University of Dundee

Sourcing of fly ash and its effect on durability of concrete

Szállópernyeforrásai és hatása a beton tartósságára

Laszlo Csetenyi, 5 February 2024, BME Faculty of Civil Engineering

Overview / Áttekintés

- Changing Situation with Coal Combustion/Fly Ash
  Új helyzet a szénerőművek / pernye terén
- Wet Storage Effects on Fly Ash Properties
  Szabadtéri (nedves) tárolás hatása a pernye tulajdonságaira
- Wet Stored Fly Ash Concrete
  Nedvesen tárolt pernyéből készült beton
- Processing and Use of Wet Stored Fly Ash
  Nedvesen tárolt pernye feldolgozása és alkalmazása
  - Laboratory Scale / Laboratóriumi kísérletek
  - Benchtop/Pilot Scale / Félüzemi kísérletek
- Summary / Összefoglalás

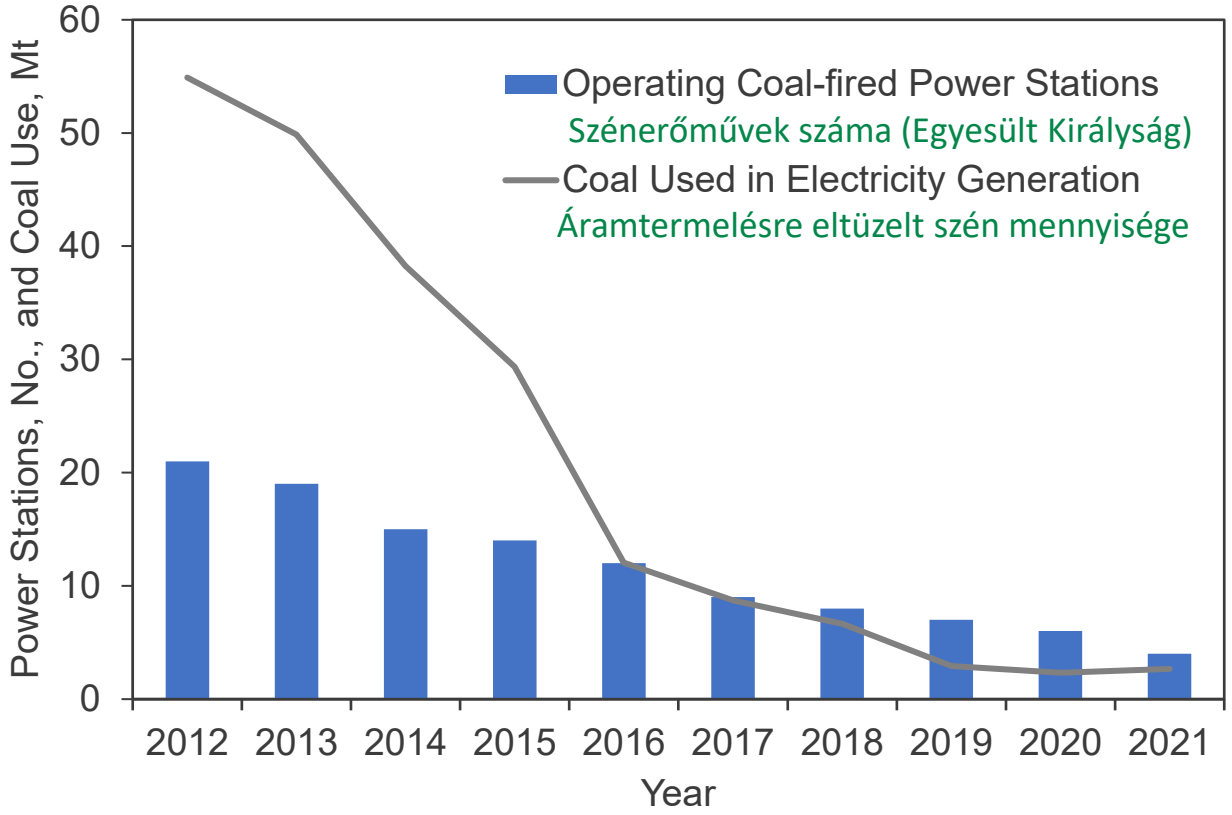
Changing Situation with Coal Combustion/FlyAsh
Új helyzet a szénerőművek / pernye terén

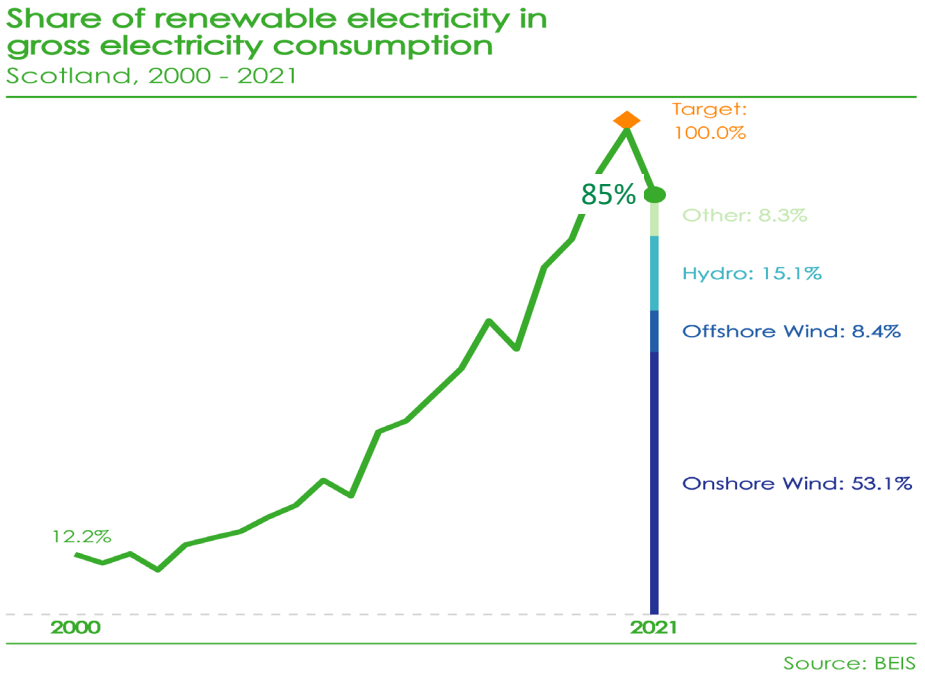
- Decarbonization roadmaps with energy-intensive sectors developed (published in 2015). CO_2 kivezetési tervek az energiaigényes iparokból
- In the cement industry this referred to the substitution of clinker with alternative materials, including fly ash. A cementiparban a klinker kiváltását célozzák pl. pernye hozzáadásával
- In November 2015, plans were announced to close all coal-fired power stations by 2025. Hamarosan minden szénerőmű leáll a UK-ban (Skóciában már 2016 óta nincs)
- This process is on-going with implications for fly ash supply.
  A zajló folyamatok kihatnak a pernye beszerzési lehetőségeire, forrásaira

Sources: Departments for Energy and Climate Change/Business, Innovation and Skills (2015) and Business, Energy and Industrial Strategy (2017)

