INTERNATIONAL WORKSHOP ON:
Durability and Sustainability of Concrete Structures
(DSCS 2015)

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Greener Concrete Using Post-Consumer Products

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For sustainable developments: Reduce, Reuse, Recycle, and Repair.

Minimize use of manufactured materials. Maximize environmental benefits: resource conservation, clean water, and clean air should be the concern of everyone.
Basic Approach

WA$T€ is wasted if you waste it, otherwise it is a resource. Resource is wasted if you ignore it and do not conserve it with holistic best practices and reduce societal costs. Resource is for the transformation of people and society.

Focus on turning brown fields into green fields – opportunities are here, now!!
Basic Approach

Recycle. Recycle as is.

Whenever possible, recycle without additional processing (i.e., without adding any cost to it).

Disposal leads to GHGs.
Solid Waste Management

Landfills contributes to global climate change because it releases GHGs (Water Vapor, Methane, and CO2). “Methane (is) 20 more powerful than CO2.” Therefore, recycling “creates a double carbon saving.” (Financial Times, March 1, 2009).

US-EPA declared in April 2009 that CO2 is a danger to human health (Financial Times April 18/19, 2009).

Alternatives? Increase recycling rates, as well as MSW to energy and composting.
Needs to develop greener concrete is increasing day-by-day with the desire to:

- Resource conservation;
- Contribution to the reduction in the causes of global climate change;
- Reduce carbon footprint of concrete and concrete-making materials by using recyclable materials …industrial by-products & post-consumer products; and,
- Develop sustainable infrastructures.
We can make 100% green-concrete using all recyclable materials

For 100% green-concrete, use:
• Recycled concrete, air-cooled slag, foundry cupola slag, etc. as coarse aggregates;
• Used foundry sand, tires, plastics, and glass as fine aggregates;
• Combustion ash from coal, biomass & rice-husk, limestone & marble quarry fines, CKD, LKD, etc. as other cementitious or pozzolanic materials; and,
• Wash water from R/M plants, STP, etc.
Post-Consumer Products in Greener Concrete.

- Used Tires;
- Plastics; and,
- Glass.
Used Tires

• Roughly 300 million scrap (used) tires are generated each year in the United States.

• With all reuse and recycling efforts each year, about 9% of scrap tires are disposed in landfills.

• Among all the possible methods of tire disposal, the creation of rubber crumbs potentially offers the most effective environmental solution.
Used Tires in Portland Cement Concrete System

Coarse aggregate from scraped tire

Crumbed rubber aggregate.
Crumb Rubber Modifier (CRM)

• Ground form of tire

• Particles ranging in size from 4.75 mm (No. 4 Sieve) to less than 0.075 mm (No. 200 Sieve).

• The composition of CRM depends greatly upon the original chemistry of the tire-rubber and subsequent contamination during its use
Used tires in the form of chips and CRM, with or without surface treatment, can be used as a partial replacement of coarse aggregate and fine aggregate of concrete, respectively.
Fresh Properties of Concrete with Tire Aggregates

- **Workability**
  - Decrease with increase in maximum size or percentage of rubber chips.
  - Insignificant change up to 25% replacement of sand with CRM
- **Unit weight**
  - A reduction with replacement of coarse aggregate with tire chips.
  - Smaller reduction for replacement of sand with CRM
- **Air content**
  - Increase with increase of tire aggregates
Benefits of Using Tire Aggregates in Concrete

- Improvement in freeze-thaw durability,
- Reduction of mass density
- Improved ductile behavior with capability of absorbing a large amount of energy under compressive and flexural loads
- Improvement in non-structural crack resistance property,
Properties of Concrete with Tire Aggregates

- Compressive, Splitting tensile strength, and Modulus of Elasticity
  - Significant reduction especially for more than 50%
  - the decrease in mechanical and elastic properties depend on the aggregate size and content.
Appropriate Technology To Overcome Limitations

- Use of magnesium oxychloride cement
- Use of micro-fine CRM in cement concrete
Post-consumer Plastics

• The amount of plastic in MSW has increased from 1% in 1962 to 13% in 2011.

• Plastics can be divided into two major categories: thermosets and thermoplastics.

• It is difficult and uneconomical to recycle all the different types of post-consumer plastics.

• The recycling rate for different types of plastic varies. About 30% of HDPE bottles and PET bottles and jars were recycled in 2011.

• Overall plastics recycling rate in 2011 was only 8%. 
Recycling Post-consumer Plastics for Concrete

• The most widely recycled post-consumer plastic is polyethylene terephthalate (PET).

