CSI)

- Sustainability in initial design (durable flexible designs, off-site prefabrication, and deconstruction design)
- Optimum use of input materials in design (reuse, recycling, building energy efficiency)
- On-site waste management plans (maximize the potential for materials reuse and recycling and minimize negative environmental and health effects)

These aspects should be reasonably incorporated into green building rating systems. At present, not enough.
Concluding Remarks  
(To be cont’d)

- Concrete should be repeatedly recycled with less energy.
- More efficient recycling technologies should be developed.
- Recycling should be of high quality from the user’s point of view.
Concluding Remarks (Cont’d)

- The reasonable regulations and design/green-rating systems should be established to promote concrete recycling.
- Concrete recycling will become one of the most important elements for construction sustainability
Acknowledgment

I would like to thank Dr. Noguchi, The University of Tokyo, and Dr. Shigeyoshi and Prof. Ohtsu, Kumamoto University, for providing their PPT information on concrete recycling.