Coal Use and ElectricityGeneration / Szén az energiatermelésben

Typical coal levels used from 2000 to 2011 were around 50 Mt per annum

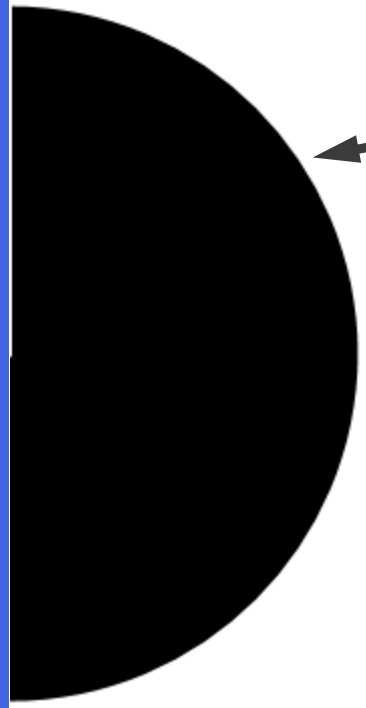


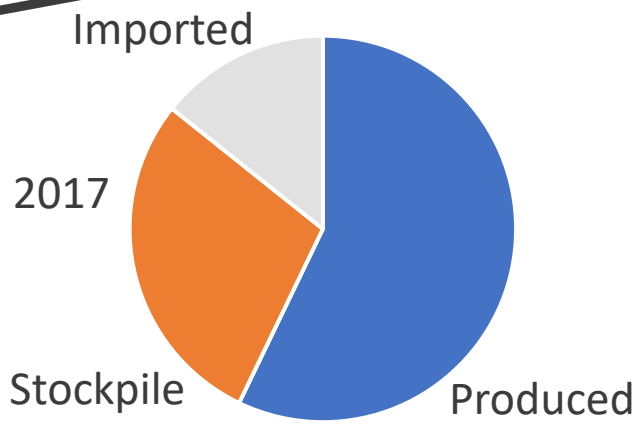


Sources:
Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy (2022) Power Stations of the UK: https://www.powerstations.uk/coal-countdown/ (accessed 10 May 2023)

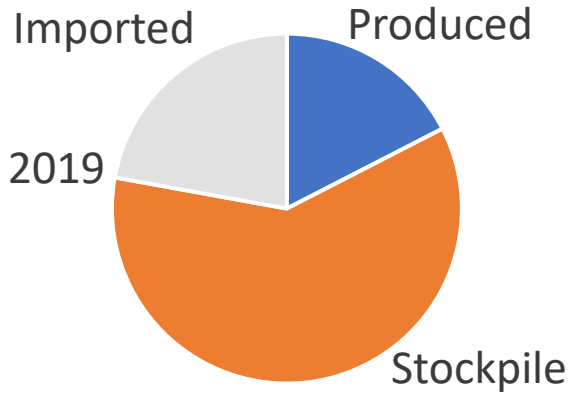
Changing Sources of FlyAsh / Pernye származási megoszlása

2012: 6 Mt Produced: 3 Mt Consumed; 3 Mt Stockpiled

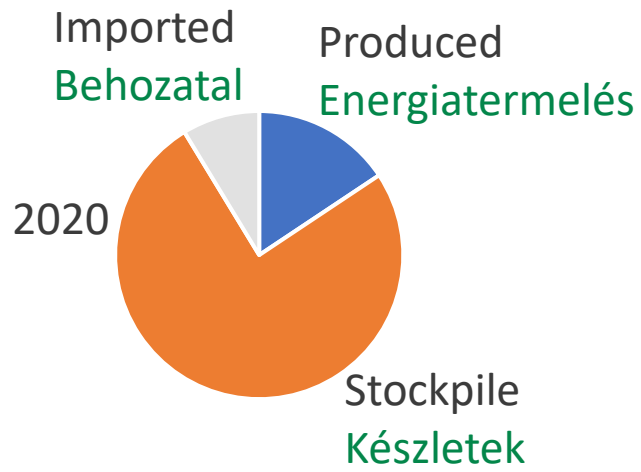




Total Used: 1.75 Mt



Total Used: 1.48 Mt



Total Used: 1.11 Mt
Felhasználás mindhárom forrásból összesen

Source: Cooke, UKQAA (2023)

Fly Ash Uses in Construction / Pernyefelhasználás

- Cement and Concrete / Cement és beton

  Well established use offering several benefits to concrete.
  Jól ismert anyagrendszer, számos előnyös tulajdonsággal

- Autoclaved Aerated Blocks / Gázbeton

  Lightweight precast concrete units, with fly ash used as a siliceous component.
  Könnyű előregyártott elemek, melyekben a pernye a szilikátos adalék

- Cementitious Grouts / Önterülő habarcsok

  Applications include ground stabilization, filling of old mine shafts. Used with Portland cement at relatively high levels. Nagy pernyetartalmú térkitöltő és stabilizáló keverékek

- Cement Kiln Feed / Cementgyártási nyersanyag

  Used as raw kiln feed in Portland cement manufacture.
  Klinkergyártás során szilikátos komponensként adagolva a kemencébe

Options for Sourcing FlyAsh / Pernyeforrások

- Importing fly ash could serve as an alternative to dry material. Quantities are currently low. Import pernye (pl. lengyel, indiai), egyelőre kis mennyiség
- Change engineering specifications so PC/fly ash blends / concretes are used to meet technical performance requirements. Megfelelőségi kritériumok átgondolása, ahol az anyag még így is kielégítő betont eredményez
- Use of fly ash from wet storage areas. The UK Quality Ash Association estimate that there are 100 Mt of fly ash accessible for recovery. Pernye kitermelése szabadtéri nedves tárolókból; az Egyesült Királyság Pernyeszövetsége 100 Mt készletet tart számon.

Sources: Department for Business Energy and Industrial Strategy (2017) and Cooke, UKQAA (2023)

Characteristics of Wet Stored Fly Ash (Physical/Chemical)
Kültéri tárolású pernye tulajdonságai

Property[1]	Wet Stored Fly Ash / Szabadtéri (nedves) tárolású pernye	
	Stockpile – Range of 45 Samples (Mean)	Lagoon – Range of 34 Samples (Mean)
Physical and Loss-on-ignition (LOI)		
Fineness[2]	31.1 – 42.4 (36.7)	12.0 – 61.9 (39.8)
d_{50}[3], µm	27.4 – 43.6 (34.8)	13.4 – 100.5 (43.7)
LOI / Ízz. veszt.	11.2 –25.4 (15.3)	3.8 – 20.2 (8.2)
Chemical Composition		
CaO	1.2 – 3.5 (2.2)	2.0 – 4.3 (2.7)
SiO_2	35.8 – 45.8 (40.4)	40.0 – 52.5 (47.4)
Al_2O_3	19.5 – 23.6 (21.5)	24.3 – 31.4 (28.5)
Fe_2O_3	5.3 – 8.5 (6.7)	3.3 – 6.8 (4.9)
K_2O	1.7 – 3.1 (2.6)	0.7 – 1.6 (1.1)
Na_2O	0.3 – 2.0 (0.6)	0.3 – 3.8 (1.1)
SO_3	0.2 – 1.8 (0.7)	0.2 – 1.2 (0.6)
Cl^-	0.0 – 3.0 (0.3)	0.4 – 6.4 (1.8)

[1] Percent unless indicated otherwise
[2] Percent retained on a 45 µm sieve / 45 µm vizes szitálás maradéka
[3] Median particle size

Source: McCarthy et al. (2013)

Characteristics of Wet Stored Fly Ash (Physical/Chemical)
Laboratóriumi száraz és nedvesen tárolt pernye tulajdonságai