• Recycled plastic is generally used to produce:
  – Resin;
  – Fibres; and,
  – Aggregate.
Absence of a chemical bond between plastic filler and cementitious matrix does not help improve its fracture toughness. Therefore, chemical treatments to plastic is needed.

- **Chemical treatments used**
  - Water;
  - Bleach ("candeggina"); and,
  - Bleach plus NaOH.
• Effects on slump and unit weight of concrete containing plastic filler:
  – Slump higher than the conventional concrete
  – Unit weight lower than the conventional concrete

• Effects on mechanical properties:
  – Compressive strength, modulus of elasticity, and tensile strength of concrete decreases with increase in the plastic aggregate content.
  – Better structural efficiency (lightweight concrete) and toughness are some important beneficial properties.
# Effect of water-treated plastic content on compressive strength of concrete

<table>
<thead>
<tr>
<th>Mixture No.</th>
<th>P 0 (0% plastic)</th>
<th>P 0 (0.5% plastic)</th>
<th>P 0 (1.5% plastic)</th>
<th>P 0 (2% plastic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-day compressive strength, psi (MPa)</td>
<td>4074 (28.1)</td>
<td>4103 (28.3)</td>
<td>3147 (21.7)</td>
<td>2146 (14.8)</td>
</tr>
</tbody>
</table>
• Almost all concrete mixtures developed reduced compressive strength than the reference concrete.

• The mixture containing plastic treated with bleach plus NaOH performed the best, followed by the water-treated plastic sample.

• Concrete containing plastic treated with water showed that 0.5% of plastic could be used in concrete without compromising the compressive strength.

• Beyond 0.5% addition of plastic particles by the weight of the concrete, concrete strength decreased.
Better structural efficiency and toughness encourage use of post-consumer plastic fibres for the manufacturing of precast products:

- Sewer pipes
- Underground vaults
- Power line transmission poles
- Median barriers of roads and other similar products.
Post-consumer Glass

• 11 million tonnes of post-consumer glass (2011).
• 5.5% of total MSW.
• 28% of glass was recovered for recycling in 2011.
• About 90%, went into new glass containers.

• Three types of glass
  – Borosilicate;
  – Soda-lime; and,
  – Lead glass.
Glass consists of:

– Silica or fused silica sand; and,
– Smaller amounts of lime sand and soda ash.
Applications of glass in cement and concrete

- Crushed glass exhibits properties similar to an aggregate material
- Post-consumer glass after crushing can be used as:
  - a partial replacement of coarse aggregate
  - a partial replacement of fine aggregate
  - a partial replacement of cement
### Chemical composition of glass

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Borosilicate</th>
<th>Soda-lime</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>81</td>
<td>73</td>
<td>63</td>
</tr>
<tr>
<td>R₂O₃</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>K₂O</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>13</td>
<td>Trace</td>
<td>-</td>
</tr>
<tr>
<td>CaO</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>MgO</td>
<td>-</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>PbO</td>
<td>-</td>
<td>-</td>
<td>22</td>
</tr>
</tbody>
</table>
Chemical compositions of soda-lime glass, Class F fly ash, and silica fume (% weight)

<table>
<thead>
<tr>
<th>Chemical compositions</th>
<th>Soda-lime glass</th>
<th>Class F fly ash</th>
<th>Silica fume</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>72.8</td>
<td>40.7</td>
<td>96.5</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>1.4</td>
<td>17.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>-</td>
<td>29.9</td>
<td>2.0</td>
</tr>
<tr>
<td>SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$</td>
<td>74.2</td>
<td>88.5</td>
<td>99.0</td>
</tr>
<tr>
<td>CaO</td>
<td>4.9</td>
<td>2.8</td>
<td>0.8</td>
</tr>
<tr>
<td>MgO</td>
<td>3.4</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>-</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.3</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>16.3</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>-</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>-</td>
<td>0.9</td>
<td>-</td>
</tr>
<tr>
<td>B$_2$O$_3$</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Color</td>
<td>White</td>
<td>Grey</td>
<td>Dark</td>
</tr>
</tbody>
</table>
Concrete mixtures details for the replacement of sand with crushed glass

