EXPLORING OPTIONS FOR USING WET-STORED STOCKPILE FLY ASH IN CONCRETE

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TOPICS COVERED

• Background
• Effect of Moisture on Fly Ash
• Using Wet-Stored Fly Ash in Concrete
• Adjustments to the mix
• Processing / Beneficiation
• Concluding Remarks

TOPICS COVERED
WET-STORED FLY ASH

Pond: Fly ash slurried with water (water to fly ash ratios 10:1 to 3.5:1) where it is allowed to settle.

Stockpile: Water added to fly ash at low levels (conditioned 10 to 20%) and kept in a storage area.

Pond (Lagoon): Fly ash slurried with water (water to fly ash ratios 10:1 to 3.5:1) where it is allowed to settle.
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>1995</th>
<th>2005</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>3.0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>1.5</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>3.0</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

1.5
3.0
1.0
1.5
3.0
1.0
3.0
0.5
3.0
0
2
4
6
8
10

**LIMIT ON FA MOISTURE, %**

**Lower end of moisture range for moistened FA (10-20%)**

**MOISTURE LIMITS**

Data from 1999/2000

BS EN 450 / BS EN 450-1

1995: Stored and transported to the purchaser in a dry condition.

2005: Reference made to processing (including drying). Fly ash should be stored and delivered in a dry condition.

2012: Reference made to processing (including drying)
MOISTURE EFFECTS ON FINENESS

Moisture Content (6 months storage)

Fineness, % ret 45μm

Storage Time (10% moisture content)

Dry 0 m 1 m 3 m 6 m 12 m 18 m

FA P1 FA D2 FA P2 FA P3 FA D4 FA D8 FA D6
10% moisture, 18 months storage

Dry Fly Ash

Wet-stored Fly Ash

Wet-stored Fly Ash
LOSS-ON-IGNITION

Storage Time (10% moisture content)

LOI, %

FA P1
FA P2
FA P3
FA D2
FA D4
FA D6
FA D8

dry 0m 1m 3m 6m 12m 18m
STRENGTH FACTOR

![Graph showing strength factor over time for different moisture conditions and storage times.](image-url)
ADJUSTING THE CONCRETE MIX

28 DAY CUBE STRENGTH, N/mm²

W/C RATIO

Dry
1 month
6 months

Fine FA (10% moisture)

35 N/mm²

concrete

0.3 0.4 0.5 0.6 0.7
## USING IN CONCRETE

### DRY FLY ASH MIX PROPORTIONS, kg/m³

<table>
<thead>
<tr>
<th>DESIGN GRADE, N/mm²</th>
<th>TOTAL CEMENT</th>
<th>PC</th>
<th>DRY FA</th>
<th>SP, % total cement</th>
<th>FREE WATER, l/m³</th>
<th>NATURAL AGGREGATE</th>
<th>W/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 mm 10 mm Sand</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>265</td>
<td>185</td>
<td>80</td>
<td>0.50</td>
<td>165</td>
<td>810 410 705</td>
<td>0.62</td>
</tr>
<tr>
<td>35</td>
<td>330</td>
<td>230</td>
<td>100</td>
<td>0.50</td>
<td>165</td>
<td>810 410 645</td>
<td>0.50</td>
</tr>
<tr>
<td>50</td>
<td>445</td>
<td>310</td>
<td>135</td>
<td>0.75</td>
<td>165</td>
<td>810 410 555</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Fine FA
Workability 75 mm target slump
COMPRESSIVE STRENGTH DEVELOPMENT

TEST AGE, days
0 30 60 90 120 150 180
CUBE STRENGTH, N/mm²
Dry
1 month
6 months
Fine FA (10% moisture)