Property[2]	Dry & Laboratory Wet Stored Fly Ash[1] / Száraz és laborpernye[1]						Stockpile Fly Ash SFA1 – SFA8 Range
	DFA1	DFA1 730 d	DFA3	DFA3 730 d	DFA5	DFA5 730 d	
Physical and LOI							
Fineness[3]	33.9	59.2	5.7	45.6	18.4	36.4	41.1 – 63.2
d_{50}[4], µm	39.4	45.1	4.3	32.0	23.9	29.7	28.3 – 43.9
LOI	8.3	9.3	5.6	5.9	13.6	13.4	3.5 – 15.9
Chemical Composition							
CaO	4.5	5.4	3.1	3.4	2.2	2.1	2.1 – 4.4
SiO_2	47.9	46.3	50.1	49.2	41.3	40.1	41.2 – 51.2
Al_2O_3	20.3	20.1	22.4	22.9	23.4	22.2	19.5 – 25.2
Fe_2O_3	7.4	7.7	7.6	7.2	6.7	5.8	5.8 – 9.4
K_2O	2.2	2.1	2.5	2.8	2.3	1.6	1.7 – 2.8
Na_2O	1.5	1.1	1.7	1.3	0.7	0.6	0.7 – 1.1
SO_3	1.8	1.7	1.2	1.3	2.0	2.2	0.8 – 2.3

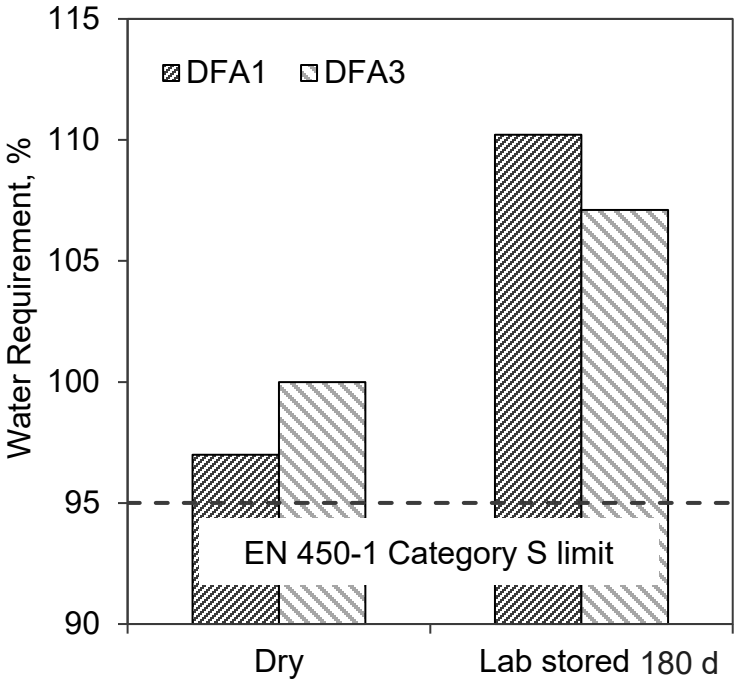
[1] 10% moisture, 730 d sealed storage in the laboratory at 20°C / Egyes minták 2 évig tárolva a laborban 10% nedvességet hozzáadva 20°C-on
[2] Percent unless indicated otherwise
[3] Percent retained on a 45 µm sieve (Dry fly ash tested to EN 450-1 (EN 451-2), wet stored fly ash - mean of 6 tests)
[4] Median particle size

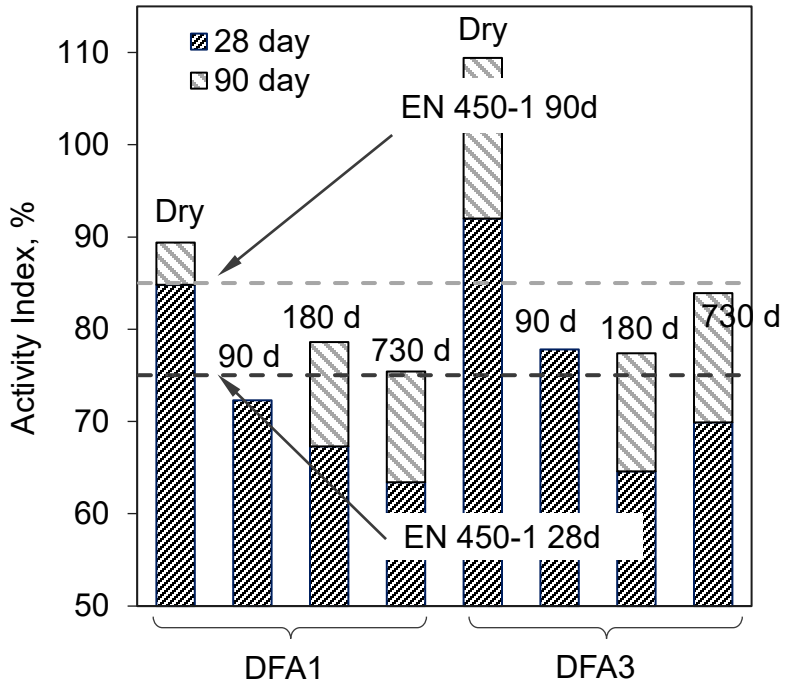
Dry

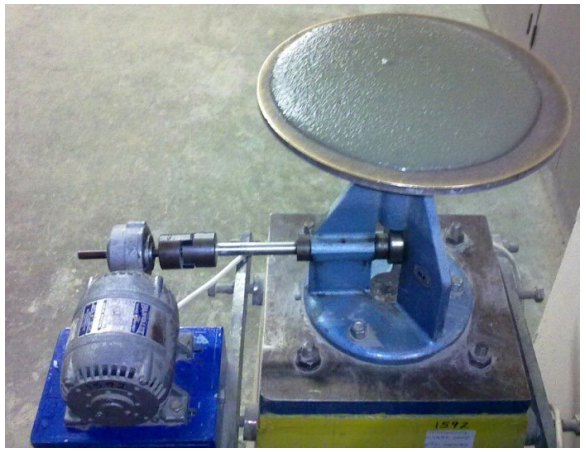
180 d Lab. Stored

Source: McCarthy et al. (2023a)

Characteristics of Laboratory Wet Stored FlyAsh / Laborpernye (Water Requirement/Reactivity) / Vízigény és aktivitás