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Quantity (kg/cubic meter)</th>
<th>A0</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B0</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td>429</td>
<td>427</td>
<td>426</td>
<td>421</td>
<td>362</td>
<td>361</td>
<td>361</td>
<td>359</td>
</tr>
<tr>
<td>Fly Ash</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>79</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td>720</td>
<td>611</td>
<td>499</td>
<td>389</td>
<td>677</td>
<td>574</td>
<td>477</td>
<td>375</td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td>0</td>
<td>99</td>
<td>197</td>
<td>292</td>
<td>0</td>
<td>98</td>
<td>196</td>
<td>295</td>
</tr>
<tr>
<td>Stone</td>
<td></td>
<td>1079</td>
<td>1073</td>
<td>1071</td>
<td>1059</td>
<td>1073</td>
<td>1071</td>
<td>1071</td>
<td>1067</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>178</td>
<td>173</td>
<td>174</td>
<td>176</td>
<td>179</td>
<td>178</td>
<td>177</td>
<td>177</td>
</tr>
<tr>
<td>W/Cm</td>
<td></td>
<td>0.42</td>
<td>0.41</td>
<td>0.41</td>
<td>0.42</td>
<td>0.41</td>
<td>0.41</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Unit Wt</td>
<td></td>
<td>2406</td>
<td>2384</td>
<td>2367</td>
<td>2337</td>
<td>2371</td>
<td>2363</td>
<td>2362</td>
<td>2353</td>
</tr>
<tr>
<td>Slump, mm</td>
<td></td>
<td>85</td>
<td>70</td>
<td>65</td>
<td>70</td>
<td>65</td>
<td>85</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>Air Cont, %</td>
<td></td>
<td>1.4</td>
<td>1.8</td>
<td>1.8</td>
<td>2</td>
<td>1.4</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Concrete mixtures details for the replacement of sand with crushed glass (cont’d)

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Quantity (kg/cubic meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C0</td>
</tr>
<tr>
<td>Cement</td>
<td>298</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>160</td>
</tr>
<tr>
<td>Sand</td>
<td>642</td>
</tr>
<tr>
<td>Glass</td>
<td>0</td>
</tr>
<tr>
<td>Stone</td>
<td>1069</td>
</tr>
<tr>
<td>Water</td>
<td>177</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.39</td>
</tr>
<tr>
<td>Unit Wt</td>
<td>2346</td>
</tr>
<tr>
<td>Slump, mm</td>
<td>90</td>
</tr>
<tr>
<td>Air Cont, %</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Fresh Properties of Concrete with Glass Aggregates

• Slump (Generally depends on shape and size)
  – Decreases with increases in the level of replacement of sand by crushed glass

• Unit weight
  – Decrease with increase in glass content

• Air content
  - Insignificant effect
28 Days linear expansion of concrete mixtures versus crushed glass content
Strength and expansion of concrete

• Compressive and splitting tensile strengths of concrete decreased slightly with an increase in the replacement of the sand with the crushed glass.

• Class F fly ash could only delay the onset of expansion, while with high amount of fly ash (45%) concrete was immune to ASR.
Conclusions

- There is an excellent potential for the utilization of post-consumer materials (tires, plastics, and glass) in production of green-concrete in several forms including as fine aggregate, coarse aggregate, binder, and filler-powder.

- Aggregate derived from the used tires, with or without surface treatment, can be used as a partial replacement of aggregates to be used in the manufacture of a green-concrete.
Conclusions (Cont’d)

- Reduced mechanical properties of concrete containing used tires aggregate can be brought to the acceptable level by the use of currently available knowledge.

- Among all post-consumer plastics, PET and HDPE are most widely recycled plastics for use in manufacturing of ingredients for a concrete; i.e. aggregate, binder, and even as an additional ingredient as fibres for imparting desirable benefits to the concrete.
Conclusions (Cont’d)

- Crushed post-consumer glass can be used as a partial replacement of aggregates and cement in the manufacturing of a greener concrete.

- The chance of alkali-silica reaction in concrete containing coarse aggregate derived from post-consumer glass can be avoided by using higher amount of coal fly ash.
Sustainable/Durable Concrete

- Use less cement
- Use less water
- Use project specific durable aggregates
- Use powder additives and liquid admixture
RESOURCE CONSERVATION

“The earth, the sea (water), and the air are the concern of every nation.” President John F. Kennedy, September 1963, in a speech to the U.N. General Assembly.
The Beautiful Earth – La Bella Terra
http://cbu-uwm.info/

<http://www4.uwm.edu/ceas/faculty_profiles/TNaik.html>
Fourth International Conference on Sustainable Construction Materials & Technologies, Las Vegas, Nevada, USA
August 7-11, 2016
Ringrazio molto per il vostro interesse.
Thank you very much for your interest.