Production of lightweight fillers (LWFs) from recycled glass and paper sludge ash (PSA)

Charikleia Spathi\textsuperscript{a,b}, Luc Vandeperre\textsuperscript{a}, Chris Cheeseman\textsuperscript{b}

\textsuperscript{a} Department of Materials, Imperial College London
\textsuperscript{b} Department of Civil and Environmental Engineering, Imperial College London
Background to the project

- EPSRC Industrial Case PhD Award
- Mixed colour glass cannot be reprocessed
- Sustainable solutions for PSA required as an alternative to landfill
- Manufacturing LWFs from waste glass and PSA would be a novel re-use application
Background to the project

- EPSRC Industrial Case PhD Award
- Mixed colour glass cannot be reprocessed
- Sustainable solutions for PSA required as an alternative to landfill
- Manufacturing LWFs from waste glass and PSA would be a novel re-use application
- Industry demand for lightweight fillers (LWFs) and cenospheres
UPM-Shotton

By Mike Turton

Aylesford Newsprint

By Mike Turton

Despite a considerable amount of inclement weather in recent weeks, major maintenance on infrastructure and two-way traffic – assuming the project continues in a timely fashion. We’ve been losing about two days of output per week.
Life cycle of paper

End users → Paper → Printing → Paper → Distribution → RECOVERED PAPER → Chemical pulp → PULP → Paper → Energy production → ENERGY

PAPER SLUDGE → PSA → BY-PRODUCTS
Life cycle of paper


Chemical pulp

Printing

Energy production

Paper

Distribution

End users

RECOVERED PAPER

PAPER

ENERGY

PAPER SLUDGE

BY-PRODUCTS
Paper Sludge Ash (PSA)

Residue from combustion of wastepaper sludge
125,000 tonnes of PSA was produced in 2006
88,000 tonnes beneficially reused in UK markets
37,000 tonnes landfilled

Increasing volumes produced and opportunity for new applications

<table>
<thead>
<tr>
<th>Material for combustion</th>
<th>Amount (tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper sludge</td>
<td>275,000</td>
</tr>
<tr>
<td>Biomass (virgin and clean non-virgin timber)</td>
<td>120,000</td>
</tr>
<tr>
<td>Plastics</td>
<td>17,000</td>
</tr>
</tbody>
</table>

### Waste glass & PSA: Chemical and mineralogical composition

#### X-Ray Fluorescence data

<table>
<thead>
<tr>
<th></th>
<th>SiO$_2$</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>MgO</th>
<th>Al$_2$O$_3$</th>
<th>K$_2$O</th>
<th>Fe$_2$O$_3$</th>
<th>SO$_3$</th>
<th>TiO$_2$</th>
<th>P$_2$O$_5$</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste glass</td>
<td>75.8</td>
<td>12.0</td>
<td>7.3</td>
<td>2.3</td>
<td>1.4</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
<td>nd</td>
<td>nd</td>
<td>-</td>
</tr>
<tr>
<td>PSA</td>
<td>21.2</td>
<td>61.2</td>
<td>nd</td>
<td>2.8</td>
<td>12.6</td>
<td>0.4</td>
<td>0.9</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

#### X-Ray Diffraction data

- a: calcium silicate (Ca$_2$SiO$_4$), c: calcite (CaCO$_3$), g: gehlenite (Ca$_2$Al$_2$SiO$_7$), l: lime (CaO), m: mayenite (Ca$_{12}$Al$_{14}$O$_{33}$), q: quartz (SiO$_2$)
PSA: Microstructure

- Agglomerated particles
- Loosely bonded
- Porous
PSA: Dilatometer results

Samples fall apart at \( T = 1180 \, ^\circ C \)

Inadequate sintering

As-received PSA
PSA and recycled glass: Dilatometer results

Recycled Glass:
- $T_{\text{onset}} = 594 \, ^\circ\text{C}$,
- $T_{\text{end}} = 664 \, ^\circ\text{C}$
- $dL/L_o = 23.2 \%$
PSA: Thermogravimetric Analysis (TGA)
**PSA: Thermogravimetric Analysis (TGA)**

- \( T_{\text{onset}} = 600 \, ^\circ\text{C} \)
- \( T_{\text{end}} = 780 \, ^\circ\text{C} \)
- \( m_{\text{loss}} = 5.5 \, \text{wt\%} \)

\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]
Mechanisms for expansion during rapid sintering

Green particle

particle packing
Mechanisms for expansion during rapid sintering

Green particle → Liquid phase sintering

Heating

particle packing → vitreous phases formed
Mechanisms for expansion during rapid sintering

- Green particle
- Liquid phase sintering
- Particle packing
- Vitreous phases formed
- Gas evolution
Mechanisms for expansion during rapid sintering

- **Green particle**
- **Liquid phase sintering**
  - Gas evolution
- **Rapidly sintered particle**
  - Vitreous phases formed
  - Closed cell structure
Specifications of potential LWF products

**Desired properties**

- Low density $\sim < 1 \text{ g cm}^{-3}$
- Relatively low water absorption
- High strength
- Particle size ranging from $\sim 60\mu\text{m}$ to 2mm
Industrial manufacturing process

Raw materials (recycled glass) → Ball milling → Mixing → Pan pelletising → Sintering (rotary kiln) → Quality Control

As used by Poraver, Liaver and Ecoglass manufacturers
Laboratory manufacturing process

1. Raw materials
   Fine glass powder
   PSA

2. Grinding
   1-4 hours

3. Mixing
   Water

4. Pelletising
   Angle and rotation speed adjusted

5. Rapid sintering
   Temp.: 800 °C
   Time: < 40 min

6. Sieving
   Size: 1 – 7 mm
Effect of PSA content on density and water absorption

Wet milled for 1 hour, $T_{sint} = 800^\circ C$, $t_{sint} = 20$ minutes
Effect of sintering time: 20% PSA-80% glass mix
Effect of sintering time: 20% PSA-80% glass mix

- Heating
- Glass softening
- Gas evolution
- Stable phase
- Potential coarsening

Particle density (g cm$^{-3}$) vs. Sintering time (min)
Effect of sintering time: 20% PSA - 80% glass mix
Effect of sintering time on microstructure

Sintering time: 5 minutes

Sintering time: 10 minutes
Effect of sintering time on microstructure

Sintering time: 15 minutes

Sintering time: 20 minutes
20% PSA-80% glass mix: Effect of pellet size on CS (10)
Conclusions

- Identified LWFs as the target product – cenosphere-type products
- PSA can be mixed with glass (1:4) to form LWFs
- Laboratory production process mimics industrial manufacturing
- Promising results to date:
  - Light weight fillers are produced at particle sizes ranging from 1-7 mm
  - Relatively low sintering temperature (800 °C) and time (15 min)
  - Optimum PSA-glass LWFs have higher crushing strength than commercial LWFs
Questions and Answers

I think I have too many apps.

Thank you!