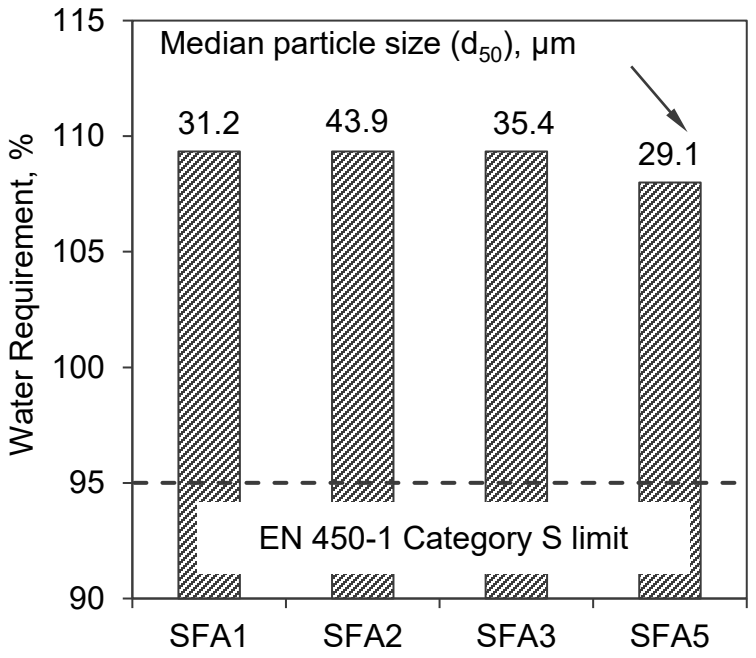




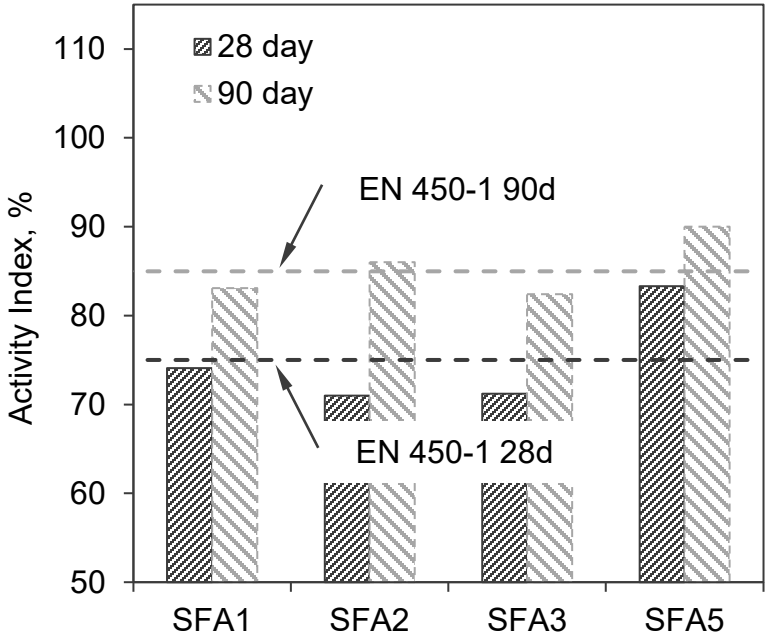
Laboratory storage conditions: 10% moisture/sealed at 20°C

Laboratóriumi szimulált nedves tárolási körülmények: 10% vízzel, zárt zsákban 20°C-on

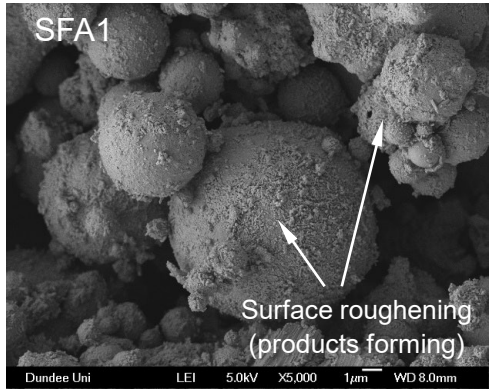
Characteristics of Stockpile Stored FlyAsh / Kültéri pernye (Water Requirement/Reactivity) / Vízigény ésaktivitás

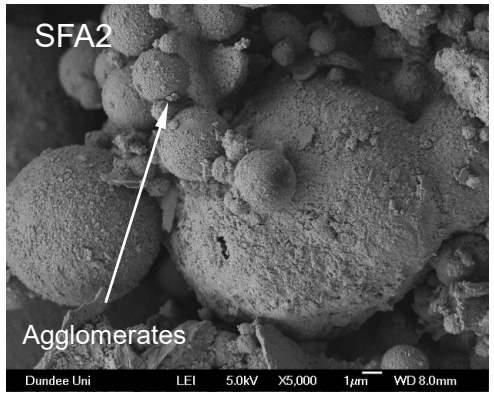


Stockpile fly ash



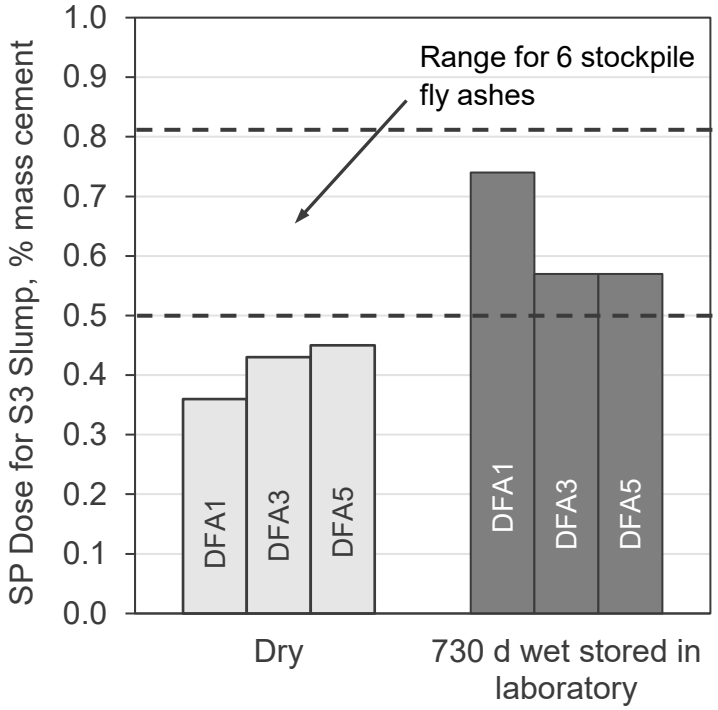
Stockpile fly ash

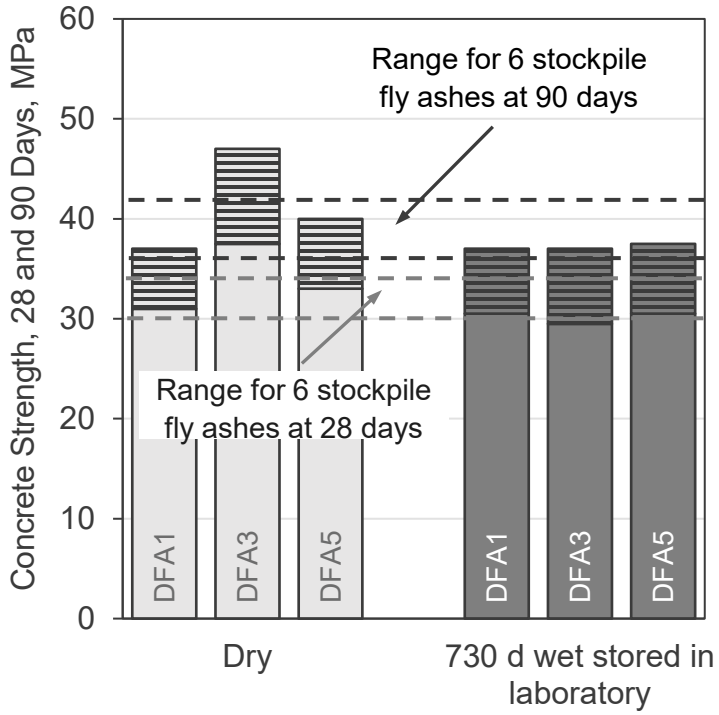




Stockpile Fly Ashes

Laboratory Wet Stored Fly AshConcrete / Laborpernye beton (Fresh Properties/Strength) / Roskadás, nyomószilárdság





<u>Concrete Mix</u> (w/c = 0.53)

Portland cement – 350 kg/m³
Water – 184 l/m³
10/20 – 790 kg/m³
4/10 – 395 kg/m³
0/4 – 640 kg/m³
(Gravel 20 mm max. size/ local sand aggregate)

Fly Ash in Cement – 30%
30% pernye a kötőanyagban
Target slump – S3
Célzott roskadási osztály – S3

Laboratory storage conditions: 10% moisture/sealed at 20°C

Processing of Stockpile Fly Ash in the Laboratory
Kültéri tárolású pernye laboratóriumi feldolgozási módjai

- Screened (sieved at 600 and 63 µm). Szitálás 600 és 63 µm szitán
- Ball milled with different loads/for various periods of time. Golyósmalom
- Thermally (heat) treated in a furnace at 500°C for 1 hour. Hőkezelés