- 60 N/mm²
- 50 N/mm²
- 35 N/mm²
- 25 N/mm²
CARBONATION RESISTANCE

Strength: 35 N/mm²
Fine Fly Ash

Test exposure: 4.0% CO₂, 20°C, 55% RH

EXPOSURE PERIOD, (weeks) 0.5

CARBONATION DEPTH, mm

Dry
1 month
6 months
CHLORIDE DIFFUSION

Strength: 35 N/mm²
Fine Fly Ash
- Dry Fly Ash
- 1 month
- 6 months

Increasing storage

10% moisture

COEFFICIENT OF CHLORIDE DIFFUSION, cm²/s x 10⁻⁹

FINENESS OF DRY FLY ASH
% ret. 45 µm

Grade 35 N/mm²
Strength: 35 N/mm²
Fine Fly Ash
Dry Fly Ash

10% moisture
**HOPPER DISCHARGE TESTS**

All dimensions in mm

- Height: 600
- Width: 65
- Angle: 30°

**Vibration (Vibtec)**
- Speed: 3000 RPM

**Discharge Rate, kg/s**

- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2
- 1.4

**Quantity of Material Discharged, %**

- 0%
- 20%
- 40%
- 60%
- 80%
- 100%

**Fly Ash (a)**

- 0
- 20
- 40
- 60
- 80
- 100

**Graph Details**

- 1 month
- 6 months

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**Dimensions in mm:**

- All dimensions in mm
- 600
- 65
- 30°
### HOPPER DISCHARGE TESTS

Mean Rate of Discharge, kg/s

<table>
<thead>
<tr>
<th>Effect of use paint lining on discharge (10% Moisture)</th>
<th>Fly ash (a)</th>
<th>Fly ash (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not used</td>
<td>0.48</td>
<td>0.52</td>
</tr>
<tr>
<td>Used</td>
<td>0.54</td>
<td>0.53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect of storage time in hopper on discharge (10% Moisture)</th>
<th>Fly ash (a)</th>
<th>Fly ash (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 hours</td>
<td>0.91</td>
<td>0.53</td>
</tr>
<tr>
<td>48 hours*</td>
<td>0.79</td>
<td>0.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect of interruption to flow on discharge (10% Moisture)</th>
<th>Fly ash (a)</th>
<th>Fly ash (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not used</td>
<td>0.91</td>
<td>0.53</td>
</tr>
<tr>
<td>Used</td>
<td>0.81</td>
<td>0.51</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overburden load applied (10% Moisture)</th>
<th>Fly ash (a)</th>
<th>Fly ash (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min compaction</td>
<td>-</td>
<td>0.54*</td>
</tr>
<tr>
<td>125 kg</td>
<td>-</td>
<td>0.54*</td>
</tr>
<tr>
<td>250 kg</td>
<td>-</td>
<td>0.52*</td>
</tr>
<tr>
<td>500 kg</td>
<td>-</td>
<td>0.52*</td>
</tr>
</tbody>
</table>

All wet stored material needed vibration to discharge

* Manual rodding required to initiate discharge

6 months storage
FULL-SCALE TRIALS – READY MIX

WET FA STOCKPILE

FA DISCHARGED TO HOPPER

FA CONVEYED TO TRUCK

FA CONCRETE MIXED

FOUNDATION ELEMENTS
FULL-SCALE TRIALS

STOCKPILE FLY ASH

STOCKPILE FLY ASH CONCRETE

CONCRETE COMPACTION

COMPLETED ELEMENTS
## FLY ASH/CONCRETE PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fineness, % ret 45</td>
<td>5.7</td>
<td>35.5</td>
</tr>
<tr>
<td>LOI, %</td>
<td>5.9</td>
<td>9.4</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>0.2</td>
<td>13.7</td>
</tr>
<tr>
<td>CONCRETE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slump, mm</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Plastic density, kg/m³</td>
<td>2340</td>
<td>2350</td>
</tr>
<tr>
<td>Cube strength, 7d, N/mm²</td>
<td>23.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Cube strength, 28d, N/mm²</td>
<td>36.5</td>
<td>29.0</td>
</tr>
</tbody>
</table>

Cement content 355 kg/m³, 30 % Fly Ash, w/c ratio 0.48, nominal slump 50 mm, 25 N/mm² design strength
OUTCOMES OF RESEARCH

• Feasibility for stockpile fly ash use in concrete

• Some practical challenges associated with handling

• Alternative routes for using stockpile fly ash may be necessary

• Processing / Beneficiation?
INITIAL PROCESSING TESTS ON FLY ASH

Stockpile (1560 MW, Operational since 1966)

16 Mt stockpile
50 Hectares
Recently produced, 5-10 and 10-20 years old
INITIAL PROCESSING TESTS ON FLY ASH

- Material was dried in the laboratory
- Passed through 600 µm sieve
- 63 µm sieve
- Air classifier (BS EN 450 Type S)
- Grinding (laboratory ball mill)
## EFFECTS ON PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Sample / Process</th>
<th>Characterisation of the Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fineness, 45µm sieve ret., %</td>
</tr>
<tr>
<td>Original properties</td>
<td>33.1</td>
</tr>
<tr>
<td>Passing 63 µm sieve</td>
<td>10.2</td>
</tr>
<tr>
<td>Air classification</td>
<td>12.9</td>
</tr>
<tr>
<td>Grinding in ball mill</td>
<td>0.61</td>
</tr>
</tbody>
</table>
PARTICLE SIZE DISTRIBUTION

CUMULATIVE VOLUME, %

0
20
40
60
80
100

PARTICLE DIAMETER, µm

original
63 µm sieved
air classified
ground

Fly Ash Sample 5

% CUMULATIVE VOLUME
COMPRESSION DEVELOPMENT

w/c ratio 0.53, fly ash level 30%
RESEARCH PROJECT: PROCESSING OF STOCKPILE FLY ASH (UKQAA / EPSRC)

- Literature Review
- Survey of Stockpile Material Characteristics
- Laboratory Processing Tests
- Reactivity Tests in Cementitious Systems
- Pilot / Full-scale Trials
CONCLUDING REMARKS

- Fly ash tends to coarsen / agglomerate when wet-stored in a stockpile and this develops with time. The effect tends to be greatest around 10% moisture.

- Water requirement and reactivity are correspondingly affected with wet storage.

- By minor adjustment to the concrete mix via w/c ratio, equivalent hardened concrete properties to dry fly ash can be achieved.

- Hopper discharge tests indicate that vibration was required to discharge wet material from a small hopper.
CONCLUDING REMARKS

- Site trials have been carried out, producing satisfactory concrete.

- Details of initial tests to consider processing of stockpile fly ash are described.

- Initial tests by sieving, air classifying and grinding indicated that enhancements in reactivity, strength and other properties can be achieved.

- The tests suggest potential for use of the material in concrete. A new project has been established to extend the earlier work, with a view to enabling stockpile material use in concrete.
ACKNOWLEDGMENTS

The UKQAA and its members, BAA, C V Buchan, Castle Cement, DETR and EPSRC are thanked for supporting the work described / now in progress.