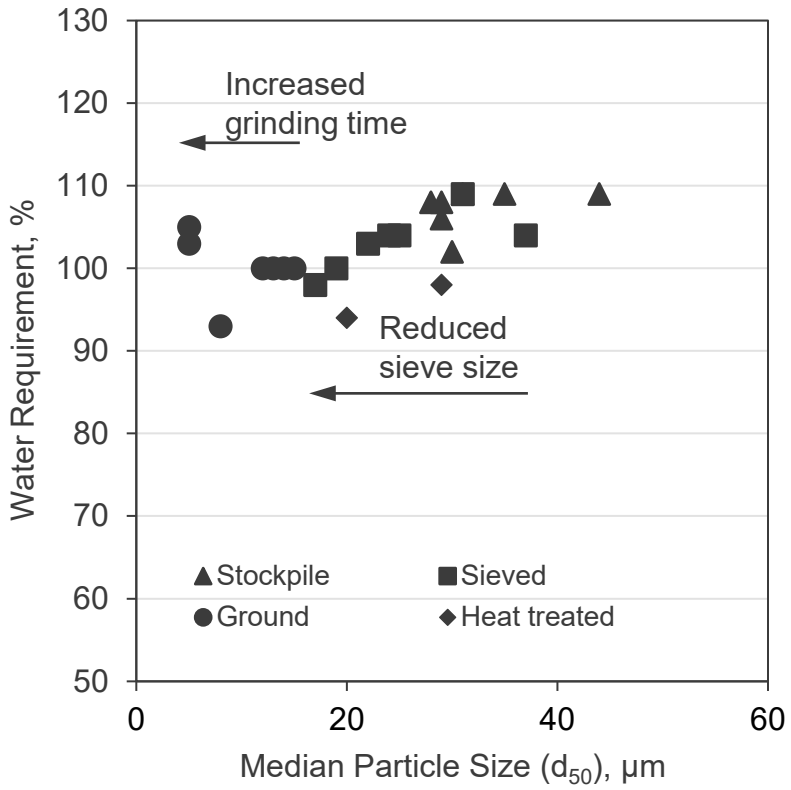
In some cases, screening at 600 µm was used before applying the other methods. Egyes esetekben a 600 µm-en szitált anyagot őröltük / hőkezeltük

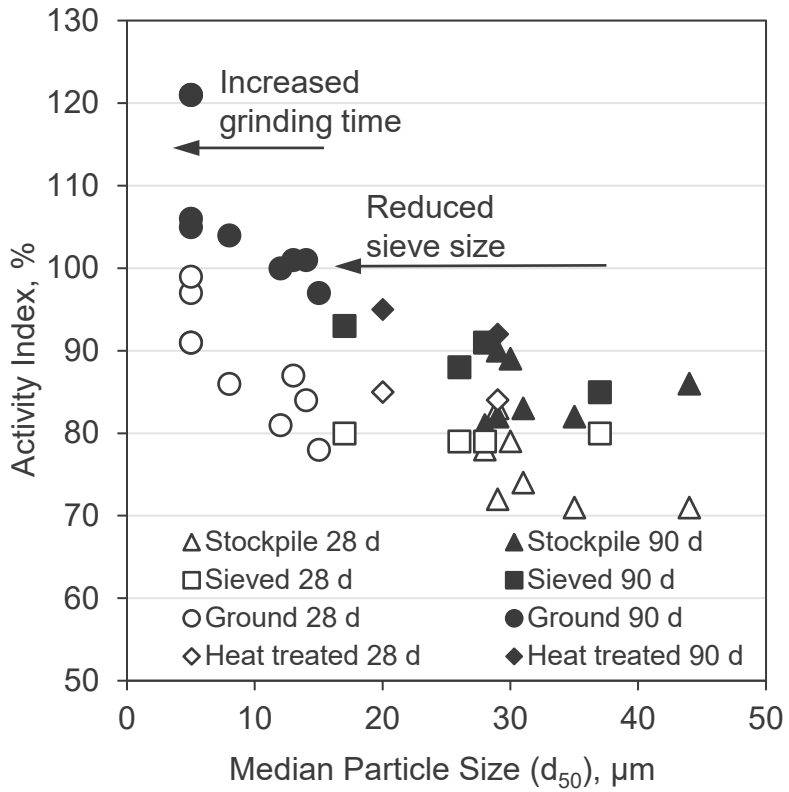
Processing of Stockpile Fly Ash in the Laboratory / Kültéri pernye (Physical/Chemical Properties) / Feldolgozás utáni tulajdonságok

Property[4]	Sieving[1] / Szitálás[1]			Grinding[2] / Őrlés[2]		Heat Treated[3] / Hőkezelés[3]	
	SFA1	SFA1 < 600 µm	SFA1 < 63 µm	SFA2 < 600 µm	SFA2 < 600 µm 120 mins BM	SFA4 < 600 µm	SFA4 < 600 µm 500°C 60 mins
Physical and LOI / Szemcseméret és ízzítási maradék							
Fineness[5]	53.8	52.7	8.5	36.0	0.8	40.5	31.9
d_{50}[6], µm	31.2	31.5	25.3	37.3	5.0	30.0	25.4
LOI	9.7	9.8	8.9	9.2	9.7	16.3	11.8
Chemical Composition / Oxidos összetétel							
CaO	4.4	5.1	5.0	2.5	2.6	2.0	1.9
SiO_2	44.3	42.7	46.4	47.0	49.4	42.9	44.9
Al_2O_3	21.8	20.9	23.0	25.0	24.8	23.3	24.4
Fe_2O_3	9.0	8.8	9.3	8.6	9.4	7.6	8.0
K_2O	2.0	2.0	2.3	2.5	2.5	2.1	2.1
Na_2O	0.8	0.9	0.8	0.9	0.9	1.0	0.7
SO_3	1.6	1.9	1.6	1.0	1.3	1.0	0.9

[1]< 600 µm, < 63 µm passed through sieve size indicated (finer fraction tested), [2]Passed through sieve size indicated and finer fraction balled milled (BM) for 120 minutes,
[3]Passed through sieve size indicated and finer fraction heat treated for 60 minutes at 500°C, [4] Percent unless noted otherwise,
[5]Percent retained on a 45 µm sieve (Processed fly ash tested to EN 450-1 (EN 451-2), stockpile fly ash - mean of 6 tests), [6] Median particle size

Processing of Stockpile Fly Ash in the Laboratory / Kültéri pernye (Water Requirement/Activity Index) / Vízigény, aktivitási index





Reference Mortar Mix

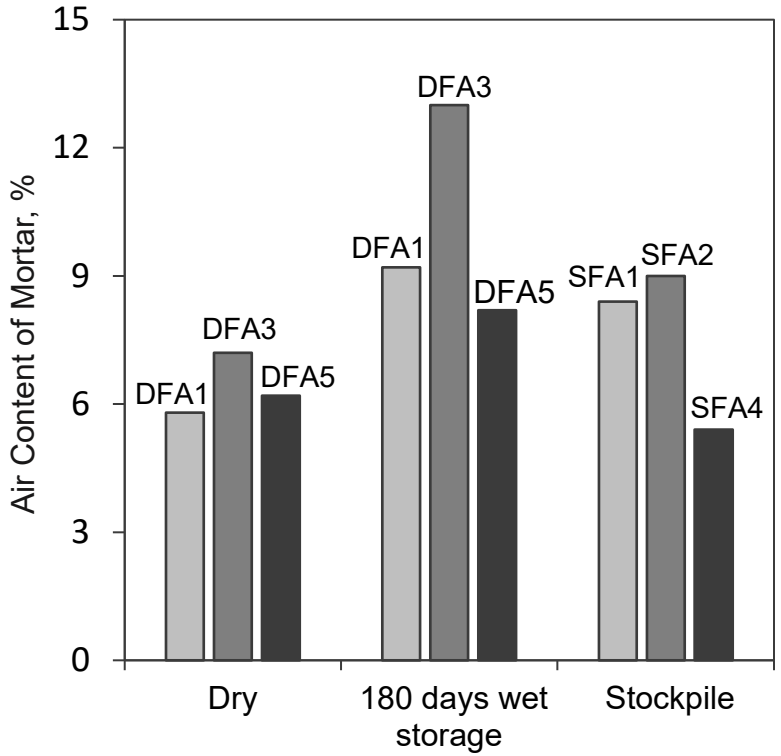
Portland cement – 450 g
Water – 225 g
Standard sand – 1350 g

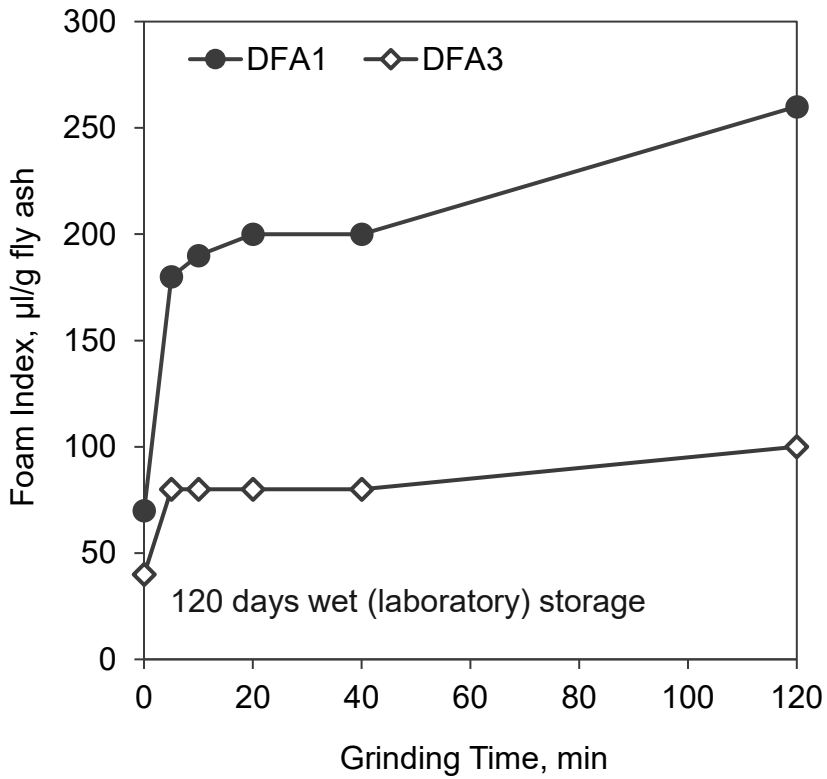
Fly Ash Mortar Mixes

As above except
Water Requirement –
30% fly ash in cement and variable water for equal flow
30% pernye és változó mennyiségű víz azonos folyósághoz

Activity Index – 25% fly ash in cement / Aktivitási indexhez 25% pernyével a kötőanyagban

Characteristics of Laboratory/Stockpile Fly Ash (Air entrainment)
Pernyés habarcsok légpórustartalma és a pernyék adszorpciója





Air content - mortar

Foam index test

Reagent: Sodium dodecyl benzene sulfonate (SDBS), 1 g in Standard mortar – (20% fly ash in cement)

Reagent: SDBS, 0.01 mol/l
Variation in foam index with grinding

Laboratory storage conditions: 10% moisture/sealed at 20°C Source: McCarthy et al. (2023b)

Laboratory Processed Stockpile Fly Ash Concrete / Kültéren tárolt, de laboratóriumban feldolgozott pernyés beton (Fresh Properties/Strength) / Friss tulajdonságok, szilárdság

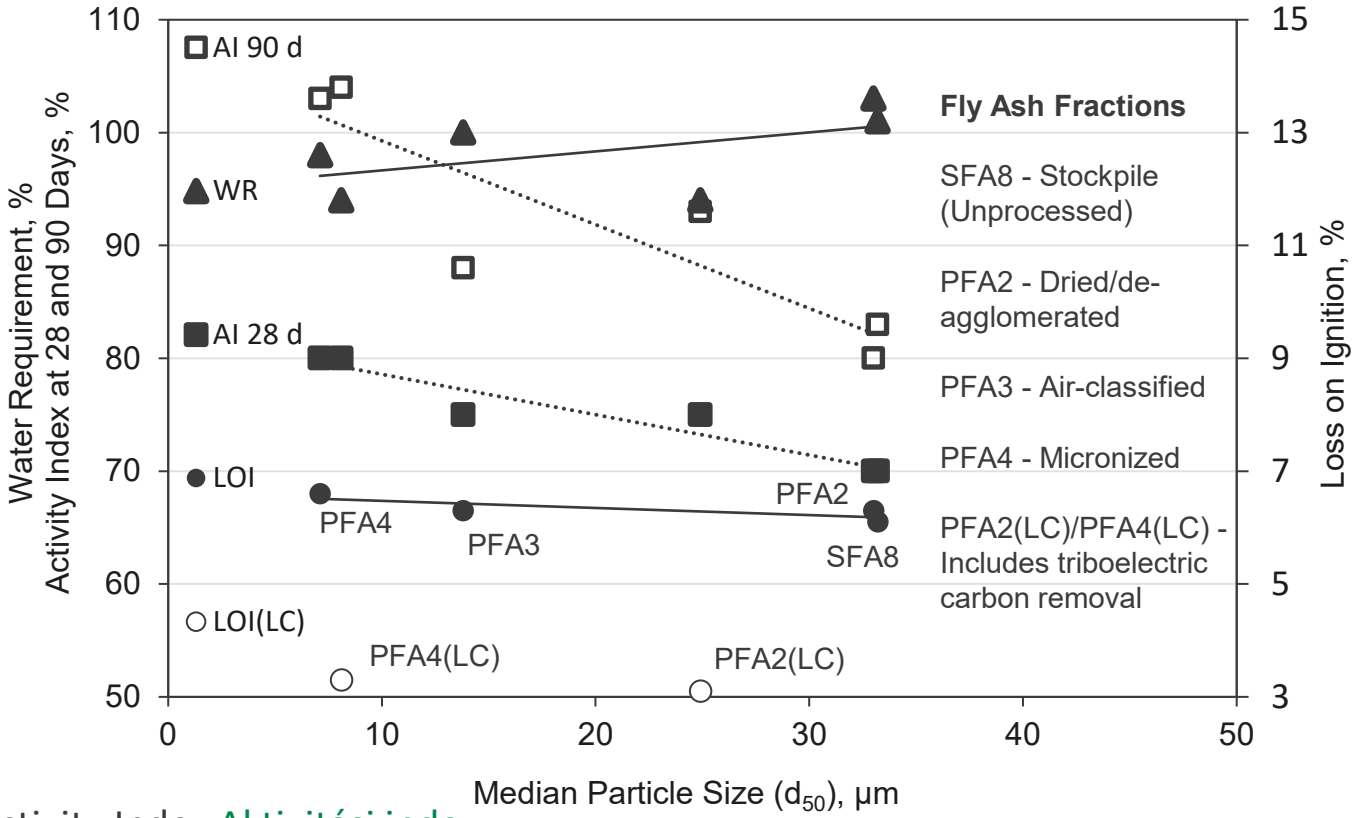
Fly Ash/Processing	Median Particle Size (d50), µm Szemcseméret	SP Admixture Dose for S3 Slump, % mass cement Folyósítószer S3-hoz	Cube Strength, MPa Nyomószilárdság kockán	
			28d	90d
SFA2	43.9	0.56	31.5	39.5
SFA2 < 600 µm	37.3	0.58	32.5	41.5
SFA2 < 600 µm/BM 40	8.9	0.41	37.5	45.0
SFA2 < 600 µm/BM 80	6.3	0.43	40.0	47.0
SFA2 < 600 µm/BM 120	5.0	0.37	40.0	50.5
SFA6	28.6	0.68	33.0	40.5
SFA6 < 600 µm	28.0	0.71	33.5	43.5
SFA6 < 600 µm/BM 120	4.9	0.36	41.0	48.5

<600 µm – fly ash passed through 600 µm sieve before testing/ball milling, BMXX – Fly ash ball milled for XX mins
<600 µm – szitált pernye, 600 µm-on áthullott hányad, BMXX – golyósmalommal őrölve XX percig

Concrete Mix (w/c = 0.53)
Portland Cement – 350 kg/m^3
Water – 184 l/m^3
0/4 – 640 kg/m^3
4/10 – 395 kg/m^3
10/20 – 790 kg/m^3
(Gravel 20 mm max size/ local sand aggregate)

Fly Ash in Cement – 30%
30% pernye a kötőanyagban
Target slump – S3
Célzott roskadási osztály – S3

Pilot/Benchtop Scale Processing of Stockpile FlyAsh
Kültéri pernye feldolgozása félüzemi méretekben

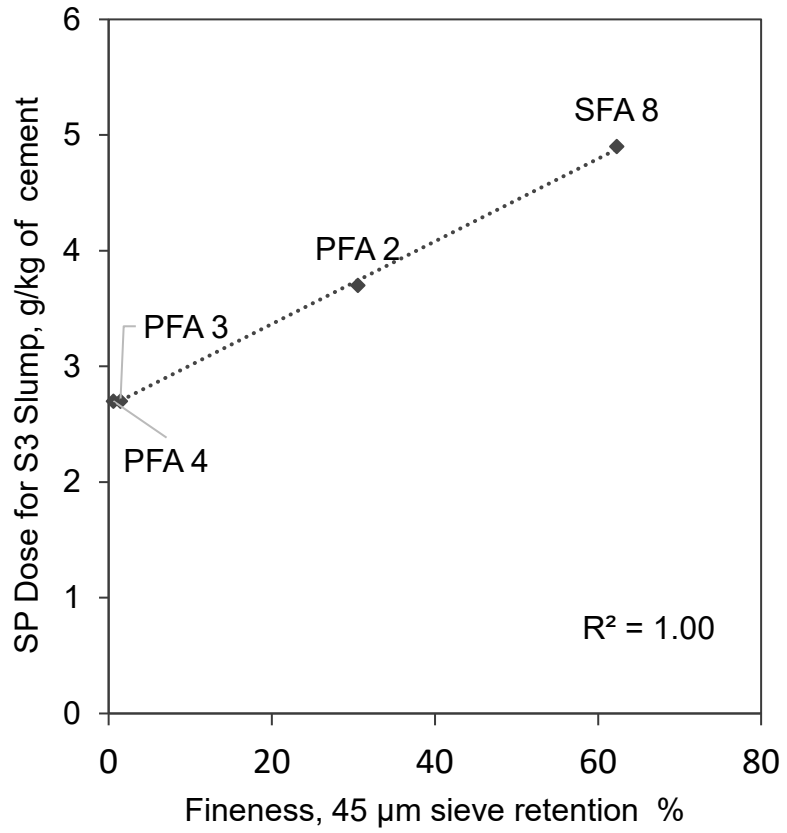


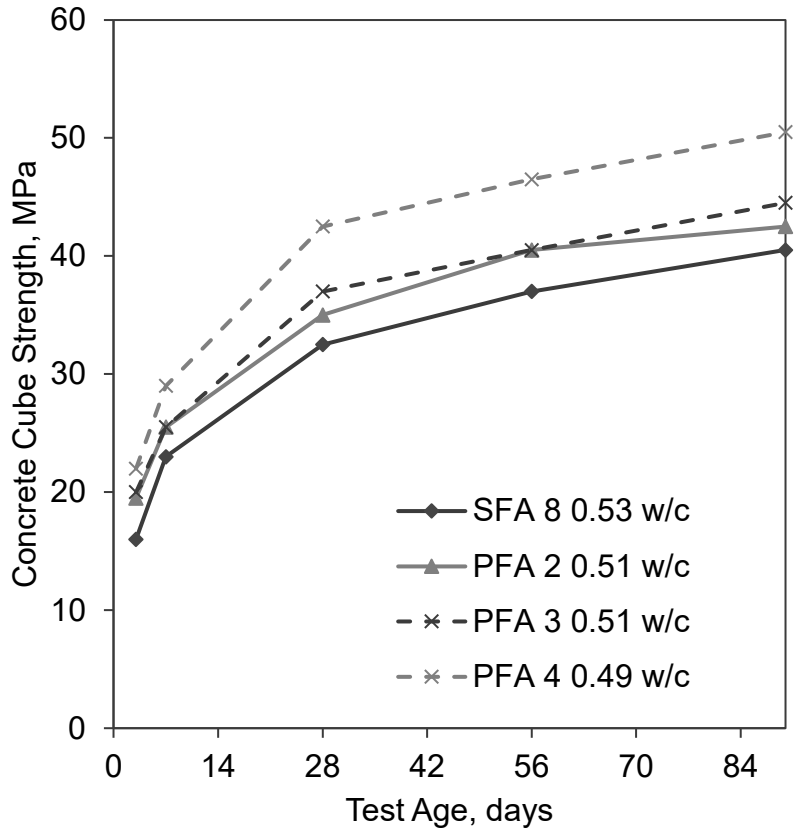
Atritor Ltd - Processing Equipment

AI – Activity Index Aktivitási index
WR – Water Requirement Vízigény
LOI – Loss on Ignition Ízzítási veszteség

Source: McCarthy et al. (2022) / (2023a)

Pilot/Benchtop Scale Processed Stockpile Fly Ash Concrete
Félüzemi méretekben feldolgozott kültéri pernyés beton





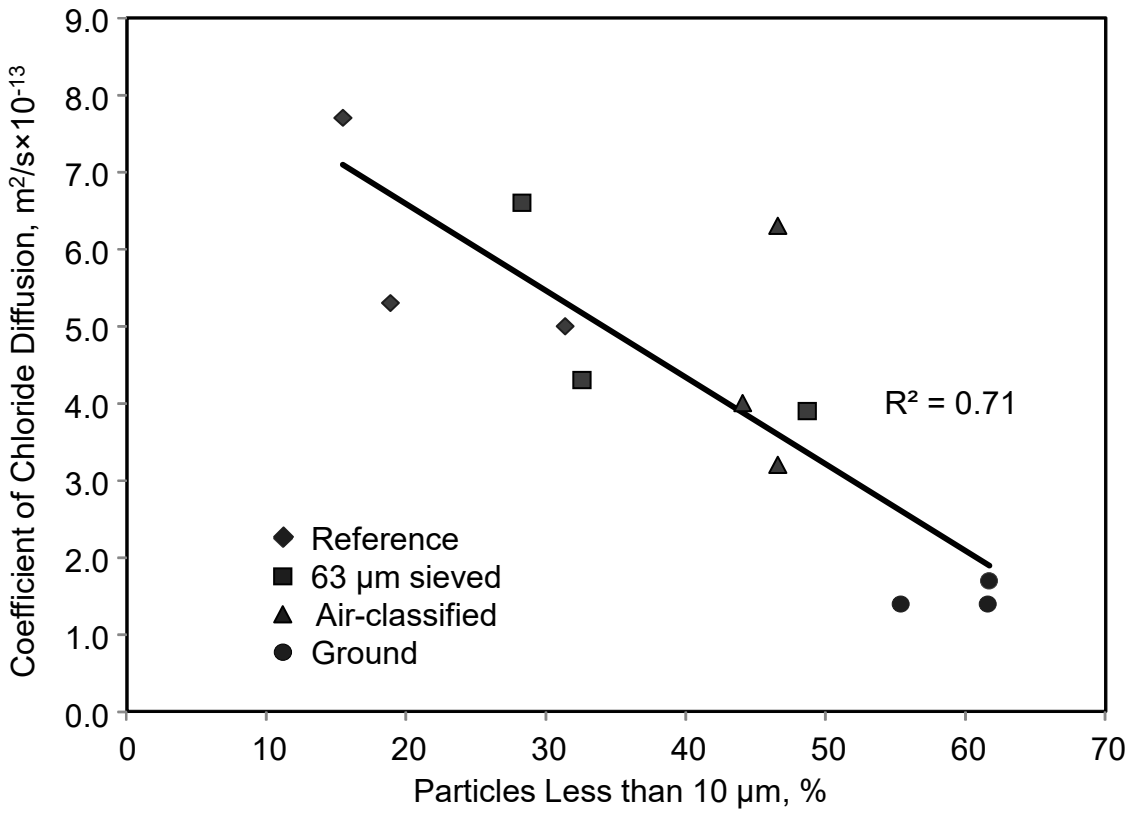
Water Saving Concretes (Fixed SP dose)
Állandó folyósítószer mennyiséggel

<u>Concrete Mix</u> (w/c = 0.53)

Portland Cement – 350 kg/m^3
Water – 184 l/m^3
0/4 – 640 kg/m^3
4/10 – 395 kg/m^3
10/20 – 790 kg/m^3
(Gravel 20 mm max size/ local sand aggregate)

Fly Ash in Cement – 30%
30% pernye a kötőanyagban
Target slump – S3
Célzott roskadási osztály – S3

Processed Lagoon/Stockpile Fly Ash Concrete Durability
Kültéren tárolt pernyés beton tartóssága kloriddiffúzióval mérve



Source: McCarthy et al. (2018)

<u>Concrete Mix</u> (w/c – 0.53)

Cement – 350 kg/m^3
Water – 185 l/m^3
Fly Ash – 30% in cement
30% pernye a kötőanyagban
Target slump – 100 mm
Célzott roskadás 100 mm
Chloride diffusion
Two compartment cell/
Fick's First Law Kloriddiffúzió
kétkamrás elrendezésben,
Fick első törvénye szerint
1 stockpile and 2 lagoon
fly ashes tested
1 meddőhányós és
2 zagytárolós pernye alapján

Summary / Összefoglalás

- With changes in electricity generation, alternative options for sourcing fly ash for use in construction are required.
  A szénerőművek leállása miatt pernyét máshonnan kell beszerezni
- A possible route for this is the reserves of wet stored material from holding areas (stockpiles, landfills). Pl. meddőhányókból, zagytárolókból
- Material in these areas has often undergone changes with implications for handling and meeting the requirements of Standards. Ezek a pernyék sokszor csak feldolgozás után felelnek meg a szabványoknak (pl. összetapadt szemcsék)
- Consideration of the need for processing to increase fineness, reduce carbon content and enhance reactivity may then be necessary. A szemcseméret finomítása, a széntartalom csökkentése és az aktivitás növelése szükséges

Summary / Összefoglalás

- Processed fly ashes could meet the requirements of EN 450-1, including fineness, loss-on-ignition and reactivity. A megfelelően feldolgozott pernye megfelelhet az EN 450-1 szabványnak (szemcseméret, ízz. veszt., aktivitás)
- In concrete SP dose generally reduced with fly ash fineness, at least up to a point by processing. Concrete strength generally improved with increased fly ash fineness. Finomabb pernyéhez általában kevesebb folyósítószer kellett és a beton szilárdsága is javult
- Larger scale trials gave similar behaviour to that obtained in the laboratory. A félüzemi kísérletek is alátámasztják a laboratórium eredményeket
- Initial durability tests (chloride diffusion) described, indicate that processing can give improvements to this aspect of concrete performance. A pernye feldolgozása segít tömörebb, tartósabb betont készíteni (lásd Cl-diffúzió)

Future Work and Acknowledgements / Tervek, köszönet

- Research into durability of recovered/processed fly ash covering key physical and chemical aspects continues. A feldolgozott pernyés betonok tartóssági javulását további mérésekkel is igazoljuk majd
- Work has examined energy requirements for processing (Cooke, 2023) and there are plans to take this further. A feldolgozás energiaigényét is nézzük
- The use of recovered/processed fly ash in ternary blends for concrete is also being considered. Többkomponensű betonokat is vizsgálunk majd

Thanks are given to the EPSRC and the UK Quality Ash Association and its members for supporting the research described. Acknowledgement is given to Drs Robert Carroll and Nigel Cooke for their input during the project. The contributions of Atritor Ltd and STET in processing material is also much appreciated.
Köszönet illeti a kutatás támogatóit: Engineering and Physical Sciences Research Council, UK Quality Ash Association; nagyra értékeljük Dr Carroll és Dr Cooke szakmai tanácsait és az Atritor Ltd és STET cégek mintafeldolgozási segítségét

References/ Hivatkozások

Cooke N (UKQAA, 2023). Securing stockpile reserves of coal-derived fly ash as a national asset. Concrete, Vol 57, No 3, pp 44 – 47.

Department for Business, Energy and Industrial Strategy (2017) Fly ash and Blast Furnace Slag for Cement Manufacturing. BEIS Research Paper No. 19, BEIS, London, UK, 34 pp

Department of Energy and Climate Change and the Department for Business, Innovation and Skills (2015). Industrial decarbonisation and Energy Efficiency Roadmaps – Cement, 94 pp.

Department for Energy Security and Net Zero and Department for Business, Energy and Industrial Strategy (2022). Historical coal data: coal production, availability and consumption. https://www.gov.uk/government/statistical-data-sets/historical-coal-data-coal-production-availability-and-consumption.

McCarthy MJ, Jones MR, Zheng L, Robl TL and Groppo JG (2013). Characterizing long-term wet-stored fly ash following carbon and particle size separation. Fuel Journal, Vol 111, pp 430 – 441.

McCarthy MJ, Zheng L, Dhir RK and Tella G (2018). Dry processing of wet-stored fly ash for use as an addition in concrete. Cement and Concrete Composites, Vol 92, pp 205 – 215.

McCarthy MJ, Hope TA and Csetenyi LJ (2022). Influence of wet storage on fly ash reactivity and processing for use in concrete. Advances in Cement Research, Vol 34, No 10, pp 427 – 442.

McCarthy MJ, Hope TA and Csetenyi LJ (2023a). Sourcing fly ash for use in concrete from stockpile deposits. Institute of Concrete Technology (In press).

McCarthy MJ, Hope TA and Csetenyi LJ (2023b). Wet storage effects on fly ash properties relevant to its use in air-entrained concrete. Magazine of Concrete Research, Vol 75, No 3, pp. 149 – 162.

Power Stations of the UK. https://www.powerstations.uk/coal-countdown/ (accessed 10 May 2023).